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OTMAR LÖHNERTZ* & DIETER HOPPMANN**

Viticultural Evaluation of the Vineyard Survey in Hesse

1. Introduction

Grape vines require very specific climate and soil conditions for optimal growth. Along the northern margin of the wine-growing zone successful wine production is restricted to those sites with outstanding soil properties and climate.

Nevertheless, grape yield and quality fluctuates substantially from year to year and site to site. Winegrowers must take site conditions into account when selecting grape varieties and rootstocks.

In addition to this, intensive grape production has a profound impact on the landscape. Winegrowers must take on the responsibility for adopting sustainable viticultural practices, with particular emphasis on soil conservation. Growing wine on steep slopes increases the erosion risk. In the past, intensive tillage and excessive nitrogen fertilization has resulted in the pollution of groundwater with nitrate. Today, erosion and nitrate leaching can be reduced by cover-cropping. However, cover crops also draw on the natural water supply consisting of precipitation and water stored in the soil during the winter. This can lead to water stress in dry years on locations with low soil water reserves. The positive sustainable aspects of cover–cropping with respect to soil conservation can therefore collide with the legitimate demands of the winegrowers for ensuring high yields and quality.Current legislative framework concerning water protection and soil conservation emphasizes the importance of safeguarding natural resources.

The methodical survey of the wine-growing regions in the Federal State of Hesse dates back to 1947. The first soil survey was carried out by H. ZAKOSEK and completed in 1960. The climate survey of the wine-growing regions in Hesse was initiated in the 1950s. The first viticultural atlas at a scale of 1 : 50.000 was published by ZAKOSEK et al. (1967). Additional site investigations revealed new aspects in relation to the influence of soil and climate on grape vine growth. The results obtained by BECKER (1967), HOPPMANN & SCHALLER (1981) and HOPPMANN (1988) are especially worth noting in this context.

Many viticultural requirements have changed since the publication of the first edition of the viticultural atlas in 1967 (ZAKOSEK et al. 1967). The increased focus on soil conservation and water protection require winegrowers to pay more attention to soil management – without neglecting qualitative aspects. HÜSTER (1993) addressed the issue concerning the water demand of vines and produced a water budget model to estimate water stress in clean-cultivated vineyards and those implementing a cover-cropping system. In this context, it is necessary to note that the Rheingau is a very dry wine-growing region with less than 550 mm annual rainfall.

Further site investigations, new water budget models and a survey of available water contents (AWC) formed the basis for producing a quality map of the Rheingau (HOPPMANN 1999).

* Prof. Dr. O. Löhnertz (e-mail: Otmar.Loehnertz@fa-gm.de), Forschungsanstalt Geisenheim, Fachgebiet Bodenkunde und Pflanzenernährung, Postfach 1154, D-65358 Geisenheim.
** Dr. D. Hoppmann (e-mail: dieter.hoppmann@web.de), National Meteorological Service (DWD), Agrometeorology, Kreuzweg 25, D-65366 Geisenheim.

The present publication aims to collect the experiences gathered over the past decades and the results of scientific investigations of the wine-growing regions in Hesse and publish these in the form of a set of maps.

The wide range of topics provides winegrowers with the necessary information to optimize the quality of their vineyards and help to protect and manage the soil as a natural resource.

This set of maps is also aimed at political decision makers to ensure that site conditions are not neglected in future revisions and creation of laws and regulations.

2. Site climate maps

Grape vines are particularly demanding with respect to temperature. Production is therefore restricted to those locations with a favorable climate: high solar radiation coupled with a low risk of wind or cold air.

