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SOIL MOISTURE REGIME IN DRYLAND VINEYARDS OF CATALUNYA (SPAIN) AS INFLUENCED BY CLIMATE, SOIL AND LAND MANAGEMENT

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Abstract

Vineyards, under dryland conditions for wine and cava production, have been and still are one of the main crops in the region of Catalunya (NE Spain). In the last decades, following EU policies, many areas with vineyards have been abandoned, while in others the cropping practices have been intensified, frequently with large changes in land and soil management. These changes have mainly affected the hydrology of the cropped lands, and especially the soil moisture regime, with effects on the quantity and quality of grape production. The effects are more marked due to the high variability and concentration of rainfall events in the local Mediterranean climate.

The results of evaluations and monitoring of soil hydrological properties and processes in two of the main areas with dryland vineyards, for high quality cava (Alt Penedés) and wine (Priorat) production in Catalunya, are used for deducing and simulating the soil moisture regime. This regime is evaluated under different and changing conditions of climate, soil, land management and soil conservation practices. The interpretation is based on the different soil water requirements of vines during their annual growing cycle, and on the potential erosion processes. It is concluded that the different tested soil and water management and conservation practices may have positive or negative effects depending on the other soil and climate factors. These effects must be evaluated or simulated before recommending or adopting any new management or conservation practice.

Introduction

Vineyards, for dryland grape wine production, are a traditional crop in the steeply sloping agricultural lands of Catalunya (NE Spain). Presently, there are approximately 100,000 ha of vineyards in Catalunya, mostly under dryland conditions, which accounts for 8 % of the total production of Spanish wine (by volume) and 99 % of the cava production. In Catalunya, as well as in other regions of Mediterranean Europe, dryland vineyards have suffered great changes in the last decades. In part, following EU policies, some cropped lands have been abandoned, but in others, with vineyards dedicated to production of high quality wine and cava, the cropped area has increased, with more intensive and highly mechanized agricultural systems (Pla and Nacci 2003). In some cases limited irrigation has been introduced (mostly drip irrigation) but only as a remedial practice if there is extreme drought. The removal of large volumes of soil, due to terracing and levelling with bulldozers to change the topography of slopes to facilitate water retention and mechanization, has affected the hydrological properties of the soils and the natural drainage of the lands, favouring erosion and mass movements, though mainly restricted to extreme events (Pla and Nacci 2001; Nacci et al 2002). Additionally, there is a trend of increasing frequency of dry years and at the same time of more aggressive extreme rainfall events, apparently as a consequence of general climate changes in the Mediterranean region (Ramos 2001).

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 dryland vineyards it may cause more water deficiencies and insufficient nitrogen supply, particularly in dry years (Rupp & 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 the Catalunya region 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 work reported here presents the actual and potential effects of these changes in land management on soil and water conservation as studied in two representative areas (Alt Penedés and Priorat), covering the range of the more common soils, topography, climate and land management changes in dryland vineyards of Catalunya (Spain) and of many other Mediterranean regions. These studies included evaluations of soil and land hydrological properties and processes, through field and laboratory measurements and field monitoring. The studies were integrated, using flexible models based on hydrological processes, to deduce the potential effects on soil surface and mass erosion, and on the soil moisture regime affecting the sustainability, quantity and quality of grape and wine production, under changing scenarios of climate and land conditions (Pla 1997; 2002).

Materials and methods

Experimental areas

The study areas were located in commercial fields representative of two of the regions (Alt Penedés and Priorat) of Catalunya (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. Presently there are approximately 30,000 ha of vineyards in Alt Penedés, and 5,000 ha in Priorat. 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 variabilities 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 (Alquézar et al 1990; Ramos and Porta 1994). 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 both regions in the last 25 years. The extrapolation to the future of past or historical information may be unreliable due to greenhouse effects on climate changes. In any case, the past information about extraordinary events is of concern due both to the lack of long-term measurements and to the low quality of the measurements (Gallart 1990).

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), 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).

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 & Nacci 2003).

