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SUSTAINABLE WATER MANAGEMENT UNDER CLIMATE CHANGE

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1. Abstract

Water, that is often the main limiting factor of plant growth, is also the main factor directly or indirectly responsible for soil and land degradation processes. These processes affect the conservation of the increasingly scarce soil and water resources, because they are strongly linked to unfavorable changes in the hydrological behavior affecting soil water balance and soil moisture regime. They are related to soil and climate characteristics, but inappropriate land use and soil and water management are the main factors responsible of those processes. The previewed effects of global climate changes would mainly affect hydrological processes in the land surface mostly related to the soil water balance. Soil water management, both under dry-land and irrigated conditions, may affect more the soil hydrological processes than the previewed climate changes, or may increase the influence of those changes on soil degradation processes. In any case it is important to include the effects of climate change in the performance of current or planned water management systems. Weak knowledge of the hydrological processes involved, generally associated to the inadequacy of methods for assessing and monitoring such processes, including the use of pedo-transfer functions, has usually hampered the adoption of adequate integral soil and water management policies for prediction and prevention of soil and water degradation of soil and water resources in situ and related effects like surface and groundwater contamination, droughts, flooding, landslides, sedimentation, etc. To avoid these failures there would be required non empirical modeling approaches, mainly based on soil hydrological processes together with rainfall records, under different scenarios of changing climate, soil properties, topography, and land use and water management. Simulation models based on hydrological processes allow to integrate and to convert the measured or estimated soil, climate and management parameters into predicted soil water balances and soil moisture regimes for each particular combination, actual or previewed, of them. Those models must allow to incorporate potentially significant and highly uncertain information about potential climate change. Such approach has been applied to the evaluation of the effects on the soil water balance and soil moisture regime, associated to new land and crop management systems, ant to the previewed climate changes, in dry-land and irrigated vineyards for quality wine production in NE Spain. The generated information has been used in planning strategies for land use, and in the selection of the soil and water management practices, based on probabilities of success, levels of risk and long term sustainability. Special attention is given to the water use efficiency, under the semiarid Mediterranean climate, with low and very variable and erratic rainfall, and with scarce availability of water for irrigation, in relation to the production, both in quantity and quality of grapevines and wine. The management strategies may be evaluated against different scenarios of changing climate conditions, taking decisions after assigning probabilities to each scenario and weighting the results.

Water management, climate change, hydrological processes, sustainable management, soil degradation

2. Introduction

Together with population growth and increased water demands, long term climate change is adding uncertainty to water resource planning and management. Global climate changes may alter the quantity and timing of local and regional precipitation that will affect the water supply, water quality and flood management. These effects must be understood as much as possible for guiding future planning of water resource management. Major recent water-related disasters including both floods, landslides and extensive droughts are reminders of both the destructive power of water and the tragic consequences associated to the lack of it in many regions of the World. These extreme events are only the final consequences of changes in land use and management that are affecting the soil and water resources, under very different climate and land conditions. In some cases these effects may be linked, at least partially, to global climate changes. The previewed climate changes may also affect water availability, because there is a strong link among soil degradation, climate change and water resources (Gleick, 2003; Milly et al, 2005). The predictions are more runoff from rain, hotter and drier summers, leading to more flooding and more frequent droughts. (IPCC, 2007; Easterling et al, 2000)

Changes in population, both in total number and distribution, are also strongly affecting the quality and quantity of the available freshwater, and the land use and management. To the increased demand of water for agriculture there must be added the demands for urban and industrial uses and for energy generation. Global warming would affect water supplies and share of those supplies among competing interests. Water resources must be managed not only to satisfy people direct needs, but also for nature conservancy. The combination of different economic, environmental and social pressures often results in increased water use competition and pollution, generally associated to inefficient water supply practices. As a result, in many parts of the world available quantity of water is decreasing and quality is worsening. About 1/3 of the world population suffer from deficient supply in quantity and quality of water, and about 900 million people do not have enough food and water for a healthy life (FAO, 2008; Brown, 2004).

Climate, especially precipitation and temperature, is the primary driver of water resources, interacting with land and topography. Yet, all components of the hydrological cycle (precipitation, infiltration, runoff, evaporation and transpiration) must be taken into account for water management planning. It is very important to understand the role played by each of those components. Changes in land use and management, associated to deforestation, urbanization and increase or abandonment of farmland, all significantly influence the soil and water resources, moreover than the effects of climate change. Besides, the river regimes are being influenced in many regions of the world through construction of dams and diversions. All these changes makes more difficult to predict the future impacts of climate change. Soil management practices strongly impact quality of surface and ground waters, because chemical characteristics of soils, and the application of chemical fertilizers, manure, and other chemicals affect the quality of water flowing over and through it. In the increasing water scarce regions of the world, the necessity of reuse for irrigation of treated waste, polluted water, also impacts quality of water and soil resources. In any case, increase in water efficiency should be a water management approach to future climate change impacts (NRDC, 2007).