2.1 Radiation

The temperature regime of a location is mainly determined by solar radiation. Sites that are optimally inclined to receive solar radiation will heat up more rapidly than less optimally inclined locations. The viticultural atlas published in 1967 includes a map of the astronomical maximum potential radiation. However, these radiation values do not take into account the reduction of radiation by the atmosphere or the fluctuating cloud cover at the location. Further developments, which take into account atmospheric parameters have led to the "Offenbach Evaluation Scheme" (BRANDTNER 1973). This makes it possible to calculate the solar radiation for any given time and location in relation to slope and aspect, latitude, sunshine duration and atmospheric turbidity. Long-term radiation measurements revealed that the turbidity values used in the scheme were too low and subject to seasonal variation. In addition to this, turbidity has increased in the past decades. The revised radiation model takes these aspects into account. However, the fundamental observation that must weights are closely correlated to solar radiation does not depend on the basic values (HOPPMANN & SCHALLER 1981). The phenological development proceeds faster on favorably exposed slopes, allowing grapes to ripen over a longer period of time. Thus, the onset of flowering in a level vineyard may be delayed by an average of 5 to 7 days when compared to grapes growing on a S-facing slope with a 20° gradient. This results in a difference in must weights by 4–6 °Oechsle (HOPPMANN 1988). Radiation Map I (see chapter Radiation) depicts the effect of exposure on the radiation value. However, solar radiation does not account for all the qualitative differences between the vineyards. Although radiation increases with elevation, the thermal conditions for viticulture rapidly deteriorate with height. Elevation is the limiting factor determining grape production. The upper limit for late ripening varieties on favorably exposed vineyards lies between 230 and 250 m above sea level in Hesse. The upper limit for early ripening varieties such as the Müller-Thurgau group on favorably exposed slopes is 300 m above sea level. The temperature decrease can be integrated into the radiation model using a statistical procedure. The effect of elevation is equated with a reduction of the available energy from direct solar radiation (Radiation map II) (see chapter Radiation) HOPPMANN & SCHALLER (1981) investigated the overall effect of elevation and radiation for the Rheingau. The results indicate that 40 % of the observed must weight variation between vineyards can be explained by the factors radiation and elevation. An increase by 3 kJoule/(cm²×vegetation period) corresponds to a must weight increase by about 1 °Oechsle and a reduction of acidity by 0.2 %. Because of the confirmed effect of radiation and elevation on must weight, the reduced radiation was used to define vineyard locations (compare Map of exact demarcated vineyards)

Many vineyards extend over a large range of elevations. In a few cases, slope aspect may also vary within a single vineyard. Therefore, radiation may differ considerably within a single vineyard (see Table 3, chapter Radiation). As a result, it is unrealistic to make a single evaluation of the climate for any given vineyard (see Vineyard map). Similarly it is impossible to assign a particular vineyard to a specific quality class.

2.2 Cold air and wind risk

The cold air risk for the wine-growing regions of Hesse is available as a map produced according to the survey guidelines of the Weather Service. The frost risk maps reveal the risk of experiencing late and early frosts. Late frosts (–2 °C) are particularly important since these threaten the young leaves of the vine. However, the frequency of April and May frosts has dropped considerably in the past decades (Table 19).

Even though the risk of frost in May is much lower than 30 years ago, the maps (–2 and –4 °C Frost probability) illustrate the relative differences in terms of cold air hazard within the region. Frost probability is still very high in small areas near Hochheim and Wicker as well as in the Bergstrasse. The phenological records over the past two decades indicate that the timing of bud break has continually moved forward to an earlier date (about 10 days). Consequently, the frost risk has shifted from early May to the second half of April. The clear night cold air streams have a detrimental effect on quality (see Chapter 6.2). The information presented on the cold air risk map is also important for assessing the effects on plant health. Cooler vineyards tend towards early dew formation during the night, which increases the risk of infection with downy mildew (Plasmopara viticola). Such sites are predisposed to early infestations by the peronospora since the leaves dry much slower after rain or dew formation. Cold air locations are not so well aerated.

Cover crops should be kept short in cold air locations during frosts. Figure 1 shows how long grass has lead to frost damage of the young vine shoots.

Tab. 1. Frequency of frosts during a period of 30 years in Geisenheim (April and May)

Period of time	April	May
1931–60	67	11
1951–80	71	4
1961–90	56	2

Fig 1. Frost damage of young wine shoots

Mapping wind risk was a much greater challenge. Buildings, vegetation cover and terrain all change the direction and speed of wind resulting in a highly variable flow pattern even within small distances. Clear day wind speeds and directions are particularly important from an ecological point of view.

For this reason, E-facing slopes are less suitable for growing wine in the Rheingau than W-facing slopes. E-facing slopes will benefit from planting windbreaks. Daytime temperatures on clear days are about 2 – 3 °C lower in wind-exposed locations than in protected vineyards (HOPPMANN et al. 1987). The Lower temperatures can result in a deterioration of quality by a maximum of 3 °Oechsle (HOPPMANN 1988). The frequency of east winds should also be taken into account when planning vineyard layout (row aspect). Generally a north- south orientation of the rows is to be preferred.

