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RELATIONSHIPS BETWEEN SITE-SPECIFIC SOIL HYDROLOGICAL PROPERTIES AND WINE PRODUCTION IN TRANSFORMED VINEYARDS OF CATALONIA (NE SPAIN)

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ABSTRACT

The traditional extensive dry-land vineyards, for high quality wine production, in sloping lands of Catalonia (NE, Spain) have been partially substituted in the last two decades by more intensive systems to increase production and to facilitate mechanization of all operations. These changes have been associated to new land and conditioning (land leveling, terracing), use of green covers, and introduction of complimentary irrigation. The main consequence have been changes in the original variability of soil hydrological properties, specially the ones affecting the soil moisture regime, which under the very variable rainfall of the Mediterranean climate, is the most critical factor determining the quantity and quality of grapes and wine production. The studies included the continuous registration for several years of the soil moisture regime in carefully selected sites in three different zones of Catalonia producing high quality wines, under different rainfall conditions (amount and distribution), and different soil, water and crop management. There was evaluated the correspondence of such information with the one generated using a simple water budget model (SOMORE), with the objective of deducing risks of drought, water-logging, runoff and soil erosion, under the previewed varying rainfall conditions. The results demonstrate the potential use of variable soil and water management practices across de field, for improving both the efficiency of use of the scarce available water resources and the quantity and quality of wine production and for reducing environmental impacts. Those management practices are deduced through integration in models of on site-specific soil hydrological properties from field measurements and trials, and of the previewed variable rainfall and water requirements during the different growing periods of vines under Mediterranean climate.

Keywords: Hydrological properties, vineyards, modeling, management systems

INTRODUCTION

Precision agriculture can be defined as the process of adjusting agricultural practices according to the spatial variability of different biophysical factors affecting productivity and environmental protection. It requires site specific management, which means management of inputs (tillage, irrigation, fertilizers, pesticides) in the right place and at the right time based on site specific information. By using site specific knowledge, precision agriculture can target rates and proper spatial allocation of the external inputs (Clay et al, 1998). Larson et al (1997) analyzed the potential environmental protection benefits of precision agriculture. Site specific management has been used for fertilizer and herbicide applications, reducing environmental problems (Johnson et al, 1997). Delgado et al (2001) studied best management practices to maximize N use efficiency and minimize N loses in the environment.

Sources of variability justifying differential management may be natural (soils, topography, life cycles of the crop), random (rainfall), and resulting of management itself (land leveling, erosion, compaction). In many cases the sources of variability are visually or estimated indirectly, but direct field measurements and field trials, complemented with simulation modeling must be preferred for such evaluation (Pla, 2002a).

Variability of soil physical properties is important to assess the potential for variable rate management of some crop inputs and for delineating management zones. Within field variation in potential yield may be due to variations in plant available soil water, but at the same time different water holding capacities affect yield differently in different years depending on weather. Plant available water estimated from soil hydraulic properties and rooting data has been used in a simple water budget model (Pla, 1997, 2002a, 2005) to make drought risk assessments for different management systems with varying weather conditions. Delin and Berglund (2005) suggest a way to create management zones based on risk levels for drought and water logging using a soil water budget model estimated from soil and crop type. Marques Da Silva and Alexandre (2005) studied the influence of complex topography and soil characteristics in spatial variability of spray-irrigated corn yield.

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, 2002a).

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, 2002a). These conditions may be modified by soil and plant management practices as tillage, irrigation, drainage, etc. 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. This requires 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.

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. 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). 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. 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.

Vineyards, for dry land grape wine production, are a traditional crop in the steeply sloping agricultural lands of Catalonia (NE Spain). Presently, there are approximately 100,000 ha of vineyards in Catalonia, mostly under dry land conditions, which accounts for 8 % of the total production of Spanish wine (by volume) and 99 % of the cava (Spanish champaign) production. The water use of vines through the growing season is characterized by lessened requirements in the periods before bloom and after harvest until fall (autumn) in the northern hemisphere, 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 vines (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 vines under drought conditions (Maigre et al 1995).

