

COVER CROPPING IN A SLOPING NON-IRRIGATED VINEYARD: II - EFFECTS ON VEGETATIVE GROWTH, YIELD, BERRY AND WINE QUALITY OF 'CABERNET SAUVIGNON' GRAPEVINES

ENRELVAMENTO EM VINHA DE ENCOSTA NÃO REGADA: II - EFEITOS NO CRESCIMENTO VEGETATIVO, PRODUÇÃO E QUALIDADE DO MOSTO E VINHO, CASTA 'CABERNET SAUVIGNON'

C.M. Lopes, A. Monteiro, J.P. Machado, N. Fernandes, A. Araújo

Instituto Superior de Agronomia, Universidade Técnica de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal.
E-mail: carlosmlopes@isa.utl.pt, Tel.: 351-213653450. Fax: 351-213 623262.

(Manuscrito recebido em 29.02.08. Aceite para publicação em 23.06.08)

SUMMARY

Grapevine vegetative growth, yield, fruit composition and wine quality were studied in the Estremadura Winegrowing Region of Portugal in a 'Cabernet Sauvignon' sloping non-irrigated vineyard. During three seasons three treatments were compared: soil tillage (control), permanent resident vegetation, and permanent sown cover crop. When compared to soil tillage, the inter-row sward treatments displayed a lower predawn leaf water potential from bloom to mid-ripening. These differences in vine water status did not affect vine yield or berry sugar accumulation; however, in the third season after experiment setup it induced a significant reduction in vegetative growth in the sward treatments, compared to soil tillage. This vegetative growth reduction had a positive effect on grape composition by reducing titratable acidity and increasing berry skin total phenols and anthocyanins. Those differences were also detected in the wines by the judges who gave a better classification to the wines from the sward treatments. Our results indicate that cover cropping can be a valuable tool for controlling vigour and enhancing wine quality in this winegrowing region.

RESUMO

Numa vinha da casta 'Cabernet Sauvignon' instalada na região da Estremadura – Alenquer - estudou-se o efeito do enrelvamento da entrelinha no crescimento vegetativo, rendimento e qualidade da uva e do vinho. Durante três anos compararam-se três tratamentos alternativos: mobilização da entrelinha (testemunha), relvado natural e relvado semeado. Comparativamente à modalidade mobilizada as videiras das modalidades relvadas apresentaram um potencial de base mais baixo durante o período floração-meia maturação. Estas diferenças no estado hídrico da videira não afectaram o rendimento nem a acumulação de açúcar nos bagos no entanto, no terceiro ano de ensaios, provocaram uma redução significativa no crescimento vegetativo das videiras das modalidades relvadas, comparativamente à modalidade mobilizada. Esta redução do crescimento vegetativo induziu um efeito positivo na composição da uva através da redução da acidez total e do aumento da concentração de antocianinas e fenóis nas películas do bago. Estas diferenças foram também detectadas na análise sensorial do vinho, na qual os provadores atribuíram uma melhor classificação aos vinhos das modalidades relvadas. Os nossos resultados indicam que, neste "terroir", o enrelvamento da vinha é uma técnica cultural recomendável pois permite controlar o vigor e, indirectamente, melhorar a qualidade da uva.

Keywords: grapevine, cover crops, growth, yield, quality.

Palavras Chave: videira, enrelvamento, crescimento, rendimento, qualidade.

INTRODUCTION

The advantages of using cover crops in vineyards are well known. The benefits are many, covering a wide range of subjects, from the environment (Folorunso *et al.*, 1992; Gulick *et al.*, 1994; Costello and Danne, 1998; Prichard, 1998; Pradel and Pieri, 2000; Morlat and Jaquet, 2003; Campos *et al.*, 2006) to the vineyard management, vigour control and grape quality (Pacheco *et al.*, 1991; Maigre *et al.*, 1995; Agulhon, 1996; Geoffrion, 1999; Le Golf-Guillou *et al.*, 2000; Linares *et al.*, 2007).

