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Grapevine water stress risk in perennial cover-cropping systems

1. Introduction

There are several reasons for using perennial cover-cropping systems in vineyard management. Cover crops enhance trafficability of the alleys even in wet conditions. They increase humus content and reduce nitrate leaching into the groundwater (Berthold 1991). A green cover also increases the soil infiltration capacity during intense rainfall events and therefore contributes towards minimizing surface runoff and soil loss in the vineyard.

Winter annual cover-cropping is a frequently implemented management practice. However, this system cannot prevent soil erosion since the main season for erosive rainfalls is summer (Emde 1992). Cover crops are plowed under in spring to conserve soil water and subsequent mineralization may release large amounts of nitrogen. In view of these disadvantages, perennial cover crops are better suited for environmentally sound, sustainable vineyard production systems.

However, excessive competition between vines and cover crops for water is an issue under certain conditions, which may lead to reduced yields and quality (Breil 1991).

Tab. 1. Long-term precipitation average during the hydrological years 1961–1990 at selected stations in the wine-growing regions of Hesse

	Total year Nov.–October	Vegetation period April–October
Geisenheim	548 mm	342 mm
Eltville	612 mm	382 mm
Wiesbaden	636 mm	391 mm
Bensheim	828 mm	521 mm

The Rheingau is one of the German wine-growing regions, with the lowest precipitation rate and therefore this risk is especially high here. The problem is expected to be less severe in the Bergstrasse region where annual precipitation is significantly higher (Table 1).

The annual precipitation in the Rheingau increases between Geisenheim in the West and Wiesbaden in the East.

The vegetation period of the cover crops begins earlier than that of the vine. In areas with low precipitation rates, this could lead to an early decline in soil water content (Berthold 1991). In some years soil moisture conditions may be significantly lower under cover crops than in clean cultivated vineyards.

Hoppmann & Hüster (1988a) assessed water budgets in vineyards using the climatic water balance, which largely depends on estimates for potential evapotranspiration. However, these values are only valid for plants with an optimal water supply. This is not the case in dry weather when soil water contents are low. Another fundamental factor in the equation is evapotranspiration, which estimates the actual evaporation and transpiration. In dry conditions, vines restrict their water consumption, soil surface evaporation is reduced and cover-crop growth is impeded. Consequently, evapotranspiration is lower than potential evapotranspiration. Evapotranspiration is difficult to estimate, since it also depends on the seasonal dynamics of soil water content. Soil moisture simulation software is a useful tool for modeling soil water regimes.

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In order to evaluate the risk of perennial cover-cropping it is necessary to calculate the seasonal dynamics of soil water contents beneath a short grass cover. This approach, introduced by HÜSTER (1993), does not take into account other interactions between vine and cover crop.

2. Estimating water stress risk

Evaluations of water stress risk must also take into account the water demands of the vine. Water demand must be differentiated from water uptake, which depends on water supply. Grape quality and yield depends on the water demands of the vine.

To date it is very difficult to assess the effect of water stress applied at different development periods of grapevines on yield and wine quality. Many factors interact to affect wine production and quality and the magnitude of the effect may shift during the vegetation period. It is very difficult to evaluate the influence of a single factor such as water supply, especially under field conditions. Therefore, most results have been obtained in experiments using container-grown vines (SMART & COOMBE 1983, BERAN 1986).

Grape quality, usually expressed in sugar content and total acidity, is noticeable influenced by temperature and sunshine hours. According to HOPPMANN & HÜSTER (1988b) water balance has a more profound effect on yield. However, there is some evidence to suggest that water stress may be related to the development of “untypical aged off-flavor” in wines (SCHWAB 1996).

The following assessment of water stress risk is limited to the developmental stage in which water stress is expected to produce the greatest losses. Among many other authors BETTNER (1979) reports that water deficit has the greatest negative impact on yield during the early period of berry formation. This is the stage during fruit set in which the total number of berries is established and further division of the cells determines the number of cells per berry. This is followed by a period of cell expansion where cell division ceases and the cells accumulate solutes. According to CURRLE et al. (1983) this phase lasts about 44 to 46 days for late ripening varieties such as Riesling and is shorter for early ripening varieties such as Müller-Thurgau.