Highly technified vineyards for production of good quality wines and cava, has become in the last 20 years a more economically attractive alternative to the traditional extensive vineyards in several regions of Catalonia (NE Spain). This evolution has been associated to changes in the land and crop management, including planting systems and physical land conditioning to facilitate mechanization of all operations, use of green covers and introduction of complementary irrigation. Such changes have mainly affected the soil moisture regime, which, especially under Mediterranean climate, is the main factor determining the quantity and quality of wine production.

Tillage has been the traditional practice to resolve several, perceived, in-field problems: weed control, and the loosening of compacted and crusted surface soils to increase rain water infiltration, to reduce losses of water by evaporation and to improve the rooting depth of vines. Although the benefits of no-tillage in association with green cover crops are recognised (particularly to protect the soil surface against direct raindrop impact, to increase the soil organic matter content, and to reduce runoff and surface erosion) it is considered that in dry land vineyards it may cause more water deficiencies and insufficient nitrogen supply, particularly in dry years (Rupp and Fox 1999). Additionally, it is known that in certain circumstances a green cover crop or cover residues will increase the survival rate of pathogens, and will favour the development of mildew. Experience in Catalonia (Spain) has shown that the use of some herbicides in association with no-till, particularly in areas with less than 500 mm rainfall and in soils with low organic matter and light textures, may cause phyto-toxicity problems in the vines.

The purpose of this research has been to study the effects on the soil moisture regime of the soils of the changes in land and crop management, under the variable Mediterranean climate conditions in three of the main regions –Penedés (Barcelona), Priorat (Tarragona) and Costers del Segre (Lleida) - with vineyards dedicated to the production of high quality wines and cava in Catalonia. The final objective is to evaluate the requirements of different management practices under the different natural and human introduced land and cropping conditions to decrease the risks of drought and soil degradation, and to improve the production and quality of grapes and wine. 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).

MATERIALS AND METHODS

The study areas were located in commercial field's representative of three of the regions (Penedés, Priorat and Costers del Segre) 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 there has been a drastic change from traditional practices, including the introduction of new varieties. In the three regions the climate is Mediterranean semiarid, with an annual rainfall very irregularly distributed, with the greatest rains in autumn-winter (Penedés and Priorat) and in autumn-spring (Costers del Segre), a very dry summer, and with large variability in totals from one year to another (400-750 mm in Penedés , 300-900 mm in Priorat and 150-600 mm in Costers del Segre). 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 those regions in the last 25 years.

In the 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. They have a high susceptibility to surface sealing (Ramos et al, 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. Recently, there has also been introduced the use of green covers, using different grasses, including rye and oats.

In the Priorat region, the topography is mountainous, with cropped areas in 10-80 % slopes, at 200-650 m a.s.l. 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. In the Costers del Segre region, the topography of the area is partially undulated, with flat lower lands, and cropped fields in 0-20% slopes, and altitudes of 220-300 m a.s.l. The soils generally have low or not profile development, mainly as a result of previous levelling operations to permit mechanization of all operations, including harvesting. With a climate drier than in the other two regions, there are installed fixed drip irrigation systems to apply irrigation water when it is needed. Irrigation is generally applied without differentiating sloping or flat areas. In most of the areas there are used green covers with different grasses, with very irregular cover in the sloping areas. Periodically (once every two or three years) the land between rows, and occasionally in the same row, is superficially (0-20 cm) tilled.

