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Transpiration of grapevines and co-habitating cover crop and weed species in a vineyard. A "snapshot" at diurnal trends

C. Lopes[1)], A. Monteiro[1)], F. E. Rückert[2)], B. Gruber[3)], B. Steinberg[3)] and H. R. Schultz[2, 3)]

[1)] Instituto Superior de Agronomia, Tapada da Ajuda, Lisboa, Portugal
[2)] Fachbereich Weinbau und Getränketechnologie, Fachhochschule Wiesbaden/Geisenheim, Deutschland
[3)] Institut für Weinbau und Rebenzüchtung, Forschungsanstalt Geisenheim, Deutschland

Summary

The objective of this study was to quantify transpiration rates of two cover crops, *Festuca rubra* subsp. *rubra* (red fescue) and *Medicago lupulina* (black medick) and 4 weeds, *Chenopodium album* (fat hen), *Cirsium arvense* (creeping thistle), *Malva neglecta* (common mallow) and *Taraxacum officinale* (dandelion) occurring in a mixed stand in a commercial steep-slope, North-South oriented vineyard as compared to vines, cv. Riesling near Johannisberg (Rheingau), Germany. Leaf transpiration (E) was measured directly on the cover crop and weed species with a portable gas exchange measurement system. Grapevine transpiration was measured concomitantly using custom-made Granier-type xylem sap flow gauges. Measurements were conducted on two days in August (15th and 22nd) in 2001 under hot and sunny conditions. All herbaceous species presented a similar diurnal pattern of E, with low values in the morning and afternoon and peak values between 12 and 15 h. In contrast E of grapevines peaked mid-morning (between 8 and 10 h) remained relatively stable until mid-afternoon (16 h) before decreasing continuously until darkness. Significant differences in E between the herbaceous species were observed throughout the day. In general transpiration rates were highest for *M. neglecta* and lowest for *C. arvense*, *T. officinale* and *F. rubra* subsp. *rubra*. We estimated the projected leaf area indices (leaf area per surface area covered) for each species and calculated possible transpiration rates for pure stands assuming that all leaves were well exposed. Potential transpiration rates ranged from about 1 mm d^{-1} (one l m^{-2} of soil surface) for *F. rubra* subsp. *rubra* to = 5 mm d^{-1} for *M. neglecta* as compared to only 0.9 mm d^{-1} for grapevine. These results underline the importance of appropriate cover crop species and the control of some weed species with respect to water use.

Key words: cover crops, weeds, vineyard, evapotranspiration, sap flow, gas exchange.

Introduction

Cover crops are extensively used in viticultural areas with summer rainfall mainly to facilitate mechanisation and to prevent soil erosion and leaching of nutrients such as nitrate. They increase the water holding capacity and infiltration rates into the surface soil layers due to the formation of stable aggregates (Parker and Jenny 1945, Free *et al.* 1947, Toenjes 1954, Blasse 1961). Cover crops may compete with grapevines for water and nutrients, and this competition may be beneficial if soils are deep and soil moisture is excessive. Under these conditions vegetative growth of vines and bunch rot (*Botrytis cinerea*) can be reduced (Steinberg 1970) and canopy microclimate and berry composition will be improved (Smart and Robinson 1991). Most temperate regions, however, experience periods with evaporative demands exceeding water supply during mid-summer. In these cases, the contribution of cover crops and/or developing weeds to total vineyard evapotranspiration may become substantial, and the competition for water between vines and cover crop may accelerate the development of water stress (Eggert 1957, Blasse 1961, Steinberg 1972, Arneth 1979, Prichard 1998). The interactions between vines and cover crop with regard to the demand for water, but also nitrogen, are still poorly understood and there is a lack of quantitative data on how much water is used by different cover crop species and weeds under field conditions.

