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Aru A., Tomasi D.

in

Zdruli P. (ed.), Steduto P. (ed.), Kapur S. (ed.).
7. International meeting on Soils with Mediterranean Type of Climate (selected papers)

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 50

2002
pages 345-356

SOIL VARIABILITY AND IRRIGATION IN MEDITERRANEAN ENVIRONMENTS

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Introduction

This paper is intended simply as a brief outline of the use of irrigation water in the soils of Mediterranean region and of the criteria adopted when establishing priorities in the choice of irrigable areas. Since prehistoric times, man has established its settlements where water was readily available to satisfy his needs.

In this context, water availability permitted the establishment of large settlements in the vicinity of watercourses, large springs or in areas where water could be easily transported. In many cases, the water was simply drawn from springs or from superficial aquifers. Later, more sophisticated techniques were used.

In Italy irrigation is known to have been practised since Roman times and perhaps even before. During the various stages of expansion of the Roman Empire, water availability played a crucial role in the choice of settlement sites. During Arab domination, especially in the Mediterranean region, the land was placed under irrigation to assure the supply of basic foodstuff.

Arab influence in the Iberian Peninsula is marked by evidence of irrigated agriculture. For centuries the relationship between man and irrigated agriculture did not change substantially and the area under irrigation as well as the irrigating techniques remaining practically unchanged, except for the Tiberina Valley as one of the few exceptions.

It was not until the 1800's that in Italy some advances began to be made again in this sector, with the construction of major irrigation works especially in the more extensive plains such as the Padana Valley. Many areas underwent irrigation development, following major land reclamation operations, including parts of the coastal belt of Tuscany, Latium and Sardinia, especially after the enforcement of the 1933 Serpieri law on land reclamation.

However it was after the Second World War that the most significant expansion of irrigated land occurred, particularly in the more arid areas of Italy. Important laws like the one introduced by the *Cassa per il Mezzogiorno* (Development Agency for Southern Italy), resulted in the construction of a number large reservoirs, mainly for irrigation purposes and to a lesser extent for power generation and drinking water supply.

Until the 1970's and 80's, the construction of reservoirs and the delimitation of irrigable land completely overlooked the issue of soil quality that determines irrigation suitability and its convenience, in addition to the agronomic practices for maintaining soil fertility. A large number of often-costly projects, led to the spread of irrigation development in wider variety of areas and on very different soils.

The lack of the right criteria, especially in terms of soil quality, produced the first negative effects back in the 1950's. On lands where soils exhibited good irrigation capability, agriculture experienced sustained growth and development that has been maintained till the present times. Other extensive areas, where soil characteristics have been ignored, were abandoned.

Many projects turned out to be a waste of public money, as the inadequate knowledge of the soils led to the failure of the project. The design of irrigation schemes placed more emphasis on the cost of water conveyance rather than on the profitability of irrigated agriculture. On the other hand, on soils that exhibited good and high suitability to irrigation, sustainable and profitable agriculture has been assured.

The most common soils under irrigation

Soils irrigated with water supplied by public works are found on flat and gently undulating terrains. In geological terms, these soils are formed from alluvium and colluvium deposits of different age. The recent alluvium materials show extremely different characteristics that depend on their source of origin.

Dominant parent materials include Pliocene and Miocene clay or clay-limestone formations, basalt plateaux and other volcanic rocks, the “red earths” of Mesozoic and Palaeozoic limestone, granite and metamorphic rocks of the Palaeozoic. The gentler landforms lacking outcropping rock and often expose eolian sands and sand dunes.

In terms of USDA Soil Taxonomy classification the soils belong to the following orders:

- Alfisols
- Inceptisols
- Entisols
- Andisols
- Vertisols
- Ultisols
- Aridosols

The existence of seven soil orders demonstrates the significant spatial variability of the soils. Clearly soil genesis plays a fundamental role in differentiating soil properties, that in turn play a crucial role in function of irrigation scheme designs or other land use purposes.