The soils in Penedés and Costers del Segre, with predominating silty-loam textures are derived from calcareous lutites, while the soils in Priorat are predominantly stony (more than 50 % coarse fraction), developed on slates and schist , calcareous only in the deeper soil where the clay content (mainly smectites) slightly increases. The main changes in land management in those three regions include levelling and use of green cover in rain fed vineyards of the Penedés, terracing and tillage in rain fed vineyards (occasionally with a limited complementary irrigation) of the Priorat, and levelling, complementary irrigation and use of green cover in the Costers del Segre. 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. This requires guided vine lines with lateral pruning, with rows 2.4 – 3.2 m apart, and 1.2 – 1.4 m between the plants. This gives a much lower soil surface protection than the traditional planting systems, although in both cases the protection is low in autumn-winter when the strong storms commonly occur. Mechanization also requires long and straight lines, sometimes in favour of the slope. 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 (Nacci et al 2002; Pla and Nacci 2003). Accompanying this large increase in vine area has been a drastic change from traditional practices, including the introduction of new varieties.

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 during 3-5 years, complemented with laboratory measurements. These have been used as a basis for the application and validation of the model SOMORE (Pla, 1997, 2002a, 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 and Nacci 2001; Pla et al, 2005), under different actual or potential climate conditions and management systems. The different periods during the growing season of vines in the three regions included in the study are:

-Resting period (October-February)
-Budburst-Bloom (March-April)
-Bloom-Veraison (May-July)
-Veraison-Harvest-Fall period (August-September)

In many cases adaptations and changes in the methodologies were required to make adequate measurements, particularly under field conditions in sloping and stony soils (Pla, 1990; 2002a). 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 (Fig. 1, 2, 3, 4). Among the management practices there are included clean tillage (NO COVER), and the use of green cover grass (GREEN COVER) during the resting-bloom period (October - May), followed by dry cover (killed with herbicide if necessary) during the rest of the growing periods (May to September). There were selected different growing seasons in each region, including the driest (low rainfall), the and the rainiest (high rainfall) during the last ten years, with return periods of about 5 years, and one with the more common rainfall (average rainfall) with return period of 2 years. In the selected seasons, the rainfall was highly concentrated in autumn (Priorat), in autumn – early winter (Alt Penedés), and in autumn-spring (Costers del Segre). In many years it is more important the rainfall distribution during the growing season than the total rainfall.

In the Penedés region two soil and land conditions were considered, one in the essentially non disturbed area (NON LEVELLED)) and the other in an adjacent highly disturbed (by land levelling) area (LEVELLED), with slopes 6-10%. Both sites are planted with the Chardonnay vine variety. The production in those areas varies from 6000 (LEVELLED) to 12000 Kg (NON LEVELLED) of grapes per hectare in humid years, to 1000 (LEVELLED) to 8000 Kg (NON LEVELLED) in dry years. The quality of production is also much lower in the disturbed area.

In the Priorat region, two soil and land conditions were selected, one in the sloping (30-60% slope) lands, with effective rooting depths of 40 cm (SLOPES), in a field with traditional management system. The other site and soil condition was in a neighbouring bench terraced land (TERRACES). Both sites are planted with the Garnatcha vine variety. The production in the non terraced site (SLOPES), with very old plantations, varies from 1000-3000 Kg of grapes per hectare, depending on the amount and distribution of rainfall. In the terraced land (TERRACES), with newer plantations and higher planting densities, the production may reach 6000 Kg of grapes per hectare, but in very dry years the production may be almost none. Besides, the quality of the production from older plantations in the slopes is much higher, reaching market prices per Kg of grapes sometimes 5-10 times the price for one Kg of grapes from the new terraced plantations.

In Costers del Segre region, the two selected conditions were in a sloping land (10-12 % slope) (SLOPE) and in the neighbouring lower flat area (FLAT LAND), both with drip irrigation. In both areas the planted variety is Tempranillo, with productions from 10000 to 12000 Kg of grapes per hectare in the sloping land (SLOPE) and from 8000-10000 Kg in the lower flat land (FLAT LAND), depending on the year (rainfall distribution). In this case the rainfall water deficits are covered with irrigation water, but the concentrated rainfall water may result in runoff and erosion in the sloping land and in temporal water-logging in the lower flat land. The quality of production is higher in the sloping land.