The greatest problem assessing water stress is specifying the threshold value of soil moisture. MÜLLER (1980) puts this value at 30–40 % of the field capacity for soils with a low water retaining capacity under field conditions. BERAN (1986) reports that a significant effect occurs at surprisingly low soil moisture contents under field conditions

For the present risk assessment the threshold water stress value is equated with a defined residual water content of the available water capacity (AWC), expressed in mm rather than a percentage. This assessment compares soils with a wide range of available water capacities. The residual water content of these soils is different between a given percentage of AWC and the wilting point (Table 2).

In addition to this, the water potential at a defined percentage of AWC will also vary between these soils. In a calculation of soil water potentials according to CAMPBELL (1985), ZIMMER (1997) found that the pF value at 40 % AWC is less than 2 for sandy soils and around 3 for loess. These values vary slightly according to the amount of the plant unavailable water, and is much higher for clay soils.

Tab. 2. Available water content of different soil types at 50 %, 40 % , and 30 % of available water capacity (to a depth of 100 cm)

	AWC	50 %	40 %	30 %
Sand	110 mm	55 mm	44 mm	33 mm
Loess	220 mm	110 mm	88 mm	66 mm

Generally, soil water content, as well as matrix potential can only be an approximate, indirect measure for water stress. Stress is a physiological phenomenon, strongly influenced by the adaptability of the plant. Responses to water stress may be modified by the nutrient status of the plant. Plants may also be capable of acclimatizing to stress to a certain degree.

The evaluation of water stress risk is based on mean soil water contents during the 40–day period following vine flowering for each year. The threshold value for water stress is defined at 40 mm, which is equivalent to 40 % of an AWC of 100 mm. The originally proposed approach to count days with water contents below the threshold was abandoned. This procedure led to grave misinterpretations of the results in years where the water contents during the evaluation period fluctuated only slightly above and below the threshold.

Although vines are capable of developing very deep roots, this assessment only takes into account soil properties to a depth of 1 m. SMART & COOMBE (1983) and STEINBERG (1968) showed that the bulk of vine roots grow in this depth. In addition to this, it is difficult to obtain the necessary values for the deeper parts of the soil profile and to establish their spatial distribution. Soil moisture measurements are particularly difficult in coarse soils. The vines on most of these locations are capable of tapping into water reserves in the deeper soil profile or subsoil. However, the success of this response depends on the properties of the parent material, especially in soils developed on solid rock.

The calculated water stress risk frequencies are only valid for the specified evaluation period. However, the relative differences of water stress risk between locations can be applied to later periods of the year. Water stress is intensified during the vegetation period on soils that tend to dry out early in the year, but vines are less affected later in the season. As yet the effect of water stress on wine quality cannot be linked to distinct threshold values or stages during the vegetation period.

The decision to introduce a cover-cropping system depends on the expected frequency of water stress events. In view of the inadequate availability of long-term soil moisture measurements, a simulation model will be used to estimate soil water contents over a period of 30 years. This is a standard time period for meteorological studies and ensures that the variability of the weather patterns is taken into account. The globally agreed standard time-period for such studies is 1961-1991. This ensures comparability of all results.

3. Calculation of the soil water contents

3.1. Simulation model

The program is based on the multi-layer model by Baier & Robertson (1966) simplified for the Food and Agriculture Organization (FAO) of the UN by Gommes & Robertson (1983). The model was tested in 1993 and 1994 in different representative locations including clean-cultivated vineyards and those implementing cover-cropping systems. The data was compared to measured values and the model modified accordingly. The result was a single-layer model, which produced sufficiently acceptable, sometimes even better, simulation results than the more detailed 3-layer model. The simplified version also takes into account slope gradient and exposition. The decisive factor for choosing this model was that it only requires a small number of basic and easily obtainable values.