The majority of Alfisols have formed on Pleistocene formations. The classification of soils by age and parent material is important for determining irrigation suitability of the land. The older the soil the more weathered it is, the greater the extent of clay illuviation, the higher the desaturation, especially in soils derived from acid substrata and the greater the loss of natural fertility in the broadest sense.

Interesting correlations were found while observing three soil profiles in Quaternary formations of different age within the same catchment basin. It was revealed that where the deposited material is fairly homogeneous, from the oldest to the youngest soils the following differences are evident: a decrease in the degree of weathering, variations in the clay-to-silt ratio, pH, differences in structure, porosity, permeability, a decrease in illuvation, variations in cation exchange capacity and base saturation, variations in water retention capacity and irrigation water requirements.

If all other environmental conditions remain equal, there are these properties that determine the variability in suitability of soils to irrigation and the choice of crops to be cultivated. In the irrigation plans and projects designed in Italy, the suitability for irrigation was based simply on the cost of water conveyance.

Over the last few decades, and especially from the 1950's onwards, irrigated agriculture on soils of early Pleistocene age, especially those formed on acid substrata, has been unsuccessful. Many local government agencies invested public funds in projects that were doomed to failure.

In Sardinia the abandonment of the land developed for irrigation by ETFAS (Government Land Reform Agency) indicates a clear soil border. All the Ultic Palexeralfs and often Ultisols were abandoned by farmers a few years after coming into possession of the land. The development of land for irrigation in the frame of the Land Reform Act involved a major financial commitment, especially as the areas concerned were provided with costly infrastructures and services.

Satisfactory results were achieved in a few cases, in major investments for monocrops or animal raising and where projects were aimed at land reclamation to combat malaria. In these areas (for instance Arborea in Sardinia) there was no limit to the amount of money spent nor was their efficiency evaluated.

The soils formed during the Middle Quaternary period still create problems, but those of Late Quaternary age (Palexeralfs, Haploxeralfs, Rodoxeralfs, etc.) can be rendered suitable for irrigation combined with good agricultural practices.

For the Alfisols, the major limitations for irrigation suitability are permeability, poor aggregation in the upper horizons, massive structure and cementation in the deep horizons, low field capacity, and the difficulty in the choice of type of crop for similar environmental conditions.

In Mediterranean environments, many Alfisols are characterised by more or less strong carbonate accumulation conferring high base saturation to the soil and resulting in reduced illuviation. Carbonate accumulation is related to the age of the soil as is the solubility and compactness of the carbonates.

As far as suitability for irrigation is concerned, these soils are less problematic than the previous groups, unless they contain a calcic or petrocalcic, superficial and strongly cemented horizons. A detailed study of the relationship between soil-climate and quality of agricultural products, especially for irrigated crops, is recommended because of the variety of Quaternary soils in the Mediterranean regions.

The Inceptisols are commonly found on all types of substrata and landforms, and differ substantially depending on the substrata, texture, clay minerals, cation exchange capacity, base saturation, nutrient reserves, permeability, porosity, and field capacity. The variability of the properties of these soils is related to the parent material, landform, exposure, erosion, and aggregation.

The delimitation at the great group, sub group and phases level is the "*sine qua non*" condition for their inclusion in irrigable areas. Typical examples are the Inceptisols on recent alluvium (Fluventic Xerochrepts), sometimes with andic properties if Andisols are present in the area or vertic properties if the materials are clayey and calcareous.

These groups of soils occupy entire alluvial belts and are sometimes prone to flooding, however, in the Mediterranean region, they represent some of the most important soil resources, especially for irrigated agriculture. Unfortunately, these prime farmlands is often converted for urban and industrial expansion, resulting in the loss of natural resources and in serious contamination, in some cases irreversible.

The Entisols of major interest are commonly found in alluvial areas (Fluvents) or on calcareous, arenaceous, marly or clayey formations, in gently sloping or undulating landforms. The properties of Fluvents differ according to rock type of the supply basin. Soils range from sandy-gravely to clayey, with different problems of drainage or hydromorphy, such as those formed on alluvial areas close to the deltas of numerous rivers in Italy, that can be moderately saline when the aquifer contains brackish water.

