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Preliminary results of investigations into photosynthetic activity and water conditions with the grapevine cultivar 'Zierfandler' (*Vitis vinifera* L.)

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The objective of this research is to investigate the eco-physiological behaviour of the grapevine cultivar 'Zierfandler' under non-irrigated field conditions in Hungary. Severe water deficit, high air temperature and low relative humidity were typical of the studied period in 2003. In comparison, the average of monthly precipitation was significantly lower than the values of many years (1953 to 2003) during flowering, pea berry size, veraison and ripening. The seasonal changes of the canopy structure were investigated. In this case, no close relationship was found between the changes of canopy structure and the water stress conditions. The maximum value of average canopy breadth was measured at the developmental stage of pea berry size. The photosynthetic rate (A) of 'Zierfandler' decreased by 32 % between flowering and veraison at nearly constant leaf surface temperature. Similarly to the decrease of the photosynthetic rate, lower transpiration rates (E) and stomatal conductance (g_s) were measured. This behaviour showed that 'Zierfandler' has a relatively sensitive mechanism of stomatal regulation during the drought period. The values of predawn leaf water potential ($\psi_{predawn}$) indicated a moderate soil water deficit even at the pea berry size period. During the growing season, from flowering to ripening, the values of midday leaf water potential (ψ_{midday}) showed a medium water stress level (from -1.04 MPa to -1.42 MPa), however, a considerable, rapid increase of the ψ_{midday} towards the end of the vegetation period was measured which was probably caused by a heavy rain fall during this period.

Key words: 'Zierfandler', net photosynthesis, transpiration, stomatal closure, canopy structure, leaf water potential, drought resistance

Vorläufige Ergebnisse von Untersuchungen der Photosyntheseaktivität und des Wasserhaushalts bei der Rebsorte 'Zierfandler' (Vitis vinifera L.). *Ziel dieser Studie war die Untersuchung des ökophysiologischen Verhaltens der Rebsorte 'Zierfandler' in unbewässerten Weingärten in Ungarn. Großes Wasserdefizit, hohe Temperaturen und niedrige relative Luftfeuchtigkeit kennzeichneten die untersuchte Zeitspanne im Jahr 2003. Im Vergleich zur mittleren Niederschlagsmenge der Jahre 1953 bis 2003 war die Niederschlagsmenge während Rebblüte, Erbsengrößestadium, Reifebeginn und Reifungsperiode deutlich geringer. Auch die saisonalen Veränderungen in der Blattzone während der Wachstumsphase wurden untersucht. Korrelationen zwischen Wasserstress und Veränderungen in der Blattzone wurden nicht festgestellt. Der Maximalwert der durchschnittlichen Blattzonenbreite wurde während der Entwicklungsphase des Erbsengrößestadiums gemessen. Die Photosyntheserate (A) von 'Zierfandler' verringerte sich zwischen Blüte und Reifebeginn um 32 % bei annähernd konstant bleibender Blattoberflächentemperatur. Ähnlich dem Rückgang der Photosyntheserate fand eine Verringerung der Transpirationsrate (E) und der Leitfähigkeit der Stomata (g_s) statt. Die Werte für das Wasserpotenzial vor Sonnenaufgang ($\psi_{predawn}$) zeigten während des Erbsengrößestadiums bereits leichtes Wasserdefizit im Boden. Während der Wachstumsphase zeigten die Werte für das Blattwasserpotenzial zur Mittagszeit (ψ_{midday}) mittlere Wasserstresswerte (-1.04 MPa bis -1.42 MPa). Gegen Ende der Vegetationsperiode wurde jedoch ein starker Anstieg in ψ_{midday} gemessen, was vermutlich auf einen starken Niederschlag während dieser Periode zurückzuführen ist.*

Schlagwörter: 'Zierfandler', Nettophotosynthese, Transpiration, Stomataregulation, Laubwand, Blattwasserpotenzial, Trockenheitsresistenz