In the Alt Penedés region, the topography of the area is strongly undulated, and even hilly, with cropped fields on 4-20% slopes, and altitudes of 250-400 m a.s.l. The soils generally have minimal profile development, mainly as a result of levelling operations for smoothing the land surface for mechanization. These soils, formed from calcareous lutites, are inherently low in organic matter (< 1.5%), high in silt (40-60%) and very rich in calcium carbonate. They have strong susceptibility to surface sealing (Ramos et al 2000), resulting in large runoff and surface erosion rates. Periodical tillage does not encourage root growth in the surface 15-20 cm of soil, which is maintained in a loose condition for most of the year to increase rainfall water infiltration, to decrease evaporation of deeper soil water, and to control weeds.

One practice for water conservation, found in some areas, are narrow (2-3 m wide and 15-20 cm depth) bench terraces across the slope, every 10-15 vine rows (depending on the slope) where the weeds are not removed, 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. The resultant gullies receive concentrated surface runoff and subsurface flow of water coming from more elevated parts of the field.

In the Priorat region, the climate is also semiarid, and the topography is mountainous with cropped areas on 10-80 % slopes, at 200-650 m a.s.l. Soils are developed on slates and schist, are not calcareous, slightly acid, very poor in organic matter, and very stony (20-60% by volume), 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 strongly weathered and fragmented rock.

Traditionally the vineyards in the Priorat are planted with varieties producing wines of high graduation and good quality, but low yields (usually less than 3 Mg/ha). The planting pattern mainly follows the contour lines, in very small individual fields, with vines and lines 2-3 m apart. The original relief and slopes are normally retained, and the only conservation structures are non-continuous stone walls, located across the drainage ways and in places where local experience says there is 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. Today, this practice has almost disappeared, except where a gentler slope allows the use of a small tractor, and the control of weeds is done with herbicides. As a result of continuous no-tillage the vine roots tend to concentrate on the surface soil, where the effects of drought or poorly distributed rainfall are more marked.

The new plantations of vines in the Priorat region are established to facilitate mechanical operations in the vineyards, aiming for increased soil water retention and greater and more stable grape and wine production. There are built bench terraces, 2-5 m wide, depending on the slope, with very steep and unstable embankments. These necessitate forest clearing, for new vineyards, followed by the removal of large volumes of soil and underground rock using heavy bulldozers. One to three rows (2-3 m apart) of vines are planted in the terraces, generally of newly introduced and more productive varieties that are planted with 1.2 m spacing between plants. In most cases, the very steep embankments of the terraces are not protected, except by the slow re-growth of natural vegetation. 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 experiments

Most of the problems of soil and water conservation in the Alt Penedés and Priorat regions are associated with the effects of climate change and of soil and cropping management practices on the soil water regime. 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) (Figure 1) 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 vines at different growth stages (Pla 1997; Pla and Nacci 2001). In many cases adaptations and changes in the methodologies were required to make adequate measurements, particularly under field conditions.

Table 1: Rainfall distribution in selected extreme dry and rainy growing seasons (return period: 5 years) of grapevines during the last ten years in the Alt Penedés and Priorat regions (Catalunya, NE Spain)

					mm rainfall							
MONTH: YEAR	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Ap.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sept.**
Alt Penedés												
Dry (D) 408	29	0	106	53	20	8	32	40	9	22	4	85
Rainy (H) 723	130	150	135	118	0	17	44	19	57	9	44	0
Priorat												
Dry (D) 333	81	19	0	12	28	15	53	67	10	8	17	63
Rainy (H) 733	370	63	62	20	15	24	46	51	7	48	12	15

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. Several treatments were included: the present clean tillage management (NC), the potential use of green cover grass (C) during the resting period (R), followed by cover (utilising the killed grass residues) during the rest of the growing periods. Presented here are the selected growing seasons in each region, being: the driest (D) and the rainiest (H) during the last ten years, with return periods of about 5 years. In the selected rainy (H) seasons, the rainfall was highly concentrated (> 70 % of the total annual rainfall) in autumn (Priorat) and in autumn – early winter (Alt Penedés) (Table1).

In the Alt Penedés region two soil conditions were considered, one of the essentially non disturbed area (AP-1) and the other a highly disturbed (by land levelling) area (AP-2), with slopes 6-10%. A further treatment was in one of the small bench terraces (AP-T) built every 10-15 rows (Table 2).