The increase in the extent of saline soils (Salorthids) in coastal areas and especially near to the mouths of the rivers and streams is to be attributed to groundwater over extraction resulting in seawater intrusion and to the use of brackish water for irrigation.

The soils on recent alluvium are an important resource and measures should be taken to safeguard them from urban expansion. Italy is well aware of the economic implications of the loss of soils and the damage caused by floods (MEDALUS Project, 1998). Other Entisols of interest for irrigated agriculture can, depending on their properties, be important for particular crops and technologies. These soils do however require conservation measures, whatever the land use will be.

Andisols and soils with andic properties occupy extensive areas in the volcanic regions of Italy. The main characteristics of these soils, related to their mineralogic composition, are bulk density that influence high water retention capacity in addition to high fertility in terms of chemical nutrients.

On level ground, like for example in Campania between Caserta and Salerno, in the Premungiana Fossa in Puglia, in the Catania province in Sicily, in Latium etc., Andisols have always been one of the most important agricultural soil resources.

Compared to the other soil orders for similar climatic conditions, the irrigated agricultural productivity of Andisols is certainly far more interesting. The major issue in this case is the conservation of the natural physical and chemical properties of the soils that can be achieved using appropriate irrigation technologies and systems.

Vertisols are also commonly found throughout the Mediterranean and have formed on a variety of rock types and landforms: recent alluvia, basalt, calcareous marly formations of Miocene and Quaternary age, Pliocene clays, etc. The most salient properties of these soils in terms of irrigation suitability are: high expandable clay content; low permeability of wet soil, high field capacity, high bulk density. In spite of being highly fertile in terms of chemical nutrients, these soils do have some problems as far as infiltration velocity and physical properties are concerned.

Soils maps and irrigation suitability

Soil maps represent the spatial distribution of soils and serve as the basis for the interpretation of the different types of land use. It is important that these maps are not only used by the experts in soil sciences, but they should contain all the soil and environmental data required for practical applications.

One of the most important applications of the soil maps is to determine the suitability of soils for irrigation. In the past the problem was approached by examining the main properties of the soils, their productivity for specific crops and for determining the type of crop to be cultivated in compatibly with the climatic conditions.
The basic characteristics were:

- water/soil relationships;
- determination of irrigation water requirements;
- uptake of water by plants;
- root expansion in the soil;
- salinity and leaching requirements;
- water quality and relationship with the soils;
- reclamation of soils with specific problems;
- management;
- monitoring for changes in soil properties over time (structure, aeration, permeability, erosion resistance, climatic properties,etc.); and
- monitoring of organic matter, fertilisation, etc.

A continuous correlation between the control of the changes in soil properties and the quality and type of soil in terms of taxonomic classification does not always exist. This correlation is of major importance at whatever scale is used and for the different purposes for which the soil map is used.

Clearly, the greater the detail required, the more problematic is mapping with regard to irrigation suitability. For this reason a major effort should be devoted to collecting as much information as possible. Computerisation of the data gathered and their organisation into a data base will facilitate handling the large amount of information and allow correlation with other land related data, essential for different objectives. Soil science in the third millennium should be oriented towards the production of these documents.