With a growing population, the available land and water resources per capita shrink, and higher productivity is required to compensate. On average it takes about 3000 liters of water per person to produce the daily uptake of food (Brown, 2004). Although rain-fed agriculture is still dominating in the world, irrigation is required as a reliable supplement of rainfall where soil moisture is insufficient to satisfy the needs of the crops, especially in areas with excessive climate variability (probably accentuated by the previewed climate changes), or where multiple cropping, looking for increased productivity, requires provision of water outside the rainy season (Schmidhuber et al, 2007). The amount of water available to agriculture is now being progressively limited by degraded land and water systems, competition from other economic sectors, and by climate change in some regions (Fischer et al, 2002). While agriculture is the larger user of freshwater, there is growing competition from industrial and urban users (Gleick, 2003)**.** To alleviate the increasing burden on available freshwater resources there are needed prevention strategies and new technologies that increase existing natural water resources, reduce demand and achieve higher use efficiency. Water re-use and desalinization and harvesting rainwater are some of the potential methods to increase the availability of water resources. Soils are complex porous media that are highly relevant for the sustainable use of water resources They are the essential basis for agriculture, but they also act as a filter for clean water, and depending on soil properties, affected by land use and management, they reduce or intensify surface runoff and thus susceptibility to erosion, floods and sedimentation (SWCS, 2003). Additionally, the interaction of soil water with the atmosphere and the related energy flux is an important part of modern weather and climate models. Soil resources will have to be managed to enhance water use efficiency, denature and filter pollutants, enhance aquifer recharge, and improve water quality and yield from protected watersheds. Water conservation practices can generate not only benefits for water supplies, but for reducing energy consumption and greenhouse gas emissions. Future planning of water management must also consider extreme events such as droughts and major flood events, which climate modeling indicate that are likely to become more frequent and intense in the future (Easterling et al, 2000).

3. Climate change and water resources

Integrated water management approaches to climate change response must consider multiple benefits, including supply, water quality, energy, flood management, and ecosystem benefits. Water management strategies considering global warming effects shoul include:

- Agricultural water conservation
- Saltwater groundwater intrusion
- Floodplain management
- Ocean water desalinization

In any case, to improve the strategies and the efficiency in the use of the available water resources there is required a better understanding of the hydrological systems, and of the regional and local water balance estimates. Quantifying the hydrological balance at high temporal resolution is necessary to evaluate field-scale management effects on soil water storage. This requires an accurate modeling and prediction of soil water dynamics, which especially at large spatial scales, is complicated by the heterogeneity of soils and changing topography. It is further limited by a severe decrease of the basic hydrological data collection, owing to economic problems, budget constraints and lack or deficiencies in professional education. As an alternative there have been used empirical models, using pedo-transfer functions, to estimate the required soil hydraulic parameters from other available or easily measurable soil properties. With a general lack or incomplete set of reliable and consistent data of subjects relevant to soil water balance, large scale simulations of water dynamics in soil may be imprecise to completely wrong (Pla, 2006).

Among the most significant consequences of climate change will be impacts on the hydrological cycle (IPCC 2007). As the climate changes, among the hydrological impacts will be changes in precipitation intensity and duration, and a risk of both more floods and droughts. The previewed effects of global climate changes would mainly affect hydrological processes in the land surface, mostly related to the soil water balance. In terms of ecological and social impacts of climate change, changes in moisture availability are more important than changes in precipitation alone. Low levels of moisture availability are associated with droughts and desertification. Reductions in mean annual rainfall leads to drier conditions, but increase in climate variability during the year, or increasing frequency of very dry years, could be equally or more important.

Climate change is only one among several different change factors, like increasing population and especially urban populations, growing per capita water use, and land use and management changes, causing large, and sometimes disastrous changes in the water resources. In the last century the human water use has increased six times, while the population has increased only three times. Human activities leading to land degradation processes may affect more the soil hydrological processes than the previewed climate changes, or may increase the influence of those changes (Pla, 2002). Forests usually regulate stream flows, protect land from erosion, reduce flooding in adjacent areas, minimize the silting of rivers, canals and dams, and contribute to a stable hydrology essential for providing stable sources of water for human needs and irrigated agriculture. This water balance may be drastically upset by the consequence of inappropriate changes in land use and management, and especially by the resulting land degradation. Supply of available water may decrease irreversibly under unchanged soil properties and stable hydrological soil parameters due to reduced water income, increasing water consumption, or both. Under unchanged water income by rainfall, the hydrological parameters of soils may change irreversibly as a result of soil degradation (sealing, compaction, erosion, decreased water retention capacity, etc), leading to the same effects of decreasing available water supply (Pla, 2006). Although the effects of a still uncertain global climate change may be important, other changes and development factors may be equally or more important at local level. Therefore, the water managers have to understand the total effects on the water resources from a range of impact factors, and not only from recent climate changes.

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinization, one of the processes of soil degradation leading to land desertification (Pla, 2006). The salinity problems are a consequence of salt accumulation in zones and depths where the soil moisture regime is characterized by strong losses of water by evaporation and transpiration, and by reduced leaching of the remaining salts. Inadequate irrigation and drainage water management is the main cause of soil salinization. The salt accumulation may conduce to a partial or complete loss of soil capacity to provide the required amounts of water to plants, changing fertile lands to deserts (Pla, 1996). Figure 1 shows an example of how the direct and indirect influences of climate change could affect the factors responsible for growth and production of different crops under semiarid Mediterranean climate conditions (Palutikof et al, 1996). The average annual rainfall of 500-600mm is very irregularly distributed, with the greatest rains in autumn-spring, a very dry summer, and very large variability in totals from one year to another (300-800 mm). Rainfall is typified by many storms in autumn, and occasionally in spring of high concentration and intensity. Climate change may increase the irregularity of this rainfall, the frequency of dry years and the probability of extreme events, phenomena that have been observed in the last 25 years. The previewed future climate changes would affect both the balance of water and solutes, and the irrigation requirements, due to the predicted decreased water supplies, increased water requirements, and decreased available irrigation water quality.