Résultats provisoires de l'examen de l'activité photosynthétique et de l'équilibre hydrique du cépage 'Zierfandler'. *Le but de la présente recherche était l'examen du comportement éco-physiologique du cépage 'Zierfandler' dans des vignobles non irrigués en Hongrie. La période de recherche en l'an 2003 a été marquée par un déficit hydrique important, des températures élevées et une basse humidité relative de l'air. Comparée à la pluviosité moyenne des années 1953 à 2003, la pluviosité a été notablement inférieure pendant la floraison de la vigne, le stade où les grains atteignaient la taille d'un pois, la véraison et la maturation. Les changements saisonniers de la structure du feuillage au cours de la phase de croissance ont également été examinés. On n'a trouvé aucune corrélation entre le stress hydrique et les changements de la structure du feuillage. La valeur maximale de la largeur moyenne du feuillage a été mesurée au cours du stade du développement des pois. Le taux photosynthétique (A) de 'Zierfandler' s'est réduit de 32% entre la floraison et la véraison, la température de la superficie des feuilles étant restée plus ou moins constante. Tout comme le taux photosynthétique, le taux de transpiration (E) et la conductance stomatique (gs) ont également baissé. Les valeurs du potentiel hydrique foliaire, mesurées avant le lever du soleil (ψ predawn), indiquaient déjà un faible déficit hydrique du sol au stade où les grains atteignaient la taille d'un pois. Au cours de la phase de croissance, les valeurs du potentiel hydrique foliaire indiquaient à midi (ψ midday) un niveau de stress hydrique moyen (de -1.04 MPa à -1.42 MPa). Vers la fin de la période de végétation, on a cependant mesuré une forte croissance de la valeur ψ midday, probablement due aux fortes précipitations au cours de cette période.*
Mots clés: 'Zierfandler', photosynthèse nette, transpiration, régulation stomatique, haie foliaire, potentiel hydrique foliaire, résistance à la sécheresse

'Zierfandler' (synonyms: 'Spätrot', 'Cirfandli') is an authentic grapevine cultivar in Austria and Hungary. This white grape cultivar is grown in Niederösterreich (~200 ha), and in the wine region of Pécs, Hungary (~20 ha). Presumably, the 'Zierfandler' originates from a natural hybridization between 'Traminer' (or Traminer-type cultivars) and 'Roter Veltliner' (REGNER, 2000). 'Zierfandler' is late ripening, with a high ability of sugar accumulation, its wine is rich in aromas and flavours. (CSEPREGI and ZILAI, 1988). The cultivar is sensitive to drought according to the results so far (DIÓFÁSI and SÉLLEY, 1995), and requires rich soils so that it is well supplied with nutrients (NÉMETH, 1967). The eco-physiological behaviour of different grapevine (*Vitis vinifera* L.) cultivars under water stress conditions was studied intensively (BRAVDO et al., 1972; DÜRING, 1980; RÜHL and SAVELKOULS, 1986; SCHULTZ, 1996; GOMEZ-DEL-CAMPO et al., 2004). Grapevines, characterised by photosynthesis of the C3 type, developed numerous protective mechanisms against drought. Sensitive stomatal regulation (closing the stomata as well as decreasing photosynthetic activity and transpiration) moderates the water loss of the plant. The sensitivity of stomatal regulation varies between cultivars, so that the level of photosynthetic activity is also different.

Apart from stomatal regulation, grapevine cultivars also have osmotic (using osmo-active substances) and elastic (changing the cell wall elasticity) regulatory mechanisms. These regulatory mechanisms play an important role in the protection of the plant against drought on the level of cells and tissues (PATAKAS and NOITSAKIS, 1999; PATAKAS and NOITSAKIS, 2001). Grapes in general are considered to have a higher tolerance level to water stress than most of the field plants. Within the species, however, different cultivars and hybrids have different specific tolerance levels to water stress (DÜRING and SCIENZA, 1975; REGINA and CARBONNEAU, 1996).

Continuous water supply is one of the most important factors in quality wine production, especially when we consider the probability of an increasing number of hot and dry periods due to the ongoing global climatic change. If water supply is not sufficient, then the specific water stress tolerance levels of the cultivars will define the quality of the yield significantly. Regina and CARBONNEAU (1996) classified the different grapevine cultivars according to water stress tolerance into (1) a sensitive group, that is characterised by a great extent of decrease in the photosynthetic rate (cv. 'Semillon', 'Ugni blanc') and (2) a more adaptable group (cv. 'Muscat of Alexandria', 'Chardonnay') that does not react to drought with such sensitivity. According to another classification system grape cultivars can be divided into (1) drought tolerant (Syrah-type) and (2) drought avoiding (Grenache-type) groups (SCHULTZ, 1996). In addition to water stress tolerance of the cultivar, an optimized production technology can also moderate the adverse effects of drought.