The simulation is based on the following meteorological variables: daily precipitation, daily temperature (t14) and vapor pressure (e14) at 2 pm. The soil parameters required for the simulation are water content at field capacity (pF 1.8) and wilting point (pF 4.2) expressed in volume percent and soil thickness (in this case 1 m). The daily variation of soil water content is calculated as follows:

$$\text{Soil water content (new)} = \text{Soil water content (old)} + \text{ precipitation} - \text{percolation} - \text{actual evapotranspiration} \qquad (1)$$

Percolation is specified as the fraction of precipitation, which exceeds that required for replenishing the soil water content at field capacity. Actual evapotranspiration (ETa) is calculated by first computing potential evapotranspiration (ETp) according to Haude (1963). The results are presented in Table 3.

The input parameters required for this procedure are easy obtainable. Sponagel (1980) and Ernstberger (1987) compared several methods for estimating potential evapotranspiration for soil moisture regime calculations. Their results indicated that there are no distinct advantages in using the more usual method devised by Penman (1948). Potential evaporation estimates for a specific vegetation cover must take into account monthly and phenological empirical factors. However, the Penman method was not used in this study because the feedback effect of the reduction function described below effectively compensates fluctuations. Furthermore the data for the wind function required for the Penman method are only available for a few weather stations.

In the method proposed by Haude (1963) potential evapotranspiration is equated with the amount of water that must evaporate at 2 pm to compensate the saturation deficit of the atmosphere. The saturation deficit is computed by subtracting the measured air humidity (e14) and the potential maximum atmospheric water content at the temperature measured at 2pm (t14). Humidity is expressed as vapor pressure in hectopascal.

The saturation vapor pressure (E) is calculated using the equation according to Magnus:

$$\text{Saturation deficit at 2 pm} = (E - e14) \qquad (2)$$

$$E = 6{,}1078^{\,(17{,}08085 \times t14/(234{,}175 + t14))} \qquad (3)$$

$$\text{potenzielle Verdunstung (Etp)} = \text{Faktor} \times (E - e14) \qquad (4)$$

Tab. 3. Factors for determining the potential evaporation (ETp) according to HAUDE for different vinyard management systems. Potential evaporation is reduced to actual evapotranspiration (ETa) in correlation with the actual soil water content

cover-cropped	0.20	0.21	0.29	0.29	0.28	0.26	0.25	0.23	0.22	0.20
Phenological day	60	91	121	152	182	213	244	274	305	366
Clean cultivated			0.1	0.16	0.18	0.21	0.21	0.19	0.12	0.10
Phenological day			124	150	175	208	242	288	300	366

Estimates of potential evapotranspiration must also take into account the characteristics of the vegetation in clean-cultivated vineyards and those planted with cover crops. The plant specific factors for grapes used for clean-cultivated vineyards were obtained by Hoppmann (1988) at the meteorological station Geisenheim (National Meteorological Service - DWD). These values were slightly modified for the purposes of this investigation. The plant-specific factors for grass were used for calculating of ETp in vineyards planted with cover crops. Each factor only applies to a specific period during the year. The phenological day denotes the last day of this period (see Table 3).

$$\mathrm{ETa} = (\text{Current water content / max. water content})^{0{,}4} \times \mathrm{ETp} \tag{5}$$

Figure 1 shows the relationship between soil water content and assumed actual evapotranspiration. The value for calculated actual evapotranspiration is equivalent to about 70 % of the calculated potential evaporanspiration, when the soil water content is at 40 % field capacity. Actual evapotranspiration is increasingly restricted as water contents decrease and ceases altogether, when the AWC is depleted. For many locations this relationship gives the best approximation of the actual soil water content fluctuations. In some cases, the estimated water loss from the soil is greater than the measured value.

These locations are either known to be affected by or likely to be affected by down-slope groundwater flow or simultaneous water removal from deeper horizons. An overestimation of water loss is more acceptable in this type of investigation than underestimation. This analysis produced no verifiable evidence for a correlation between other soil factors such as soil type or AWC and evapotranspiration.

This model does not take into account the proportion of precipitation intercepted by the canopy. Although interception reduces the amount of water reaching the soil surface, this omission has no significant effect on the accuracy of the simulation.