In the Priorat region, two soils were selected in the sloping (30-60% slope) lands, with effective rooting depths of 70 cm (P-1) and 40 cm (P-2), in a field with traditional management system. Also, one soil was investigated in a neighbouring bench terraced land (P-T) (Table 2).

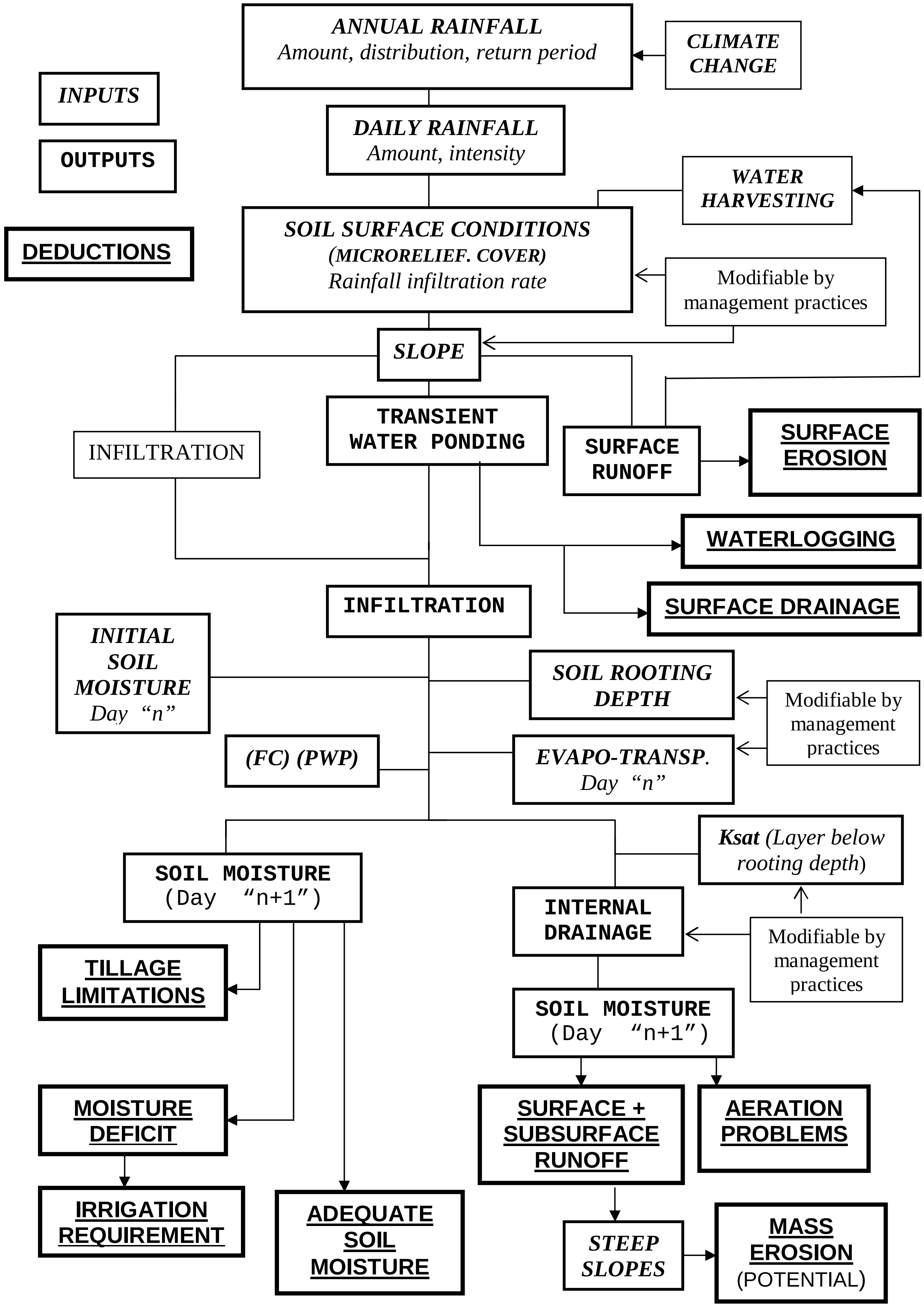
Table 2: Soil Characteristics and hydrological properties in selected sites of the Alt Penedés and Priorat regions (AWC: Available Water retention Capacity; NC: No Cover; C: Cover; Ksat: Saturated Hydraulic Conductivity)