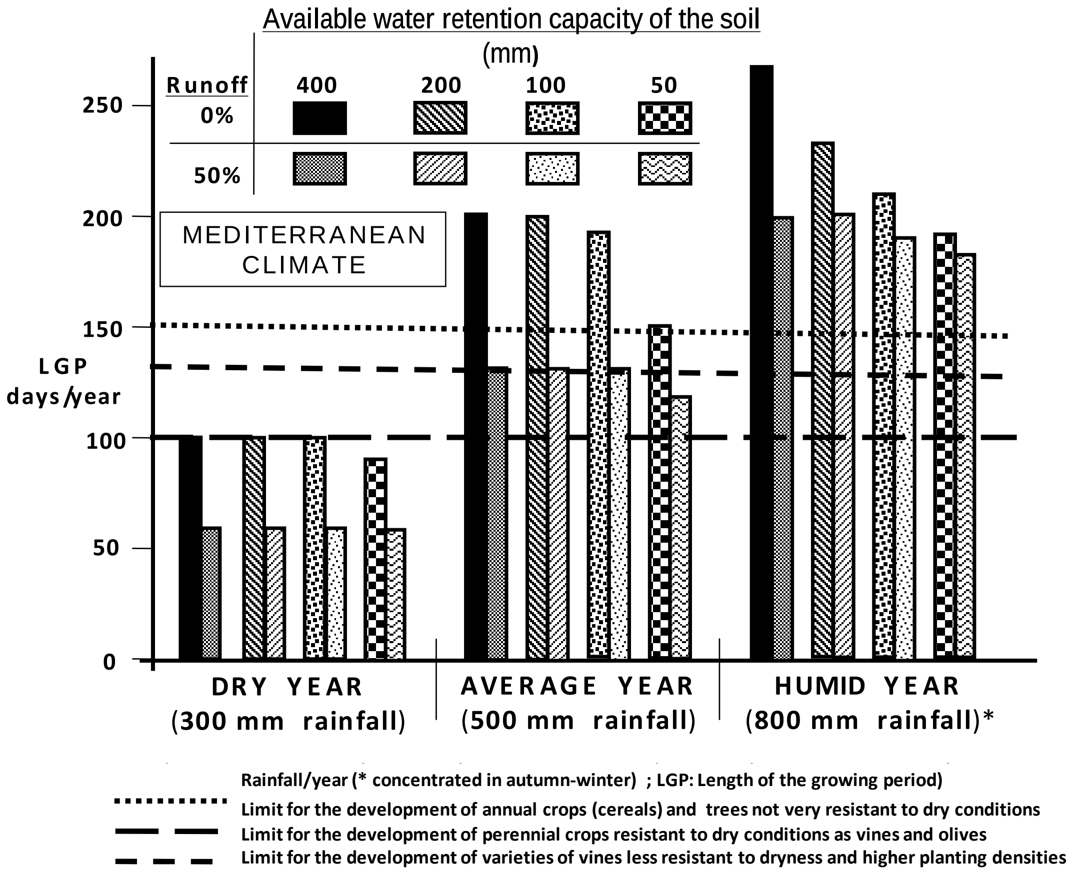

Figure 1 Potential length of the growing period in days/year (LGP) under semiarid Mediterranean climate conditions, as affected by the main critical factors derived of climate changes (increased frequency of dry years, more intense rainfall and poorer land cover increasing runoff, and higher erosion decreasing water retention capacity of the soil)

From the previous arguments, it follows that to cope effectively with climate changes and other associated effects, there would be necessary to develop diverse and flexible water resource management strategies allowing to reduce demands and to adapt water supplies to changing climate and hydrological conditions. Approaches based on water balance models are the more adequate to predict the reliability of the water supply for a plant during its growth. This would be the main basis for determining the suitability of the land for various uses under given conditions of management. There is required research into the basic hydrological processes determinant of the soil water balance, including climate and soil data. Research is also required on the hydrological changes as a result of various alternative land uses and agricultural systems and practices. The soil water balance may be quantitatively determined in terms of certain physical properties and water regime of soils (annual supply of available water in the root zone), using soil hydrological parameters (Pla 2002; 2006).

4. Planning water management under climate change

Climate conditions have to be considered for long term planning choices, design and construction of water reservoirs and supply structures, agricultural planning, urban water allocation and structures, and reservoir operating rules. Long term climate change is adding more uncertainty to the already difficult task of water resource planning and management, because the impacts of climate change on the water resources will be very complicated and at least partially unpredictable. Nowadays water planning and management generally relies on the assumption that the future climate would be the same as the past, without considering future human-induced climatic conditions. Studies have shown that it is important to include the effects of climate change in local water planning, seeking to link present day planning decisions to uncertain future climate projections (IPCC, 2007; Groves, 2008)). This would require the adaptation to new hydrological conditions of existing and planned water management systems, under a wide range of future climatic conditions changes, and no just to past climatic variability. In general there would be required policies, strategies and investments to create sustainable water management systems adapted to the climate change, to assure sustainable water supply for the different uses, and sustainable food, forest and other land-based production (NRDC, 2007; FAO, 2008). Additionally, they have to consider how the timing, amounts and form of precipitation derived of the climate change will exacerbate extreme events such as droughts, landslides and major floods.

