Agriculture and Water Management Strategies in Different Climate conditions

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Awareness on the global crisis of "water supply" and "food shortage" is being raised among societies, through large conferences, activist groups or media reporting. In addition, scientific studies, data, statistics and other documentation are increasingly provided by international organisations such as the OECD, the FAO or the United Nations, addressing these issues. For example, the AQUASTAT database enables analyses of water availability and renewable fresh water resources, confirming the problems existing in all continents. At the same time, issues of food and malnutrition are closely related to natural resources and environmental problems. While some progress has been made throughout this century, around 1,000 million people suffer food or fresh water scarcity. The expected global population growth will also lead to increased water-related problems, particularly in water-scarce countries.

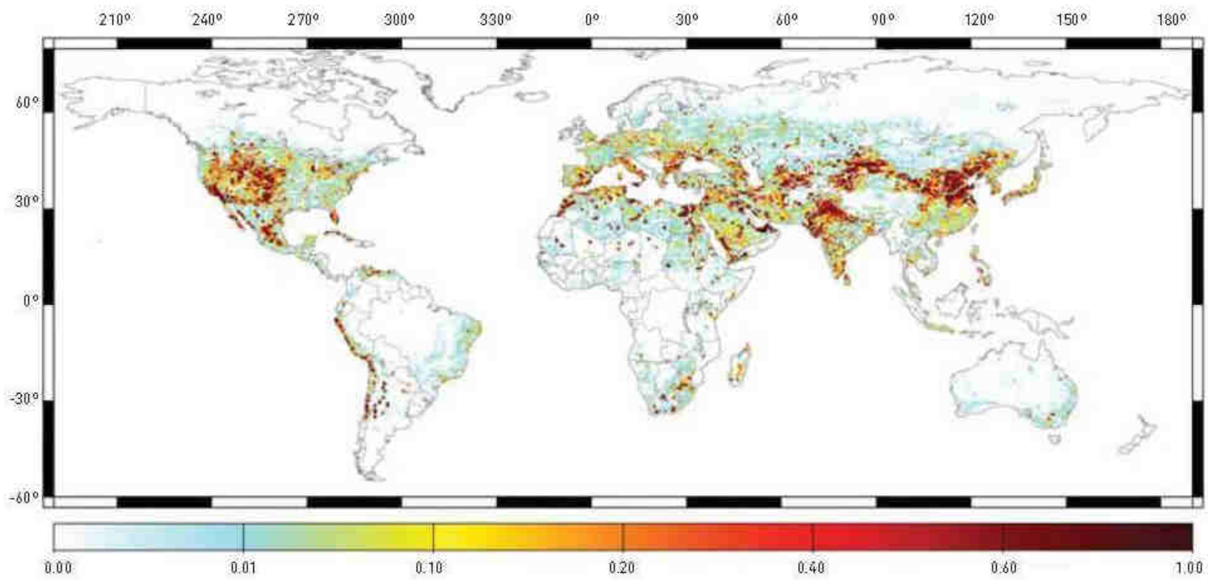
The effects of climate variability and change are relevant factors that contribute to an increase in water-related hazards. Several climate change models predict global water cycle scenarios framing more severe and persistent droughts and drier climates for areas already suffering water scarcity, such as Southern Europe and Northern Africa (OECD, 2008). Moreover, most regions with typical dry seasons are often affected by strong water cycle variations and anomalies, at seasonal or inter-annual level, resulting in uncertain precipitation patterns and evapotranspiration rates. Consequently, this leads to enhanced vulnerable conditions and risks of water supply to population. Such climate conditions are also contributing to the deterioration of ecosystems, due to the impacts of water stress resulting in lower water quality, soil degradation, decrease in biodiversity and habitats, thus affecting agricultural activities (dependent on precipitation or irrigation practices).

