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Hydrological approach to soil and water conservation 1

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Hydrological Effects of Land Use Changes under Mediterranean Climate Conditions

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Summary
The processes of soil and water degradation are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime. These are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources. In the arid and semiarid Mediterranean climates, the rainfall is highly variable among years and during the year, and usually occurs in erratic storms of short duration and high intensities, increasing the risks of land degradation processes. In the past, the most important human actions that have triggered or intensified the processes of land degradation in the Mediterranean region have been overgrazing, deforestation and forest fires, and in recent decades new land management practices, associated to agricultural intensification, mechanization, inadequate maintenance or abandonment of vast areas of terraced agriculture, over-drafting of surface and groundwater for irrigated agriculture, tourism, etc. These new land use and management practices are a consequence of changes in social economic conditions, market prices and public policy-led subsidies, consumption patterns, etc, associated to technological progress and changing production systems. Hydrological approaches are essential to identify and assess the causes and processes of land degradation. The evaluation of the hydrological processes, under different scenarios of changing climate, soil properties, and land use and management, with flexible simulation models based on those processes, help to predict and to identify the biophysical causes of land degradation at local, national and regional levels. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes, and to the related social economic and security problems. There is proposed an integrated framework for the development of this kind of approach, with potential application under Mediterranean conditions.

Introduction
The processes of land degradation affect the conservation of soil and water resources, because they are strongly linked to unfavourable changes in the hydrological behaviour affecting soil water balance and soil moisture regime. They are related to soil and climate characteristics, but inappropriate land use and management is the main factor responsible of those processes.
In the past decades, the degradation of previously naturally vegetated or productive agricultural lands, leading in many cases to barren, desertified, landscapes, has dramatically extended in many regions of the World. The reasons are mainly unfavourable biophysical conditions and negative human impacts. The negative human impacts are mainly through inadequate land use, including deforestation, overgrazing, and deficient agricultural practices, leading to soil erosion, salinization and vegetation degradation, as a consequence of drastic changes in the water balance. This might be further aggravated by the ongoing threat of climate change.
Land degradation in the more vulnerable areas with arid and semiarid climate in the Mediterranean region goes back over millennia (Dupre, 1990). The most important human

actions that have triggered or intensified the processes of land degradation have been overgrazing, deforestation and forest fires, and in recent decades new land management practices, associated to agricultural intensification, mechanization, inadequate maintenance or abandonment of vast areas of terraced agriculture, over-drafting of surface and groundwater for irrigated agriculture, tourism, etc. (EC, 2003). These new land use and management practices are a consequence of changes in social economic conditions, market prices and public policy-led subsidies, consumption patterns, etc, associated to technological progress and changing production systems. Land degradation has affected more hilly sloping lands, but in valley bottoms where irrigation is being used for increasing productivity, salinization and sodification have become a widespread form of soil degradation. There are evidences that land degradation processes leading to desertification in the Mediterranean region are getting worse, because of different or mixed causes varying from one place to the other (EC, 2003).

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. In the medium or long term, it is previewed that global climate changes may contribute to accelerate the processes of desertification in the Mediterranean region (Imeson and Emmer, 1992), but at short term, land use practices leading to soil degradation processes would increase the negative influence of those 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. This will mainly affect the land hydrology (Palutikof and Wigley, 1996).

Increasing frequency of droughts, based upon reduction in annual rainfall, leads to land desertification, but widespread incidence of drought could be a result of changing land use, without a necessary change in climate, through a reduction in the effectiveness of rainfall by land degradation processes. Climate variability changes in the frequency and magnitude of extreme events could have a greater impact than changes in mean climate alone. In mountainous areas of the Mediterranean region, with already degraded lands, heavy seasonal rainfall and extreme events may result in concentrated runoff, rushing down in great volumes as flash floods, causing extreme damage downstream. Landslides may also be initiated by those intense rainstorms in mountain areas.