Despite those potential benefits the adoption of cover crops in Mediterranean non-irrigated vineyards has been limited by the concern of excessive water competition between the swards and vine, one of the

most reported disadvantages of cover crops. However in some "terroirs" the additional water use by the swards can be advantageous. In the spring of Mediterranean climates, growth favourable temperatures and soil water availability induces high vine vegetative growth rates enabling a fast canopy establishment. In some situations (deep soils and/or high rainfall) this induce a dense canopy creating unbalanced vines with unfavourable microclimate at cluster zone that can be deleterious for berry health and ripening (English *et al.*, 1990; Smart and Robinson, 1991). Furthermore, those high vigorous vines need more intensive canopy management, like shoot trimming and defoliation, thus increasing vineyard management costs. The additional water used by cover crops in Spring (Lopes *et al.*, 2004; Pellegrino *et al.*, 2004; Monteiro and Lopes, 2007)

can be an advantage as it can induce a mild water stress enabling an early stop of vegetative growth and a consequent reduction of vine vigour (Morlat *et al.*, 1993; Caspari *et al.*, 1997; Geoffrion, 2000; Maigre and Aerny, 2001; Afonso *et al.*, 2003). This control of canopy development reduces water consumption during ripening and improves water use efficiency (Linares *et al.*, 2007). The decrease in the competition between vegetative and reproductive growth and lower canopy density increases cluster exposure, enabling an improvement of the fruit colour and anthocyanin concentrations in red grape varieties (Dokoozlian and Kliewer 1996; Keller and Hrazdina 1998; Spayd *et al.*, 2002). Moreover, if the moderate stress occurs after berry set it can reduce berry size which is an oenological advantage as it induces a higher skin/flesh ratio. Also the possibility of a reduction in berry set caused by the water competition like it was observed in a 'Merlot' vineyard by Linares *et al.* (2007) can be an advantage if lower yields are needed for high quality wines.

In Portuguese vineyards the most widely used floor management techniques are soil cultivation combined mainly with herbicides in the row (Monteiro and Moreira, 2004). In the last years, the use of cover crops have been increased however this increase was not supported by regional studies. The objectives of the present study were to determine the influence of permanent green cover on grapevine vigour, yield, berry composition and wine sensory attributes in a sloping non-irrigated vineyard growing in the Estremadura winegrowing region. This study is part of a large research project where water use (Monteiro and Lopes, 2007), weed communities, structure and biomass evolution, (Monteiro *et al.*, 2008) and beneficial arthropods abundance (Campos *et al.*, 2006) have also been monitored.

MATERIAL AND METHODS

The trial was carried out during three growing seasons (2002-2004) in a 15-year-old 'Cabernet Sauvignon' (*Vitis vinifera* L.) sloping vineyard (7%), located at Alenquer, Estremadura Winegrowing Region, Central Portugal (lat. 39° 01' N; long. 9° 06' E). The soil is a sandy clay loam with the following average characteristics: clay 23.6%; silt 20.2%; sand 56.2% (USDA classification); organic matter 0.7%; pH of 8.4. For a detailed description of the seasonal pattern of volumetric soil moisture in the 0-1.0 m profile see Monteiro *et al.* (2007).

The vines were grafted on 110 R rootstocks and spaced 2.5 m x 1.0 m on a clay calcareous soil. The training system was a vertical shoot positioning with movable wires being the vines spur-pruned on a bilateral Royat Cordon system. Shoots were trimmed twice, between bloom and veraison, at a height of about 1.0 m. The experiment was laid as a randomized complete

block design with four replications and the following three treatments: (1) soil tillage over the between row (ST); (2) permanent resident vegetation cover between row (RV) and (3) permanent sown cover crop between row (SCC). Each replicate (plot) had four rows with 100 vines each and all the measurements were made in the two central ones. For a more detailed description of the soil management techniques and climate data see the companion paper (Monteiro *et al.*, this volume).