For each cultivar the specific training systems result in a cultivar-specific canopy structure that also defines the microclimate of the canopy. The photosynthesis of the vines, bud differentiation, fruit maturity as well as the maturation of the shoots are in close relation with the seasonal change of the canopy (PONI et al., 1996). In the case of 'Zierfandler', according to the research so far (DIÓFÁSI, 2003), the optimum training system is the mid-high cordon.

The goal of this research is to define the change in photosynthetic activity, canopy structure and regulation mechanisms of vine water status for 'Zierfandler' cultivated with mid-high cordon training system.

Materials and methods

This study was carried out in the Szentmiklós vineyard of our institute in Pécs. The size of the vineyard is 30 ha with several grape cultivars and among them 9000 'Zierfandler' vines in 2.3 ha. We studied the 'Zierfandler' grapevine cultivars, which by natural classification belongs to *Vitis vinifera* L. *convar. occidentalis* (NÉMETH, 1967). Five-year-old vines were grown in our non-irrigated vineyards (grafted on Berlandieri x Riparia 'Teleki 5C') on the south-facing slopes of the Mecsek Hills (latitude: 46°07' N, longitude: 18°17' E, 180 to 200 m above sea level). The soil is Ramann-type brown forest soil on red sandstone. The experimental plots are situated on southern terraces. The training system is mid-high cordon. Row and plant spacing is 2.2 x 0.8 m. Weather conditions, i.e. net radiation, precipitation, air temperature and relative humidity, were registered by means of an automatic weather station (Lufft HP-100, Germany) placed in the experimental vineyard.

Changes in soil moisture were monitored by the conventional gravimetric method (drying to weight-balance at 100 °C in oven) from budbreak to ripening.

We monitored the canopy light microclimate and light conditions of the cluster zone by means of a linear ceptometer (AccuPAR Model PAR-80, Decagon, USA). This device recorded PAR data, PAR (photosynthetically active radiation) is defined as the radiation in the 400 to 700 nanometer waveband. It represents the portion of the spectrum which plants use for photosynthesis. Changing of canopy structure and influence of canopy management on shoot development were registered by 'point-quadrate method' by SMART (SMART and ROBINSON, 1991). Periods of sampling: phenological stage of flowering, pea berry size, veraison and ripening.

Leaf gas-exchange measurements were conducted on mature, healthy, sun-exposed leaves with an ADC-LCA 4-type open-system infrared gas analyser (ADC Bioscientific Ltd., Hoddesdon, England). We measured the following parameters: photosynthetic rate (A), transpiration rate (E) and stomatal conductance (g_s).

Leaf water potential (SCHOLANDER et al., 1965) was determined using a pressure chamber water status console 3000 (Soilmoisture Corp., Santa Barbara, USA). Predawn leaf water potential was measured at the end of the night, between 2 and 3 o'clock by mature leaves from bloom till ripening on eight measurement days. Data showed the plant water status at zero plant water flux ($\psi_{predawn}$), a parameter which was found closely related to soil water matric potential (VAN ZYL, 1987; LEBON et al., 2003). Midday leaf water potential (ψ_{midday}) of healthy mature leaves (exposed to direct sunlight) was measured on ten occasions during the growing season. Leaf samples were taken three times, from randomly chosen vines during each phenological phase from flowering till post-harvest period. Statistical analysis was carried out by Excel (Microsoft Corp., Redmond, USA) and SPSS (SPPS Corp., Chicago, USA).