RESULTS AND CONCLUSIONS

In table 1 there are presented the main characteristics and hydrological properties of the soils as affected by the different land conditions in the experimental sites of the three regions included in the study.

Table 1. So me s oil characteristics and hyd raulic p roperties of the soils, unde r different conditions, in the three regions included in the study

Region Conditions	Slope	Coarse fraction	Effective rooting depth *	AWC	Rainfall infiltration NC	C	Ksat (subsoil)
	%	%	cm	mm	mm/hour		mm/hour
PENEDÉS							
NON LEVELED	10	5	20 - 80	200	21	48	3.2
LEVELED	6	8	15 - 60	120	5	19	0.4
PRIORAT							
SLOPES	52	55	0 – 40	61	350	320	220
TERRACES	0	42	10 – 70	110	180	154	93
COSTERS DEL SEGRE							
SLOPE	12	12	10 – 100	160	6	18	2.4
FLAT LAND	0	8	5 – 55	110	1.2	6	1.3

*>95% roots; AWC:Available Water Capacity; NC:No cover; C:Green cover

The information obtained in the experimental sites was integrated in the model SOMORE (Pla 1997, 2002) based on hydrological processes, in order to predict the soil water balance and soil water regime under different conditions. Fig. 1, 2, 3 and 4 show the values of the different calculated components of the soil water balance during the different growing periods of vines for wine production, in the different selected growing seasons, under variable soil and management conditions.

The results clearly show that the changes in land conditions, in land management and in cropping practices in the dry land vineyards of the Penedés and Priorat regions result in drastic changes in the soil moisture regime. The major direct effects are on surface runoff, surface erosion and potential mass movements, and in the retention of rainfall water in the soil for utilisation by the grapevines.

It may be appreciated that in the Penedés region, the risks of erosion and drought would be much higher in the disturbed levelled lands. It is also shown that the only possibility to have a green cover 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. A positive effect of the green cover crop in Penedés would be a reduction in the water runoff losses and in the accompanying soil water erosion, especially in the more humid years with concentrated rainfall.

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 average rainfall to humid years, but higher risks of drought in 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

