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Soil Erosion and Water Use Efficiency in Dry-land Vineyards of NE Spain

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ABSTRACT

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 recent decades the past, the most important human actions that have triggered or intensified the processes of land degradation in the Mediterranean region have been 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. This research evaluated the hydrological effects, and associated land degradation processes, of changes in land management, associated to levelling, terracing and use of cover crops, in two areas with dry land vineyards of NE Spain. The major effects were on surface runoff, surface and mass erosion, and on the conservation and effective use of the rainfall water by the grapevines, affecting both quantity and quality of production.

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. Desertification, is considered an advanced process of land degradation, with diminution or destruction of the biological potential of the land, that can lead ultimately to desert-like conditions, usually in dry lands, but sometimes even in humid ones

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.

Uncertainties at the regional and national levels in the Mediterranean region, on the causes, the extent and the seriousness of land degradation and desertification, 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). Empirical models, like the so called Universal Soil Loss Equation (USLE) and its revised version RUSLE (Renard et al, 1991) have been commonly used in the countries of the Mediterranean region, frequently without verification, for large scale water erosion risk mapping. Although the outputs and mapping using GIS may be impressive, they can hardly be used with a guaranty of success for development or prevention of desertification purposes (Pla, 2002b). There are required other non empirical modelling approaches mainly based on soil hydrological processes, deduced from soil hydrological properties together with historical rainfall records, under different scenarios of changing climate, soil properties, topography, and land and crop management, which may be combined in computer-based programs.

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.

THEORY

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).

Table 1. 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).

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

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 with vineyards in areas with annual rainfall as low as 330-400 mm (Fig. 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.

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 (Table 1). Therefore, 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.

MATERIALS AND METHODS

Study areas: 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). There were evaluated problems of soil water supply to the plants through the different growing periods in the year, and 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 (Spanish Champaign) 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 years and the probability of extreme events, phenomena that has been observed in both regions in the last 25 years.

In the Alt Penedés region, the topography of the area is highly undulated, and even hilly, with cropped fields in 4-20% slopes, and altitudes of 250-400 m a.s.l. The soils generally have low or not profile development, mainly as a result of levelling operations for smoothing the land surface for mechanization. These soils, formed from calcareous lutites, are low in organic matter (< 1,5%), high in silt fraction (40-60%) and very rich in Ca carbonates. They have a high susceptibility to surface sealing (Ramos, Nacci and Pla, 2000), resulting in high runoff and high surface erosion rates. Periodical tillage at 15-20 cm depth, do not allow root growth in the surface 15-20 cm soil, which is maintained loose most of the time to increase rainfall water infiltration, to decrease evaporation of deeper soil water, and to control weeds.

As a water conservation practice, in some cases there are built narrow (2-3 m wide and 15-20 cm depth) bench terraces across the slope, every 10-15 vine rows (depending on the slope), with reverse slope, with the purpose of absorbing and deviating runoff water and sediments coming from the upland rows. These terraces, made of loose surface soil frequently suffer mass movements, especially after extraordinary rainfall events, originating active growing gullies, when they receive concentrated surface runoff and subsurface flow of water coming from higher parts of the field (Pla and Nacci, 2001). Recently, there has also been introduced the use of green covers, using different grasses.

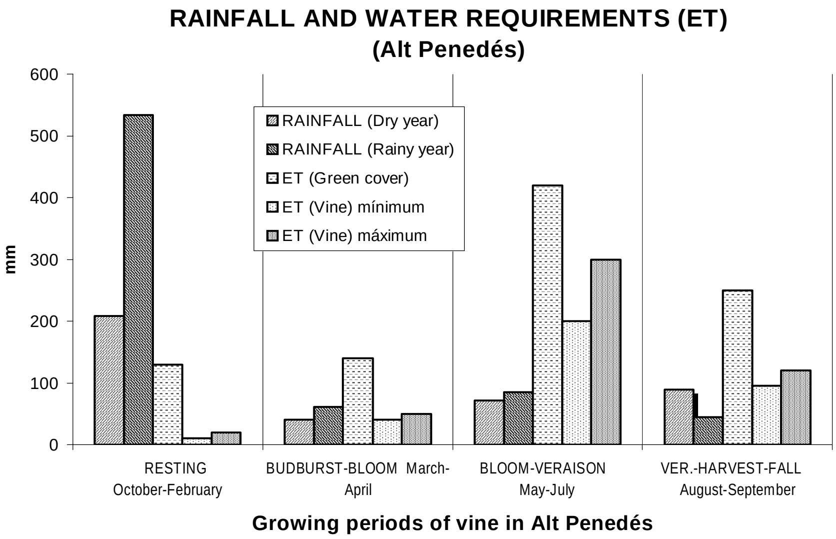
In the Priorat region, the climate is also semiarid, and the topography is mountainous, with cropped areas in 10-80 % slopes, at 200-650 m A.S.L. Soils are developed on slates and schist , and are not calcareous, slightly acid, very poor in organic matter, and very stony (20-60% by weight), sometimes with a gravely pavement in the soil surface. Fine soil fractions, mainly smectite clays increase with soil depth, which is generally less than 50-60 cm, on top of a highly weathered and fragmented rock.