Therefore, an adequate planning of soil and water management requires a good understanding and prediction of the interaction between climate characteristics and soil properties, under different scenarios of changing climate and changing land use and management practices and systems. These complex interactions may be integrated over time using simulation modeling based on hydrological processes. The generated information may be used in planning strategies for land use, and in the selection of the soil and water management practices, based on probabilities of success, levels of risk and long term sustainability. Models must be based on well established cause-effect relationships for prediction, and flexible enough to be able to include the variety of possible soil-climate-use and management situations, and to be constantly improved as more is known about the characteristics of the previewed climate changes and their influence on the soil water balance and derived soil and water degradation processes.

The flow diagram of figure 2, showing the relations of climate change and water management with soil degradation processes and related disasters based on hydrological processes, has been used as a basis for a flexible simulation model (SOMORE) (Pla, 1997, 2006) accomplishing those requirements. This simulation approach has been successfully tested and used in planning strategies for land use, and in the selection of the soil and water management practices under different and variable climate, soils and water management in tropical and Mediterranean conditions (Pla 1997, 2005, 2006). In any case, simulation modeling requires data collection, updating of information and monitoring. Poor, incomplete and inaccurate basic data on soils and climate would result in poor planning of soil and water use and management. The analysis itself by models does not add any new information, and when it is based on empirical statistical approaches developed for different soil and climate conditions, using pedo-transfer functions to substitute non available local data, it may lead to gross inaccuracies and misinterpretations.

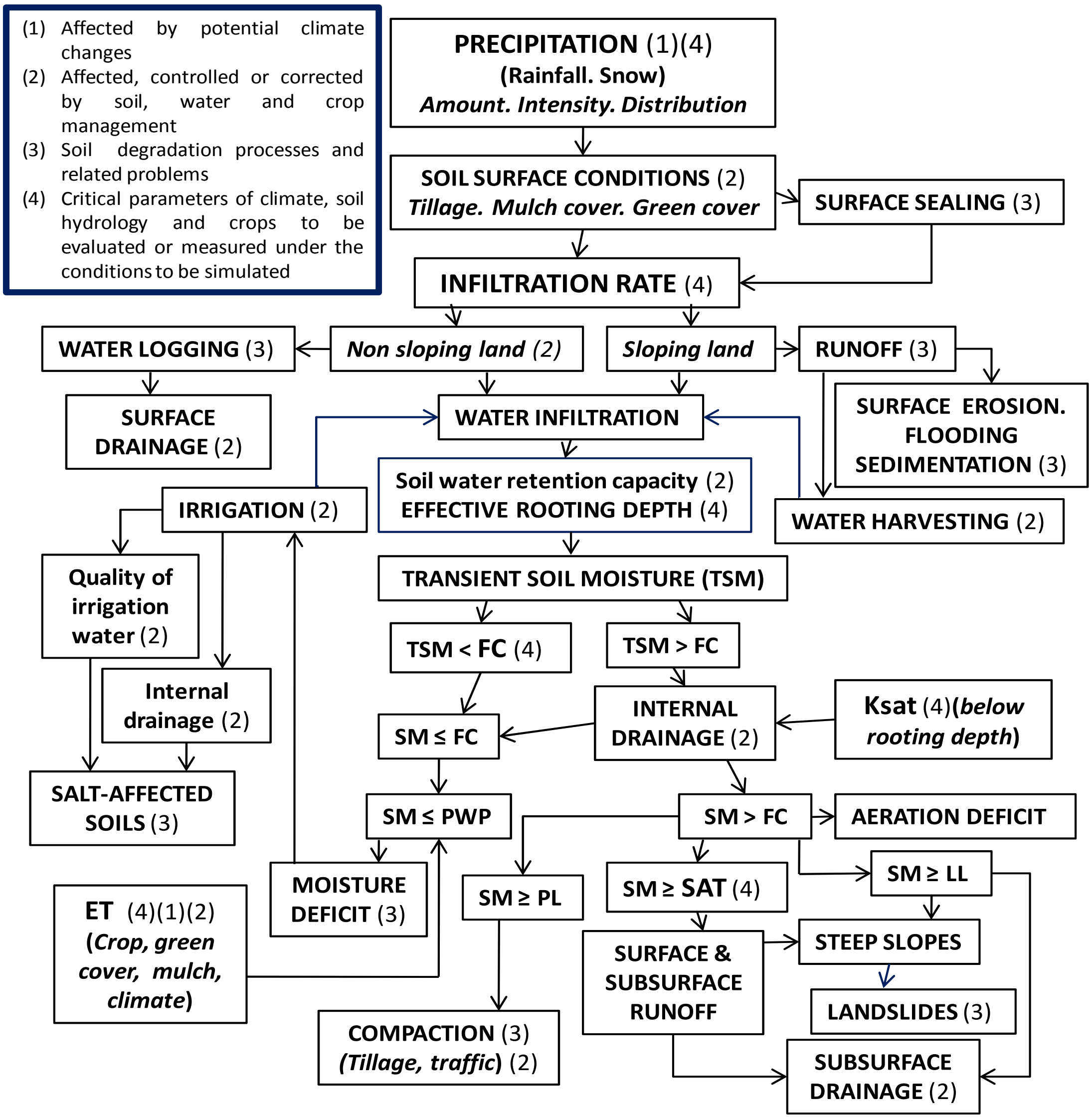

Figure 2. Flow diagram of a simulation model (SOMORE) based on hydrological processes to predict soil water balance, soil moisture regime and derived soil degradation processes under different scenarios of climate, soil and soil and water management (Adapted from Pla, 1997, 2006) (SM: Soil moisture at root depth; SAT: Saturation; LL: Liquid Limit; PL: Plastic Limit; FC: Field Capacity; PWP: Permanent wilting point; ET: Evapo-transpiration; Ksat: Saturated Hydraulic Conductivity)