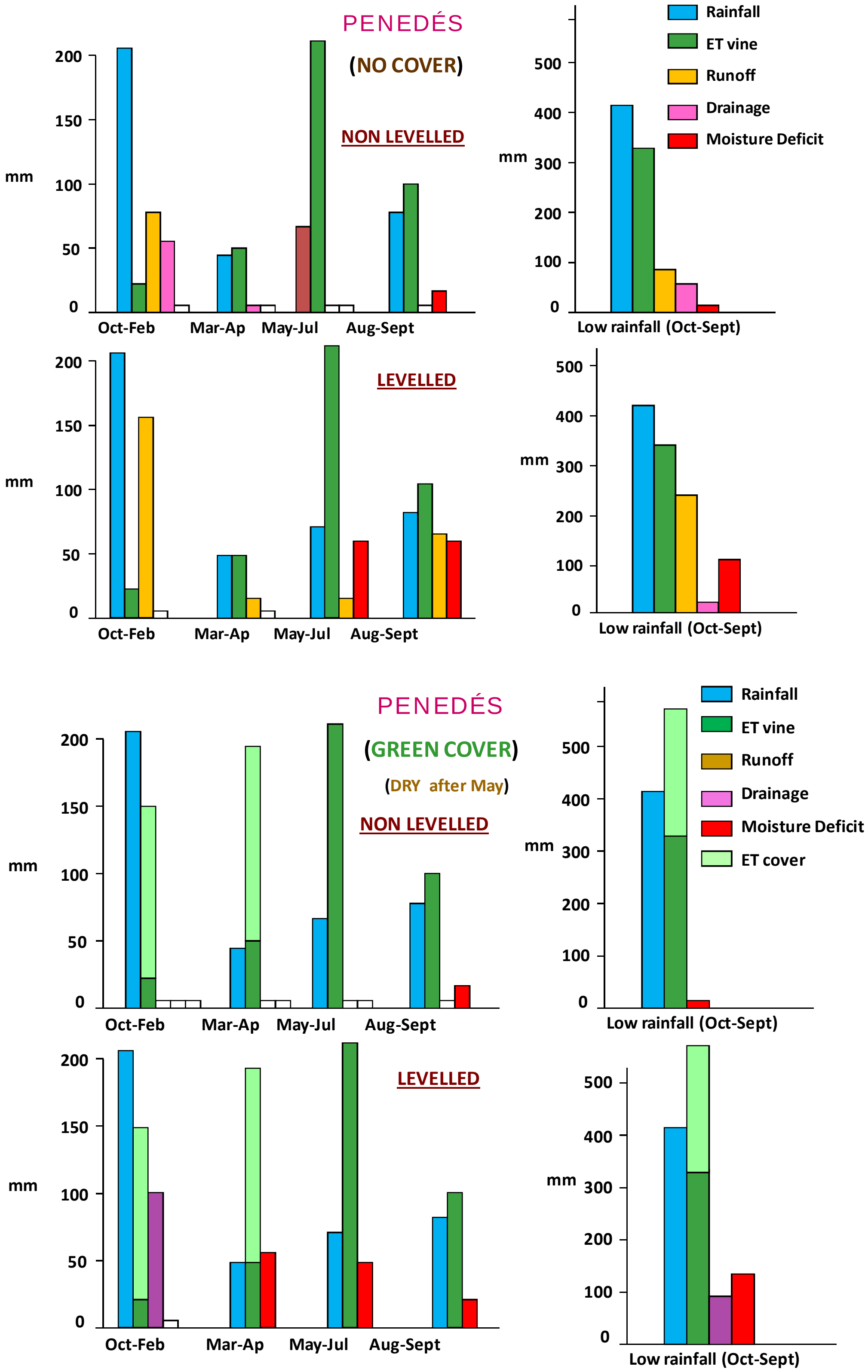

Fig. 1. Rainfall and soil water balance components in rainfed vineyards of the Penedés region in a year with low rainfall (return period:5 years) in non levelled and levelled land without and with green cover