Water Scarcity, Aridity and Droughts

Water scarcity (WS) is a phenomenon induced by human or natural conditions reflecting the imbalance between the demand (concerning different needs) and the availability to supply water. Through a global approach, recent data suggest an increase of "physical" WS, due to reduction of precipitation and flows (e.g. related to climate change) and increasing water requirements (e.g. population growth and irrigation development, sometimes associated with lakes and groundwater overexploitation). It is worth mentioning the problem of "economic" WS, i.e. when countries have sufficient water resources to meet needs, but have to increase water supplies through additional storage, conveyance and regulation systems.

Problems of water scarcity at a global/macro-level are illustrated in Figure 1, presenting the "water scarcity index". In long-term analysis, this index reflects the balance between the annual water withdrawal and the maximum available renewable freshwater resource. One can note that the Mediterranean is particularly vulnerable to water scarcity. The situations of water deficit associated to natural factors can be identified as "aridity" or "drought". On the one hand, aridity is a permanent condition and is very often associated with long-term pressure on water use and land degradation in a region, resulting in insufficient water to supply agriculture. On the other hand, drought is defined as a temporary and recurring climatic event. Both are usually caused by low rainfall or high evapotranspiration periods, thus contributing to growing water scarcity.

Figure 1
Water scarcity index (GEO, 2010)



Detailed results of water use are being assessed (IEEP, 2001) showing that, in most Mediterranean countries, the main reason associated with water higher demand is the duplication of irrigation areas in 40 years (1961-2000). The strategies of Mediterranean countries to increase water availability and reduce water demand (particularly in agriculture) must also take into account the lack of sufficient water resources, due to the impact of dry seasons and recurrent droughts. In this context, challenges regarding physical or economic water scarcity call for improvements in water saving, efficiency and agro-environmental policy.

Annual Runoff – Renewable Freshwater Resources

Figure 2
Annual runoff (mm/year) (GEO, 2010)