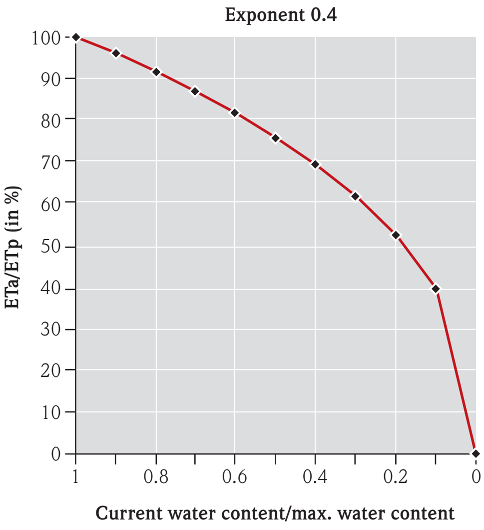

Fig. 1. Reduction of the ratio potential evaporation to actual evapotranspiration in correlation to the ratio between current soil water content and maximum water content relative to the available water content.

The model must also take into account the effect of slope gradient and exposition on solar radiation and surface runoff.

Solar radiation is not included in the original scheme for calculating potential evapotranspiration according to Haude (1963). The present model uses the values obtained by Haude (1963) corrected for the effects of exposure and slope gradient on solar radiation (Table 4). SE or E facing slopes were treated as SW or W facing slopes. Terrestrial shielding was not taken into account.

Precipitation falling on a horizontal surface is expressed in l/m². Such standard values must be corrected for slope since the surface area of a given horizontal area increases when projected onto slope.

The proportion of precipitation that will infiltrate the soil depends on the amount of precipitation, but also on slope and management practices, which affect surface runoff (Fig. 2).

The simulation program calculates soil moisture continuously, without assuming that the water removed from the soil during the vegetation period will be completely replenished in winter. This is a prerequisite for estimating annual percolation. In addition to this, for several years of the evaluation period the amount of winter precipitation was too low to replenish the soil water reservoirs depleted in the summer.

Tab. 5. Maximum estimated winter precipitation (November–March) in percent of years

Percentile	**10 %**	**25 %**	**50 %**
Geisenheim	139 mm	173 mm	207 mm
Bensheim	195 mm	257 mm	322 mm

The expected winter precipitation is summarized in Table 5. The values indicate that winter precipitation in Geisenheim will only exceed 200 mm in 50 % and fall below 139 mm in 10 % of the years. These estimates for a possible replenishment do not take into account winter evaporation. There is always a risk in continuous simulations that an error in the calculation will affect the results for many years. However, this is only possible whenever soil water reservoirs are not replenished. Locations with a high AWC are more likely to be affected than those with low field capacities and high water stress risks. The haphazard occurrence of very wet winters precludes the possibility of an error affecting results over a very long time.

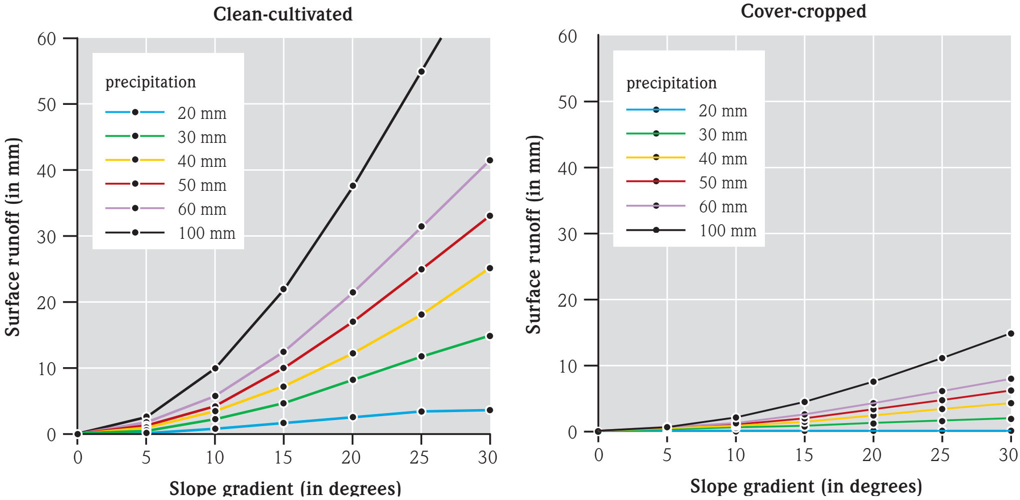

Fig. 2. Correlation between surface runoff, precipitation and slope gradient in cover-cropped and clean-cultivated vineyards

Tab. 4. Evaporation correction factors according to Haude for different slope gradients and aspects.