Additionally, there are no field data available, which directly compare the amount of water consumed by grapevines as compared to cover crops or weed species. Since competition for resources such as nitrogen is thought to play a major role in stress development and the formation of off-flavours in white grapes in dry years (Maigre *et al.* 1995, Schwab *et al.* 1996), we compared the water use of some cover crops and weed species with that of grapevines in a preliminary trial in the field. The objectives of the present study were to determine the diurnal pattern of transpiration rates of different cover crops, weed species and whole-plant transpiration rates of grapevines to compare water use of co-habiting species in a vineyard.

Material and Methods

Experimental site: Data were collected in a commercial 25-year-old White Riesling (*Vitis vinifera* L.) (clone 239 Gm) vineyard, grafted on 5 C rootstocks (*V. berlandieri* Planch. x *V. riparia* Mich.) at the Johannisberger Schloβberg, Geisenheim, Germany (50° N; 8° E), in August 2001. Row orientation was North-South with a slope of 45-50 %. Plants were spaced 1.5 m between and 1.3 m

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Correspondence to: Prof. Dr. H. R. Schultz, Forschungsanstalt Geisenheim, von Lade Str. 1, 65366 Geisenheim, Deutschland. Fax: +49-6722-502140. E-mail: h.schultz@fa-gm.de

within the rows and trained to an espalier-type Guyot system (vertical shoot-positioning, VSP) with a trunk height of 0.5 m and a canopy height of 1.2 m. The soil was deep loamy loess with 30 % sand, 53 % silt and 17 % clay and a pH ($CaCl_2$) of 7.4; it contained 2.1 % organic matter in the upper 30 cm and was rich in nutrients. After extraordinarily high amounts of rainfall in July (97 mm) soil water content in the upper 0-50 cm was 49 % of field capacity, while at 50-100 cm and 100-150 cm it was still 74 % and 77 % of field capacity, respectively as determined with a *DIVINER 2000* frequency domain reflectometry probe (Sentek, King Town, Australia).

Cover crop and weed species: The inter-row plant cover consisted among others of a mixture of *Festuca rubra* L. subsp. *rubra* (red fescue), *Medicago lupulina* L. (black medick) and *Sanguisorba minor* Scop. (salad burnet) which was sown in 1999. *S. minor* was the least abundant of the three. Weeds within the row were controlled by a single application of glyphosate in spring but re-emerged during summer. Among the weeds, *Chenopodium album* (fat hen), *Cirsium arvense* (creeping thistle), *Malva neglecta* (common mallow) and *Taraxacum officinale* (dandelion) were the most abundant. All of the above mentioned plants were used for the transpiration and photosynthesis measurements with the exception of *S. minor.* The growth stages (BBCH scale, Hess *et al.* 1997) of the plant species at the dates of measurements (August 15 and 22) were: *F. rubra* subsp. *rubra* 25/29, *M. lupulina* 51/55, *C. album* 16/18, *C. arvense* 16/19, *M. neglecta* 51/55, *T. officinale* 15/18.

Gas exchange measurements: Field measurements of photosynthesis and transpiration rates were conducted every two h between 8 and 18 h using a portable gas exchange system (LCA-4, ADC, Hoddesdon, England). For the dicotyledonous species three different plants were selected and two leaves of each plant were measured every 2 h. For the monocotyledonous species *F. rubra* subsp. *rubra,* a perennial, tufted and rhizomatous plant with a linearly shaped and enrolled leaf blade with an average width of 0.5-1 mm (max. 4 mm) (Behrendt and Hanf 1979), as many leaves as possible were introduced into the measuring cuvette. For this species 6 tufted plants in the middle of the inter-row were selected, and two measurements per plant were conducted each time. Daily transpiration integral was calculated from the 6 instantaneous measurements assuming a linear evolution between successive measurements.