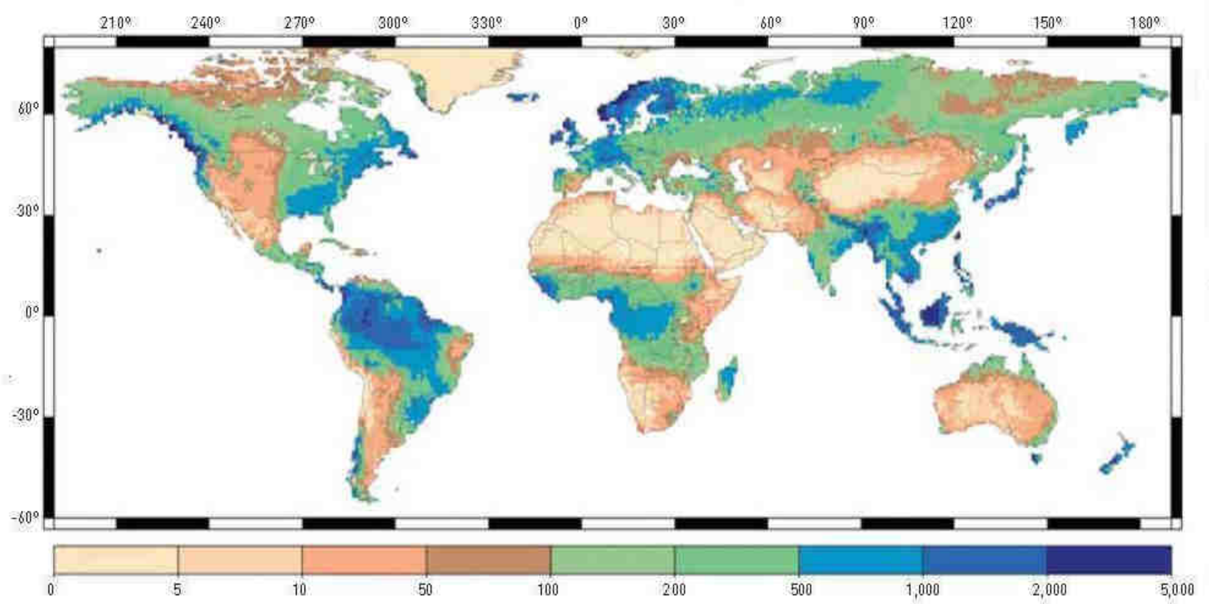


Figure 2 gives a global overview of annual runoff (RF) regimes (macro-scale), which indicate the maximum availability of renewable freshwater resources (RFR). One can observe that RFR values are associated to the RF, considering both the internal flow (difference between precipitation and evapotranspiration in national territory) and the external inflow (from neighbouring countries). There is a remarkable difference between European (except Spain) and Mediterranean African countries, as RF ranges from around 200-500 mm/year (or more) to 100 mm/year (or less) respectively. In the latter case the value is indicative of water stress conditions.

Referred to as the "water stress index", an RFR indicator (Rijsberman, 2005) is defined in terms of annual water availability volume per year and per capita. A value of 1,700 m3/capita/year is proposed as the threshold to satisfy the needs of countries (household, industry, agriculture and environment). At national level and long-term annual averages, across the Mediterranean, RFR also reflects a wide range of values, from lower than 500 m3/capita/year in islands (e.g. Cyprus, Malta) and Algeria, around 1,000 m3/capita/year in Egypt, Lebanon or Morocco, to higher than 2,000 m3/capita/year in most European countries (e.g. Spain: 2,500; Turkey, France, Italy: 3,000; Portugal and Greece: 6,500) (OECD, 2008).

Mediterranean Climate Conditions in Portugal

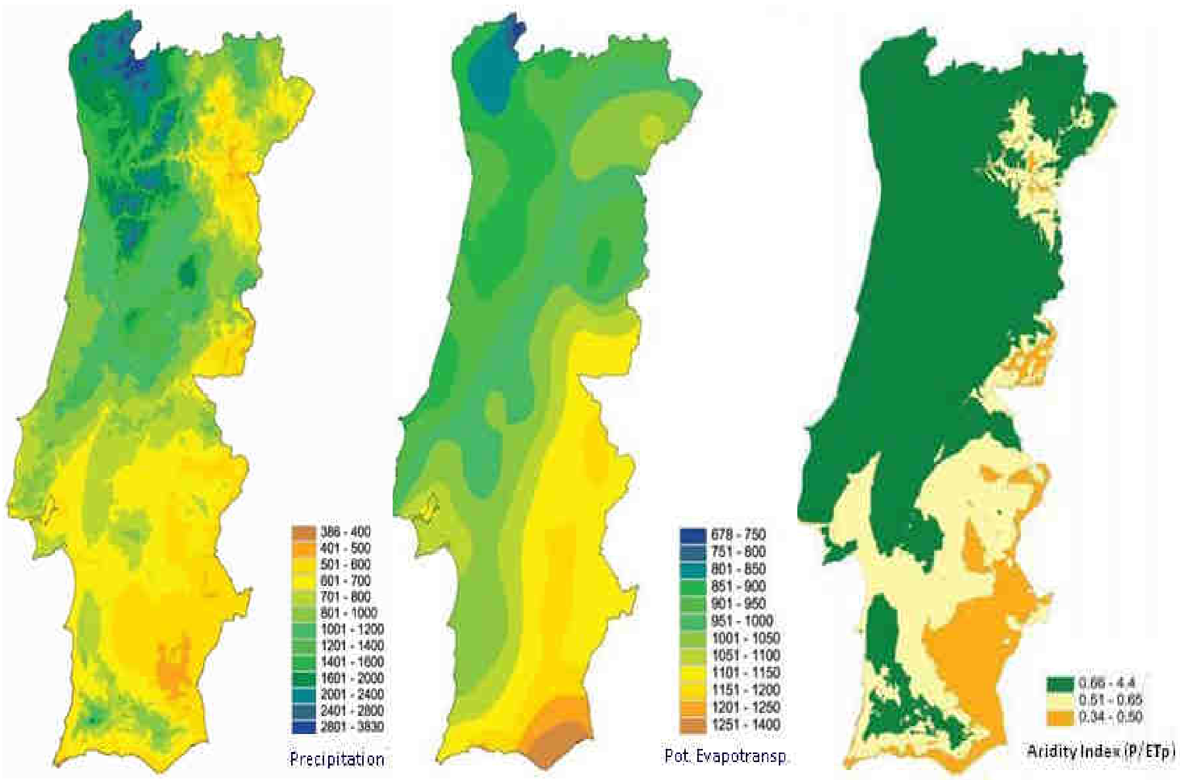
Table 1
Renewable freshwater resources in Portugal