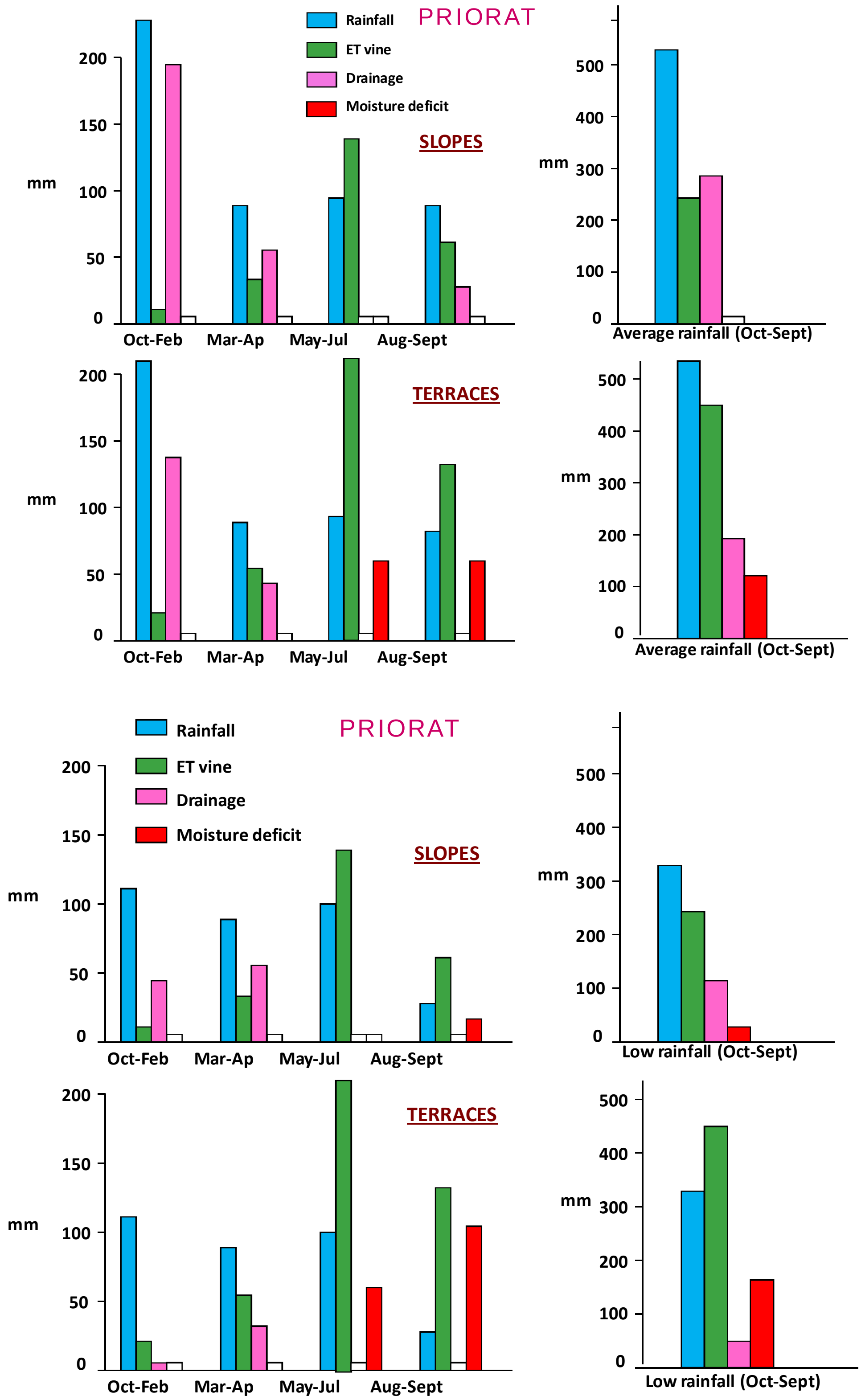

Fig. 2. Rainfall and soil water balance components in rainfed vineyards of the Priorat region in years with average rainfall (return period:2 years) or low rainfall (return period:5 years) in slopes (no tilled) and terraces (tilled).