Vine pre-dawn leaf water potential was periodically measured between bloom (beginning of June) and harvest (end of September). The measurements were carried out on an adult leaf from six replicate plants from each treatment within the two central plots (3 leaves per plot), using a pressure chamber (Model 1000; PMS instrument Co., Corvallis, OR, USA). Leaves were enclosed in a plastic bag, immediately severed at the petiole and sealed into the humidified chamber for determination of the balancing pressure. Leaf area per shoot was assessed periodically in a sample of 16 count shoots per treatment from bud burst onwards in a non-destructive way, using the methodologies proposed by Lopes and Pinto (2005). Leaf area per plant was calculated multiplying the leaf area per shoot by the average shoot number. Canopy wideness was assessed on a sample of forty vines per treatment (10 per plot) by the insertion of a pre-marked rod perpendicularly to the row at the fruit zone.

Fruit composition was evaluated at harvest using a sample of 200 berries per plot. The berries were weighed and crushed being the juice analysed for pH, soluble solids (°Brix) and titratable acidity according to the O.I.V. (1990) procedures. Berry skin anthocyanins were measured using the sodium bisulphite discoloration method (Ribéreau-Gayon *et al.*, 1972) and total phenols were determined by spectrophotometry, measuring Ultraviolet absorption at 280 nm (IFT). At harvest the number of clusters and their total weight per vine was recorded on forty previously selected vines per treatment (10 per plot). In the 2003 and 2004 fifty kg of fruit per treatment was sampled and used for small scale wine-making. The grapes were mechanically destemmed and transferred to 50 l stainless-steel containers, sulfited at 50 mg SO₂/kg and inoculated with a commercial yeast strain at 200 mg/kg. The wine lots were punched down twice daily until the end of alcoholic fermentation (5 days) after which the wines were transferred to stainless-steel containers. After malolactic fermentation the wines were racked and transferred to 5 L glass containers. The wines were bottled in the following spring and submitted to a sensory panel of 9 judges using a discontinuous scale with pondered attributes. At winter pruning the shoot number and fresh pruning weight were recorded.

Statistical data analysis was performed by analysis of variance and LSD tests in accordance with GLM

procedures, from the SAS® program package (SAS Institute, Cary, NC, USA).

RESULTS AND DISCUSSION

Leaf water potential

In the first year of the experiment (2002) pre-dawn leaf water potential (Ψ_{pd}) was only measured during the ripening period attaining values between -0.36 and -0.45 MPa without significant differences between treatments. In 2003 Ψ_{pd} displayed a decreasing pattern from bloom to harvest (June to mid-September) in all treatments. Despite the consistently higher values presented by ST vines after bloom, the differences were only significant during the first half of the ripening period (August). In 2004 a similar pattern was observed from bloom to veraison however, the decrease was not as intense as that observed in the 2003 season, and during the ripening period the Ψ_{pd} values were higher than those observed at the 2003 season. During most of the 2004 growing season ST presented a significantly higher Ψ_{pd} than the two sward treatments which displayed similar trends, except at the last measurement, after the September rains, when RV presented a significantly

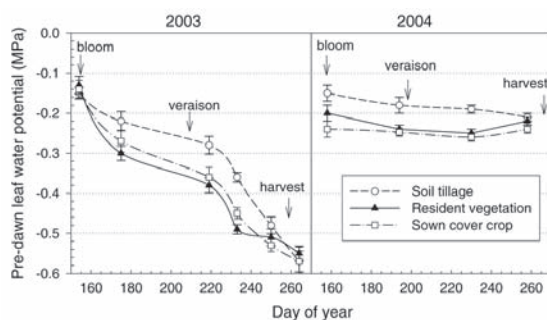


Fig. 1 – Effect of soil management techniques on pre-dawn vine leaf water potential measured during 2003 and 2004 growing seasons. Each point represents the average of 6 leaves with the standard error.

Efeito das técnicas de manutenção do solo no potencial hídrico foliar de base medido em 2003 e 2004. Média e erro padrão de 6 folhas.

higher value than SCC (Fig. 1).

The decreasing pattern of the pre-dawn leaf water potential that was observed in all the treatments reflects the fall in soil water availability (Monteiro and Lopes, 2007), as pre-dawn is a very good indicator of the mean soil water potential of the more wetted soil volume exploited by roots (Rodrigues *et al.*, 1993; Cifre *et al.*, 2005). The pre-dawn values present important differences between the two seasons caused mainly by the different patterns of rainfall and temperature. Whereas in 2003 the period between budbreak and bloom (mid-March to end of May) experienced 187.8 mm of rainfall, in 2004 it only rained 33.2 mm during the corresponding period.