COUNTRY	Precipitation		Internal Flow	Inflow of surface and ground waters	Renewable freshwater resources		Renewable freshwater per capita
	($m^3 \times 10^6$	- mm)	($m^3 \times 10^6$)	($m^3 \times 10^6$)	($m^3 \times 10^6$	- mm)	(m^3)
PORTUGAL	82 164	900	38 593	35 000	73 593	800	6 893

(Source: OECD, 2008)

As indicated in Table 1 displaying a summary of water cycle-related data (macro-scale), RFR of Portugal are primarily derived from the impact of the annual precipitation across the territory. It is important to bear in mind the fact that in Portugal and in other Euro-Mediterranean areas, the internal flow usually reaches 40-50% of precipitation, but in most African Mediterranean countries, the internal flow is only about 10-20% of precipitation, as a consequence of the higher magnitude of the evapotranspiration. As one can see in Table 1, the external resources (inflow of surface and ground waters from Spain) account for an important amount of water. In accordance with the presented results, RFR in Portugal exceed the widely accepted thresholds to sustain domestic/economic sectors needs (OECD, 2008). Even though in most regions, with reference to weather average conditions along typical seasonal dry periods, the precipitation and RFR values will not ensure the water availability to meet demand.

Figure 3
Components of the water cycle (P and ETp) and the Aridity Index (P/ETp) (Rosario, 2004)



Portugal (mainland) registers a mean annual precipitation of around 900 mm, but 75% is concentrated in the humid semester (i.e. October to March) and there are considerable differences between most northern and southern regions as illustrated in Figure 3 (Rosario, 2004), considering historical series (1960-90) of potential evapotranspiration (ETp) and precipitation (P).

These variables are crucial components of the water cycle and the basis for indicators applied in weather forecast, hydrology and climate change models. For example, the annual "aridity index" (AI = P/ET) may be used to establish an aridity classification, thus allowing the definition of climatic regions (UNESCO, 1979). An aridity mapping of Portugal developed by Rosario (2004) observed in Figure 3, shows three main climate classes: 1) semi-arid ("AI" below 0.5), 2) dry sub-humid ("AI" between 0.51 and 0.65), and 3) humid (a wide "AI" range above 0.65).

Regarding the approach proposed, four different typical conditions of Mediterranean climate, which may be found in Southern Portugal (Table 2) were identified by means of the "AI", ranging from less than 0.5 (semi-arid) to 1 (sub-humid).

Table 2
Climatic regions in Portugal (southern mainland) using the Aridity Index

COUNTRY	Climatic regions (Mediterranean)	P - (Annual) mm (75% Oct-Mar)	ETp - (Annual) mm	Aridity Index (P/ETp) $mm.mm^{-1}$
PORTUGAL (Southern)	A - Semi-arid	500	1200	< 0.5
	B - Dry sub-humid	600	1100	0.55
	C - Sub-humid	700	1000	0.7
	D - Sub-humid	1000	1000	1.0

Water Management and Irrigation in Mediterranean Regions

Mediterranean regions are characterised by a wide diversity of soils reflecting differences in climate, landscape and the long-term influence of human activities. In this regard, one major concern is the potential impact of climate change to increase the intensity and frequency of extreme meteorological events, contributing to vulnerabilities in water cycle processes and negatively affecting soil-water-plant systems (e.g. intense runoff, erosion and loss of organic matter and crops).