Results and discussion

Meteorological parameters

The meteorological parameters showed that 2003 was the driest and warmest year of the last 50 years (Tab. 1). The growing season running from April, 1st, to October, 31st, in the Carpathian Basin is marked grey in the table. The amount of sunshine hours was significantly higher in all months than the long-term average of 50 years and finally gave an increase of 310 hours during the vegetation period compared to average. The analysis of monthly average temperature indicates that in January and February the temperature was colder than the 50 years average, in February the deviation was -4.4 °C. On the other hand, the annual average temperature was higher by +1.3 °C than the long-term average. During the vegetation period the mean annual temperature was even higher by +3 °C compared to the long-term average. Additionally we measured a very strong deficit in precipitation, this value was lower

Table 1:
Meteorological data of the year 2003

	Hours of sunlight (h)			Air temperature (°C)			Precipitation (mm)		
	50 year*	2003	deviation	50 year*	2003	deviation	50 year*	2003	deviation
January	72	75	+3	0.2	-0.6	-0.8	45	66	+21
February	101	117	+16	2.3	-0.2	-4.4	45	39	-6
March	141	197	+56	6.4	7.2	+0.8	47	16	-31
April	181	235	+54	11.7	12.4	+0.7	70	13	-57
May	235	296	+61	16.6	20.4	**+3.8**	74	45	-29
June	242	291	+49	20.0	25.2	**+5.2**	95	20	-75
July	280	319	+39	21.8	24.1	**+2.3**	81	68	-13
August	271	346	+75	21.6	26.5	**+4.9**	76	27	-49
September	204	236	+32	17.9	18.9	+1.0	58	29	-29
October	159	163	+4	12.6	10.5	-2.1	56	142	+86
November	76	138	+62	6.2	10.5	+3.6	72	56	-16
December	59	130	+71	2.0	9.8	+1.0	63	23	-40
average				11.6	12.9	+1.3			
amounts	2021	2548	+527				782	544	-238

*mean of years from 1951 to 2000 (FVM SZBKI Pécs), grey: during the vegetation period

by 252 mm rain fall in comparison with the long-term average. Moreover, the frequency of precipitation was unfavourable during the vegetation period. The high temperature and the strong water deficit with low relative humidity of air induced severe water stress conditions.

Canopy structure

On the mid-high cordon the average leaf number of 'Zierfandler' increased from flowering to veraison and showed a minimal decrease during ripening. For this cultivar, the shoot development was of average tendency (Kozma, 2000), we measured the most intensive shoot growth at the flowering and at the pea berry size.

Table 2:
Description of canopy structure on 'Zierfandler' by point-quadrat method (Smart-analysis) and light conditions (PAR-Photosynthetically Active Radiation) of fruit zone from bloom to post-harvest period (Pécs-Szentmiklóshegy); n = 10

	Bloom	Pea berry size	Veraison	Post-harvest
Average leaf layer number	2.9	4.0	4.7	2.7
Percentage of interior leaves (%)	30.0	57.1	54.6	31.6
Average canopy breadth (cm)	24.3	32.4	31.6	25.6
PAR above the canopy (µmol/m^2/s)	1515.4	1300.8	1507.4	1118.0
PAR in the fruit zone (µmol/m^2/s)	164.3	172.4	64.0	77.2

The 'point-quadrat' method (Smart-analysis) was used for canopy description. Measurements were carried out by horizontally inserting a metal rod into the fruit zone. Then contact points with leaves and clusters for each insertion (10 insertions per 1 meter length in a straight line) were recorded to determine the leaf layer number, the percentages of interior leaves and other canopy parameters. The average leaf layer number was 4 (an increase by 27 %, Tab. 2), this value showing the average number of leaf contact points of ten insertions. The leaf layer number did not correspond absolutely to the number of shoots in the canopy.
The percentages of interior leaves started to decrease from the veraison period; at the harvest time it was 31 % of total leaves which was close to the values of the flowering period. Yet a number of studies stated (Schultz and Matthews, 1988; Winkel and Rambal, 1993), that a soil water deficit caused a decrease of the total leaf area, especially at the beginning of the growing season, when the vegetative growth was on the maximum. The 'Zierfandler' showed intensive shoot development at beginning of growth season (characteristic for the cultivar), signs of water stress were determined only at beginning of the veraison period. The measured PAR values into the fruit zone reached between 60 mmol/m^{2}sec and 170 mmol/m^{2}sec, a set of light conditions that made sure of favourable ripening of cluster.