Irrigation and water availability

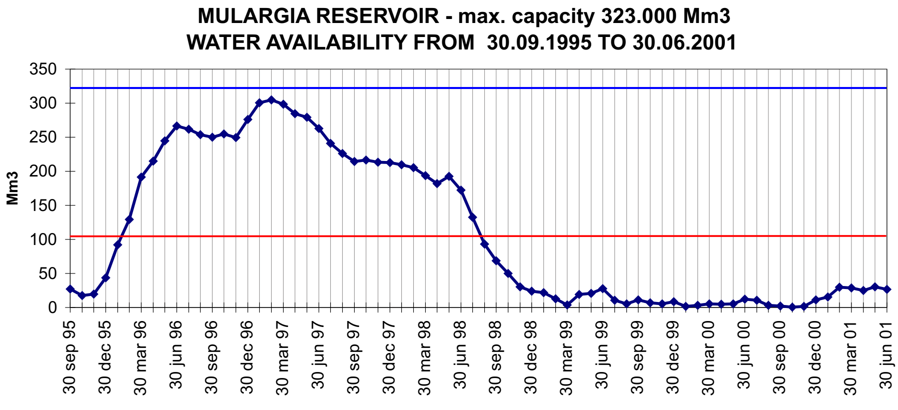
As mentioned earlier, until a few decades ago, the planning and design of irrigation projects was based on the cost of water conveyance. Many projects were unsuccessful because there was an inadequate knowledge of the soils and of their irrigation suitability and not because of the scarcity of water for all users. There is no doubt that the decrease in rainfall in latter years and the irregularity of surface water runoff has been accompanied by an increase in water consumption in all sectors.

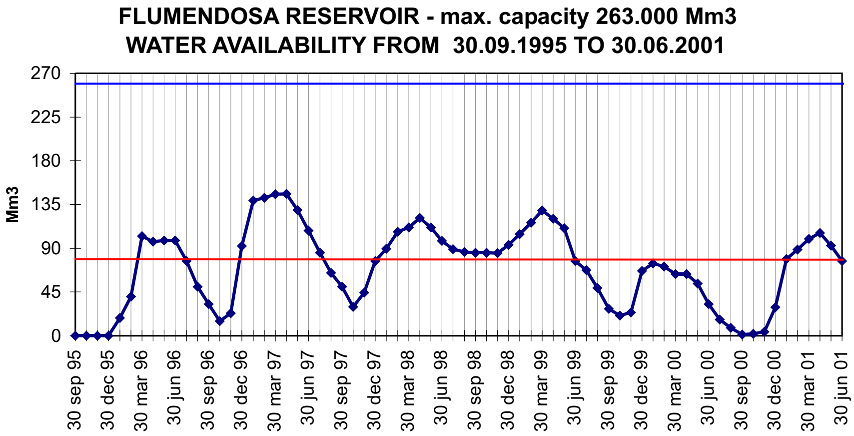
In the past, irrigation planning relied on the constant availability of water. Domestic water demand increases from one year to another. In the Mediterranean coastal regions, tourism is growing steadily and water requirements likewise, uncontrolled groundwater abstraction has caused salination of aquifers, industrial expansion has been matched by increased water demand. All these factors create conflicts over water use.

The irregular precipitation in Mediterranean in recent decades has resulted in the need to irrigate crops in winter and spring. Because of irregular surface runoff many reservoirs remain empty or well below normal capacity to the extent that they are no longer able to guarantee water supplies to meet the basic needs. The case of Sardinia, which typifies the situation in most other Mediterranean regions with a more arid climate, is particularly interesting.

The Flumendosa water system is the most important on the island and comprises four reservoirs: Flumendosa, Mulargia, Simbirizzi, Basso Cixerri with a capacity of 263, 323, 30, 25 million cubic metres respectively. The water is used to satisfy domestic demand for an estimated 700,000 inhabitants, the tourist related water demand along the south coast for an estimated population of 300,000, industrial (predominantly petrochemical) and agricultural demand for an irrigated area of around 57,000 hectares.

The diagrams for the reservoirs show the inflow from the end of September 1995 up to June 2001. During that period the Flumendosa Lake never filled to maximum capacity, the volume of water falling practically to zero in 1999 and 2000. The Mulargia Lake has been practically empty since 1998 while the Simbirizzi reservoir contains some water as it collects the surface runoff not used throughout the year. Similar situations are encountered in other reservoirs with the exception of those in North Sardinia.





The diagram in Fig. 3 clearly shows the current water deficit for the Flumendosa system for the different water uses.

As far as agricultural use is concerned, with respect to demand over the last five years there is a deficit of 62.3%, against 48.8% for the entire system (Fig.4).

