CONTRIBUTION OF SOIL AND ATMOSPHERIC CONDITIONS TO LEAF WATER POTENTIAL IN GRAPEVINES

P.A. Myburgh and M. Laker

ARC Infruitec-Nietvoorbij, Private Bag X5026, 7599 Stellenbosch, Republic of South Africa
myburghp@arc.agric.za

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Abstract

Since grapevine water status, which is a function of soil and atmospheric conditions, affects grapevine physiology it will also play an important role in grape and wine quality. Water status in dry-land Sauvignon blanc was measured simultaneously both at a warm and a cool locality in the Stellenbosch region at different phenological stages during the growing season. Leaf water potential (Ψ_l) appeared to be a logarithmic function of soil matric potential (Ψ_m). Grapevine water stress tended to increase at a slower rate when Ψ_m dropped below *ca* -0.3 MPa. Under the given conditions, vapour pressure deficit (VPD) did not seem to have an effect on pre-dawn Ψ_l, but in combination with Ψ_m could explain 85% of the variation in Ψ_l measured at 14:00. These results indicated that grapevine water status was a function of atmospheric conditions as well as soil water content. The non-linear response of Ψ_l appeared to be the result of partial stomatal closure that increased Ψ_l at certain stages during the day. Sap flow rates in grapevines cultivated on the drier soil (*i.e.* Ψ_m = -0.75 MPa) showed pronounced reductions during the day at the cooler locality compared to those at the warmer one where Ψ_m was *ca* -0.12 MPa. This confirmed that grapevine water status was regulated via partial stomatal closure at the cooler locality, despite the lower VPD that was recorded at this particular locality.

In studies with irrigated grapevines, where Ψ_m was higher than -0.08 MPa, absence of significant stomatal control was probably the reason for the reported linear response between Ψ_l and Ψ_m. However, measuring Ψ_l at 15 minute intervals revealed that stomatal closure occurred in irrigated grapevines under semi-arid conditions where VPD increased from 1.0 kPa pre-dawn to 4.6 kPa in the afternoon despite soil water content being near field capacity (*i.e.* Ψ_m = *ca* -0.01 MPa). Due to stomatal control, the relationship between Ψ_l and VPD was also non-linear. Under these specific conditions, minimum Ψ_l was *ca* -1.6 MPa. These results showed that even where soil water content was not a limiting factor, harsh meteorological conditions were able to cause partial stomatal closure, thus preventing the evolution of extremely low Ψ_l values in grapevines. From the foregoing, it is suggested that Ψ_m as well as VPD should be considered for the quantification of terroir effects on grapevine water stress.

Resumé

Etant lié au sol et aux conditions atmosphériques, le statut hydrique influence la physiologie de la vigne d'une part, mais joue aussi un role important en ce qui concerne la qualité du raisin et donc du vin d'autre part. Nous avons mesuré, dans la région de Stellenbosch, le statut hydrique sur des pieds de Sauvignon Blanc non irrigués, implantés sur 2 terroirs différents, l'un froid, l'autre plus chaud. D'après ces mesures, il semble que le potentiel hydrique foliaire (Ψ_l) soit lié par une fonction logarithmique au potentiel hydrique du sol (Ψ_m). De plus, l'augmentation du stress hydrique du cep semble être plus lente lorsque Ψ_m descend en dessous de -0.3 MPa. Sous certaines conditions, le déficit en pression de vapeur ne semble pas influencer le Ψ_l (mesuré à l'aube), cependant lorsque les

valeurs obtenues pour ce dernier sont combinées avec celles obtenues pour Ψ_m, alors 85% de la variabilité de Ψ_l mesuré à 14:00 peut être expliqué. A partir de ces résultats, nous pouvons donc conclure sur l'existence d'une fonction entre le statut hydrique de la vigne et les conditions atmosphériques ainsi qu'entre le statut hydrique et la teneur en eau du sol. Les résultats non linéaires du potentiel foliaire, caractérisés par des augmentations momentanées obtenus à différents moments de la journée peuvent être expliqués par une fermeture partielle des stomates. Les valeurs du flux de sève, observées pour des vignes cultivées sur les sols secs (Ψ_m = -0.75 MPa) du terroir plus froid, montrent de fortes diminutions pendant la journée, comparé à celles obtenues sur le terroir plus chaud où Ψ_m = -0.12 MPa. Ceci confirme bien que le statut hydrique de la vigne, situé sur le terroir plus froid, est régulé grâce à la fermeture partielle des stomates et ce, malgré le faible déficit en pression de vapeur enregistré sur cette même localité.