Leaf area and projected leaf area index: Leaf area and projected leaf area index (leaf area per unit covered soil surface area) were determined in 16 randomised vineyard subplots with 1.4 x 3.6 m spacing each. In order to estimate leaf area of the species in question, all leaves in the 16 subplots were sampled and their dry weight determined after drying at 100 °C until constant weight. 10 sub-samples of each species were taken at the same time, the leaf images scanned into a computer (Fig. 1) and the leaves dried and weighed as described. The leaf area was calculated from the leaf images using the PhotoShop 6.0 program (Adobe, San Jose, USA) and then correlated with dry weight. Total plant leaf area from the other samples was then estimated using the obtained regression equations (Fig. 2).

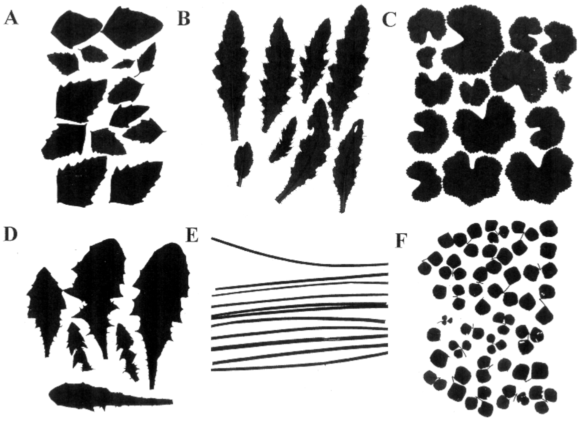

Fig. 1: Scanned leaf images of the tested species, (**A**) *Chenopodium album*, (**B**) *Cirsium arvense*, (**C**) *Malva neglecta*, (**D**) *Taraxacum officinale*, (**E**) *Festuca rubra* subsp. *rubra* (**F**) *Medicago lupulina*.

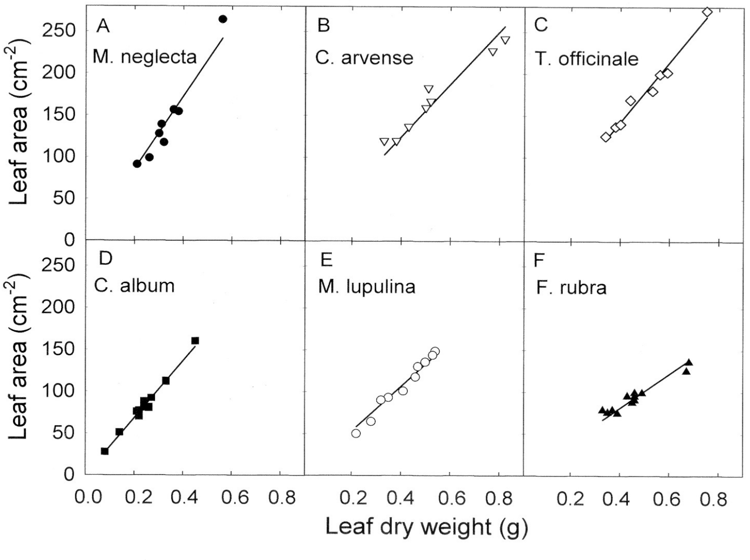

Fig. 2: Relationship between leaf area (cm^2) and leaf dry weight (g) for the 6 tested species, (**A**) *Malva neglecta*, y = 431.72 x, R^2 = 0.94, (**B**) *Cirsium arvense*, y = 318.08 x, R^2 = 0.92, (**C**) *Taraxacum officinale*, y = 358.18 x, R^2 = 0.98 (**D**) *Chenopodium album*, y = 341.38 x, R^2 = 0.98, (**E**) *Medicago lupulina,* y = 265.91 x, R^2 = 0.97, (**F**) *Festuca rubra* subsp. *rubra,* y = 203.47 x, R^2 = 0.89. The relationships were forced through the origin.