The inclusion in the system of treated wastewater from the municipality of Cagliari has reduced the total deficit from 48.8% to 34.8%. If we examine the inflow year by year the situation that emerges is dramatic.

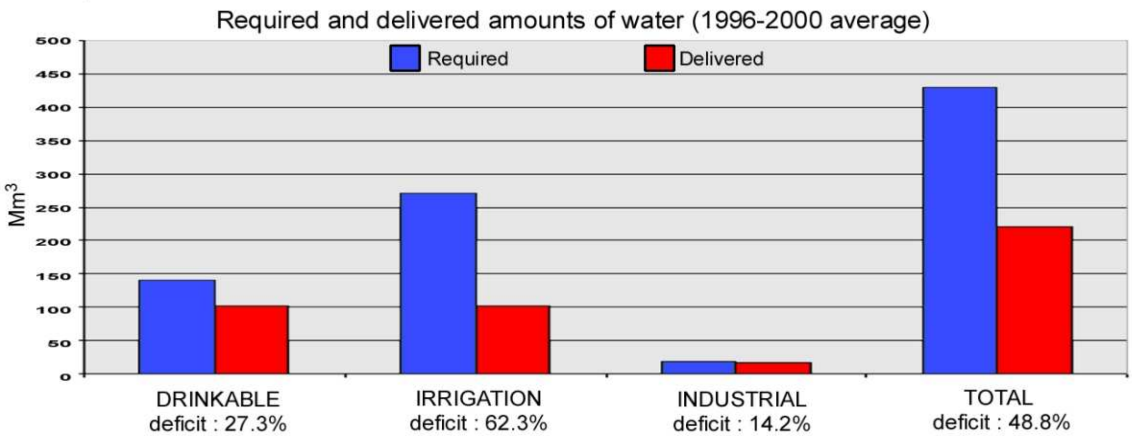


Figure 3. Deficit in the Flumendosa - Campidano - Cixerri water system

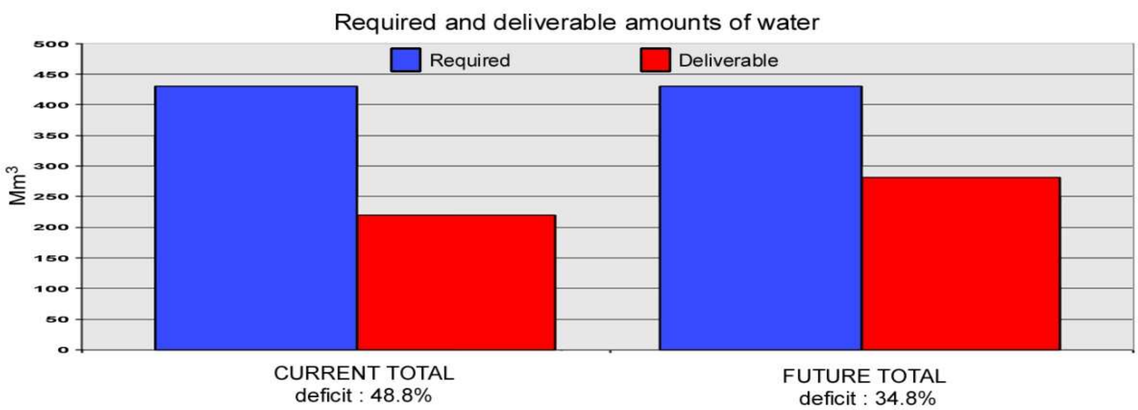
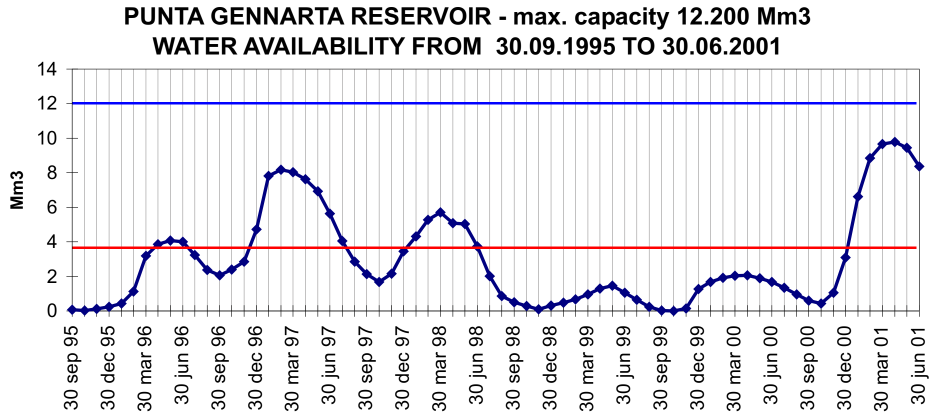