During the ripening period, in 2003 the rainfall was very low (11.6 mm), while in 2004 it rained 45.6 mm.

At the end of spring, whereas in 2003 the pre-dawn indicates a non-water-stress situation in all three treatments (pre-dawn > -0.2 MPa), in 2004 the two sward treatments present values below -0.2 MPa, which is indicative of a mild water stress situation (Koundouras *et al.*, 1999). During the ripening period the opposite situation was observed, with 2003 pre-dawn values indicating a moderate-to-severe water stress situation (-0.4 MPa > pre-dawn > -0.6 MPa) (Deloire *et al.*, 2003), while in the 2004 season the pre-dawn values were always indicative of a mild water stress situation (-0.2 MPa > pre-dawn > -0.25 MPa).

Despite not always statistically significant, the general effect of the soil management strategies on vine pre-dawn leaf water potential was similar in all seasons indicating a better water status for ST vines than for the sward treatment ones. These results can be explained by the additional water use by the swards in spring (Monteiro and Lopes, 2007). These differences in vine water status can primarily affect vine growth if the water stress occurs earlier on (Williams and Matthews, 1990), as was the case in 2004.

Vegetative growth

While no significant differences were found on shoot number and primary leaf area over all the three seasons, in the 2003 and 2004 seasons the secondary leaf area presented a significant reduction on the two sward treatments when compared to ST (Table I).

The pruning weight increased from 2002 to 2004 on all treatments but with a smaller rate on the two sward ones. During the first two seasons of the experiment no significant differences were observed in the pruning weight and shoot weight but in the third season (2004) a significant reduction was observed in the RV and SCC treatments, compared to the ST (Table I). This effect of the sward treatments on grapevine vegetative growth reduction is a consequence of the sown and resident plant species competition for water and nutrients as reported by several authors (Morlat *et al.*, 1993; Caspari *et al.*, 1997; Geoffrion, 2000; Maigre and Aerny, 2001; Afonso *et al.*, 2003). Compared to ST the observed vegetative growth reduction in the two sward treatments can be beneficial to grape health and berry ripening, especially in high vigour situations, as it allows a more open canopy with a better light microclimate at the cluster zone (Dokoozlian and Kliewer 1996; Keller and Hrazdina 1998). Indeed, during the last two seasons of the experiment, a significant reduction of the canopy wideness at the cluster zone was observed on the two sward treatments compared to ST (Table I).

The maintenance of similar pruning weight values in

TABLE I

Effect of soil management techniques on vine vegetative growth and canopy wideness at fruit zone. ST – soil tillage over the between row; RV – resident vegetation between row; SCC - permanent sown cover crop between row. In each row, different letter suffixes show statistically significant differences at $P < 0.05$ by LSD test.

Efeito das técnicas de manutenção do solo no crescimento vegetativo e na espessura da sebe na zona de frutificação. ST – mobilização na entrelinha; RV – relvado natural; SCC – relvado semeado. Em cada linha, médias seguidas de letras diferentes indicam diferenças significativas para $P < 0.05$ pelo teste da MDS.