Photosynthetic activity - gas exchange

We described the photosynthetic activity of 'Zierfandler' by measuring photosynthetic rate (A = net assimilation) in healthy, mature leaves. The photosynthetic rate (Fig. 2) was higher than 16 mmol/m^{2}sec at flowering period, these values were measured at a high leaf surface temperature above 33 °C on the 7th to 8th node. The values of the photosynthetic rate (A) decreased by 37 % at the same high leaf temperature at flowering, pea berry size and at veraison. This change indicates a partial closure of the stomata caused by an increasing water deficit. The photosynthetic rate even showed a pronounced decrease at beginning of ripening (< 6 mmol/m^{2}sec), but we measured a short regeneration period at the beginning of August (August, 11th). In this phase, the average value of photosynthetic rate (A) was 8 mmol/m^{2}sec, this indicates favourable conditions for assimilation.

In accordance to the change of net assimilation rate (A), a parallel increase of transpiration rate (E) and stomatal conductance (g_s) was measured (Fig. 1 and 2). In this case, the higher level of CO_2 uptake was due to higher water losses via stomatal transpiration. The decrease of leaf surface temperature by 4 °C was an important factor in the development of a favourable assimilation rate. However, caused by the continuous water stress conditions present during the growing season, we measured a low level of photosynthetic activity in 'Zierfandler' leaves from flowering to post-harvest period. This lower photosynthetic rate was caused by stomatal closure due to high water deficit. Available evidences (Düring and Scienza, 1975; Escalona et al., 1999; Pospisilova, 2003) suggest that abscisic acid is synthesised in the roots under water stress conditions and then is transported to the leaves, where it induces the closure of the stomata. The abscisic acid, as a chemical signal, plays an important role to decrease the water loss in grapevine leaves. We found a very close relationship between the seasonal change of photosynthetic rate (A), transpiration rate (E) and stomatal conductance (g_s) in 'Zierfandler' leaves - the conductance of stomata and the intensity of transpiration decreased in parallel with the change of net photosynthesis. The increase of water deficit and the increase of leaf surface temperature did not cause an increase in transpiration rate in 'Zierfandler' leaves. This indicates that this cultivar has a sensitive stomatal regulation under severe water stress like most other grapevine cultivars. The stomatal closure caused by strong water deficits inhibited the large-scale water loss via transpiration and it made the survival of 'Zierfandler' vines possible in addition to low photosynthetic rate during the severe drought period.

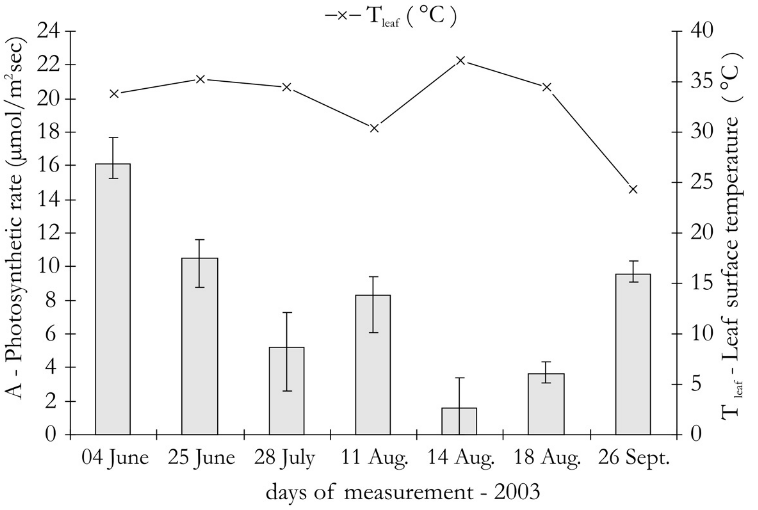

Fig. 1: Seasonal changes of photosynthetic rate (A - mmol/m^{2}sec) in 'Zierfandler' leaves from June to October (Pécs-Szentmiklós-hegy); n = 3