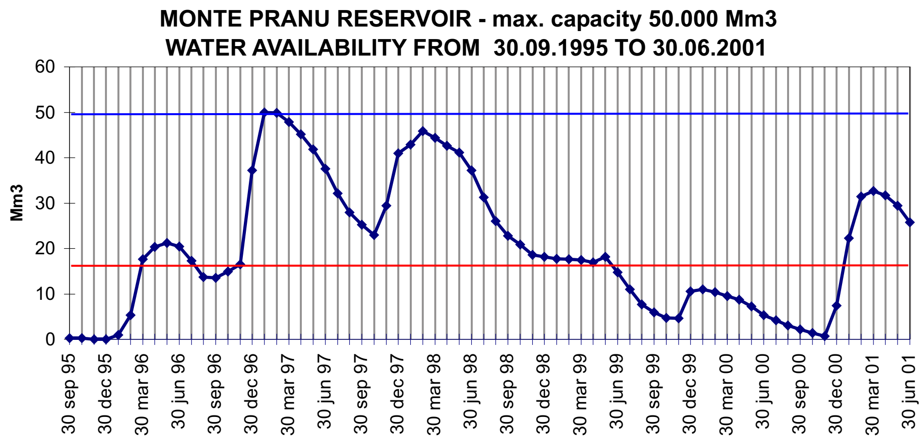
Figure 4. Deficit in the Flumendosa - Campidano - Cixerri water system

A similar trend is observed in the other reservoirs comprising the Flumendosa-Campidano system, except for the Simbirizzi reservoir which receives excess irrigation water and the Basso Cixerri into which flow the (untreated) waste waters from five municipalities (Iglesias, Villamassargia, Musei, Domusnovas, Siliqua). The Flumineddu reservoir registered a deficit from September 1996 to February 1999, and another deficit again in 2000.

Another striking example is the Punta Genarta reservoir in SW Sardinia that only filled to maximum capacity in the first years after its construction. The extent of the water deficit from 1999 to date precludes the use of water for irrigation. The scarce water available is used for domestic supplies. From July 1998 to 2000 the reservoir was practically unused.



Similar considerations hold for the Monte Pranu reservoir, situated in the SW that again has seldom reached maximum capacity. Between 1998 and 2000 the deficit reached a peak and rrigation water supplies were suspended.



The largest reservoir on the island is situated in central Sardinia and has a capacity of over 400 million cubic metres. From July 1996 to July 2000 it was unable to satisfy water requirements to irrigate an estimated 35,000 hectares.