La linéarité de la relation entre Ψ_l et Ψ_m, sur vignes irriguées où Ψ_m était supérieur à -0.08 MPa, peut expliquer l'absence de contrôle stomatique significatif. Cependant, en mesurant Ψ_l toutes les 15 minutes, on peut observer la fermeture stomatique sur des vignes irriguées en climat semi-aride, où le déficit en pression de vapeur passe de 1.0 kPa à l'aube à 4.6 kPa dans l'après-midi, malgré une teneur en eau dans le sol proche de la capacité au champ (Ψ_m = *ca* -0.01 MPa). Le contrôle stomatique, une fois encore est à l'origine de la non- linéarité de la relation entre le déficit en pression de vapeur et Ψ_l. Ce dernier était, dans ces mêmes conditions, de –1.6 MPa. Ces résultats nous indiquent que là où la teneur en eau du sol n'est pas un facteur limitant, de difficiles conditions climatiques peuvent provoquer la fermeture des stomates, réduisant ainsi une chute trop sévère du potentiel hydrique foliaire. Le potentiel hydrique du sol, ainsi que le déficit en pression de vapeur, devraient donc permettre, par la suite, de quantifier l'effet du terroir sur le stress hydrique de la vigne.

Introduction

Environmental variables such as net radiation, relative humidity, temperature, wind, atmospheric pollutants, soil conditions as well as plant factors can affect grapevine water status on a diurnal and seasonal basis (Smart & Coombe, 1983). However, they suggested that diurnal fluctuations in grapevines could be more closely linked to the atmospheric conditions than to the soil water potential. Under controlled conditions, this might not always the case. Studies with irrigated Colombar grapevines (Van Zyl, 1987) showed that grapevine water status, quantified by means of leaf water potential (Ψ_l), was linearly related to soil water matric potential (Ψ_m). This relationship was obtained with grapevines subjected to different levels of soil water depletion under the same meteorological conditions. In this particular study, the matric potentials were higher than -0.1 MPa. A linear response of Ψ_l in Sultanina to volumetric soil water content was also assumed where the latter varied between 8% and 18% (Williams *et al.*, 1994). However, Ψ_l in Colombar only showed a linear decrease when the solution osmotic potential was higher than *ca* -0.4 MPa in water cultures where the range of PEG induced solution osmotic potentials was extended to –1.0 MPa (Van Zyl & Kennedy, 1983). Under conditions where Ψ_m was higher than -0.1 MPa (Van Zyl, 1987; Myburgh, 2003), adequate water uptake and/or absence of significant stomatal control was probably the reason for the reported linear response between Ψ_l and Ψ_m.

When data were collected at different stages over the growing season in the same field trial, *i.e.* under varying atmospheric conditions, Ψ_m only explained 35% of Ψ_l variation measured at 14:00 in irrigated Sultanina grapevines (Myburgh, 2003). However, when Ψ_l was related to Ψ_m as well as vapour pressure deficit of the atmosphere (VPD) by means of multiple linear regression, 83% of the variation in Ψ_l measured at 14:00 could be explained. This indicated that grapevine water status was a function of soil water content as well as atmospheric conditions.

The aim of this paper is to report on some findings regarding the combined effect of varying soil water and atmospheric conditions on grapevine water status measured at different localities.

Materials and methods

Diurnal cycles of water status in dry-land Sauvignon blanc grapevines were measured simultaneously in the Stellenbosch district on each of two soil types at a relatively warm locality (Papegaaiberg) as well as at a cooler one (Helshoogte). Measurements were made at flowering (October), pea size (December), prior to harvest (February) and post harvest (March) during the 2002/03 season. To quantify grapevine water status, leaf water potential was measured hourly using the pressure chamber technique according to Scholander *et al.* (1965). During daytime, mature leaves, fully exposed to the sun were used. Soil water matric potential was measured by means of tensiometers (Continental Fan Works, Cape Town) at 300 mm, 600 mm and 900 mm depths. During the first part of the season, *i.e.* when the soils were relatively wet, a neutron probe (CPN, **City**) was calibrated against Ψ_m for each soil type. During the later part of the season, when Ψ_m receded below the range of the tensiometers (*i.e.* < *ca* –0.08 MPa), measurements were continued using the neutron probe. The calibration curves determined earlier in the season were used to convert neutron probe count ratios to Ψ_m. In addition to Ψ_l, sap flow rates in grapevine trunks were determined at one hour intervals over the course of the day at both localities using the heat pulse velocity technique according to the protocol described by Myburgh (1998).