5. Case studies: Modeling soil water balances in vineyards

The climate in arid and semiarid Mediterranean environments, with highly variable and erratic rainfall amount and distribution, increases the risks of land degradation and desertification. Those risks may have been further increased in the last decades, mainly due to drastic changes in land use and management, with an additional potential negative effect derived of apparent climate changes. There are significant uncertainties in predictions of regional climatic changes, but probably the Mediterranean region will warm significantly, with more precipitation in winter and less in summer, and declining annual precipitation in the southern part (N Africa and SE Spain), increasing the frequency and severity of droughts, and the occurrence of extreme events (Pla, 2006).

Some permanent dry land crops, like grapevines, with great survival capacity under drought conditions, have contributed in the past to decrease the processes and consequences of land desertification in the semiarid regions of the Mediterranean region. But in the last decades, the lands with dry land vineyards in the Mediterranean region have suffered and are increasingly suffering great changes that may seriously affect the conservation of soil and water resources. Some cropped lands have been abandoned, but in others the cropped area has increased, with more intensive and highly mechanized agricultural systems. This has required great changes in the planting and cropping systems, with previously mechanical land conditioning, reducing relief irregularities and decreasing slopes through levelling operations and bench terracing. This has lead to drastic changes in the soil properties, both in surface and subsurface soil, mainly affecting the hydrological properties, the effective rooting depth of the vines, and the drainage system.

The interaction of changes in land use and management, and in climate, with land degradation processes associated to unfavourable changes in hydrological processes has been studied in two different areas (Penedés and Priorat) with vineyards for high quality wine production in Catalonia (NE Spain). There were evaluated problems of soil water supply to the plants through the different growing periods in the year, of surface and mass erosion, of runoff, of flooding, and related problems, derived of changes in hydrological behaviour under the new levelling, terracing, planting and management practices (Pla, 2006; Pla and Nacci, 2001, 2003; Pla et al., 2004, 2005, 2007).

In both regions the climate is Mediterranean semiarid, with an average annual rainfall of 500- 600 mm. The rainfall is very irregularly distributed, with the greatest rains in autumn-winter, a very dry summer, and with large variability in totals from one year to another (400-750 mm in Penedés,and 300-900 mm in Priorat). Rainfall is typified by many storms in autumn, and occasionally in spring of high concentration and intensity. Climate change may increase the irregularity of this rainfall, the frequency of dry years and the probability of extreme events, phenomena that have been observed in the last 25 years.

	Slope *%*	Coarse fraction *%*	Effective rooting depth *cm*	AWC *mm*	Rainfall Infiltration *mm/hour*		K sat (subsoil) *mm/hour*
					No cover	**Cover**	
PENEDÉS							
NON LEVELED	***10***	***<5***	***20 → 80***	***200***	***20***	***50***	***3***
LEVELED	***6***	***5-10***	***15 → 60***	***120***	***5***	***20***	***0,4***
PRIORAT							
SLOPES	***50***	***50-60***	***0 → 40***	***61***	***>200***	***>200***	***>200***
TERRACES	***0***	***30-60***	***10 → 70***	***110***	***>100***	***>100***	***>100***

(AWC: Available water capacity; Ksat: Saturated hydraulic conductivity)

Table 1. Some characteristics and hydraulic properties of the soils, under different conditions, in the two regions included in the study

The water use of grapevines through the growing season is characterized by lessened requirements in the periods before bloom and after harvest until fall (autumn), and a maximum consumption in the mid part of the growing season. If the reserve water capacity of the soil in the rooting zone is not enough, reduced amounts of rainfall during the main growing season of grapevines (June-August) may lead to a long term soil water deficit, which can affect growth, production and maturation, in spite of the natural survival capacity of grapevines under drought conditions.

In order to decrease costs of the scarcely available manual labour, to increase production and to speed all operations, the current trend is towards full mechanization of all practices, including harvesting. To proceed to a fully mechanised system there is a need for heavy land levelling or terracing operations, with drastic changes in the surface drainage network and on the effective soil rooting depth and surface soil properties (Pla & Nacci 2003). The main changes in land management in those two regions include:

-leveling, planting pattern and use of green cover in rain-fed vineyards of the Penedés
-terracing, planting pattern and tillage in rain-fed vineyards of the Priorat

Soils in Penedés, derived of calcareous lutites, are mainly of silty-loam texture. The soils in Priorat, derived of slates, are very stony (>50% coarse fraction), and calcareous only in the deeper horizons, where the clay (smectites) content slightly increases . The main characteristics of the soils in the different studied conditions are shown in table 1.

The effects of these changes on the relief and soils for new plantations, and of the changes in land management in the traditional plantations were studied under different field and laboratory conditions. Measurements and continuous monitoring of appropriate soil hydrological parameters and rainfall characteristics have been conducted at field sites, complemented with laboratory measurements. These have been used as a basis for the application and validation of the model SOMORE (Pla, 1997, 2002, 2006), based on hydrological processes, which allows the simulation and prediction of the soil water balances, soil moisture regimes and of the associated potential problems of soil erosion and of water supply to the grapevines at different growth stages (Pla 1997; Pla, 2002; Pla and Nacci 2001), under different actual or potential climate conditions (Figures 3 and 4).