From the viticultural point of view, the risk of infection is lower in wind-exposed locations, since the vines dry quicker after rain or dew formation. However, in general, quality-reducing factors prevail.

2.3 Overall evaluation of site climate

The maps are useful for estimating the positive and negative influences of climate (radiation, frost and wind). However, they do not contain the necessary information for specifying the potential quality of a vineyard – they provide a first rough orientation. The maps also provide useful information concerning soil management, plant health risks and evaporation in combination with high radiation values.

3. Water budget and soil

3.1 Grape vine water demands

As early as 1892, MÜLLER-THURGAU recommended using the specific reaction of grape varieties to water supply as a criterion for cultivation suitability. CURRLE et al. (1983) drew attention to the difference between water consumption and water demand, since the vine possesses regulatory mechanisms, which enable the plant to adjust consumption to the supply.

This capability for adaptation plays a central role in the appearance of stress situations. However, at present there is still a lack of information concerning the amount of water the grape vine requires to achieve specific yield or quality targets.

Water budget calculations are the first step towards understanding the water supply in a vineyard. Table 2 presents the water budgets for the location Mäuerchen in Geisenheim. The data was calculated using a water budget model for clean-cultivated vineyards and those implementing a cover-cropping system (HÜSTER 1993). The results reveal a substantial negative climatic

Tab. 2. Average value of the water budget in clean-cultivated and cover-cropped vineyards (l/m²) Geisenheim Mäuerchen, 1935–1991 [(May to October; Calculation by Hüster (1993)]

	Water budget potential evaporation		**Water budget actual evaporation**	
	Cultivation			
	clean-cultivated	**cover-cropped**	**clean-cultivated**	**cover-cropped**
Precipitation	292	292	292	292
Evapotranspiration	405	550	319	363
Climatic water budget	**–113**	**–258**	**–27**	**–71**
Available soil water capacity	144	144	144	144
total water budget	**31**	**–114**	**117**	**73**

water balance, confirming that this location is known to be one of the driest places in Germany. According to this investigation, grape vines may evaporate up to 405 mm water providing they are adequately supplied with water.

Cover crops require an additional 150 mm. However, the grape vines cannot meet this potential demand. The actual evaporation from clean-cultivated sites is 27 % lower than the potential values. On sites with cover crops, the difference is 51 %. This example shows how adaptable the grape vine responds to new environmental conditions. In addition to this, the increasing drought causes the cover crops to wilt and die. The vine responds to decreasing soil water contents by reducing transpiration. Griebel (1996). carried out pot experiments with vines and obtained similar results. He recorded a 39 % reduction in evapotranspiration when soil water contents decreased of from 100 % AWC to 30 % AWC. This experiment also shows how vines are able to adapt the actual evapotranspiration to the soil water supply. However, it is necessary to consider that higher radiation on favorably exposed slopes means that these require up to 20 % more water than level locations (see Radiation Map I). Since these slopes are often covered by thin or rocky soils, water deficit can be a problem for vine growth. In contrast, the high available water contents of the deep soils of the level locations results in a clear positive water balance. These locations are suitable for long-term cover crop systems. A final evaluation of water stress cannot be based on long-term averages (see Chapter 3.3).

The data concerning the total water demand varies considerably and depends on variety and location. The German average water demand varies between 300 and 400 l/m². Schmid (1997) used the xylem flow measurement method to record the water demand of the variety "Weisser Riesling" during the period between flowering and harvest in 1995. The results show that vines only use between 91 and 139 l/m² stand area. Water consumption varied considerably between individual plants. However, the water consumption per leaf area is constant at 50.4 to 51.9 l/m² (Schmid 1997).

The critical stage in terms of water stress is the early phase of berry growth. A lack of water during this phenological phase significantly reduces yield. A good water supply during the ripening phase positively affects sugar formation and anthocyanin concentration and therefore the intensity of berry color (Gurovich et al. 1996).

3.2 Soil water storage capacity (AWC values)

Soil type plays an important role in the soil water budget and therefore in the selection of a soil management system. In addition to this, soil type must be taken into account during the vineyard planning phase since it has an effect on row spacing and rootstock and variety selection.