The formulation of a sound soils policy, and the prevention and choice of solutions for the problems of land degradation leading to desertification must depend on the right identification of the processes involved and in the precise analysis, diagnosis and understanding of the causes and potential effects at specific places. Not doing so may lead to catastrophic effects. Despite the modernization of observation facilities by the use of satellite imagery and computer programs to analyse the data, there are still many uncertainties at the regional and national levels in the Mediterranean region, on the causes, the extent and the seriousness of land degradation and desertification. These uncertainties prevent those who manage land resources from planning properly, and introduce constraints in operation of early warning systems with regard to agricultural production and disasters such as flooding and landslides (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.

Hydrological effects of land use changes

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 are strongly linked to unfavourable changes in the hydrological processes responsible for the soil water balance and for the soil moisture regime, which are affected by the climate conditions and variations, and by the changes in the use and management of soil and water resources (Pla, 2002).

The soil moisture regime, determined by the changes in soil water content with time, is the main single factor conditioning moisture availability, plant growth and crop production. It is mainly conditioned by soil properties affecting the capacity and possibilities of infiltration, retention and drainage of rainwater, and the limitations to root growth under the particular rainfall characteristics (Pla, 2002). These conditions may be modified by soil and plant management practices as tillage, irrigation, drainage, etc. Moisture availability is determined both by water gains from precipitation and water losses through runoff and evapo-transpiration (Table 1).

YEAR	RAINFALL (mm/year)	RUNOFF (% rainfall)		AVAILABLE WATER CAPACITY (mm) 50	100	200	400
DRY	313	0	**LGP** (days/year):	91	95	95	95
		50	**LGP** (days/year):	65	65	65	65
AVERAGE	522	0	**LGP** (days/year):	151	197	205	205
		50	**LGP** (days/year):	122	132	132	132
HUMID*	785	0	**LGP** (days/year):	194	208	228	267
		50	**LGP** (days/year):	183	196	200	200

Table1. Length of potential growing period (LGP) during the year, under a semiarid Mediterranean climate as a function of climate variability (total rainfall and distribution), available water capacity of the soil, and % of rainfall losses as surface runoff (*year with rainfall highly concentrated in a few storms at autumn-winter time).

In the arid and semiarid Mediterranean climate, the rainfall is highly variable among years and during the year, and usually occur in erratic storms of short duration and high intensities. The concentration of rainfall in a relatively cool season (autumn and winter) permits reliable cropping in areas with annual rainfall as low as 330-400 mm (see Table 1). Under non-protected soil surface, associated to some intensive agricultural practices and overgrazing, extra precipitation in winter, occurring in intense episodes, may not be stored in the soil, but lost as runoff (Pla and Nacci, 2001). These factors increase the risks of land degradation leading to desertification processes. 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. Therefore, the term aridity for evaluating desertification, instead of only considering average rainfall conditions, would be more appropriate if it also consider variability through the whole hydrological cycle as well as climatic variations and fluctuations.

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, 2001). 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 deforestation and forest fires, and especially by the consequent 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 holding capacity, etc), leading to the same effects of decreasing available water supply (see Table 1).

Irrigation causes drastic changes in the regime and balance of water and solutes in the soil profile, which may result in soil salinisation, one of the processes of soil degradation leading to land desertification. 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. 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).

From the previous arguments, it follows that 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 of land degradation, 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 degree of aridization of soil 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, 2006).

Case studies. Dry land vineyards in NE Spain

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 during the last ten years in two different areas with dry land vineyards in Catalonia (NE Spain) (figure1). 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, derived of changes in hydrological behaviour under the new levelling, terracing, planting and management practices.

The study areas were located in commercial fields representative of two of the regions (Alt Penedés and Priorat) of Catalonia (NE Spain), where the area under vineyards for high quality wine and cava production has increased over the last 20 years. Accompanying this large increase in vine area has been a drastic change from traditional practices, including the introduction of new varieties. In both regions the climate is Mediterranean semiarid, with an average annual rainfall of approximately 600 mm, 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 Alt 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