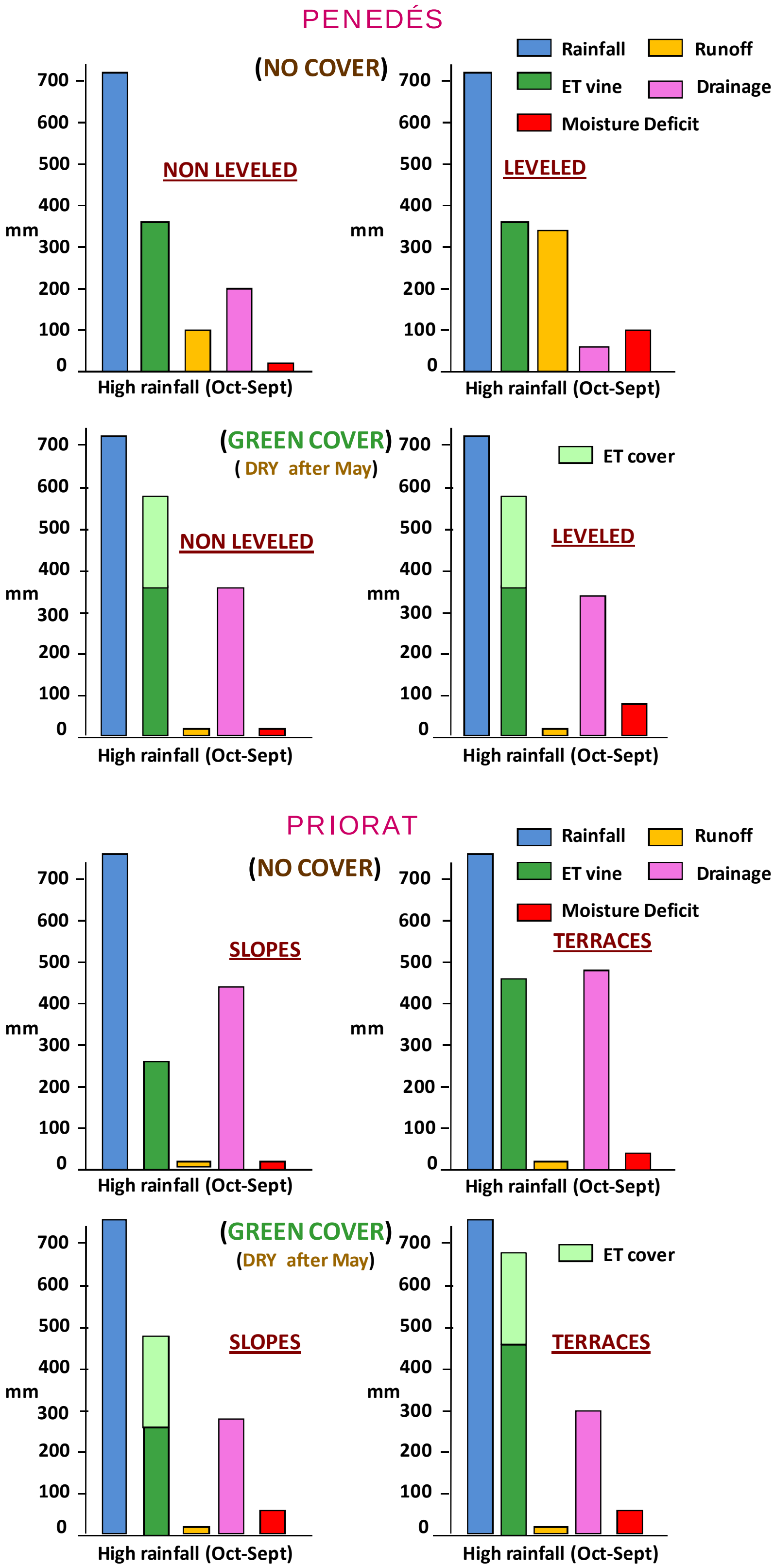

Fig. 3. Rainfall and soil water balance components in rainfed vineyards of the Penedés (levelled and non levelled) and Priorat (slopes and terraces) regions, in years with high rainfall (return period:5 years) without and with green cover