The current regional soil type maps and the closely related maps of available water capacity (AWC) are a useful source of basic information for obtaining site-specific advice, which principally affects the optimization of the water balance. Increasing dryness in the post-flowering phase during the past decade has resulted in a deterioration of must weights, an increase in wine faults and changes in the composition on soils with low available water contents. A particularly negative example is the production of 2-aminoacetophenone, a wine fault that known as “untypical ageing flavor”. Therefore, one of the most important aspects of viticultural practices is the adjustment of the production system to suit the local water budget and therefore soil type.

The soil type and available water capacity maps can also help in the decision process in relation to irrigation planning. The introduction of irrigation systems to maintain soil fertility and improve the soil water budget in vineyards with cover crops will become increasingly important in the future.

3.3 Water stress risk estimation

Standard tolerance values and averages cannot be used to determine the suitability of a site for planting cover crops. Water stress also depends on yield, grape and rootstock variety, cover crop system and the vine training system. This is why the present vineyard site maps can only be used to evaluate the risk of water stress.

The risk assessment is based on 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 flowering (HOFMANN 1996). This period was selected because the demand for water by the vine is highest in this phase (HOFÄCKER 1976, BETTNER 1979, GUROVICH et al. 1996).

The potential risk of water stress is very high for all vineyard locations with an available water capacity < 100 mm. Such sites are not suitable for permanent cover-cropping. These sites may experience low water contents (< 40 mm) during the post-flowering period in more than 50 % of the years. This class includes thin soils (< 60 cm) and very stony soils. These soils are found locally throughout the Rheingau, covering < 5 % of the total vineyard area – their role in viticulture is insignificant (ZAKOSEK et al. 1967). GRIEBEL (1996) concluded that only those locations in the Rheingau with an AWC <100 mm cannot be recommended for permanent cover-cropping. These conclusions could not be substantiated in the present survey. They apply only for the Bergstrasse region, which receives 150 to 200 mm more precipitation than the Rheingau.

Any risk assessment of the other soils with an AWC > 100 mm must take into account location as well as slope aspect and gradient. Because of this variability, it is impossible to base the risk assessment on the AWC alone. The possibility of yield loss and quality deterioration increases with each higher risk class. The consumption of water can be lowered in these locations by reducing the area under cover crops as well as frequent mulching. Planting winter cover crops or applying straw are possible management alternatives for these vineyards.

However, an abundant water supply causes the vine to react by increasing leaf production. Such conditions occur on a regular basis. The associated effects of this prolific vegetative growth on plant physiology, vine health and other viticultural aspects has a negative effect on quality. This particularly affects those vineyards located in valleys under cold air influence (see Chapter 2.2)

Any plan to implement a cover crop system must take into account target yields and quality objectives. Pruning, canopy management and green harvesting measures all have an influence on quality and yield. For example, despite the relatively high water stress risk, the vineyards of the State Winery Assmannshausen have been planted with cover crops for decades. The vines produce lower yields but suffer less from water stress than those with high yield targets.

3.4 Influence of cover crops on water and nutrient budget

Endeavors to introduce cover crop systems in the Rheingau must take into consideration the competition for nutrients and water between the cover crop and vine under the regional climatic conditions (rainfall and rainfall distribution patterns). The conditions are more favorable in the Bergstrasse region. For this reason, the new edition has been extended to include an evaluation of the water budget.

The most important components of the evaluation are the map of plant available water capacity (AWC map) and the mathematical water budget model for computing the water budget of a vineyards and estimating the risk of water stress. However, this information is inadequate for assessing the influence of water stress on grape yield and quality. Much of the published information concerning the effect of increasing water stress on yield and the formation of valuable constituents is inconsistent.

According to the results of the present survey, negative effects on wine quality induced by water stress must be expected on sites with an AWC < 150 mm (see Chapter 6.1). The probability of water stress is very low in vineyards with an AWC over 200 mm. In general, these findings suggest that whole-scale permanent cover-cropping systems are not recommended for sites with low plant available water capacities. Cover crops should be planted in alternative alleys instead, to facilitate trafficability. Vineyard managers can achieve a further reduction in water consumption by selecting mesic grassland mixtures. There is no indication that a vegetative ground cover in winter, whether natural or planted has a negative on water budgets on these sites.

Water stress evaluation is particularly important in vineyards producing white wine varieties. A clear distinction must be made in this context between red and white wine varieties. While yield and must weights are affected by water stress during the later stages of the vegetation period, the formation of quality reducing constituents poses a much greater problem.