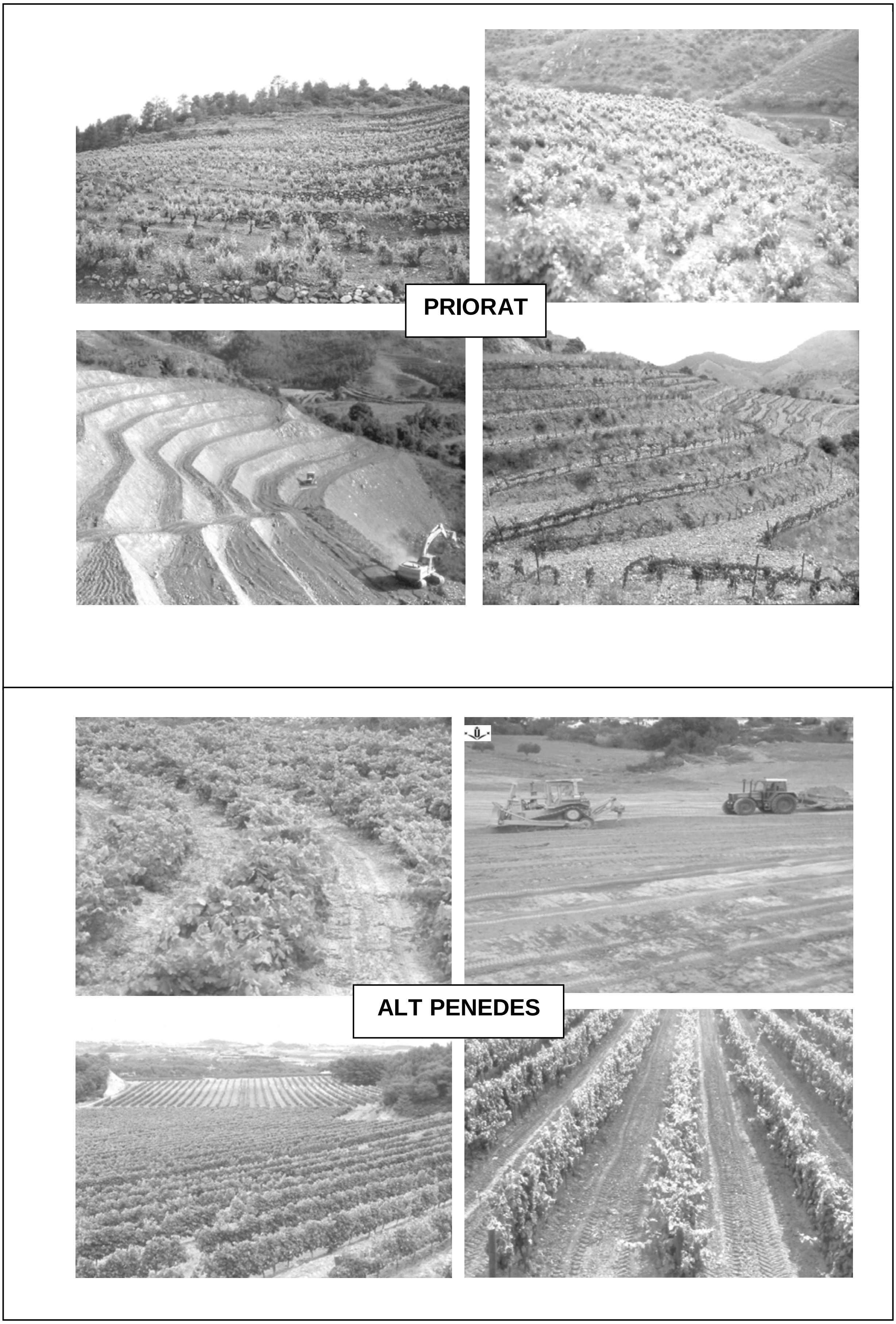
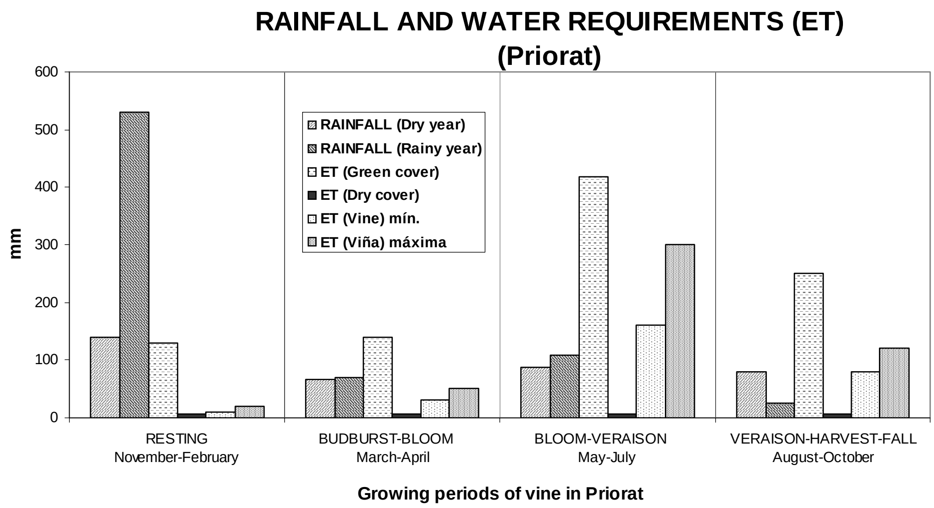