Year		ST	RV	SCC	Significance (F-test)
2002	Shoot number/vine	16.7	14.6	15.4	ns
	Primary leaf area (m ² /shoot) ⁽¹⁾	0.15	0.15	0.16	ns
	Secondary leaf area (m ² /shoot) ⁽¹⁾	0.19	0.17	0.18	ns
	Pruning weight (kg/vine)	0.48	0.43	0.55	ns
	Shoot weight (g/shoot)	28.7	29.5	35.7	ns
	Canopy wideness at cluster zone ⁽¹⁾ (m)	0.61a	0.54b	0.59a	*
2003	Shoot number/vine	17.7	17.7	15.7	ns
	Primary leaf area (m ² /shoot) ⁽¹⁾	0.20	0.20	0.18	ns
	Secondary leaf area (m ² /shoot) ⁽¹⁾	0.22a	0.13b	0.16b	*
	Pruning weight (kg/vine)	0.84	0.72	0.71	ns
	Shoot weight (g/shoot)	47.7	41.0	45.2	ns
	Canopy wideness at cluster zone (m) ⁽¹⁾	0.63a	0.55b	0.56b	*
2004	Shoot number/vine	20.2	20.1	19.2	ns
	Primary leaf area (m ² /shoot) ⁽¹⁾	0.21	0.20	0.20	ns
	Secondary leaf area (m ² /shoot) ⁽¹⁾	0.19a	0.12b	0.11b	*
	Pruning weight (kg/vine)	0.95a	0.78b	0.75b	*
	Shoot weight (g/shoot)	47.1a	39b	39.2b	*
	Canopy wideness at cluster zone (m) ⁽¹⁾	0.57a	0.51b	0.51b	*

⁽¹⁾- measured at veraison

* = significant at $P < 0.05$. ns = not significant.

the last two seasons of the experiment indicate that the observed growth reduction induced by the sward treatments was not negative for vine longevity as can be verified by the individual shoot weight obtained in 2004, which is still within the optimal vigour and vine balance range (20-40 g per shoot; Smart and Robinson, 1991).

Yield, berry composition and wine sensory attributes

All the three treatments showed statistically similar values for yield components during the three seasons being the lowest average yield 8.4 t/ha (2003) and the highest one 13.5 t/ha (2004) (Table II). These results do not agree with most part of the reported studies (Morlat *et al.*, 1993; Crozier, 1998; Geoffrion, 2000; Maigre and Aerny, 2001) where the tilled treatment induced higher yields than the cover cropping ones. The absence of yield differences observed in our experiment can be attributed to the higher plant available water of this soil and also to the low additional water used by the sward treatments (Monteiro and Lopes, 2007).

Juice soluble solids and pH were not significantly affected but the sward treatments induced a significantly lower titratable acidity than that of ST on 2003 and 2004 seasons. The two sward treatments presented similar values of berry skin total phenols and anthocyanin content but significantly higher than those of ST treatment on the last two seasons of the experiment (Table II). These results can be explained by the indirect effects of the mild water stress on vegetative growth via the improvement of the cluster microclimate. Compared to ST, the lower competition between vegetative and reproductive growth and the narrower canopy observed in the two sward treatments can have increased cluster exposure, enabling a reduction in titratable acidity and an improvement of the fruit colour and anthocyanin concentrations (Bergqvist *et al.*, 2001; Spayd *et al.*, 2002). Compared to the ST, the significant decrease in the must titratable acidity of the swards can be considered beneficial for quality, as the wines of this region usually present a higher titratable acidity.

The wines obtained in 2003 and 2004 were tasted by a trained sensory panel of 9 judges. While in 2003 no

TABLE II

Effect of soil management techniques on yield components and berry composition. ST – soil tillage over the between row; RV – resident vegetation between row; SCC - permanent sown cover crop between row. In each row, different letter suffixes show statistically significant differences at $P < 0.05$ by LSD test.

Efeito das técnicas de manutenção do solo nas componentes do rendimento e na composição da uva à vindima. ST – mobilização na entrelinha; RV – relvado natural; SCC – relvado semeado. Em cada linha, médias seguidas de letras diferentes indicam diferenças significativas para $P < 0.05$ pelo teste da MDS.