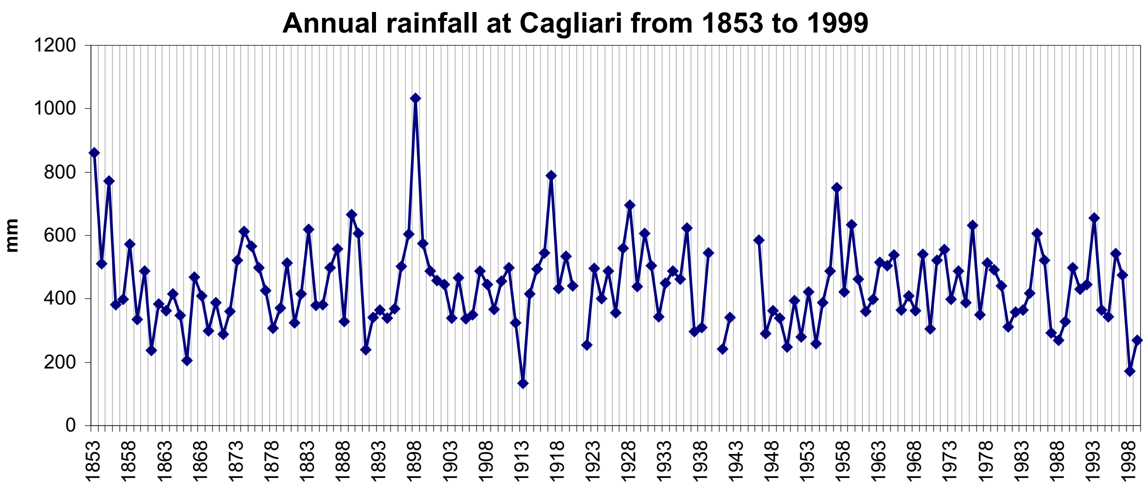
In the north of the island the situation is somewhat better, though it remains dramatic especially in the NW. From July 1997 to November 2000 the reservoir on the River Temo, with a total capacity of 59 million cubic metres, has been affected by prolonged drought.

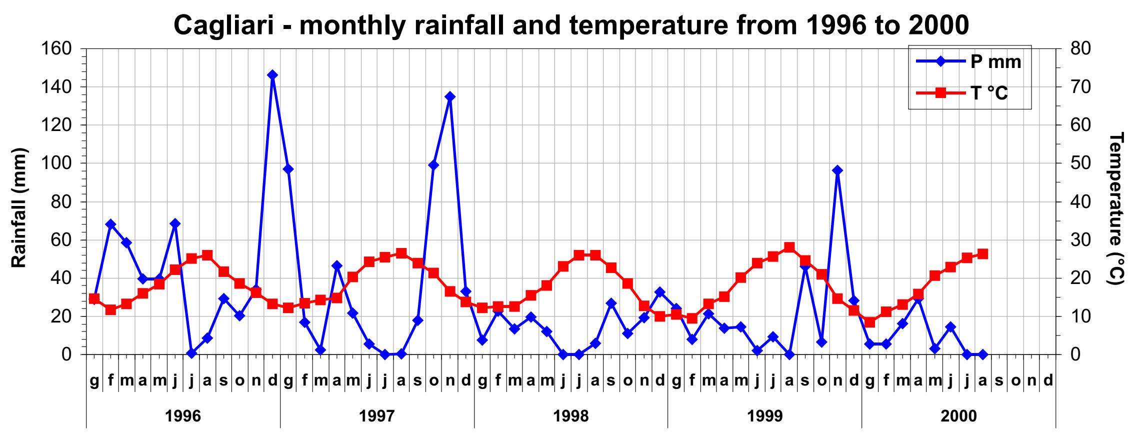
The above considerations are more or less true for the more typically Mediterranean regions. In fact, irregular precipitation is a peculiarity of the Mediterranean climate where mean rainfall is of little significance for evaluating irrigation water availability.

This aspect is not, at least for the time being, indicative of climate change but it does highlight the strong variability of the climate in this region. Examination of the historical climate data for Cagliari (Sardinia) shows a very irregular trend for precipitation over the last 150 years.

These data suggest that in southern Sardinia recurrent drought has occurred during this period without any periodicity. Examination of precipitation and temperature regimes with normal consequences on evapotranspiration, show that drought can occur in different months of the year, in other words the water deficit can occur even during the winter.

The data recorded show that in 1998-2000 precipitation was low even in January and February, meaning that irrigation of the crops was required wherever possible.





Remarks and Conclusions

Precipitation. The considerations on climate have highlighted the extreme variability in terms of both annual precipitation and monthly means. The pattern of precipitation is highly irregular, as is the occurrence of extreme events. Data provided by the Ente Autonomo del Flumendosa and the other water authorities does not show a trend towards increased aridity, anyway the observation period is not sufficiently long to demonstrate a climate change. What is certain is the periodicity of aridity (2-3 years) that is recurrent and which is well documented.