The traditional vineyards in the Priorat are planted with varieties producing very strong wines but low yields. The planting pattern mainly follows the contour lines, in very small individual fields, with vines and lines 2-3 m apart. There are usually maintained the natural relief and slopes, and the only conservation structures are non continuous stone walls located across the drainage ways and in places where based on local experience are more danger of soil movement by surface or mass erosion. In the past, the land between vine rows was removed generally after harvest, by ploughing the surface 10-15 cm using man or animal power. Nowadays this practice has almost disappeared, except where a gentler slope allows using a small tractor, and the control of weeds is mainly by herbicides. As a result of continuous no-tillage, frequently the vine roots concentrate on the surface soil, where the effects of dryness, derived of scarcity or of non well distributed rainfall, are more marked.

The new plantations of vines in the Priorat region are made in a way to allow mechanical operations in the vineyards, looking for more soil water retention and higher and more stable production. There are built bench terraces, 2-5 m wide, depending on the slope, with very steep and unstable embankments, which requires the clearing of the forest (in case of new plantations), followed by removal of very high amounts of soil and underground rock using heavy bulldozers. In the terraces there are planted one to three rows (2-3 m apart) of vines of generally new introduced more productive varieties, 1,2 m between plants. In most of the cases the very steep embankments of the terraces are not protected, except by the slow re-growth of natural vegetation.

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 (Fig. 1). 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).



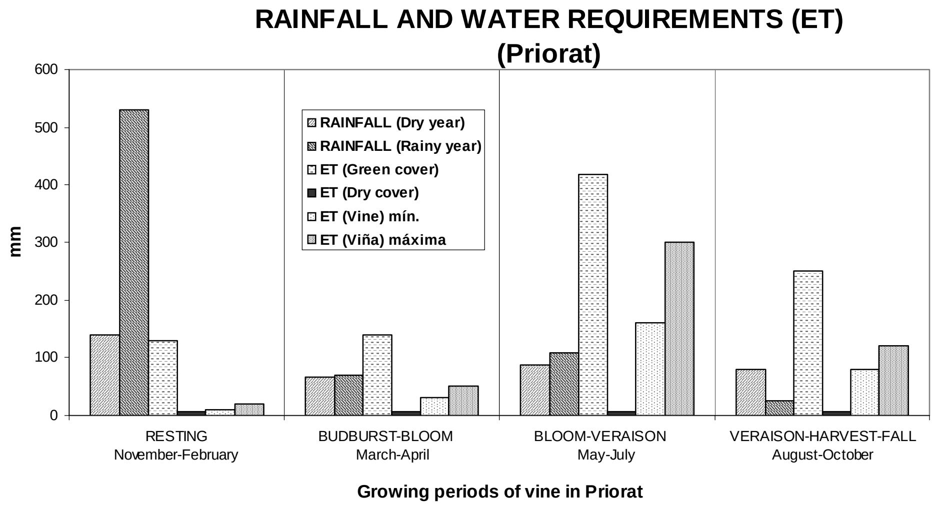


Fig. 1. Rainfall (drier and rainier years in the period 1993-2003) and water requirements (maximum and minimum) in the different growing periods of the grapevines, and of a green cover (barley).