Water stress can have a positive effect on the quality of red wines. Since phytochemicals such as phenols are involved in protecting the vine, stress can stimulate their formation and accumulation. The accumulation of pigments is a quality criterion in red wines. The response to stress factors can lead to a higher resistance.

The introduction of cover-cropping systems increases the competition for water and nutrients within the vineyard. Of course this does not always affect vine growth. The evaluation of stress due to reduced floor management must take into account the manifold and effective natural adaptation mechanisms of the grape vine (LÖHNERTZ et al. 1998), variation in the distribution of precipitation and especially the different water storage capacities of the soils in the Rheingau and Bergstrasse wine-growing regions.

3.5 Erosion control

Without doubt, cover crops are the most effective erosion control measure. However, most vineyards on steep slopes are only covered with a thin layer of soil and therefore have a problematic water budget. These are often very dry locations especially since economic constraints mean that most winegrowers do not irrigate despite an existing exemption. Basically, all locations with a slope gradient >18 % are highly susceptible (EMDE 1992), except those with a high degree of stoniness. Erosion control measures are necessary on these sites especially during the months with a high risk of strong rain events. All factors contributing towards lowering the kinetic energy, such as vegetation cover, mulching, coarse tillage reduce the erosion risk. The calcaric regosoles on loess are of particular interest in this context being both a highly valued substrate for producing wine and very susceptible to erosion.

4. Soil nitrate

4.1 Nitrate leaching

Nitrate dynamics in vineyards is very different from that in other annual agricultural cropping systems. In particular, vineyard soils are tilled throughout the year. Until the 1980s, vineyard management in the Rheingau consisted of intensive mechanical tillage combined with regular herbicide applications to the rootstock. This is the reason for the elevated levels of nitrate leached from these sites. In contrast to annual cropping systems, the vineyard soil is not completely depleted of nitrate at the end of the vegetation period. Consequently, the risk of post-harvest elevated soil nitrate content is high. In clean-cultivated, intensively managed soils, this surplus nitrate content usually exceeds the 45 kg NO_3-N/ ha limit stipulated by the SCHALVO (conservation and compensation regulation). The fraction of clean-cultivated sites with surplus nitrate contents above this threshold is relatively high. Consequently, it is recommended to encourage site managers to plant cover crops at the end of the vegetation period and cease mechanical tillage operations during the grape-ripening phase. As an alternative, a natural vegetation cover (weeds) is usually sufficiently effective. This floor management scheme can also be implemented irrespective of the soil water storage capacity. SCHALLER et al. (1994) document the results of numerous extensive studies on nitrate formation and leaching.

4.2 Nitrate supply

Soil nitrate content in permanently cover-cropped vineyards are lower and less subject to fluctuations during the year (BERTHOLD 1991). As a rule, these vineyards do not accumulate high surplus nitrate contents at the end of the vegetation period.

However, permanently cover-cropped vineyards may suffer from N shortage especially in combination with water deficits during the vegetation period. The shallow root system of the cover crops reduces percolation during the vegetation period thus diminishing the input into the root zone of the grape vine.

While N-fertilization is recommended during the initial development phase of the cover crop system to increase biomass, fertilizing an established cover crop system produces no significant positive effect.

A special problem occurs when perennial cover crops are incorporated into the soil at the end of the lifecycle. This procedure releases large amounts of organic bound nitrogen by mineralization. This potential contamination is especially high for leguminous cover crops.

Nitrogen fertilization must be adjusted to suit the demand. This is especially important on soils with a low available water storage capacity. On such soils, fertilization should be restricted to two periods: one application during the budding phase and one after flowering. Any application of higher quantities of fertilizer for example as a reserve, or in conjunction with potassium, magnesium and calcium fertilization must be avoided.

Before introducing a cover crop system, it is necessary to weigh the positive effect of reducing the surplus nitrate content at the end of the vegetation period against the possibility of an inadequate plant available nitrogen supply. The effect on wine quality is one of the main considerations in this context.

5. Overall evaluation of water budget and soil

The viticultural atlas enables the user to optimize the specific demands of rootstock and grape varieties to suit the location. The maps are also a valuable tool to help vineyard managers select between vigorous and less vigorous rootstocks.