The factors are estimated from the average radiation balance relative to a level location for the period between 1988-1992 (Jagoutz, Agrarmeteorologische Beratungs- und Forschungsstelle des Deutschen Wetterdienstes/ Geisenheim)

Aspect	South	Southwest	West	South	Southwest	West
Slope						
	January			February		
10°	1.282	1.205	1.003	1.178	1.128	0.995
20°	1.594	1.430	0.991	1.324	1.225	0.970
30°	1.928	1.663	0.962	1.429	1.285	0.924
	March			April		
10°	1.140	1.103	0.995	1.079	1.056	0.989
20°	1.245	1.173	0.968	1.116	1.077	0.951
30°	1.305	1.205	0.922	1.110	1.060	0.892
	May			June		
10°	1.042	1.027	0.983	1.001	1.002	0.988
20°	1.038	1.019	0.936	0.970	0.973	0.946
30°	0.987	0.975	0.867	0.900	0.913	0.880
	July			August		
10°	1.023	1.01	0.983	1.069	1.04	0.984
20°	1.004	0.993	0.936	1.091	1.05	0.942
30°	0.940	0.939	0.866	1.06	1.03	0.879
	September			October		
10°	1.138	1.09	0.989	1.212	1.146	0.992
20°	1.235	1.155	0.953	1.396	1.262	0.963
30°	1.281	1.168	0.897	1.533	1.33	0.916
	November			December		
10°	1.285	1.198	0.991	1.28	1.201	1.001
20°	1.548	1.371	0.968	1.565	1.379	0.988
30°	1.768	1.503	0.930	1.790	1.523	0.958

3.2. Base data

All data related to aspect and slope was obtained from the topographical maps of the regions. The aspect of slopes with gradients less than 10 % were neglected since the effect on solar radiation is negligible.

The water storage capacities of the soils are based on values from the maps of available water contents. Only the four classes <100 mm, 100–150 mm, 150–200 mm and >200 mm are considered here. Soils of the AWC class >200 mm include those with an excellent subsoil water reservoir below 1 m depth (ZIMMER 1997) which can be utilized by vine.

The meteorological data were obtained from the network of climate stations of the National Meteorological Service (Deutscher Wetterdienst).

Precipitation data for the Rheingau was available for the following stations: Lorch, Rüdesheim, Johannisberg, Geisenheim, Eltville, Eltville-Steinberg (Hattenheim), Wiesbaden and Hochheim. The precipitation in the Bergstrasse was measured in Bensheim, Heppenheim and Gross-Umstadt. Temperature data was only available from the stations in Lorch, Geisenheim, Wiesbaden, Mainz and Bensheim. However, both Lorch and Bensheim ceased recording in 1989, so that missing data had to be collected from stations in the vicinity. For some years during the evaluation period the data representing Gross-Umstadt were actually collected in Schafheim-Schlierbach. The station in Eltville-Steinberg is the highest in the network. Data collected here was used to quantify climate at elevations above 200 m for all areas. Today the station only records precipitation. However, temperature and humidity were also measured here for several years in the past. Using these data as a basis, members of the agricultural meteorological station of DWD in Geisenheim calculated a complete data series.

The precipitation data for higher locations in the Upper Rheingau were measured in Eltville-Steinberg. The station in Johannisberg provided data for higher elevations for the region around Geisenheim. Although the station is situated just below 200 m above sea level, the wine-growing area is located in close proximity. The area lies in the rain shadow of the Taunus mountain range, which is reflected in the low precipitation recorded at the station in Geisenheim. The upper locations are also affected by this position and precipitation is expected to be comparably low here as well. The Rhine Valley has cut deep into the Hunsrück and Taunus mountain ranges near Lorch so that the valley has no effect on the amount of precipitation on the upper locations near Lorch. Precipitation is higher in the Bergstrasse region and in Gross-Umstadt due to the proximity of the Odenwald mountains. The station in Gross-Umstadt is located quite high at 168 m above sea level. Bensheim is somewhat lower, at 140 m above sea level. However, the data recorded at the local station can be accepted as representative for the extremely steep and very narrow growing area on the slopes of the Odenwald. Inferring increased amounts of daily precipitation at higher elevations from data recorded at the base station would introduce significant errors to the calculation.