Year		ST	RV	SCC	Significance (F-test)
2002	Cluster number/vine	24	22.6	22.4	ns
	Cluster weight (g/cluster)	127.0	132.0	136.0	ns
	Yield (kg/vine)	3.1	3.0	3.1	ns
	Soluble solids (°Brix)	19.9	20.7	20.0	ns
	Titrateable acidity (g tartaric acid L ⁻¹)	4.90	4.50	5.60	ns
	pH	3.51	3.57	3.51	ns
	Phenols (IFC)	31.8	36.8	33.3	ns
	Skin anthocyanins (mg g ⁻¹)	0.48	0.62	0.51	ns
2003	Cluster number/vine	16.8	18.1	18.4	ns
	Cluster weight (g/cluster)	123.1	114.6	116.8	ns
	Yield (kg/vine)	2.07	2.07	2.15	ns
	Soluble solids (° Brix)	23.2	23.4	22.5	ns
	Titrateable acidity (g tartaric acid L ⁻¹)	7.35a	6.66b	6.69b	*
	pH	3.37	3.40	3.41	ns
	Phenols (IFC)	27.1b	38.8a	41.1a	*
	Skin anthocyanins (mg g ⁻¹)	0.31b	0.40a	0.48a	*
2004	Cluster number/vine	26.5	25.7	25.9	ns
	Cluster weight (g/cluster)	134.3	125.7	129.7	ns
	Yield (kg/vine)	3.56	3.23	3.36	ns
	Soluble solids (°Brix)	22.4	22.9	23.0	ns
	Titrateable acidity (g tartaric acid L ⁻¹)	8.05a	6.69b	7.20ab	*
	pH	3.30	3.35	3.28	ns
	Phenols (IFC)	42.4b	51.9a	48.7a	*
	Skin anthocyanins (mg g ⁻¹)	0.52b	0.65a	0.61a	*

* = significant at $P < 0.05$. NS = not significant.

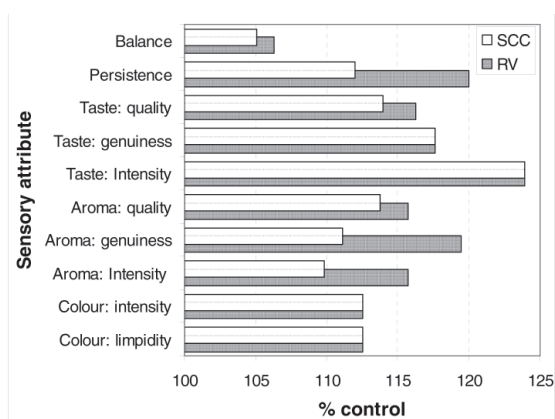


Fig. 2 - Effect of soil management techniques on 2004 wine sensory attributes. Scores expressed as a percentage of the score obtained on the control treatment - soil tillage. RV – resident vegetation between row; SCC - permanent sown cover crop between row.

Influência das técnicas de manutenção do solo nas características organolépticas do vinho de 2004. Classificações expressas em percentagem da testemunha - mobilização na entrelinha. RV – relvado natural; SCC – relvado semeado.

significant differences were detected, in 2004 the RV and SCC wines received significantly higher scores in all the sensory attributes than ST wine (Fig. 2), corroborating the differences reported for grape composition.

CONCLUSIONS

When compared to soil tillage, the inter-row sward treatments displayed a higher water use during the spring (Monteiro and Lopes, 2007), which induced a lower predawn leaf water potential from bloom to harvest. These differences in vine water status did not affect vine yield or berry sugar accumulation; however, in the third season after experiment setup the mild water stress caused by the permanent presence of the living mulch induced a significant reduction in vegetative growth in the sward treatments, compared to ST. This vegetative growth reduction had a positive effect on grape composition

by reducing titratable acidity and increasing berry skin total phenols and anthocyanins. Those differences were also detected in the wines by the judges who gave a better classification to the wines from the cover crop treatments.

These results indicate that cover cropping can be a valuable tool for controlling vigour and enhancing wine quality in this winegrowing region for soils with high water availability. The similar behaviour presented by the two sward treatments allow the conclusion that, in this “terroir” the best choice for a cover crop could be the resident vegetation as it was not more competitive and it does not need to be sown. However, long-term trials are needed in order to verify these effects, particularly on vine vigour and its consequences for vine longevity.

ACKNOWLEDGEMENTS

This study was supported by the Portuguese Ministry of Agriculture and Rural and Fisheries Development, AGRO Program, Action 8 (2002), Project nº 104 - Viticultural technology for optimising grape quality: soil and canopy management.