Whole-vine transpiration rate and leaf water potential: Vine transpiration rate was determined using Granier-type sap flow gauges implemented in the trunk (Granier 1985) according to the protocol for grapevines of Braun and Schmid (1999). Leaf water potential measurements were conducted with a pressure chamber (Soilmoisture Corp., Santa Barbara, CA, USA) at pre-dawn (ψ_{pd}). Environmental data such as global radiation, air temperature (2 m above the ground) and relative humidity were recorded by a weather station of the German Weather Service (DDW, Geschäftsstelle Landwirtschaft, Geisenheim) located within the experimental vineyard.

Results

The time during which direct sunlight reached the vineyard soil influenced stomatal aperture and subsequently transpiration rates of the studied species (Figs. 3 and 4, Tab. 1). Due to the narrow row spacing and relatively tall canopy of the vineyard, direct sun-light exposure of cover crops and weeds was less than 5 h d^{-1} around noon and in the early afternoon (Tab. 1).

In general, weeds like *M. neglecta, C. album, C. arvense,* and *T. officinale* had higher values of stomatal conductance (gs) in the morning than the cover crop species *F. rubra* subsp. *rubra* and *M. lupulina* (Fig. 3 A, B). Stomatal conductance decreased continuously during the day irrespective of light intensity for all species but *M. neglecta* (cf. Fig. 3A, B; Tab. 1). For *M. neglecta*, gs closely tracked the trend in PFD (Tab. 1) reaching values close to 700 mmol m^{-2} s^{-1} between 12 and 14 h, which were about 3-6 times as high as those of the other species (Fig. 3 A). Transpiration rate (E) did not follow the diurnal trend in gs except for *M. neglecta* (cf. Figs. 3 and 4). All species exhibited maximum values of E during maximum light exposure (Fig. 4 A, B, Tab.1). Around midday (12-14 h), *M. neglecta* had transpiration rates 2-3 times as large as those of the other weed species (Fig. 4 A). Of these, *C. arvense* had the lowest value at noon (Fig. 4 A). *M. lupulina* had a diurnal pattern of E similar to the weed *C. album* but with lower values particularly after 16 h. *F. rubra* subsp. *rubra* had the lowest gs and E values of all 6 species.

The competitive ability of a weed or cover crop may be related to its growth and/or water use efficiency (WUE, photosynthetic rate / transpiration rate) in a particular situation.

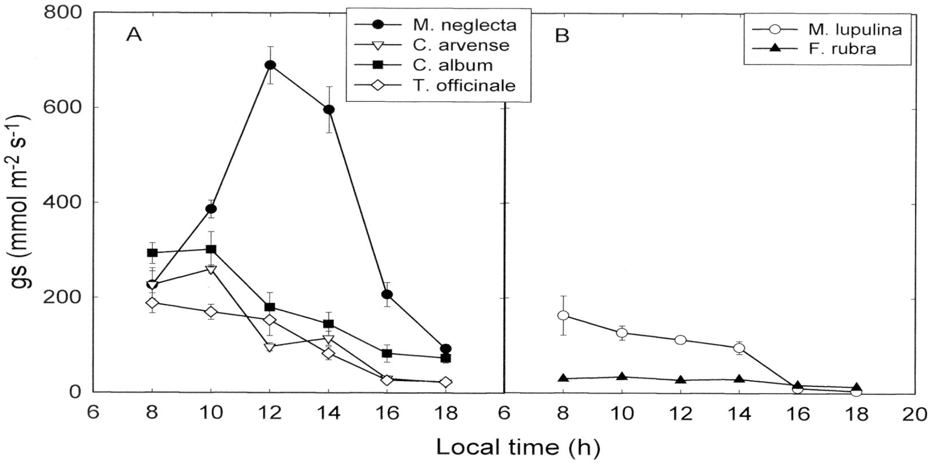

Fig. 3: Diurnal pattern of stomatal conductance (gs) of (**A**) *Malva neglecta, Cirsium arvense, Chenopodium album, Taraxacum officinale*, and (**B**) *Medicago lupulina* and *Festuca rubra* subsp. *rubra*, during August 15 and 22, 2001, in a vineyard near Geisenheim, Germany. Data are means ± SD of 6 measurements per species. Data for *Festuca rubra* subsp. *rubra* are means ± SD of 12 measurements.