Continuous field monitoring during several years, have shown that the soil water regime under the different and variable climate, soils and land management of the study sites could be reasonably well predicted with the adequate simulation of the hydrological processes, based on climate information and on changes in the soil water balance derived from the soil hydrological properties properly evaluated under field conditions. It may be observed that the recent changes in land and crop management in dry-land vineyards for wine production in the Mediterranean regions of NE Spain have mainly affected the hydrology of the cropped lands. These effects could be increased under the previewed future climate changes in the Mediterranean region.

The main effects are changes in the soil moisture regime, which under Mediterranean climate is the main factor affecting the quantity and quality of grape and wine production. Therefore, the previewed influences of the different land and crop management practices on the soil water regime are required to rationally establish the basis for a more effective soil and water management and conservation, leading to a more efficient use of the scarce available water resources and to a more sustainable and regular production of high quality wines.

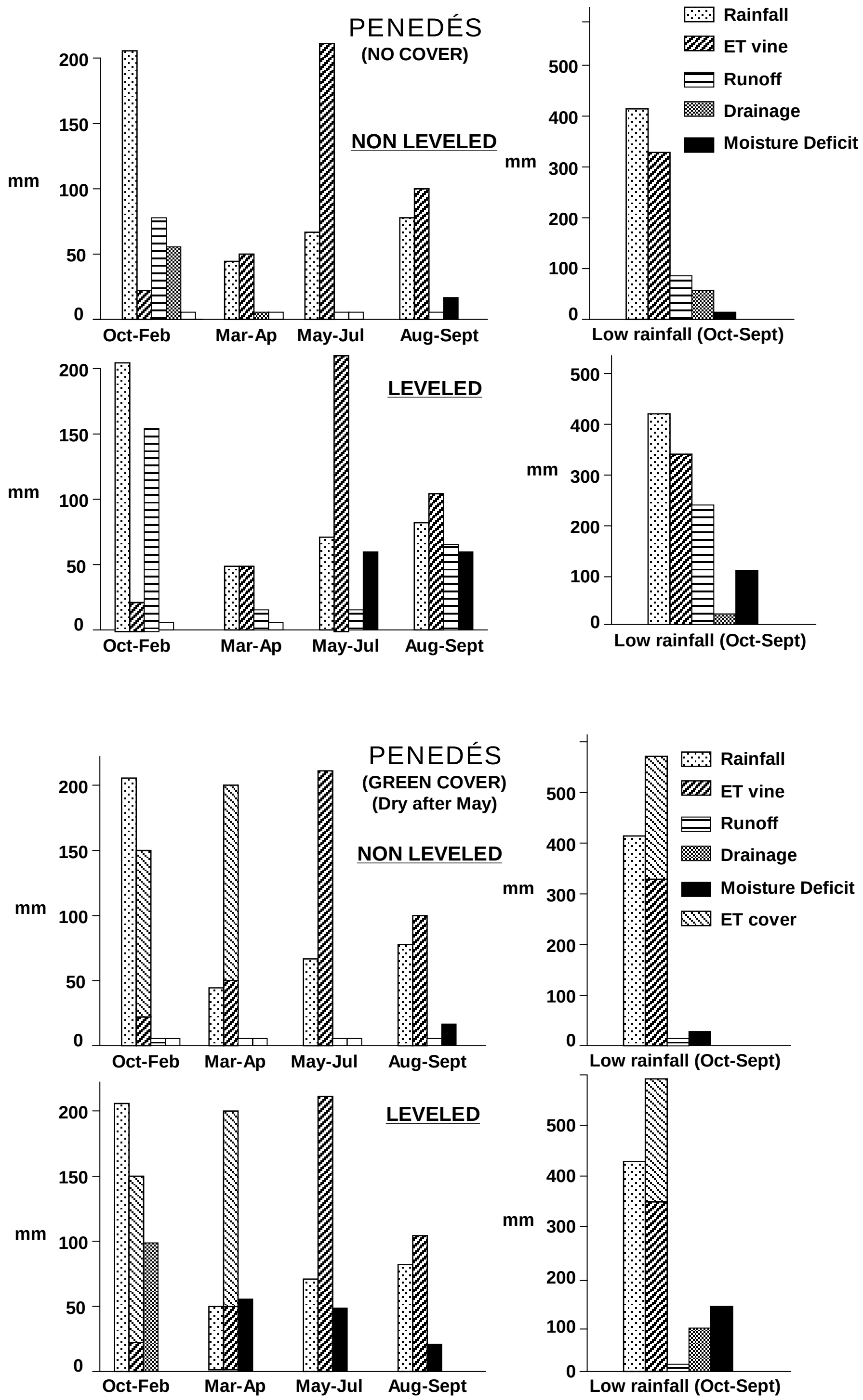

Figure 3. Rainfall and soil water balance components in rainfed vineyards of the Penedés region in years with low rainfall (return period: 5 years) in non levelled and levelled land, without and with the use of green cover from October to May.