REFERENCES

- Afonso J.M., Monteiro A., Lopes C.M., Lourenço, J., 2003. Enrelvamento do solo em vinha na região dos Vinhos Verdes. Três anos de estudo na casta ‘Alvarinho’. *Ciência Téc. Vitív.*, **18**, 47-63.
- Agulhon R., 1996. Intérêt des nouvelles techniques d’entretien des sols de vigne pour la viticulture, l’œnologie, l’environnement et la santé. *Progress Agric. Vitic.* **113**, 275-278.
- Bergqvist J., Dokoozlian N., Ebisuda N., 2001. Sunlight exposure and temperature effects on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. *Am. J. Enol. Vitic.* **52**(1), 1-7.
- Campos L., Franco J.C., Monteiro A., Lopes C.M., 2006. Influência do enrelvamento na abundância de artrópodes associados a uma vinha da estremadura. *Ciência Téc. Vitív.*, **21**(1), 33-46.
- Caspari H.W., Neal S., Naylor A., 1997. Cover crop management in vineyards to enhance deficit irrigation in a humid climate. *Acta Hort.* **449**, 313-320.
- Cifre J., Bota J., Escalona J.M., Medrano H., Flexas J., 2005. Physiological tools for irrigation scheduling in grapevine *Vitis vinifera* L.. An open gate to improve water-use efficiency? *Agric. Ecosyst. Environ.*, **106**, 159-170.
- Crozier P., 1998. Enherbement permanent et mulch: aspects agronomiques. *Phytoma*, **511**, 42-45.
- Costello M.J., Daane K.M., 1998. Arthropods. In: *Cover Cropping in Vineyards. A Grower’s Handbook*. 93-106. Ingels C.A., Bugg R.L., McGourty G.T., Christensen L.P. (eds), University of California, Publication 3338. Oakland. USA.
- Deloire A., Carbonneau A., Federspiel B., Ojeda H., Wang Z., Costanza P., 2003. La vigne et l’eau. *Progress Agric. Vitic.* **120**, 79-90.
- Dokoozlian N.K., Kliewer W.M., 1996. Influence of light on grape berry growth and composition varies during fruit development. *J. Am. Soc. Hortic. Sci.* **121**, 869-874.
- English J., Bledsoe A., Marois J., Kliewer W., 1990. Influence of grapevine canopy management on evaporative potential in the fruit zone. *Am. J. Enol. Vitic.*, **41**, 137-141.
- Folorunso O.A., Rolston D.E., Prichard T., Louie D.T. 1992. Soil surface strength and infiltration rate as affected by winter cover crops. *Soil Technology*, **5**, 189-197.
- Geoffrion R., 1999. L’enherbement permanent, 40 ans après. *Phytoma*, **519**, 25-27.
- Geoffrion R., 2000. L’enherbement permanent contrôlé des sols viticoles. Vingt ans de recherches sur le terrain en Anjou. *Phytoma*, **530**, 28-31.
- Gulick S.H., Grimes D.W., Munk D.S., Goldhamer D.A., 1994. Cover-crop-enhanced water infiltration of a slowly permeable fine sandy loam soil. *J. Soil Sci. Soc. Am.*, **58**, 1539-1546.
- Keller M., Hrazdina G., 1998. Interaction of nitrogen availability during bloom and light intensity during veraison. II Effects on anthocyanin and phenolic development during grape ripening. *Am. J. Enol. Vitic.* **49**, 341-349.
- Kondouras S., Van Leeuwen C., Seguin G., Glories Y., 1999. Influence of water status on vine vegetative growth, berry ripening and wine characteristics in mediterranean zone (exemple of Nemea, Greece, variety Saint-George, 1997). *J. Int. Sci. Vigne et Vin*, **33**(4), 149-160.
- Le Golf-Guillou I., Marsault J., Riou C., 2000. Impacts de l’enherbement sur le fonctionnement de la vigne, la composition des moûts, les durées de fermentation et la qualité des vins. *Progress Agric. Vitic.* **117**, 103-110.
- Linares R., Fuente M., Junquera P., Baeza P., 2007. Response of a Merlot vineyard to several soil management practices in a mediterranean environment. In: *Proceedings XV GESCO International Symposium*. Vol. **1**, 371-377. Inst. Agriculture and Tourism (ed.), Porec, Croatia.
- Lopes C.M., Pinto P.A., 2005. Easy and accurate estimation of grapevine leaf area with simple mathematical models. *Vitis*, **44**(2), 55-61.
- Lopes C.M., Monteiro A., Rückert F.E., Gruber B., Steinberg B., Schultz H.R., 2004. Transpiration of grapevines and co-habiting cover crop and weed species in a vineyard. A “snapshot” at diurnal trends. *Vitis* **43**, 111-117.
- Maigre D., Aerny J., 2001. Enherbement permanent et fumure azotée sur cv. ‘Gamay’ dans le Valais Central. *Revue Suisse Vitic. Arboric. Hortic.* **33**, 343-349.
- Maigre D., Aerny J., Murisier F., 1995. Entretien des sols viticoles et qualité des vins de Chasselas: influence de l’enherbement permanent et de la fumure azotée. *Revue Suisse Vitic. Arboric. Hortic.*, **27**(4), 237-251.
- Monteiro A., Moreira, I., 2004. Reduced rates of residual and post-emergence herbicides for weed control in vineyards. *Weed Res.*, **44**, 117-128.
- Monteiro A., Lopes C.M., 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. *Agri. Ecosyst. Environ.*, **121**(4), 336-342.
- Monteiro A., Lopes C.M., Machado J.P., Fernandes N., Araújo A., Moreira I., 2008. Cover cropping in a slopping non-irrigated vineyard. I – Effects on weed composition and dynamics. *Ciência Téc. Vitív.*, (this volume).
- Morlat R., Jacquet A., Asselin C., 1993. L’enherbement permanent contrôlé des sols viticoles: Principaux résultats obtenus en Anjou. In: *Proceedings 7th GESCO International Symposium*. 89-95. CIVC – Mumm Perrier-Jouet (ed.), Rheims, France.
- Morlat R., Jacquet A., 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. *Am. J. Enol. Vitic.* **54**, 1-7.
- O.I.V., 1990. Recueil des méthodes internationales d’analyses des vins et des moûts. Office International de la Vigne et du Vin (Ed), Paris.