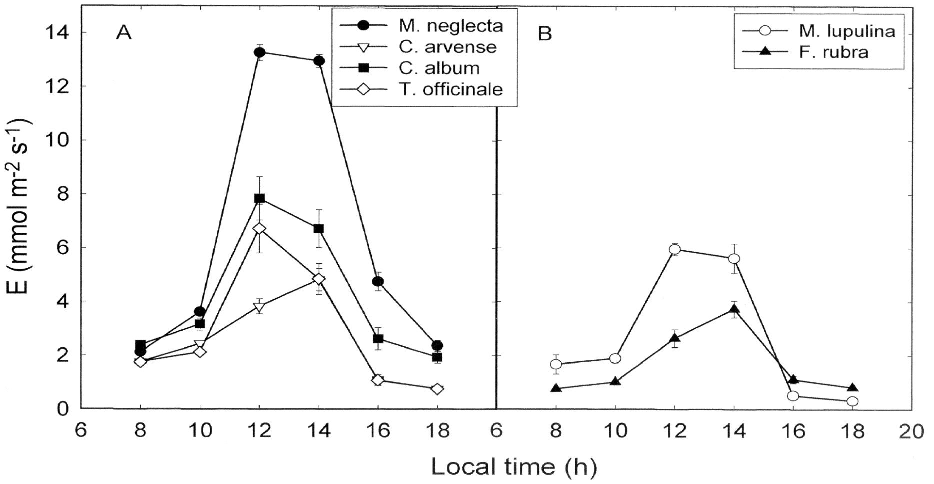

Fig. 4:. Diurnal pattern of transpiration rate (**E**) of 4 weed (**A**) and 2 cover crop species (**B**). For details see Fig. 3.

Table 1

Photon flux density (PFD, µmol m^{-2} s^{-1}) at exposed leaves of 4 weeds (August 15, 2001), and 2 cover crops (August 22, 2001) in a vineyard near Geisenheim, Germany. Data denote the mean and standard error of 6 measurements per species

Species	Local time (h)					
	8-8:45	10-10:45	12-12:45	14-14:45	16-16:45	18-18:45
Weeds						
Chenopodium album	68.3 ± 6.4	89.0 ± 5.7	1630.0 ± 19.1	1478.0 ± 50.7	99.8 ± 4.8	65.5 ± 5.3
Cirsium arvense	55.0 ± 1.6	107.2 ± 8.0	1449.8 ± 52.1	1533.0 ± 79.2	112.5 ± 1.8	63.5 ± 5.8
Malva neglecta	66.7 ± 6.5	112.3 ± 12.4	1464.0 ± 59.8	1407.7 ± 61.2	127.5 ± 35.4	55.0 ± 2.3
Taraxacum officinale	45.7 ± 1.6	76.5 ± 2.4	1251.3 ± 74.4	1316.2 ± 64.1	129.5 ± 33.9	73.3 ± 6.0
Cover crops						
Festuca rubra subsp. *rubra*	69.8 ± 4.7	118.4 ± 7.7	1470.0 ± 24.6	1522.4 ± 34.7	118.0 ± 16.1	76.7 ± 8.9
Medicago lupulina	86.0 ± 8.1	140.0 ± 5.6	1509.8 ± 37.0	1352.3 ± 36.1	99.8 ± 8.8	40.8 ± 3.6

In general, we found that cover crops had a higher WUE than weeds when integrated over the day, but, with the exception of *T. officinale*, all weeds had higher WUE's during times of high light (data not shown).

Maximum vine transpiration rate on a per unit leaf area basis was much lower than weed and cover crop transpiration rate (cf. Figs. 4 and 5D, right axis) and occurred earlier during the day (8-10 h as compared to 12-14 h). However, grapevines had relative stable values of E for about 8 h, whereas E of weed and cover crop species was much more variable due to shadows cast by the vine canopy. Despite differences in air temperature and vapour pressure deficit (VPD) between the two measurement days, rates of sap flow were very similar (Fig. 5 A-D).