Leaf water potential was also measured in Sultanina grapevines on alluvial soil under hot, dry atmospheric conditions at Upington in the Lower Orange River region on 23 January 2004. Measurements were made hourly from 04:00 until 20:00. Over the warmest part of the day, *i.e.* from 10:00 until 18:00, Ψ_l was recorded at 15 minute intervals. Due to the intensity of these measurements, Ψ_l could only be measured in two grapevines on each of two adjacent plots where Ψ_m was -0.009 MPa and -0.060 MPa, respectively. Soil water matric potential was measured at 300 mm and 600 mm depths. If the two Ψ_l values per plot varied more than 10%, Ψ_l was also measured on a third grapevine. These two plots formed part of a more extensive irrigation trial.

Atmospheric data were collected hourly at each locality using automatic weather stations (MC Systems, Cape Town). Statgraphics® was used to determine relationships between parameters by means of linear regression. Due to the absence of true replications at the Upington study, the data could only be regarded as observations.

Results and discussion

For the range of Ψ_m values measured under field conditions at Stellenbosch (Table 1), Ψ_l at 04:00 (pre-dawn), as well as at 14:00, appeared to be a logarithmic function of Ψ_m (Fig. 1). Grapevine water stress tended to increase at a slower rate when Ψ_m dropped below *ca* -0.3 MPa. This corresponds with the Ψ_l response at similarly low Ψ_m levels reported by Van Zyl & Kennedy (1983). The non-linear response of pre-dawn Ψ_l indicated that the grapevine water status could recover appreciably during the night, although Ψ_m was relatively low. This was particularly relevant for grapevines on the Tukulu soil at Helshoogte where fine root density, as reported by Conradie *et al.* (2002), was higher than for the Hutton soil (Table 2). Higher pre-dawn Ψ_l in grapevines on the Tukulu soil suggested that the higher root concentration probably exploited the available water more intensely compared to grapevines with a lower root density that were subjected to higher Ψ_m. At higher Ψ_m levels, *i.e.* at Papegaaiberg, substantial differences in root density did not seem to reflect in pre-dawn grapevine water status. As a result of the foregoing aspects, most of the pre-dawn Ψ_l values were higher than -0.5 MPa which is regarded as an indicator of the onset of water stress in grapevines (Williams *et al.*, 1994).

The non-linear response of Ψ_l during the daytime was probably the result of inadequate water uptake that induced partial stomatal closure causing an increase in Ψ_l at certain stages during the day. Pronounced reductions in sap flow occurred during the day in grapevines subjected to drier soil (*i.e.* Ψ_m = -0.75 MPa) at the cooler locality compared to slight reductions in those at the warmer locality where Ψ_m was -0.12 MPa (Fig. 2). This happened despite the fact that VPD was higher at the warmer locality (Laker, Myburgh & Archer, unpublished data). The sap flow results confirmed that grapevine water status was regulated *via* partial stomatal closure at the cooler locality. Due to stomatal control, most of the Ψ_l values were higher than –1.4 MPa. This was slightly lower than –1.2 MPa that is considered to be the daytime limit for the onset of water stress (Williams *et al.*, 1994). This, as well as pre-dawn Ψ_l, showed that the grapevines were only subjected to limited water stress at these two localities. This was in agreement with mean January/February Ψ_l values of –1.4 MPa and –1.34 MPa measured over seven years in grapevines at Helshoogte and Papegaaiberg, respectively (Conradie *et al.*, 2002). Under the atmospheric conditions that prevailed at these two localities, VPD did not seem to have any effect on pre-dawn Ψ_l, but in combination with Ψ_m it could explain 85% of the variation in Ψ_l measured at 14:00 (Table 3).