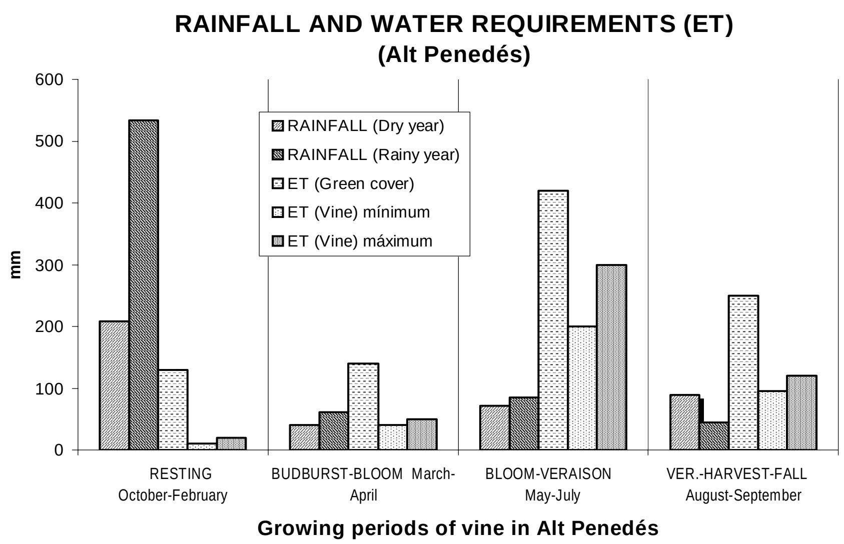
Figure 1. Transformations in dry land vineyards of Priorat and Alt Penedés (NE Spain)

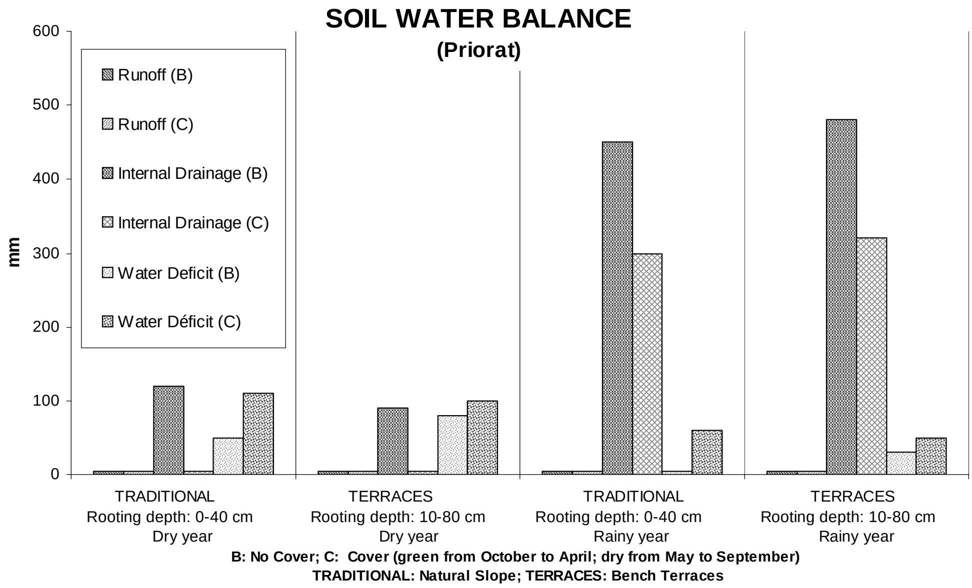
years and the probability of extreme events, phenomena that have been observed in both regions in the last 25 years.