	%	**cm**	**mm**	**mm**	**mm/hour**		**mm/hour**
	Slope	**Effective Rooting Depth (95 % roots)**	**AWC**	**Saturation**	**Rain Inf. Rate (NC)**	**(C)**	**Ksat (subsoil)**
<u>Alt Penedés</u>							
AP – 1	6	20 – 80	200	240	20	50	3
AP – 2	10	15 - 60	120	150	5	20	3
AP – T	0	0 – 20	70	80	-	50	0,4
<u>Priorat</u>							
P -1	50	0 – 70	82	140	66	66	1280
P – 2	30	0 – 40	61	96	62	62	702
P - T	0	0 – 70	110	210	100	100	743

The data from these experimental sites were fitted using a water balance model (Pla 1997) (Figure 1) to predict the water requirements of the grapevines and cover crop, during the approximate different growing periods of vines (with slight differences according to the year, to the region and to the variety) for wine production in those areas:

- Resting period (R). October- February (approx.)
- Budburst – Bloom period (Bu – Bl). March – April (approx.)
- Bloom – Veraison period (Bl – Ve). May – July (approx.)
- Veraison – Harvest – Fall period (Ve – H – F). August – September (approx.)

The given values of water requirements (ET) for vines correspond to the more common range of requirements under semiarid Mediterranean climate (Nacci 2001). The water requirements for the green cover crop correspond to those of a well developed rye crop.



(***Ksat***: Saturated hydraulic conductivity; ***FC***: Field Capacity; ***PWP***: Water retention at -1,5 Mpa)

Figure 1. Flow diagram of a conceptual model (SOMORE) based on hydrological processes, to predict the soil moisture regime and to assess the potential soil and land degradation processes (adapted from: Pla, 1997).

Table 3: Soil water balance components in relation to the crop water requirements in the different growing periods of grapevine, in the selected years (D: dry; H: Rainy) and sites of the Alt Penedés region (*green cover crop; **dry cover;***range: depending on variety and soil moisture stress; SAT: soil saturated with water)

	mm				
Growing period:	Resting	Budbreak – Bloom	Bloom-Veraison	Veraison-Harvest-Fall	TOTAL
ET (Cover)	**130**	**140**	**419**	**250**	**(639)**
ET (Vine)* **	**10 - 20**	**40 – 45**	**200 – 265**	**95 – 100**	**(340–430)**
RAIN (D)	**208**	**40**	**71**	**89**	**(408)**
AP – 1 (NC)					
RUNOFF	75	0	0	0	(75)
DRAINAGE	56	0	0	0	(56)
DEFICIT (ET)	0	0	0	0 – 5	(0-5)
AP -1 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	0	0	0	0	(0)
DEFICIT (ET)	0*	0*	0(70-135*)	0**	(0)
AP – 2 (NC)					
RUNOFF	160	10	8	65	(243)
DRAINAGE	0	0	0	0	(0)
DEFICIT (ET)	0	0	27 – 97	61 – 66	(88-163)
AP – 2 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	98	0	0	0	(98)
DEFICIT (ET)	0*	0(60-65*)	9 – 79**	6 – 11**	(15–90)
RAIN (H)	**533**	**61**	**85**	**44**	**(723)**
AP – 1(NC)					
RUNOFF	110	0	3	0	(113)
DRAINAGE	189	15	0	0	(204)
DEFICIT (ET)	0	0	0	0 – 39	(0 – 39)
AP – 1 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	320	15 (0*)	0	0	(335)
DEFICIT (ET)	0*	0*	0(4 -9*)	0 – 26**	(0 – 26)
AP – 2 (NC)					
RUNOFF	292	12	14	9	(327)
DRAINAGE	47	9	0	0	(56)
DEFICIT (ET)	0	0	9 – 74	51 – 56	(60 – 130)
AP – 2 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	310	21(0*)	0	0	(331)
DEFICIT (ET)	0*	0 (0*)	0 – 60 **	46 – 51**	(46–111)
AP – T (C)					
RUNOFF (SAT.)	250	0	0	0	(250)
DRAINAGE	190	0	0	0	(190)
Days (SAT):	20 days	0	0	0	(20 days)