The extremely hot, dry atmospheric conditions, particularly during the late afternoon, at Upington were not uncommon for the semi-arid Lower Orange River region (Fig. 3). Measuring Ψ_l at 15 minute intervals, revealed an almost cyclic behavior in Ψ_l over the warmest part of the day, irrespective of the level of Ψ_m (Fig. 4). This suggested that stomatal closure occurred in grapevines although soil water content was close to field capacity (*i.e.* Ψ_m = *ca* -0.01 MPa). The observed stomatal behavior could only have been induced by the prevailing atmospheric conditions. As a result of partial stomatal closure, Ψ_l in grapevines on the drier soil tended to be higher during the afternoon compared to those where the soil was close to field capacity. Due to stomatal control, the relationship between Ψ_l and VPD was also non-linear (Fig. 5). Under the specific conditions minimum Ψ_l was *ca* -1.6 MPa. These results showed that, although soil water content was not a limiting factor, harsh atmospheric conditions could also cause partial stomatal closure that will prevent the evolution of extremely low Ψ_l values in grapevines.

Conclusions

The foregoing confirmed that Ψ_l is primarily a function of prevailing soil, as well as atmospheric conditions. It is also clear that the relative contribution of the soil and atmosphere towards grapevine water status may vary according to the prevailing conditions. This is opposed to stem water potential (Ψ_s), which is more a function of soil water status (Choné *et al.*, 2001). Hence, Ψ_l would be appropriate to assess the combined effects of atmospheric conditions as well as soil water content on grapevine water status at a specific locality, whereas Ψ_s could be a useful tool for irrigation scheduling (Van Leeuwen *et al.*, 2001).

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Tables and Figures

Table 1. Seasonal variation in mean soil water matric potential during the 2002/03 season at two localities in the Stellenbosch district.

Table 2. Pre-dawn leaf water potential (Ψ_l) during ripening in Sauvignon blanc in relation to soil water matric potential (Ψ_m) at 900 mm depth and fine root (< 0.1 mm diameter) density in the subsoil (600 mm to 900 mm) during the 2002/03 season at two localities in the Stellenbosch district.

Table 3. Coefficients for regression equations to relate leaf water potential (Ψ_l) measured at 04:00 (pre-dawn) and 14:00 to soil matric potential (Ψ_m) and vapour pressure deficit (VPD). (n = 16 for all equations).

Figure 1. Effect of soil water matric potential (Ψ_m) on leaf water potential (Ψ_l) in Sauvignon blanc grapevines measured (A) at pre-dawn and (B) at 14:00 during the 2002/03 season at Stellenbosch.

Figure 2. Diurnal sap flow in Sauvignon blanc grapevine trunks at two localities with different soil water matric potential (Ψ_m) in the Stellenbosch area.

Figure 3. Air temperature (T), vapour pressure deficit of the atmosphere (VPD) and net radiation (R_n) measured on 23 January 2004 at Upington.

Figure 4. Effect of soil water matric potential (Ψ_m) on leaf water potential (Ψ_l) in Sultanina grapevines measured on 23 January 2004 at Upington.

Figure 5. Relationship between vapour pressure deficit of the atmosphere (VPD) and leaf water potential (Ψ_l) in Sultanina grapevines where the soil water potential was -0.009 MPa. (Curves fitted by eye. The dashed line indicates the time sequence of measurements).

Table 1. Seasonal variation in mean soil water matric potential during the 2002/03 season at two localities in the Stellenbosch district.

Locality	Soil form*	Soil water matric potential (MPa)			
		Flowering	Pea size	Ripening	Post harvest
Helshoogte	Tukulu	-0.027	-0.068	-0.750	-0.900
	Hutton	-0.031	-0.072	-0.495	-0.641
Papegaaiberg	Avalon	-0.007	-0.027	-0.150	-0.150
	Tukulu	-0.013	-0.036	-0.125	-0.150

* Soil form according to Soil Classification Work Group (1991).

Table 2. Pre-dawn leaf water potential (Ψ_l) during ripening in Sauvignon blanc in relation to soil water matric potential (Ψ_m) at 900 mm depth and fine root (< 0.1 mm diameter) density in the subsoil (600 mm to 900 mm) during the 2002/03 season at two localities in the Stellenbosch district.