This fact obviously affects surface runoff and inflow into reservoirs, which varies considerably in the period examined. With current management strategies water supply is calculated on the amount stored in the reservoirs, whatever that may be. Available data show in fact that by autumn the reserves have been depleted. Considering that severe drought continues, and recurs, for 1, 2 or 3 years, it is understandable that irrigation water availability is constantly jeopardized.

Based on this, land use planning is impossible without proper agricultural planning, and without taking into account the periodicity of drought. As drought can also occur in the winter months, action needs to be taken to compensate the water deficit also during autumn, winter and spring. Moreover, the water deficit in winter and spring has far greater ecological and economic implications than the deficit in the summer months. As a matter of fact, the profitability of water used for irrigation would be much greater than for the summer crops.

Conflicts over water use are exacerbated in periods of drought. Water demand is increasing in all sectors of human activity. Urban expansion, the steady growth of tourism, and the industry and trade sectors have heightened the competition with agriculture for water. As often happens, priority is given to the more profitable water uses, to the disadvantage of agriculture.

The imports of agricultural products from the poorer countries, has resulted in a decline of interest in agriculture from the economic standpoint by the more developed countries both in the absolute and in the relative sense.

At this juncture, some conclusions could be drawn as to which extend the soils should be used for irrigated agriculture in the more developed Mediterranean countries, especially in the coastal areas. As the reduction in water availability is anticipated, three solutions could be proposed:

- Assure irrigation water for winter crops;
- Irrigate the soils with highest suitability for summer irrigation, especially cash crops;
- Enhance interest in quality products and introducing a protection policy, for instance for market garden produce.

In this frame, clearly not all soils can be used for growing irrigated summer crops. In Mediterranean regions strongly weathered soils with poor mineralogical, chemical and physical properties (for example Ultic Palexeralfs) and extremely shallow soils (Lithic

Xerortents) should not be irrigated in summer, whereas no difficulties are encountered for the other soils (Andisols, Vertisols, Fluvents) that yield high profits.

Thus the regular supply of irrigation water needs to be assured. This could be achieved by correct management of reservoirs, conserving at least 30% of their stored volume in order to guarantee supplies during the winter too, and by irrigating only the soils that are highly suitable for irrigation or only highly valued special crops.

References

Accademia Nazionale di Agricoltura. "Agricoltura ed Ambiente". A cura di L.Cavazza, EDAGRICOLE Bologna, 1991.

Arangino A., Aru A., Baldaccini P., Vacca S. "Carta dei suoli delle aree irrigabili della Sardegna." R.A.S.-E.A.F., Cagliari, 1986.

Aru A., Baldaccini P., Malquori A., Melis R.T., Vacca S. "Il consumo delle terre a causa dell'espansione urbana del territorio attorno a Cagliari." Prog. Fin. Conserv. Suolo, U.O. 25, Cagliari, 1983.

Aru A., Baldaccini P., Vacca A. et al. "Carta dei suoli della Sardegna scala 1:250.000 e nota illustrativa". Dip. Scienze della Terra (Univ. Cagliari), R.A.S., Cagliari, 1991.

Ente Autonomo Flumendosa (E.A.F.), Ufficio per la Tutela dell'Ambiente. Banca dati ed archivio, 2000.

FAO-UNESCO. "Irrigation, drainage and salinity", Paris, 1973.

Mairota P., Thornes J.B. e Geeson N.. "Atlas of Mediterranean environments in Europe". John Wiley & Sons Ltd., 1999.

Regione Autonoma della Sardegna (R.A.S.), Ufficio Emergenza Idrica. Banca Dati, 2000.

Thorne D.W., Peterson H.B. "Irrigated soil". The Blakistan Company, New York, 1954.

Vacca S. "La valutazione dei caratteri del territorio nella pianificazione". Franco Angeli ed., 1992.