4. Results

4.1. Data presentation on maps

The map shows the percentage of years in which the mean water content of the soil to a depth of 1 m falls below 40 mm during the 40-day period after vine flowering. The percentages have been calculated for the evaluation period 1961 – 1990. Although meteorological variables may vary from those recorded during the reference period, the resulting distribution pattern of locations with higher or lower risk of water stress will remain.

The risk of water stress was divided into 4 risk classes (Table 6). Each is associated with a specific range of probabilities. The lower risk classes are more narrowly spaced. This more detailed division of the lower risk classes enables the user to predict more accurately, which locations are more suitable for cover-cropping. The decision whether or not to introduce a cover-cropping system in locations with a high risk of water stress depends on site specifics as well as operational and economic factors, which are not considered here.

The evaluation of each level of AWC, slope gradient and aspect is based on the maximum potential water stress risk. This means that a site with an AWC of 100 – 150 mm will be assigned to that risk class that includes the maximum potential water stress for an AWC of 100 mm.

An additional subclass S is available for locations with available water contents <100 mm and slopes >30°. This was necessary to take into account the fact that the number of affected years increases dramatically with increasing slope and decreasing AWC. This is why this class is defined by the minimum risk. Class S locations are rarely under cultivation. Class S locations with a minimum risk < 50 % of the years are highlighted on the maps since the water stress risk is rapidly raised to > 50 % if the site conditions deteriorate.

Tab. 6. Definition of risk classes

		Percentage of years below threshold	**max. number in 30 years**
Risk class	**I:**	10 %	3 years
Risk class	**II:**	>10 %–25 %	8 years
Risk class	**III:**	>25 %–50 %	15 years
Risk class	**IV:**	>50 %	more than 15 years
Special class	**S:**	a) AWC <100 mm b) slope >30 °	min. number in 30 years according to risk class

4.2 The spatial distribution of water stress risk

The water stress risk map depicts the risk classes calculated for individual subareas. As expected, the risk of water stress is lowest for the deep soils of the AWC class > 200 mm. However, even some of these locations may experience water stress in 25 % of the years, for example around Geisenheim, Hochheim and Lorch. In other areas and higher locations, there is only a 10 % risk of water stress on these soils.

Low risk soils assigned to AWC class 150 – 200 mm are found in Gross-Umstadt, the upper regions of the Bergstrasse, the west-facing upper slopes around Lorch and Eltville, the upper slopes around Geisenheim as well as in all other locations with a maximum slope of 10° or on west facing slopes. Otherwise these soils are assigned to risk Class II except in the lower locations around Geisenheim and Hochheim where they are assigned to Class III. In the vicinity of Lorch only those soils on steep south-facing slopes with gradients > 20° are placed in Class III.

Soils belonging to AWC class 100 – 150 mm are usually assigned to water stress risk Class II if they are located at higher elevations, except in the Upper Rheingau and around Geisenheim and Eltville where they attain Class III. In the lower elevations near Lorch, Geisenheim, Hochheim and Eltville these soils are assigned to Class IV, except those located on sites with gradients less than 10° and west-facing locations with less than 20° slope. Water stress is less likely here and these soils are assigned to Class III. The higher precipitation in the lower elevations of the Bergstrasse region and in Gross-Umstadt reduce the risk of water stress and thus the soils attain Class III.

The potential risk of water stress is very high for all soils in the AWC class < 100 mm. As long as the water storage capacity is not significantly lower than 100 mm, the distribution of these soils is similar to those of the AWC class 100 – 150 mm. However, lower water storage capacities will lead to a significant aggravation of site conditions. Those sites that have a water storage capacity about 100 mm but have not been assigned to the highest risk class are marked separately on the map (see map legend). This also applies to locations on slopes > 30°.