In the continuing trend towards increasing the vineyard area planted with red wine varieties, winegrowers will find important information in the water stress and quality maps. Water stress is less of a concern for red wine varieties since the resulting accumulation of substances does not have the same negative effect on quality. Thus, the "untypical ageing flavor" due to phenol accumulation does not occur in red wines. Consequently, planting Pinot Noire on dry locations is a very wise decision, whereas growing red wine varieties on soils with a high available water storage capacity must be seen as critical. The potential for Botrytis and other fungal infections on these sites is high. The most suitable locations for red wine production are therefore those with favorable temperature conditions and low soil water storage capacity.

The current set of maps can also help to locate sites for producing international red wine varieties such as Cabernet Sauvignon or Merlot. These varieties can only be produced on areas of exceptional "quality".

Soil type and soil group play a central role for the evaluation of vineyard water and nutrient budgets. However, the importance of soil group is somewhat lessened due to the long-term intensive vineyard management practices, which sometimes date back centuries. Deep-cultivation to incorporate additional substrate and intensive fertilization have changed the influence of the soil group. Soil type has a pronounced effect on the water budget and therefore on floor management, spacing and rootstock and scion selection.

Modifying the floor management scheme often conflicts with vineyard targets especially on soils with a low available water capacity. The appearance of stress-induced faults – more than possible yield losses – is an incentive to adapt cover crop management practices to suit the specific site conditions. Not all locations within the wine-growing regions are suitable for perennial cover-cropping systems In some cases there will be a conflict of interests between ecological necessity and sustainable, quality-orientated management. This conflict remains. The present data material can serve as a valuable aid in the decision making process.

6. Qualitative vineyard evaluation

6.1 The map of potential must weights

Vineyard classification is a widely discussed topic in all German wine-growing regions. A subjective approach is favored in most cases. However, the Association of Winegrowers in the Rheingau has decided to follow a different path. As early as 1994, a private initiative of winegrowers produced a map of "Erstes Gewächs" – primary quality wines. The authors did not disclose the criteria for the classification. This move encouraged the association to specify objective and verifiable criteria for a future classification scheme. For the Rheingau this means adopting a scientific approach with an emphasis on soil and climate criteria. The scientific approach is therefore based on the Vineyard Site Atlas of the Wine-Growing Regions of Hesse and the refined models. This approach means that it is only possible to use quality criteria that have been recorded over a long period. At the current state of knowledge, only the must weights fulfill these conditions.

The Rheingau is the first wine-growing region in the world to be classified according to scientific principles. However, this approach is subject to intense discussions among professionals since quality is not only determined by must weight. The quality of a wine in the glass is characterized by taste, character, constituents as well as flavor and fragrance. Within each vineyard quality class, these characteristics are determined by the cultivation of the vineyards and the winemaking procedure itself. The influence of the soil, for example the plant available water storage capacity or nutrient supply and viticultural components have a profound effect on the valuable components of wine such as the aroma compounds. The yields on high-quality sites must be reduced to achieve the desired qualities of the grape.

This is not really a problem for the winegrowers on steep locations with shallow, stony soils such as the slopes near Rüdesheim and Assmannshausen since the naturally low water reserves of these soils preclude high yields (HOPPMANN & SCHALLER 1981). Controlling yields is far more problematical on deep, fertile soils. These locations are often found on the lower slopes for example near Hochheim, which are covered by residual loess. Because of their relatively high available water storage capacity (AWC map), these vineyards are also distinguished as favorable sites on the map of potential must weights. A good nutrient and water supply results in high yields but also promotes leaf production on these sites. A dense canopy increases the risk of infection, so that these sites require special floor and canopy management practices (thinning, leaf removal) in order to gain full benefit from the favorable soil and climate.

The map of potential must weights is an impressive verification of the Rheingau as one of the best wine-growing regions. The favorable climate and soil properties make it possible to achieve must weights in excess of 80 °Oechsle on 50 % of the vineyard area in a 30 year period. Only 14 % of the vineyard area will potentially achieve less than 75 °Oechsle.

The favorable situation in terms of soil and climate is based on various factors:

The favorable exposure of the slopes towards S and SW results in high energy gains from solar radiation. Less than 5 % of the total vineyard area is located on unfavorably exposed slopes.

The heights of the Rheingau are covered by forest. In contrast to farmland and grassland, forest obstructs the nightly downward flow of cold air into the lower vineyards. In addition to this, there are only a few extensive side valleys that can channel cold air flows towards the lower vineyards.