The estimation of the daily transpiration integral showed that, on a clear sunny day, *M. neglecta* transpired about twice the amount of water than the other species including grapevines based on per m^2 of leaf area and that *C. arvense* and *F. rubra* subsp. *rubra* were the species with the lowest transpiration (Tab. 2). Based on the estimated projected leaf area per unit of soil surface area, E could be estimated for a pure stand of each species under field conditions. Assuming 100 % soil coverage by any particular species, potential contribution to vineyard evapotranspiration could range from less than 1 mm d^{-1} for *F. rubra* subsp. *rubra* to more than 5 mm d^{-1} for *M. neglecta,* assuming that all leaves were well exposed on a hot sunny day (Tab. 2). In the given case, E per m^2 of soil surface of all species would have exceeded E of grapevines (Tab.2, Fig 5). The water potential shown in Fig. 5 indicates that the vines did not experience water deficit.

The direct measurements conducted in the field agreed well with previously established preferences in terms of soil water content for the species tested. Tab. 3 shows a comparison of our transpiration ranking with the ranking using soil water indicator values established by Ellenberg *et al.* (1992).

Discussion

Direct measurement of transpiration on several cover crop and weed species without drought showed, that total values of E per unit soil surface were comparable to vine

Table 2

Daily transpiration integral for 4 weed- and two cover crop species between 8 and 18 h (Σ E), leaf area index (LAI) and the potential contribution of each species to vineyard evapo-transpiration if soil cover would be 100 %. Data are compared to vine transpiration measured using sap flow gauges at Schloβ Johannisberg, Geisenheim, August 15 and 22, 2001

Species	$\sum_{8\,h}^{18\,h} E$ (l m^{-2} leaf area)	LAI (m^2 m^{-2})	Transpiration per m^2 of soil d^{-1} (mm d^{-1})
Cover crops			
Medicago lupulina	1.94	1.28	2.48
Festuca rubra ssp. *rubra*	0.60	1.18	0.71
Weeds			
Chenopodium album	2.93	0.76	2.21
Cirsium arvense	1.74	1.22	2.12
Malva neglecta	4.79	0.93	4.45
Taraxacum officinale	2.08	1.38	2.48
Grapevine	0.46	2.31	0.89

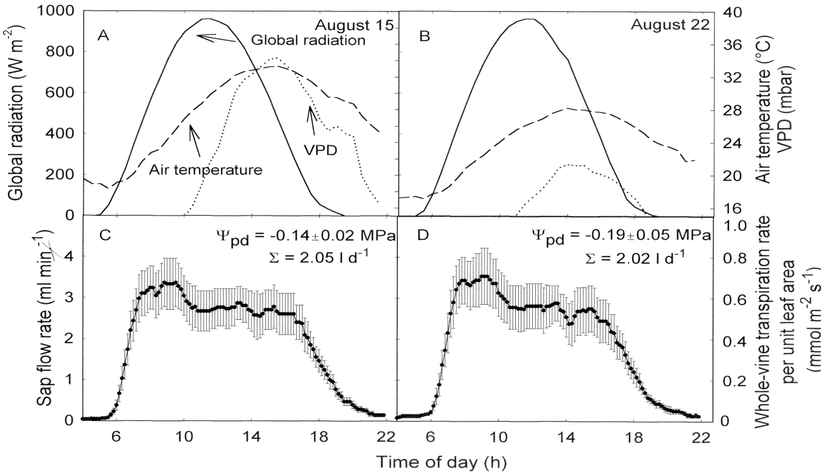

Fig. 5: Global radiation, air temperature, VPD (**A**, **B**) and average sap flow rates (ml min^{-1}), respectively whole plant transpiration rates per unit leaf area (mmol m^{-2} s^{-1}) ± SE of 5 vines on 15 August (**C**), and 22 August 2001 (**D**). Pre-dawn leaf water potential and total vine transpiration d^{-1} are also indicated.