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).







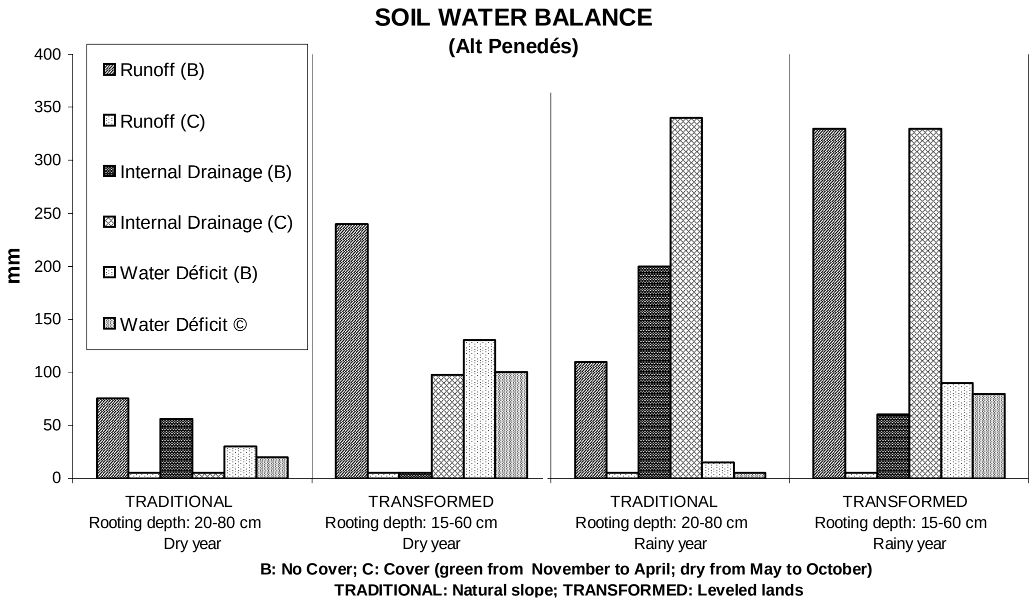


Figure 2. Rainfall, water requirements and soil water balance in the dry land vineyards of the Priorat and Alt Penedés regions under traditional and newly transformed systems.

The effects of these drastic changes on the relief and soils for new plantations, and of the changes in land management in the traditional plantations are being 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 a model (SOMORE) which allows the simulation and prediction of the 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). In many cases adaptations and changes in the methodologies were required to make adequate measurements, particularly under field conditions.