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 were studied under different field 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), 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 In many cases adaptations and changes in the methodologies were required to make adequate measurements, particularly under field conditions. The prediction of concentration of surface and subsurface runoff, and of the conditions of soil moisture permits to preview which days or periods of the year would have the greatest flood, erosion and sedimentation hazard, and what would be the most probable erosion process (Pla, 1992; 1993; 1997; 1998). This is more useful for designing erosion control strategies than the use of empirical models, which have proved not to be able to predict the time and probabilities of occurrence of concentrated runoff and erosion, and much less landslides or mass movements in general.

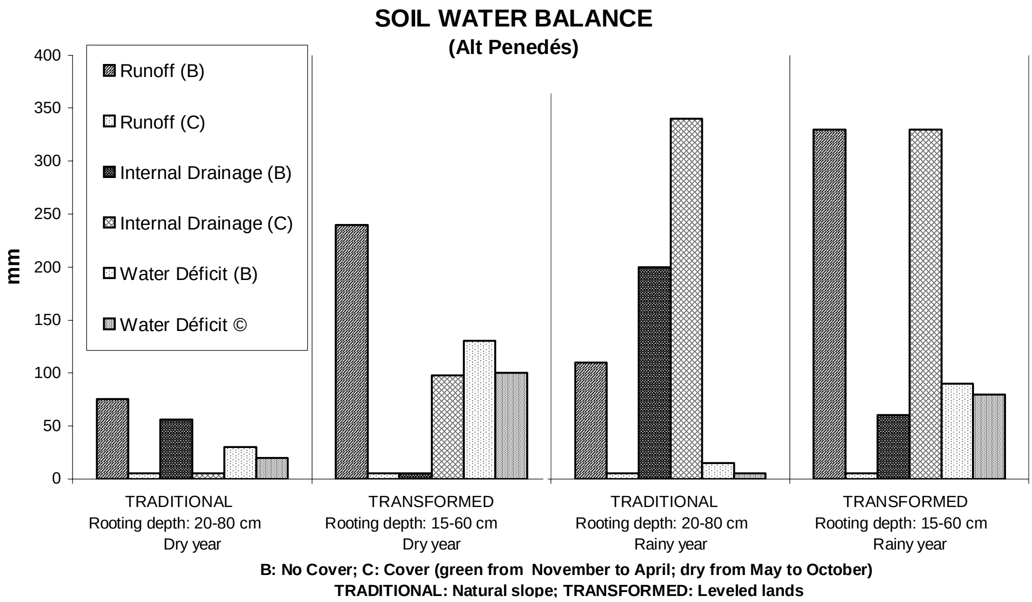
RESULTS AND DISCUSSION

In this paper we present both the results of field measurements and continuous monitoring from selected sites in commercial fields, as well as the results of simulation modelling of the range of more common conditions of soils, slope and management. Besides the land transformation by levelling (Alt Penedés) and terracing (Priorat), there was included besides the present clean tillage management (NC), the newly introduce use of green cover grass (C) during the resting period, followed by cover (utilising the killed grass residues) during the rest of the growing periods. There are presented the results in two selected cropping years in each region, being the driest (Dry year) and the rainiest (Rainy year) during the last ten years, with return periods of about 5 years. In the selected rainy years, the rainfall was highly concentrated (> 70 % of the total annual rainfall) in autumn (Priorat) and in autumn – early winter (Alt Penedés) (Fig.1).

Table 2: Soil Characteristics and hydrological properties in the study sites of the Alt Penedés and Priorat regions (AWC: Available Water retention Capacity; NC: No Cover; C: Cover; Ksat: Saturated Hydraulic Conductivity).

	% Slope	cm Effective rooting Depth (95 % roots)	mm AWC	mm Saturation	mm/hour Rain Inf. Rate (NC)	(C)	mm/hour Ksat (subsoil)
Alt Penedés							
Traditional	10	20 – 80	200	240	20	50	3
Transformed	6	15 - 60	120	150	5	20	3
Priorat							
Traditional	30	0 – 40	61	96	2600	2600	1200
Terraces	0	10 – 80	110	210	1240	1240	743