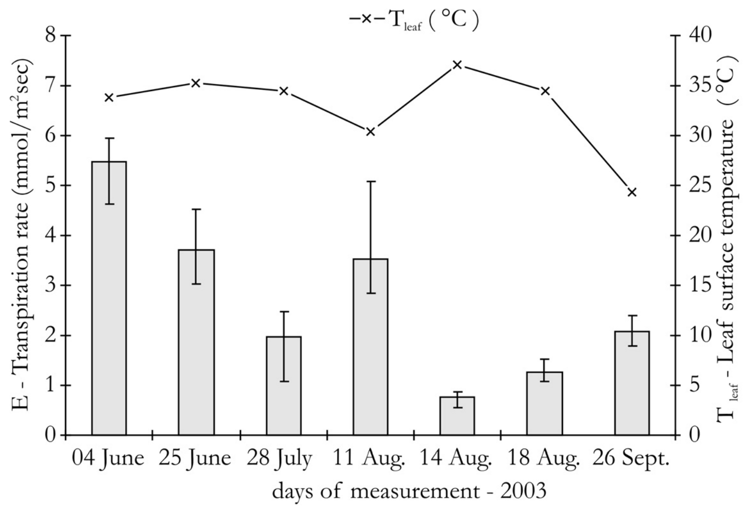

Fig. 2: Seasonal changes of transpiration rate (E - mmol/m^{2}sec) in 'Zierfandler' leaves from June to October (Pécs-Szentmiklós-hegy); n = 3

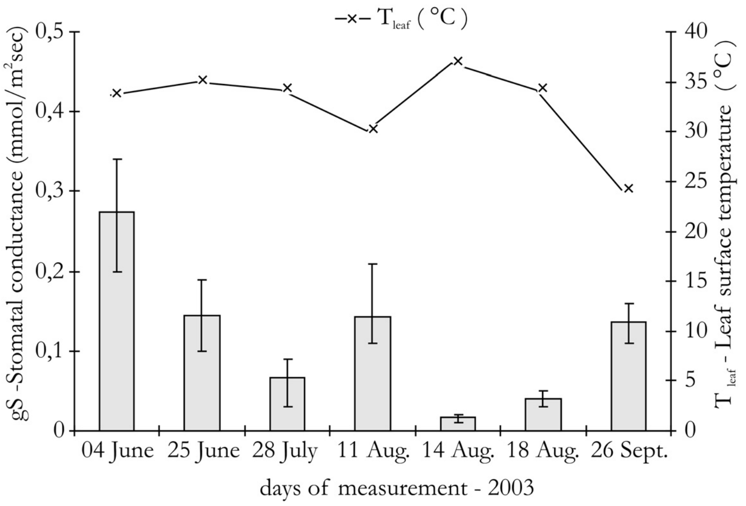

Fig. 3: Seasonal changes of stomatal conductance (g_s - mmol/m^2s) in 'Zierfandler' leaves from June to October (Pécs-Szentmiklóshegy); n = 3

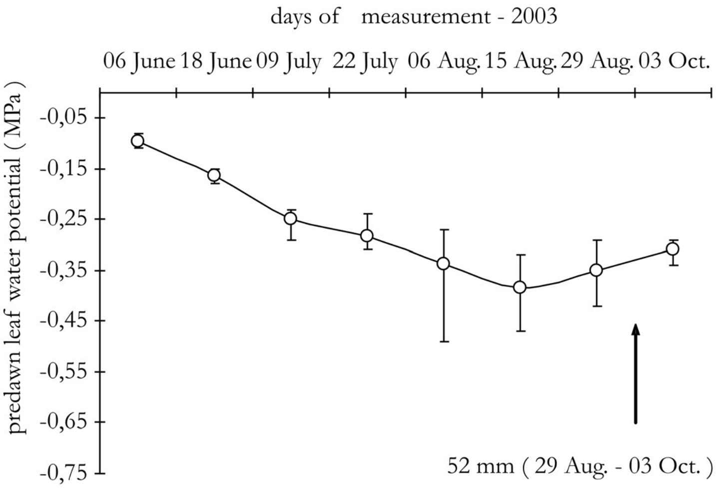

Fig. 4: Seasonal changes of predawn leaf water potential (ψ_{PD} - MPa) in 'Zierfandler' leaves from June to October (Pécs-Szentmiklóshegy); the amount of precipitation was 52 mm between August, 29th, and October, 3rd; n = 3

Leaf water potential

The predawn leaf water potential ($\psi_{predawn}$) values of 'Zierfandler' were -0.25 MPa at pea berry size, which indicated moderate water stress conditions. Data of predawn leaf water potential ($\psi_{predawn}$) decreased continuously during the measured period, only at harvest $\psi_{predawn}$ values increased slightly. The soil water content and the water supply of the root system (diminutive root-branch) were indicated exactly by $\psi_{predawn}$ values. Before sunrise, when stomata were closed, the transpiration via stomata decreased and turgor of leaves recovered (zero water flux).