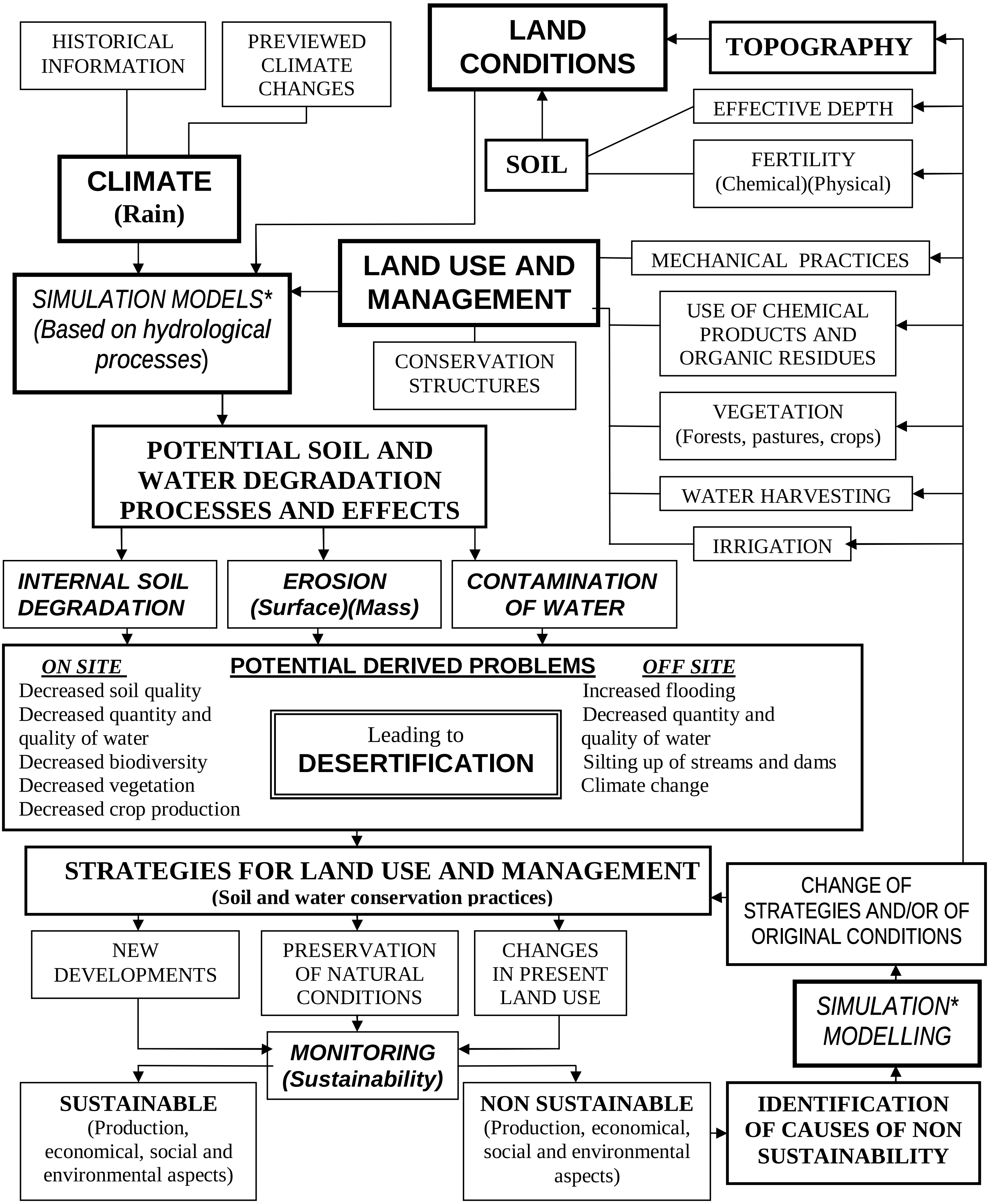


Figure 3. Integrated framework, mainly based on hydrological processes, for evaluating potential soil and land degradation and desertification, as a basis for a rational land use planning under Mediterranean climate (Pla, 2006).

Results and conclusions

It was found that most of the problems of soil and water conservation were associated with the effects of climate change and of soil and cropping management practices on the soil water regime. The new fully mechanized, land management and cropping practices in the dry land vineyards of the Alt Penedés and Priorat regions of Catalonia (Spain) result in drastic changes in the soil moisture regime. The major effects are on surface runoff, surface erosion and mass movements, and in the retention of rainfall water in the soil for utilisation by the grapevines (figure 2). Analysis, based on appropriate *in situ* evaluations of climate characteristics and of soil hydrological properties and processes, complemented with the use of simple simulation water balance models based on those processes, may be very useful, and even indispensable, for an adequate planning of more sustainable land use and management for grape wine production, or other alternative uses. The study reported here investigated different previewed scenarios of changing climate and agricultural policies with strong potential to cause changes in land use and management in the Mediterranean region (Pla et al, 2004; 2005).

In general, it may be concluded that hydrological approaches would be essential to identify and assess the causes and processes of land degradation. The evaluation of the hydrological processes, under different scenarios of changing climate, soil properties, and land use and management, with flexible simulation models based on those processes, may help to predict and to identify the biophysical causes of land degradation and desertification at local, national and regional levels. This is a required previous step for a rational land use planning, and for the selection and development of short and long term strategies and technologies to reduce or to control land degradation processes leading to desertification, and to the related social economic and security problems. There is proposed an integrated framework for the development of this kind of approach, with potential application to predict and prevent land degradation and desertification processes under Mediterranean semiarid environmental conditions (figure3).

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