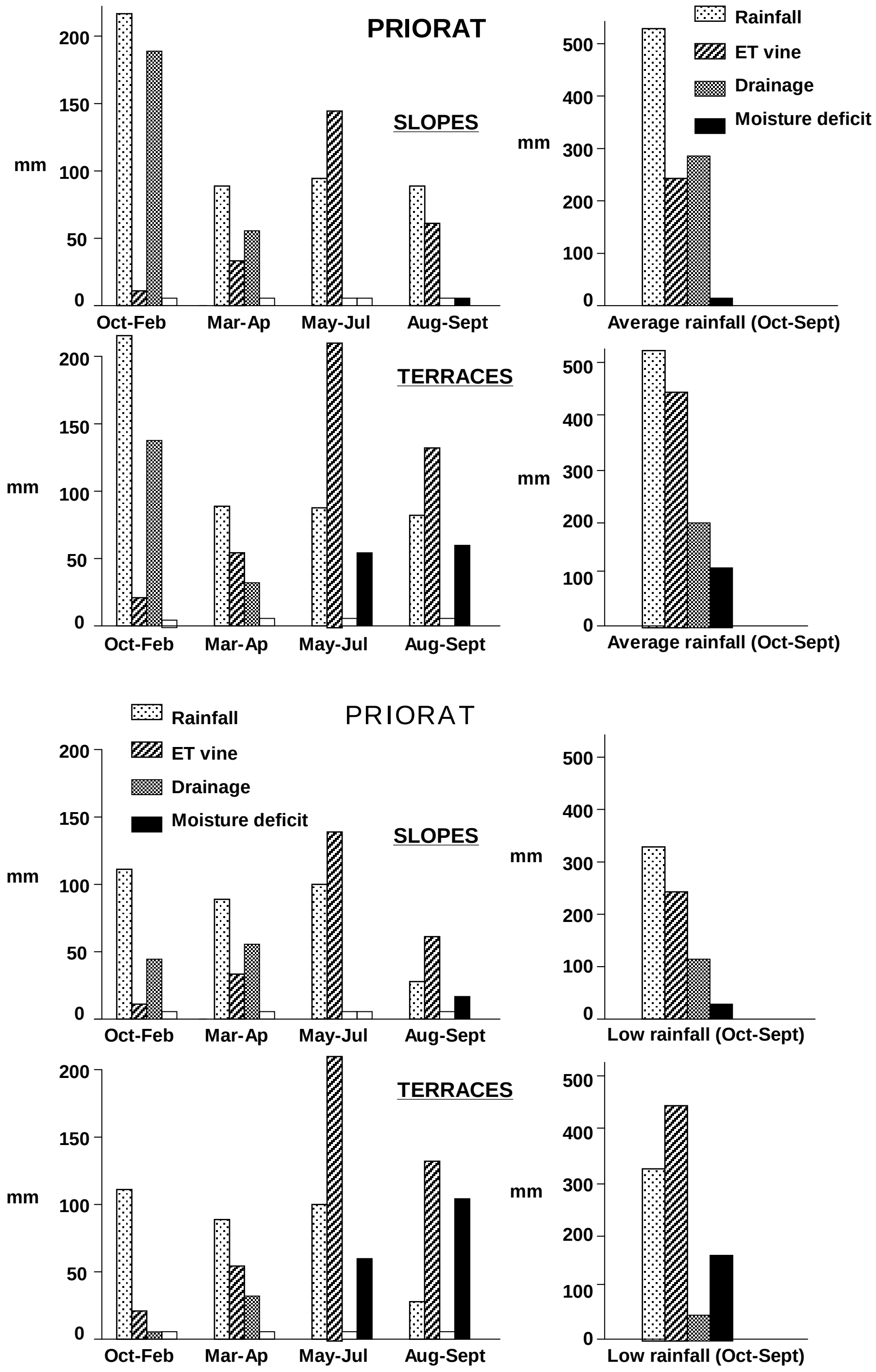

Figure 4. Rainfall and soil water balance components in rainfed vineyards of the Priorat region in years with average rainfall (return period: 2 years) or low rainfall (return period: 5 years) in sloping (no tilled) and in terraced (tilled) land.

The potential effects of the interaction of future climate changes and cropping system in the frequency of droughts in dryland vineyards for high quality wine production in the region of Priorat (NE Spain), and in the probability and frequency of landslides are shown in figure 5. In this region, with very steep slopes and stony soils, the traditional vineyards in natural slopes are being transformed in vineyards growing in excavated bench terraces, in order to increase production and facilitate mechanization (Pla &Nacci, 2003). Field evaluations of the hydrological properties together with the previewed climate changes were integrated in the model SOMORE to make such predictions. It is shown how the new more productive and mechanized cropping system in bench terraces increases the probabilities and frequency of droughts and landslides, especially under future climate change.

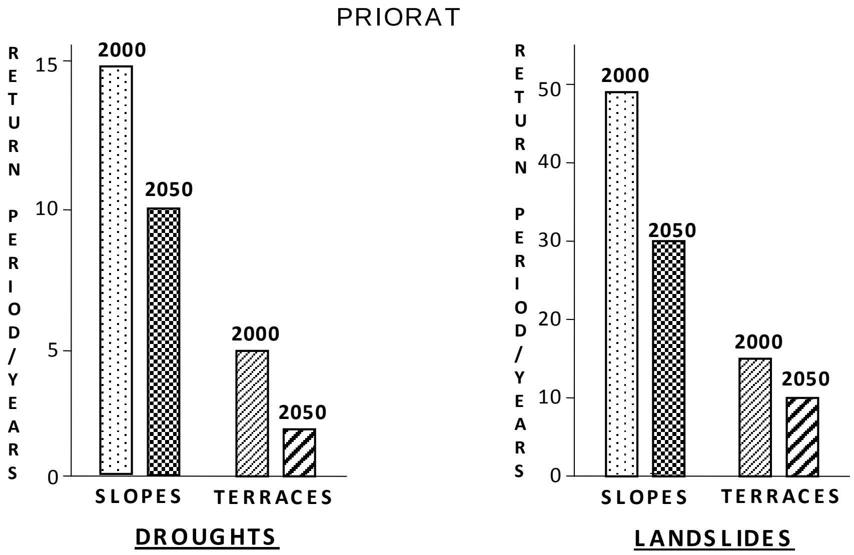

Figure 5. Potential influence of future climate changes and cropping systems, affecting the land hydrology, on the previwed frequency of droughts and landslides in dryland vineyards of the Priorat region