We measured the highest level of water stress at ripening and harvest period during the first ten days in August. Average value of $\psi_{predawn}$ was -0.38 MPa and the lowest value decreased to -0.49 MPa. High deficit of soil water content is reported to have negative effects on vine vigour, but in this experiment we could not measure an inhibition of shoot growing of 'Zierfandler'. Predawn leaf water potential values showed a minimal increase to -0.30 MPa at post-harvest period in September. Strong precipitation (52 mm rainfall) caused adverse conditions and brought a very small increase in $\psi_{predawn}$ values from September to early October. This change suggested that unequal amounts of precipitation are not sufficient to cure water deficit in vine. Furthermore the water deficit inhibits regeneration of water status in 'Zierfandler' leaves.

Midday leaf water potential (ψ_{midday}) showed no vine water deficit or moderate water stress conditions during flowering period. The values of midday leaf water potential (ψ_{midday}) indicated favourable leaf water status in spite of the severe water stress conditions analysed by other parameters. Average values of ψ_{midday} ranged between -1.04 MPa and -1.42 MPa from flowering till harvest, the lowest value measured was -1.55 MPa. Because of favourable soil structure and soil water household the ψ_{midday} parameters of 'Zierfandler' showed only moderate water stress conditions during the whole period. In contrary we measured severe water stress indicated by low ψ_{midday} values (data not shown) at the same period in other cultivars ('Sauvignon blanc', 'Pinot noir', 'Merlot'). It can be presumed, that mechanisms of stomatal regulation play an important rule in development of greater vine water status. The soil water deficit and high leaf surface tem-

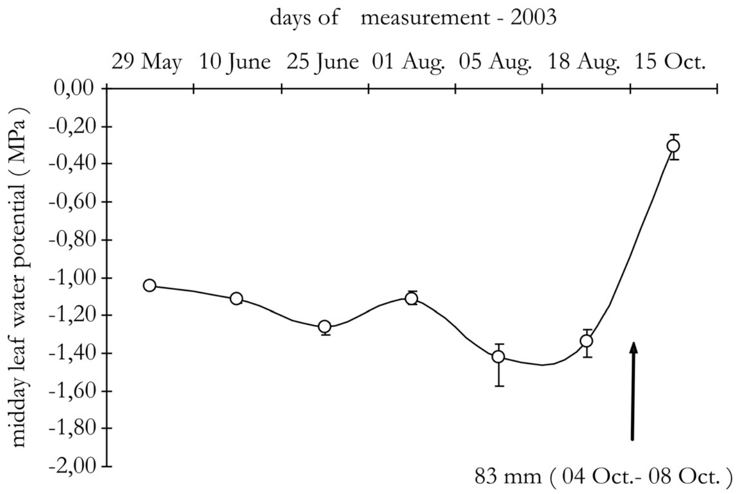

Fig. 5: Seasonal changes of midday leaf water potential (ψ_{MD} - MPa) in 'Zierfandler' leaves from end of May to October (Pécs-Szentmiklóshegy); the amount of precipitation was 83 mm between October, 4th, and October, 8th; n = 3

perature induced stomatal closure which limited the water loss via transpiration. ψ_{midday} values indicated a high degree of change in leaf water status during post-harvest period. At October, 15th, (last day of measurement) we determined a very high midday leaf water potential (less negative) similar to predawn values. The lowest ψ_{midday} was -0.30 MPa in post-harvest period, this corresponds to an increase of ψ_{midday} by 77 % in comparison with values of water stress period. The high amount of precipitation (83 mm) and lower leaf surface temperature improved the vine water status during the first ten days in October.

We suppose that this response has two principal causes:
1. severe water stress slowed down the water flow in vine throughout the growing season, thus it inhibited the transpiration of precipitation surplus;
2. vine water status will increase to a higher level without the clusters (grapes). These results confirm, that pre-harvest removal of grapes improves the water status of vine during severe water stress periods.

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