The evaluation of water stress risk reflects the meteorological differences within the region. Most sites in the high water stress risk class are found in the drier, warmer and lower locations especially around Geisenheim and Hochheim. The risk of water stress in a particular AWC class varies according to elevation and precipitation. The risk is lower for soils located in the slightly cooler and usually wetter higher locations.

The Bergstrasse region and Gross-Umstadt are both characterized by high precipitation. However, the slightly lower temperatures recorded for Gross-Umstadt mean that the risk of water stress is lower than for the Bergstrasse.

This pattern is modified and reinforced by the distribution of soil groups. Thus, soils with a low available water content (AWC-classes < 150 mm) are usually found in the Lower Rheingau and around Geisenheim, while those in the higher AWC classes are mostly situated around Eltville. Most soils with very low water storage capacities (< 100 mm) are located in higher elevations.

The risk of water stress on the widespread slightly inclined and similarly exposed areas of the Upper Rheingau clearly correlates with the distribution pattern of precipitation and the available water content. The effects of aspect and slope are much less than expected, even in steep areas such as the Bergstrasse and those found around Lorch. In a few exceptional cases, the effect is large enough to affect the classification even if the number of affected years are different.

The influence of topography on solar radiation input is greatest in spring and autumn. When the angle of incidence is high, the south facing steep slopes receive less solar radiation than flat areas. Any differences in evapotranspiration calculated for the period before the onset of flowering can be related to a higher radiation input in spring. Nevertheless, actual evapotranspiration will be lower than in summer due to the lower temperatures. The effect of exposition is somewhat larger at the beginning of veraison. The reduction function, which reduces the ratio potential evapotranspiration to actual evapotranspiration, and the water extraction depth have a great effect on the simulation results.

5. Evaluation

In some instances, the calculated soil water content in the upper 1 m of the soil profile will not necessarily be attained in the field. This will be the case where the vine is able to extract water from greater depths. The deep roots will already supply the vine with water before the wilting point in the upper 1 m of the soil profile has been reached. Thus, rootability and water storage capacity of the subsoil have an indirect influence on the real soil moisture values up to 1 m depth.

The calculated values however, give some indication on whether the vine can manage without tapping into an additional source of water or how dependant the plant would be on such a supply. In any case these findings must be verified by a site assessment. The main regional soils are represented in the individual AWC-classes. On the local scale, there is always the possibility of finding locations with better or worse conditions. For example, water supply may be better than the AWC would indicate in areas affected by impermeable layers in the subsoil or regular down-slope groundwater flow. Moreover, evaporation may be higher than that assumed for the model in extremely wind-exposed sites.

This assessment makes no attempt at rating the suitability of the locations for cover-cropping, since the decision to take on or reject a risk is ultimately based on economic factors.

Perennial cover-cropping is sometimes also practiced on high-risk Class IV locations. Cover-cropping can be possible in well-established vineyards, where vines are pruned to minimum shoot length and lower yields are acceptable.

The decision to introduce a cover-crop system must take into account the following points in relation to the risk class:

- established vineyards with well-developed rootstocks are less vulnerable than young plantations.
- established plantations may have developed deep roots. This is more likely on sites where the subsoil consists of granulated material rather than solid rock.
- Riesling vines are less susceptible to water stress than many other varieties such as Pinot noir or Müller-Thurgau.
- Not all cover-crops are equally suited for all risk classes. Great care is required when selecting a cover crop. The range of available cover crops is large: from legumes, and natural perennial covers to dry meadow mixtures.
- The degree of ground cover must be reduced as water stress risk increases. This can be achieved by planting cover crops in alternate alleys, or removing cover crops from the base of the vine.
- The cover crops must be mowed in spring in areas with a high water stress risk. The higher the risk the shorter the cut. High risk sites will benefit more from frequent mulching than from extensive cover crop management.
- Great care is required when introducing cover crop systems on high-risk sites. The degree of cover should be raised successively.

- Very little information is available concerning the effect of rootstock variants on the susceptibility of vine to water stress.

  Various management practices are possible – in the end the choice depends on the individual circumstances of the company. In any case, vineyard managers must ensure that cover crops on high-risk locations are frequently mulched.

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