Despite the fact that Southern Portugal may be considered as a small area, biophysical indicators (related to soil, climate, vegetation and land use) present a large variability and crosschecking of data suggests that more than 50% of this area is susceptible, or highly susceptible, to desertification (Rosário, 2004). It is significant to note that many watersheds (often with shallow soils and low organic matter) include high-risk zones of soil erosion due to the occurrence of heavy rainfall following a dry period. Beyond the "AI" differences (Table 2), all the climatic regions selected are subject to dry periods, thus requiring irrigation. The implementation of irrigation practices must account of the site-specific biophysical conditions, associated to the water cycle. Consistently, irrigation is somehow an artificial component of the local water cycle, when its conditions are not ensuring enough water to crop requirements. The prediction and evaluation of the normal seasonal dry periods or drought events are basic steps to establish an irrigation plan and scheduling guidelines (when and how much irrigate), considering adequate time scales, namely, on a daily or a weekly basis.

Pursuing the objective of establishing appropriate water management solutions, this study provides a set of data in Table 3 (reported to climate conditions described in Table 2) concerning seasonal conditions, that can be used to support decisions regarding irrigation.

Table 3
Irrigation requirements with respect to climatic regions (typical in Mediterranean countries)

COUNTRY	Climatic regions (Mediterranean)	Dry Period (Summer) days	A - Ps (seasonal) mm	B - ETps (seasonal) mm	B - A (≈ Irrig. Req.) mm
PORTUGAL (Southern)	A - Semi-arid	90	< 50	600	600
	B - Dry sub-humid	90	< 50	550	500 - 550
	C - Sub-humid	90	< 50	500	450 - 500
	D - Sub-humid	90	< 50	500	450

The selected climatic regions are initially characterised by their summer season (dry period). During this period, water budgets can be developed by simulating the precipitation and irrigation events that replace the soil water deficit. It must also be noted that ETp (or ETo - Reference crop evapotranspiration) for a given period can be associated to the consumptive use of water by plants. However, considering its illustrative purpose, some procedural simplifications were adopted to determine potential irrigation requirements, as a first approximation, thus they were not taken into consideration: 1) the irrigation system application efficiency (to determine water gross requirements), 2) the crop coefficients affecting ETp/ETo (to determine the ET variation during the crop development) 3) the initial soil water level, 4) the effective precipitation.

In all regions, one can observe that the seasonal precipitation - P(s) is always very low and the seasonal potential evapotranspiration - ETp(s) is 50% of the annual value. The difference between P(s) and ETp(s) was used to predict general irrigation requirements. Considering the proposed approach, the final results ranged from 450 mm, within sub-humid regions, to 600 mm, in semi-arid regions.

Agriculture Strategies and Best Practices

Various strategies and actions adressing water management and agro-environmental issues must be adopted in the framework of overall Mediterranean objectives and policies in order to face increasing vulnerabilities and risks related to dry seasons, droughts and climate change. For instance, weather forecasting reporting also return periods, based on historical trends and probability distributions of climate variables and warning services regarding irrigation management plans. In addition, to support a water supply planning, regarding the water balance associated to rain-fed and irrigation practices, the quantification of water cycle variables must be considered.