The soils provide best conditions for producing grapes. In dry years, rainfall often does not meet the demand of the vines for water. However, more than two thirds of the soils in the Rheingau can store over 150 l/ square meter during the winter half-year as a reserve for the summer.

Readers of this edition of the Vineyard Site Atlas will note that the presence of the Rhine plays absolutely no role in the evaluation of the vineyards – despite the accepted standpoint of the “professionals” that the Rhine functions as a heat store and radiation reflector. These opinions cannot be substantiated by objective investigations. The flowing water of the Rhine is cooler than the surrounding landscape during the vegetation period, thus it actually acts as a heat sink, absorbing heat from the vineyards.

The albedo from the Rhine is insignificant:

only 6 % of the incoming shortwave radiation is actually reflected to the surroundings.

However, bare dry soils can reflect about 15 % of the incoming radiation and 24 % if they are covered with vegetation. Snow covered ground has the highest albedo at 90 %. The specular reflection of radiation from the surface of the Rhine is highest when solar altitude is lowest. In this case, up to 80 % of the radiation can be reflected. However, the vineyards can benefit from this only a few minutes per day. The importance of the Rhine for growing wine in the Rheingau is however undisputed. When it changed direction behind Mainz and Wiesbaden a long time ago, it cut a deep gorge into the landscape and sculpted the south facing slopes of the Rheingau. Their other beneficial properties have already been explained.

6.2 Influence of soil and climate on yield and quality

Temperature, solar radiation, relative humidity and water supply all affect the growth of the grapes after flowering. In addition to this, yield is also affected by the weather of the preceding year, the development of flowers in the previous and current year as well as plant health, frost and hail in the current year. The favored locations with respect to yield are warm with a high available water storage capacity. Thus, the best sites are the slightly inclined, south exposed slopes with high AWC values. Water stress during berry growth reduces yield. The vine can compensate moderate water stress. Initially water budget is only of minor importance. Only a large deficit will cause a reduced yield.

Long-term observations actually reveal that yields are higher in the Rheingau during dry years. Table 3 shows that the vineyards at Schloss Johannisberg yielded an average of 68 hl/ha per year in the ten "best quality" years (average 93 °Oechsle) between 1945–1990. This is 7 hl/ha higher than that of the ten lowest quality years (average 61 °Oechsle) (HOPPMANN & LÖHNERTZ 1996).

This example shows that yield is not only determined by water budget but also reflects the variability of the annual thermal conditions. The table compares yield and quality data with precipitation surplus and deficits for each year.

The top years such as 1947, 1949, 1953, 1959, 1971 and 1976 are years with a high precipitation deficit. However the yield losses in comparison with the long-term average are insignificant. The yield in poorer years such as 1956, 1957, 1965, 1968 or 1980 is actually lower than the long-term average, despite a precipitation surplus.

Similar results were found by STEINBERG (1988) for the previously described locality Mäuerchen (AWC 0–80 cm=144 mm) in the Rheingau. On average soil management has an insignificant effect on yield. Years with a precipitation deficit are characterized by higher temperatures and longer sunshine hours.

The soil and climate maps of the Vineyard Site Atlas reveal details concerning the expected quality, which is represented by the parameters must weight and acidity. The low-lying locations with a good water supply, which are often exposed to cold air are expected to produce more acid dominated wines. Acidity also increases above an elevation of 200 m above sea level

Tab. 3. Comparison of 10 years with „best quality“ and 10 years with „lowest quality“ on Schloss Johannisberg (Rheingau) 1945–1990

Best quality years				Lowest quality years			
Years	**°Oe**	**Yield**	**RR Diff.**	**Years**	**°Oe**	**Yield**	**RR Diff.**
1945	108	231	+3	1954	61	84	+16
1947	88	70	–170	1956	55	52	+46
1948	85	78	+28	1965	53	48	+61
1949	97	55	–73	1968	62	63	+192
1950	86	68	+88	1974	65	72	+48
1953	95	68	–65	1977	65	68	–32
1959	97	88	–102	1978	60	59	–7
1971	89	74	–36	1980	65	251	+34
1976	97	72	–130	1984	56	70	+93
1989	86	88	+10	1987	65	65	+117
Average 10 years	93	68	–45	Average 10 years	61	61	+57
Long-term average	75	71	338(*)	Long-term average	75	71	338(*)