Locality	Soil form*	Ψ_m (MPa)	Fine roots** (number/m^2)	Pre dawn Ψ_l (MPa)
Helshoogte	Tukulu	-0.70	204	-0.27
	Hutton	-0.30	128	-0.41
Papegaaiberg	Avalon	-0.10	306	-0.29
	Tukulu	-0.10	108	-0.26

* Soil form according to Soil Classification Work Group (1991).
** After Conradie *et al.* (2002).

Table 3. Coefficients for regression equations to relate leaf water potential (Ψ_l) measured at 04:00 (pre-dawn) and 14:00 to soil matric potential (Ψ_m) and vapour pressure deficit (VPD). (n = 16 for all equations).

Time of Ψ_l measurement	Constant	LogΨ_m (MPa)	VPD (kPa)	R^2	Std. error of estimation
04:00	-0.519*	-0.231	-	0.692	0.095
	-0.529*	-0.232*	0.026	0.696	0.098
14:00	-1.441*	-0.348*	-	0.722	0.137
	-1.184*	-0.365*	-0.136*	0.854	0.103

* Significant ($p \leq 0.05$)

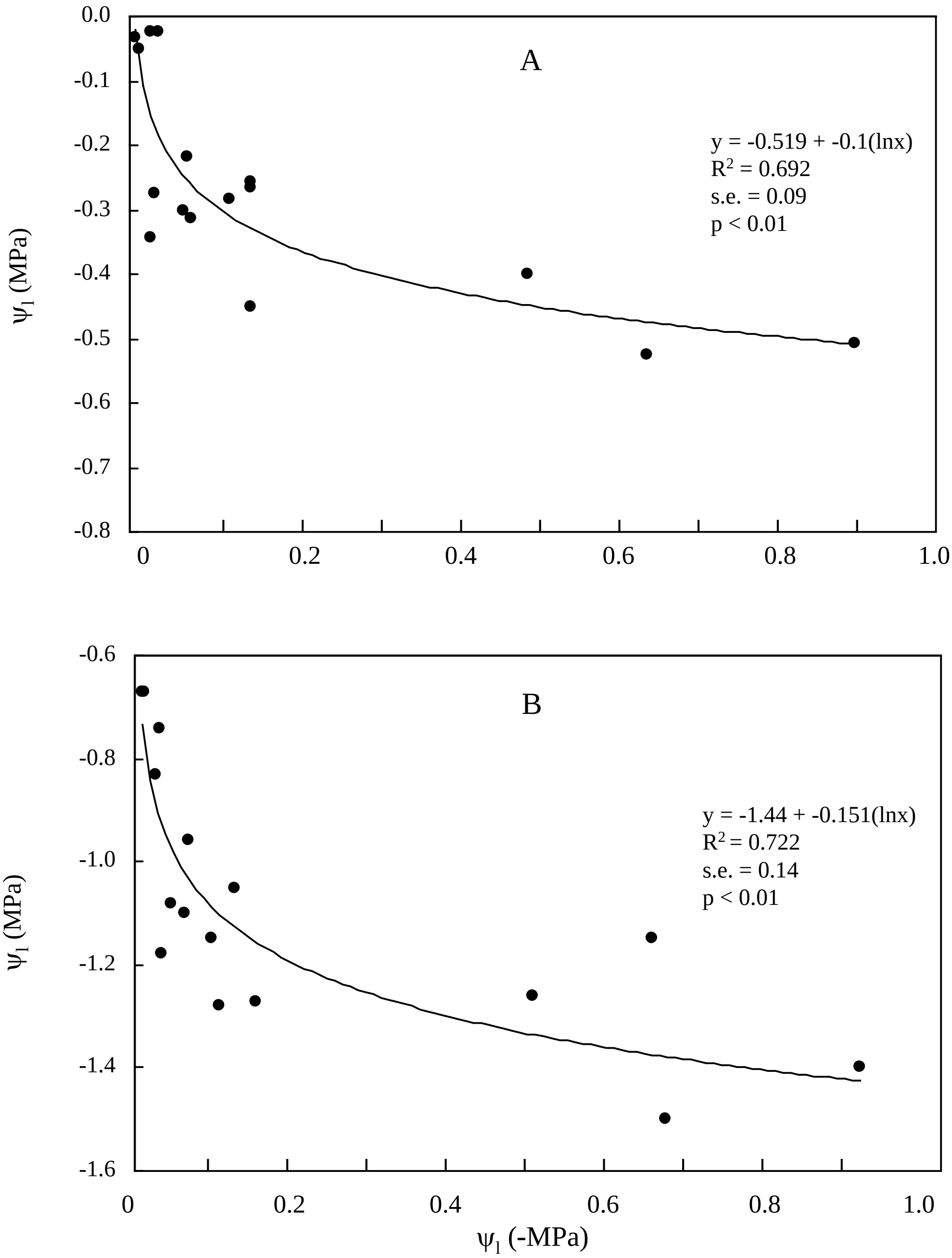


Figure 1. Effect of soil water matric potential (ψ_m) on leaf water potential (ψ_l) in Sauvignon blanc grapevines (A) at pre-dawn and (B) at 14:00 measured during the 2002/03 season at Stellenbosch.

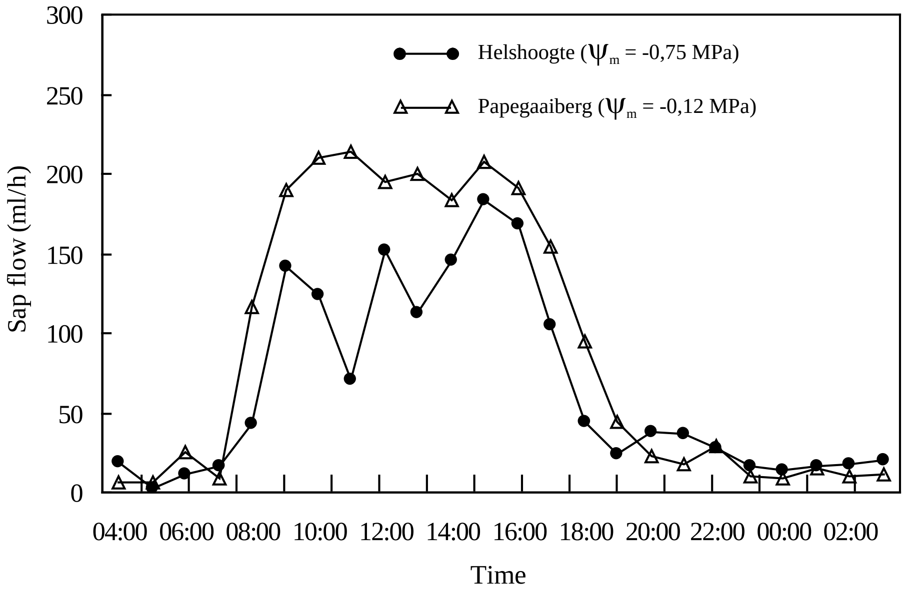
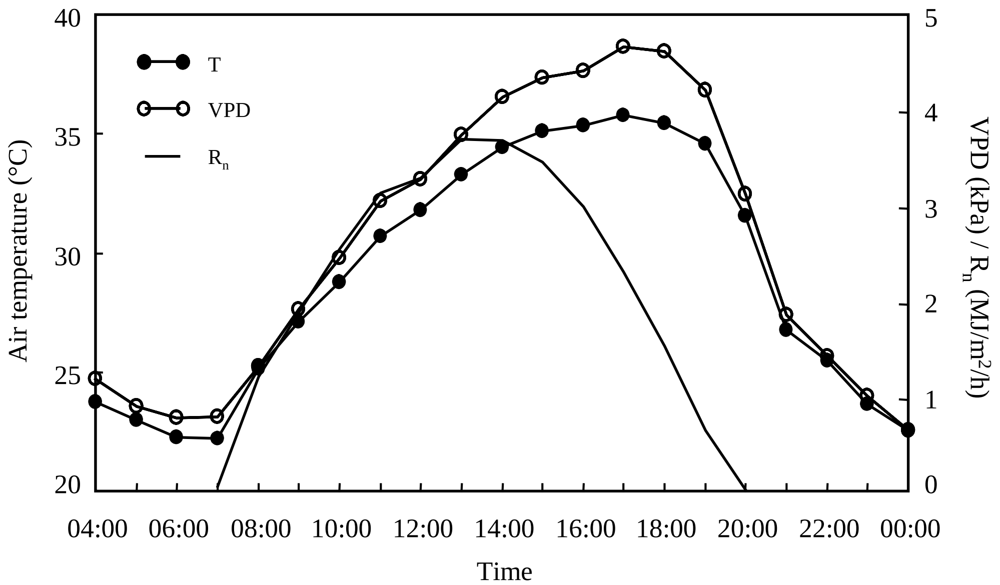


Figure 2. Diurnal sap flow in Sauvignon blanc grapevine trunks at two localities with different soil water matric potential (ψ_m) in the Stellenbosch area.