5. Conclusions

- Present and future strategies, planning and decisions about water management have to include climate change issues.
- Climate change is adding more uncertainty to water resource planning and management.
- Because of climate change extreme events such as droughts and major flood events are likely to become more frequent and intense in the future.
- With future climate change there would be required major shifts in farming systems, including water management adapted to the new production systems.
- Climate change is only one among several different global change factors like changes in population and changes in land use and management, causing large changes in water resources.

- The identification and prediction of the hydrological processes under different scenarios and changing climate, soil properties and land use and management, with flexible simulation models based on those processes, is essential for guiding alternative planning strategies for a sustainable and efficient rainfall and irrigation water management under previewed changing climate conditions.
- Management strategies may be evaluated against different scenarios of changing climate conditions, taking decisions after assigning probabilities to each scenario and weighting the results

7. References

Brown, B. R., 2004. Outgrowing the Earth: The food security challenge in an age of falling water tables and rising temperatures. W. N. Norton and Co., New York

Easterling, D.R., G.A. Meehl, C. Parmesan, S.A.Changnon,T.R. Karl, and L.O. Mearns. 2000. Climate extremes: Observations, modeling, and impacts. Science 289(5487): 2068-2074.

FAO. 2008. Climate Change, Water and Food Security. Technical background document from the expert consultation. FAO. Rome

Fischer, G. M. Shah and H. van Velthuizen. 2002. Climate Change and Agricultural Vulnerability. IIASA. Vienna

Gleick, P. H., 2003. Water use. Ann. Rev. Environ. Resour. 28:275-314

Groves, D. G., D. Yates & C. Tebaldi. 2008. Developing and applying uncertain global climate change projections for regional water management planning. Water Resour. Res. 44

IPPC. 2007. Climate Change 2007. Fourth Assessment Report on the IPCC. (Solomon et al. ed.). Cambridge University Press. Cambridge (UK)

Milly P. C. D., Dunne K. A. & Vecchia A. V. 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature Vol 438: 347-350

NRDC. 2007. Water management strategies to weather the effects of global warming. NRDC. New York (USA)

Palutikof, J. P. and T. M.L. Wigley., 1996. Developing climate change scenarios for the Mediterranean Region.In L. Jeftic and J.C. Pernetta, (Editors), Climatic Change in the Mediterranean. . Edward Arnold. London (UK), Vol 2 . pp 27-55

Pla, I., 1996. Soil salinization and land desertification. In J.L. Rubio and A. Calvo, (Editors), Soil degradation and desertification in Mediterranean environments. Geoforma Ed. Logroño (Spain), pp. 105-129

Pla, I., 1997. A soil water balance model for monitoring soil erosion processes and effects on steep lands in the tropics. In I. Pla, Ed. Soil Erosion Processes on Steep Lands . Special Issue of Soil Technology. Elsevier. Amsterdam, 11(1):17-30.

Pla, I., 2002. Hydrological approach to soil and water conservation. In J.L.Rubio et al. Ed., Man and Soil at the Third Millenium. Geoforma Ed. Logroño (Spain). I:65-87.

Pla, I., 2006. Hydrological approach for assessing desertification processes in the Mediterranean region. In W.G. Kepner et al. Ed. Desertification in the Mediterranean Region. A Security Issue. Springer. Heidelberg (Germany), pp 579-600.

Pla, I. and S. Nacci., 2001. Impacts of mechanization on surface erosion and mass movements in vineyards of the Anoia-Alt Penedés Area (Catalonia, Spain) In D.E.Scott et al.(Editors), Sustaining the Global Farm. Purdue Univ.-USDA, ARS. West Lafayette (USA), pp 812-816.

Pla, I. and S. Nacci., 2003. Tradicional compared to new systems for land management in vineyards of Catalonia (Spain). In E. Roose et al. Ed. Techniques Traditionnelles de

GCES en milieu mèditerranien.. Bulletin Reseau Erosion. Montpellier (France), 21:213-223.

Pla, I., Ramos, M.C., Nacci, S., Fonseca, F. and Abreu, X., 2004. Soil and water conservation as affected by changing Mediterranean climate and land management in vineyards of Catalonia (NE Spain). In: Proc. 4th International Congress of the ESSC. Budapest (Hungary), pp 86-91.

Pla, I., Ramos, M.C., Nacci, S., Fonseca, F. and Abreu, X., 2005. Soil-moisture regime in vineyards of Catalunya (Spain) as influenced by climate, soil and land management. In J Benitez, and F Pisante. Ed., Integrated Soil and Water Management for Orchard Development. Land and Water Bulletin 10. FAO. Rome. (Italy), pp 41-49.

Schmidhuber, J and Tubiello, F. 2007. Global food security under climate change. PNAS 104 (50) 19703–19708

SWCS. 2003. Conservation implications of climate change: Soil erosion and runoff from cropland. SWCS. Ankeny (USA)