Pacheco C.M.A., Laureano O., Tomé J.A., 1991. Culture et non culture de la vigne: résultats de production, vigueur et composition des moûts, sur huit années d'essais. In: *Annales ANPP*, **3**, 249-255.

Pellegrino A., Lebon E., Voltz, M., Wery J., 2004. Relationships between plant and soil water status in vine (*Vitis vinifera* L.). *Plant and Soil*, **266**, 129-142.

Pradel E., Pieri P., 2000. Influence of a grass layer on vineyard soil temperature. *Australian Journal of Grape and Wine Research* **6**, 59-67.

Prichard T.L., 1998. Water use and infiltration. In: *Cover Cropping in Vineyards. A Grower's Handbook*. 85-90. Ingels C.A., Bugg R.L., McGourty G.T., Christensen L.P. (eds), University of California, Publication 3338. Oakland. USA.

Ribéreau-Gayon J., Peynaud E., Sudraud P., Ribéreau-Gayon P., 1972. *Traité d'Enologie*. Tome 1. Sciences et Techniques du Vin, Dunod, Paris.

Rodrigues M.L., Chaves M.M., Wendler R., David M.M., Quick W.P., Leegood R.C., Stitt M., Pereira J.S., 1993. Osmotic adjustment in water stressed grapevine leaves in relation to carbon assimilation. *Aust. J. Plant Physiol.* **20**, 309-321.

Smart R.E. and Robinson M., 1991. *Sunlight into wine. A Handbook for winegrape canopy management*. 88 p. Winetitles, Adelaide.

Spayd S.E., Tarara J.M., Mee D.L., Ferguson J.C., 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. 'Merlot' berries. *Am. J. Enol. Vitic.* **53**, 171-182.

Williams L.E., Matthews M.A., 1990. Grapevine. In: *Irrigation of Agricultural Crops*. 1019-1055. Agronomy monographs, N° 30, ASA-CSSA-SSSA, Madison (ed.), Wisconsin, USA.