The data from these experimental sites were used to apply the water balance model SOMORE (Pla 1997, 2002), in order to predict the water requirements of the grapevines and cover crop, during the approximate different growing periods of vines, covering the range (maximum and minimum) of water use according to the year, to the region and to the variety, for wine production in those areas. Fig. 2 shows the values of the different calculated components of the soil water balance during the different growing periods of vines for wine production, in the two different selected years, under variable soil and management conditions. It may be appreciated that in all cases, the only possibility to have a green cover (C) between the vine rows, is during the resting period, and that if a cover was maintained for the rest of the year it would need to be killed with a selective herbicide, not toxic to the vines. It is evident that the use of a green cover crop in the resting period would increase the possibilities of drought in the critical Budburst-Bloom-Veraison period in drier years, and in soils with lower available water retention capacity (AWC) (associated to soil characteristics and effective rooting depth), and in climates with greater water requirements (ET) of the vine. A positive effect of the green cover crop would be in the Alt Penedés a reduction in the water runoff losses and in the accompanying soil water erosion.



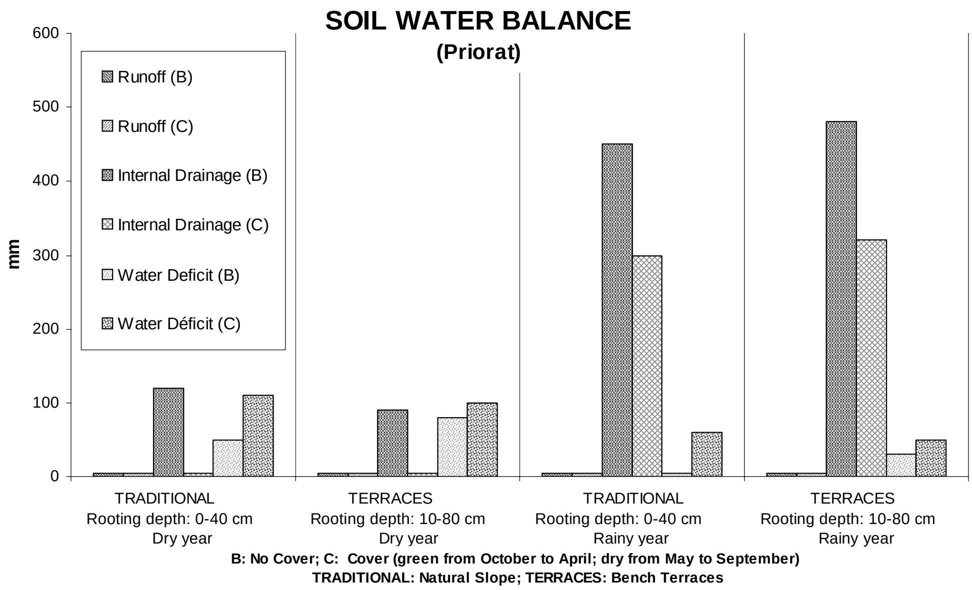


Fig. 2. Soil water balance in the dry land vineyards of the Priorat and Alt Penedés regions under traditional and newly transformed systems, with and without green cover, in a dry and a rainy year.

In the bench terraces of the Priorat region, with more effective rooting depth of vines and greater available water retention capacity, there would be less probability of drought in the drier years. In extremely humid years, especially with continuous and concentrated rainfall in the resting period, there would be potential conditions (high internal drainage following soil moisture conditions close to saturation on the soil profile for prolonged periods) for triggering landslides in the non-protected embankments of the terraces. A green cover crop in that period, using part of the excess water, would decrease the possibilities of landslides.

The results and the field observations clearly show that the new fully mechanized, land management and cropping practices in the dry land vineyards of the Alt Penedés and Priorat regions of NE 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. 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, 2006).

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, under the semiarid Mediterranean climate and previewed climate changes.

REFERENCES

Dupre, M. 1990. "Historical antecedents of desertification: climatic or anthropological factors?". In: Strategies to Combat Desertification in Mediterranean Europe, J.L. Rubio and R.J. Rickson eds. 2-39. CEC. Luxembourg

EC. 2003. Mediterranean desertification. Framing the policy context. Research results. Project EVK2-CT-2000-00085. Office for Official Publications of the European Communities. Luxembourg

Imeson, A.C. and I.M. Emmer. 1992. Implications of climate change on land degradation in the Mediterranean. In: Climate Change and the Mediterranean.(L. Jeftic et al, Eds) 95-128.Edward Arnold. London (UK)

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

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

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

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

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: Sustaining the Global Farm. (D.E.Scott et al , Ed).812-816.Purdue Univ.-USDA, ARS. West Lafayette (USA)

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