Table 3

Ranks of measured transpiration rates (I being the lowest) and the drought tolerance indicator values of Ellenberg *et al.* (1992) for the species investigated

Species	Transpiration (ranks)	Indicator Value (Ellenberg *et al.* 1992)
Festuca rubra subsp. *rubra*	I	6
Cirsium arvense	II	x
Chenopodium album	III	4
Medicago lupulina	IV	4
Taraxacum officinale	V	5
Malva neglecta	VI	5

Indicator values: 4 = close to a drought indicator, mainly found on soils with average moisture content; 5 = soils with average moisture content, absent on soils with high frequency droughts; 6 = prefers moist but aerated soils; x = indifferent, wide amplitude with respect to ecological conditions.

water use or even exceeding it, assuming the contributing species would make up a 100 % coverage of the soil. Since transpiration data were obtained from well exposed, mature leaves only, it is likely that some overestimation occurred, especially during the hours of high incident PFD. Merta *et al.* (2001) found sometimes good, sometimes limited agreement when quantifying plant transpiration of corn and rye with lysimeters and a gas exchange system, with the main problem being the scaling-up from single leaf to whole-plant values. Nevertheless, the technique used in the present study allowed some large differences between species to be documented. *M. neglecta* had transpiration rates per unit leaf area about 3 times as high as those measured on well-exposed grapevine leaves during a comparable phenological stage in the same environment (Schultz 1989). In contrast *F. rubra* ssp. rubra had the lowest water use making it a good choice as a cover crop for dry vineyard sites and confirming the data obtained by Cussans *et al.* (1995). In most cases the direct measurements of transpiration rates matched the indicator values for the preference in terms of soil water availability previously established by Ellenberg *et al.* (1992).

Plant cover of any of the investigated species usually never reaches 100 % in a vineyard situation, and some, such as *M. neglecta*, usually make up less than 5 % of ground cover (Arneth 1979). However, in a case of 50-80 % soil covered by cover crops and/or weeds, which is not an uncommon situation for a mixed stand in vineyards (Griebel 1996), even the least transpiring species or mixtures thereof could reach E values per unit soil surface close to the water consumption of vines.

Based on data of soil moisture dynamics in the field with closed stands of different cover crop species at different vineyard sites in Germany (Böll 1967 a, b), one can roughly estimate additional water consumption as compared to tilled soil. In these studies between 0.31 mm d^{-1} (mixed stand of peas and vetch, not closer specified) and 1.2 mm d^{-1} (radish seed, *Raphanus sativus*) were additionally used over a period of 15-19 d in spring (May-June). Data from the same source even indicate substantial water consumption in the range of 0.27-0.48 mm d^{-1} in late September and October (Böll 1967 a). Griebel (1996) estimated a 35 % increase in vineyard evapo-transpiration rate (ET) due to a mixed stand consisting mainly of *Poa pratensis* (Kentucky bluegrass), *Lolium perenne* (perennial ryegrass), *Agropyron repens* (quack grass) *Convolvulus arvensis* (field bindweed) and *Polygonum aviculare* (knotweed grass) as compared to clean cultivation between bud burst and bloom. This difference had vanished at full grape maturity because of substantial water deficit and consequently down-regulation of water consumption in the treatment with the cover crop - weed mixture (Griebel 1996). There is nevertheless considerable uncertainty in these analyses since it is difficult to deduct the effects of intermittent rain events on soil moisture during the measurement periods and the investigated soil depth and the real rooting profiles are usually not compared. Additionally, at least with some cover crops, the frequency of mowing may have a substantial effect on water consumption. In an early orchard cover crop management study with *Poa compressa* (Canada bluegrass) and some interspersed *Agropyron repens* (quack grass), Eggert *et al.* (1957) determined 93 mm of additionally consumed water for the unmowed as compared to the mowed cover crop by mid-August.