At farm level, solutions to water management must be based on a detailed knowledge of site-specific data. A preliminary inventory of soil, plant and climatic local conditions will contribute to reliable decisions. All design and management options shall solve potential conflicts concerning technical, environmental and socio-economical issues, in order to reconcile sustainability and competitiveness standards. In this scope, this study addresses the following recommendations to farmers and technicians concerning the effectiveness of practices related to irrigation:

- Ensure the suitability of plants to soil-water quality regulations and thresholds;
- Grow varieties properly adapted to water availability, promoting a beneficial water use efficiency;
- Schedule and control irrigation amounts and intervals, all along crop stages (with specific requirements), and according to the management allowed deficit (MAD) and local forecasting of evapotranspiration and precipitation to avoid deep infiltration or water logging. Avoid irrigation during the warmest hours of the day;
- Select irrigation systems (if pressurised) considering the relationship "application rate-soil infiltration capacity".
- Evaluate options of rainwater harvesting and storage systems. Thus, it will be necessary to design artificial structures or basin areas where rainwater falls, and develop alternatives of specific facilities (e.g. reservoirs, ponds, pipes and pumps) to divert, collect, storage and distribute water, based upon detailed calculation of parameters (e.g. area, volume, height, length, pressure).
- Heavy irrigation or rainfall events may lead to soil saturation. The occurrence of water logging and surface runoff will cause damages in plants (drowning crops, diseases, root asphyxia) and soil (erosion, lack of aeration). Drainage layers, drain holes, perforated drain pipes and systems of channels are currently available technologies to help reduce soil-water problems and some of them may also provide the possibility for diverting water to storage infrastructures. Other practices to prevent soil-water status deterioration involve crop management (mulching, crop cover);
- Implement practices of water reuse or deficit irrigation to save fresh water;
- Check potentialities of alternative energy sources to improve water-energy nexus;
- Install soil sensors to monitor allowable water deficits;
- Consider the periodic evaluation of irrigation systems and other equipment systems to ensure high operational performances.

Conclusions

Agriculture resilience in countries around the Mediterranean Basin is increasingly associated to practices, which are able to cope with climate uncertainties and vulnerabilities, thus ensuring sustainability and competitiveness standards. Authorities, technicians, farmers and other stakeholders are facing new challenges. Options and strategies related to water management are revealing the extreme importance of climate issues, particularly because droughts and water shortage periods are expected to increase in terms of frequency, intensity and extent. Advanced and integrated water management solutions must involve engineering, agro-environmental and socio-economic issues.

In addition, it is relevant to adopt services, with accurate data and information from a macro/global scale to the micro/local scale, to improve the effectiveness of water related projects (e.g. catchment, storage, treatment, distribution and application), in particular when water use is restricted. Regarding main research fields related to resources conservation (soil, water, land cover, energy) and environmental protection, INIAV is developing research to bring answers with respect to degradation and risk questions, approaching the water cycle/balance at farm and watershed scales.

Institutional regulations and policies developed by CIHEAM countries must integrate water management, climate change and agro-environmental issues. Besides, several steps are identified to increase the participation of civil society and the responsibility for water management, such as training and learning programs or the promotion and dissemination of methodological tools and procedures (e.g. Decision Support systems, Benchmarking) to evaluate both economic and non-economic value of water.

Bibliography / More information

- GEO. 2010. Crafting geoinformation. Group on Earth Observation. GEO Secretariat, Genéve, Switzerland
- IEEP, 2001. The Environmental Impacts of Irrigation in European Union. Report to the Environment Dictorate of the European Comission. Institute of European Environment Policy. London
- OECD, 2008. Towards sustainable agriculture. Contribution to the United Nations Commission on Sustainable Developme n°016
- OECD. 2008. Total renewable freshwater resources. Environmental Data Compendium, Inland Waters section. OECD. Paris.
- Rijsberman, F.R., 2005. Water scarcity: Fact or fiction? Agricultural Water Management, 80 (2006) 5-22.
- Rosário, L. 2004. Indicadores de desertificação para Portugal Continental. DGRF. Min- Agricultura. Núcleo de desertificação. Lisboa, Portugal
- UNESCO, 1979. Map of the World Distribution of Arid regions. MAB Technical Notes, 7, UNESCO, Paris.