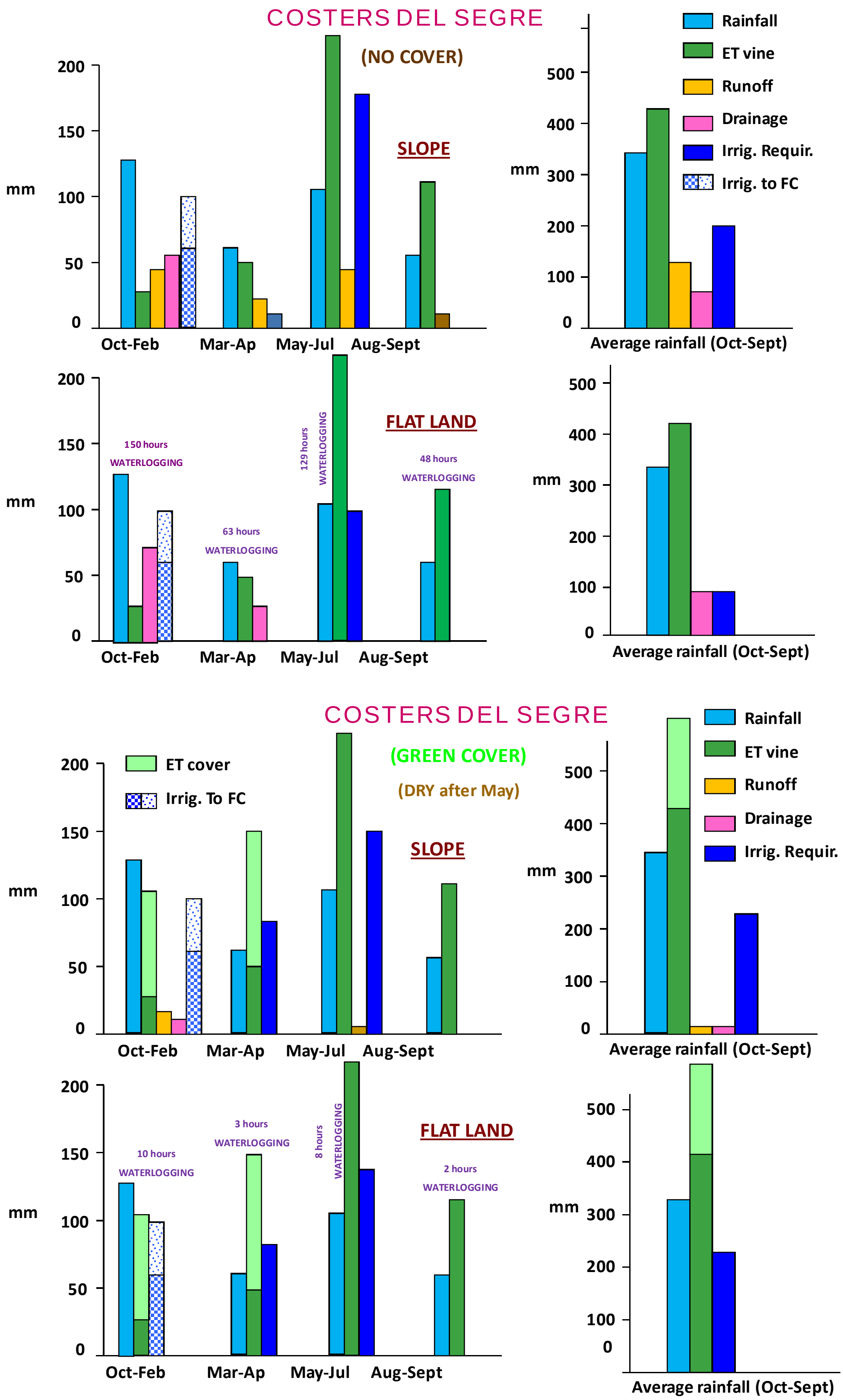

Fig. 4. Rainfall and soil water balance components in irrigated vineyards of the Costers del Segre region in years with average rainfall (return period:2 years), in slope and flat land, without and with green cover

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 simulation of the water balance under the different land conditions in the Costers del Segre region show that the irrigation requirements would be very different form the sloping land to the lower flat land, except when there is maintained a green cover. There is also shown that in some cases there would necessary to provide drainage for eliminating excess of water and reduce water-logging in the lower flat land.

It may be concluded that an 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 site specific, more sustainable, land use and management for grape wine production. 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 site specific soil and water management and conservation, leading to a more sustainable and regular production of high quality wines.

In general, it is proved that 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 potential effects of the variability of those biophysical factors on agricultural production and environmental impacts. This is a required previous step for a rational land use planning, and for the selection and development of short and long term site specific sustainable strategies and technologies for agricultural production, under the semiarid Mediterranean climate and previewed climate changes.

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