Direct measurements on a continuous grass cover *sedum album* mixture (not closer specified) in a pasture study with a new "tunnel-evaporation meter" gave transpiration rates per month between 29.3 mm for April and a maximum of 51 mm in June and an estimated April-September cumulative ET of 251.1 mm (Weiß *et al.* 2002). Others have estimated up to 6.8 mm d^{-1} of water used for tall fescue (*Festuca arundinacea*) under continuously well-watered conditions using a simulation model (Qian *et al.* 1996). In both studies, the results agreed well with lysimeter measurements but are difficult to extrapolate to a vineyard situation where species are different, the rows cast shadows onto the inter-row spaces at certain periods of the day and where high water availability is not always maintained.

In an attempt to quantify water consumption of grapevines as compared to several cover crop and weed species, Arneth (1979) and Müller *et al.* (1984) investigated the water use of grapevines with or without certain cover crops or weeds at different soil water contents in pot studies. Some caused very little additional water consumption (*Cirsium arvense* (creeping thistle) <1 %), whereas others increased water consumption by up to 38.5 % (*Lolium perenne* (perennial ryegrass)) as compared to grapevines alone (Müller *et al.* 1984). We found, that *C. arvense* had substantial rates of E in the field and given sufficient soil cover could use similar amounts of water than vines on a per unit surface area basis. In the studies of Müller *et al.* (1984) and Arneth (1979), water deficit increased the competitive ability of the cover crop or weed species compared to grapevines. For instance decreasing soil water content from 80 to 50 % or 70 to 40 %, respectively, in an experiment with a mixture of *Lotus comiculatus* (birdsfoot-trifoil), *Anthyllis vulneraria* (kidney vetch), *Medicago lupulina* and *Hieraceum pilosella* (mouse ear hawkweed), caused a relative increase in water consumption of this mixture compared to grapevines of about 3-6 % (Arneth 1979). In the same set of experiments some mixture of grassy species including some *Festuca* types increased relative water use compared to vines by about 20 % when soil water content dropped from 80 to 50 % (Arneth 1979). Similarly, Müller *et al.* (1984) found, that when vines and *Lolium perenne* were cultivated in the same pot under well-watered conditions, grass increased E per pot by 38.5 % as compared to vines alone, yet under water deficit, this proportion increased to 49.6 % documenting the competitive ability under certain conditions. In contrast, Olmstead *et al.* (2001) in a trial with 175 entries in Washington State, found that among several promising cover crop species and mixed stands tested, *Lolium perenne* depleted soil water the least and had the smallest effect on vine water potential.

Thus it seems difficult to extrapolate pot-data to field situations. There are also some interactions between crops, weeds and vines, which may go beyond the consumption of water. For example, in some cases in the studies by Arneth (1979) and Müller *et al.* (1984), shoot growth of the vines was severely inhibited despite continuous water and nitrogen supply, so that allelopathic interferences based on the release of chemical substances by certain cover crop and weed species under the conditions of the experiment could not be excluded (Einhellig 1999). Additionally, allelopathy has been documented to be more important in situations when soil moisture becomes limiting because of the increase in the concentration of chemicals such as flavonoids, polyphenols and terpenes (Einhellig 1999). The mere proximity of grapevines and cover crop species in pot studies and the limited rooting depth makes it much more likely that those interactions occur.

Conclusion

The preliminary results shown in this study demonstrate the variability in transpiration rates of cover crop and weed species in a vineyard.

Expressed in mm of water transpired for pure stands of the tested species, only *Festuca rubra* L. subsp. *rubra* (red fescue) had transpiration rates smaller than those determined by sap flow measurements on vines in the same vineyard on the same day. More field research is needed to quantify the contribution of cover crops and weeds in vineyards at different soil water supply. These data may also be valuable to be incorporated in water consumption models where the aspect of additional consumption by co-habitating species in vineyards has so far been neglected.

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