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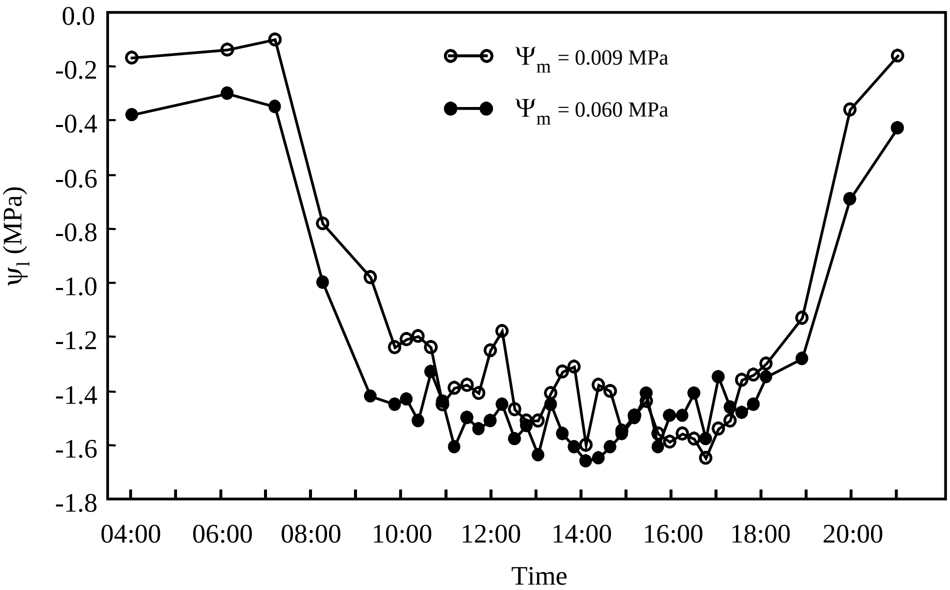

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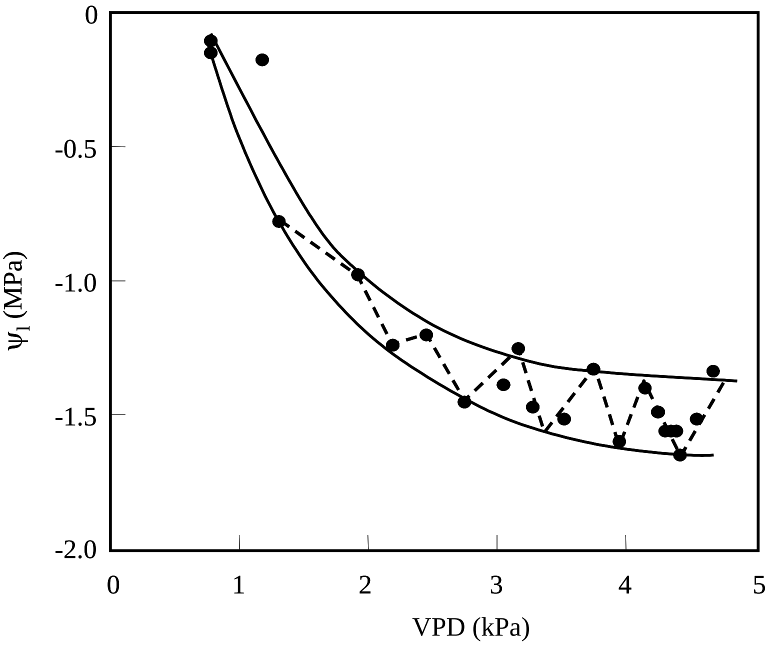

Figure 5. Relationship between vapour pressure deficit of the atmosphere (VPD) and leaf water potential (ψ_l) in Sultanina grapevines where the soil matric potential was -0.009 MPa. (Curves fitted by eye. The dashed line indicates the time sequence of measurements.)