Table 4: Soil water balance components in relation to the crop water requirements in the different growing periods of grapevine, in the selected years (D: dry; H: Rainy) and sites of the Priorat region (*green cover crop; **dry cover;***range: depending on variety and soil moisture stress; SAT: soil saturated with water)

			mm		
Growing period:	**Resting**	**Budbreak – Bloom**	**Bloom-Veraison**	**Veraison-Harvest-Fall**	TOTAL
ET (Cover)	**130**	**140**	**419**	**250**	**(639)**
ET (Vine)* **	**10 - 20**	**40 – 45**	**200 – 265**	**95 – 100**	**(340–430)**
RAIN (D)	**140**	**65**	**88**	**80**	**(333)**
P – 1 (NC)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	76	20	0	0	(96)
DEFICIT (ET)	0	0	30 – 95	15 – 20	(74–149)
P- 1 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	0	0	0	0	(0)
DEFICIT (ET)	0*	0 (87-92*)	59 – 129**	15 – 20**	(74–149)
P – 2 (NC)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	97	25	0	0	(122)
DEFICIT (ET)	0	0	51 – 116	15 – 20	(66–136)
P – 2 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	0	0	0	0	(0)
DEFICIT (ET)	0*	0 (100-105*)	67 – 137**	15 – 20**	(82–157)
P – T (NC)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	70	20	0	0	(90)
DEFICIT (ET)	0	0	2 – 67	15 – 20	(17-87)
P – T (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	0*	0	0	0	(0)
DEFICIT (ET)	0*	0 (75-80*)	47 – 117**	15 – 20**	(62-137)
RAIN (H)	**530**	**70**	**108**	**25**	**(733)**
P 1- (NC)					
RUNOFF	142	0	0	0	(142)
DRAINAGE	303	30	0	0	(333)
DEFICIT (ET)	0	0	10 – 75	70 – 75	(80–150)
P -1 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	315	30(0*)	0	0	(345)
DEFICIT (ET)	0*	0(28-33*)	10 – 75**	70 – 75**	(80–150)
P – 2 (NC)					
RUNOFF	132	0	0	0	(132)
DRAINAGE	298	30	0	0	(328)
DEFICIT (ET)	0	0	31 – 96	70 – 75	(101–171)
P – 2 (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	300	30 (0*)	0	0	(330)
DEFICIT	0*	0 (49-54*)	10 – 75**	70 – 75**	(80 – 150)
P – T (NC)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	450	30	0	0	(48)
DEFICIT (ET)	0	0	0 – 47	52 – 57	(52 – 104)
P – T (C)					
RUNOFF	0	0	0	0	(0)
DRAINAGE	320	30 (0*)	0	0	(350)
DEFICIT (ET)	0*	0 (0-5*)	0 – 47**	52 – 57**	(52 – 104)

Results and conclusions

Tables 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 seasons, under variable soil and management conditions. It is shown that in all cases, the only possibility to have a green cover (C) between the vine rows, is during the resting (R) 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 (Bl - Ve) period in drier years (D), in soils with lower available water retention capacity (AWC) (associated with 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, in many cases, would be a reduction in the water runoff losses (RUNOFF) and in the accompanying soil water erosion.

The small absorption terraces in the Alt Penedés (AP-T), may reach conditions triggering mass movements (days with soil moisture greater than the liquid limit, high runoff under saturation, and high potential internal drainage), mainly in the resting period (R) of the more rainy seasons (H).

In the bench terracing of the Priorat region (P-T), with more effective rooting depth of vines and greater available water retention capacity, there would be less probability of drought in the drier (D) years. In extremely humid years, especially with continuous and concentrated rainfall in the resting period (R), 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.

In general, it may be concluded that the new fully mechanized, land management and cropping practices in the dryland 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. 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.

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