Explanation:
* = average sum of precipitation (April–October), 1951–1980
1 = years with frost demage
°Oe = Quality (Degree Oechsle)
Ert. = Yield (hl/ha)
RR Diff. = Difference percipitation to the long-term average (*) April–October

(Hoppmann & Schaller 1981). The warm steep locations with their shallow soils produce less acid wines – in dry years the acidity may be so low that this may lead to quality problems. This pattern is reversed for must weights. Optimum must weights are achieved on sites located between 30 and 50 m above the valley floor, and drops by 3 – 4 °Oechsle per 100 m elevation (Hoppmann 1979).

Investigations in the Rheingau (Hoppmann 1978) have also revealed that must weights can be reduced by as much 6 °Oechsle on sites with a high risk of cold air influence. Here grape ripening may be delayed in comparison to warmer sites. High wind risk can reduce the must weight by 2 – 3 °Oechsle.

There is little evidence to support the premise that soil type has an influence on quality parameters such as must weight and acidity (Hoppmann & Schaller 1981). However, it is feasible that a variable water supply, different thermal conditions, different nutrient supply, especially micronutrients can affect quality. Yet available water capacity does have an effect on quality. Hoppmann (1999) showed that an AWC increase by 80 mm increases the must weight by 3 °Oechsle.

Quality cannot be exclusively based on measurements of must weight and acidity. A reduction of sugar content can only be observed as a result of extreme water stress of nitrogen deficits, because sugar reduction is compensated by lower yields. In addition to this, vineyards with a reduced vegetative growth are known to be less likely to be infected with Botrytis. Consequently, the losses due to infection are reduced. The slight increase in acidity in vineyards planted with cover crops should not be overrated.

The frequency of defects in a number of white wines from different wine-growing regions has increased in the last few years. These have been correlated to stress situations during the vegetation period. Water and nitrogen deficiency, soil management, as well as yield and the harvest date are the main causal factors currently discussion in this context.

These defective wines have been observed to age differently than normal wines (untypical ageing). This unfavorable alteration of the flavor during ageing has been observed with increasing frequency for wines from the Franken region since 1988 (Christoph et al. 1995). Initially described as a "Naphthalene note" or "Mediterranean note", the fault is now known as a "untypical ageing off-flavor". Up to 20 % of wines from a range of wine-growing regions that were rejected in quality wine tests in 1994 showed evidence of this defect.

Current research indicates that the compound 2-aminoacetophenone, first identified by Rapp et al. (1993), is linked to the negative effects of "untypical ageing off-flavor" on the bouquet of the wine. There is also evidence to suggest a correlation with indole acetic acid concentration, which is directly related to the reaction of the vine to water stress.

The formation of such "off-flavor" compounds due to water and nitrogen deficiency can have an enormous economic effect on individual wineries. This is the reason why winegrowers in many wine-growing regions have a very reserved attitude towards permanent cover-cropping systems.

Study results showing a positive effect of moderate water stress must be viewed with caution, especially in the case of white wines (Smart 1984). The Water Stress Map reveals those locations where permanent cover-cropping may cause a significant increase in the risk of water stress.

6.3 The Vineyard Site Atlas as a basis for defining terroir in the wine-growing regions of Hesse

The information contained in the new and revised edition of the Digital Atlas of the Wine-Growing Regions of Hesse can form the scientific basis for defining a terroir. No other wine-growing region in the world can boast comparable data.

The French term terroir embodies the "soil, geology, origin, location, vineyard". The intention behind defining a terroir is the desire to describe the origins of a wine (vineyard, location) to accentuate the individual characteristics.

"Terroir describes the natural surroundings of a vineyard: the interaction between soil and topography and the macro-and mesoclimate of the location" (The Oxford Companion to Wine). These natural surroundings are described in the Vineyard Site Atlas.

"Terroir means much more than just that what is happening in the soil. The term embraces the entire ecology of the vineyard and includes all aspects from the rock substrate to late frosts and autumn mists, even vineyard management and, finally, the soul of the winegrower" (Hugh Johnson).

One can expect that the natural aspects of a location will also affect the quality of the wine. This idea to use these as a basis for evaluating and classifying vineyards is not new and was first introduced in France. Here, the geographic and qualitative categorization is known as a "terroir". The Appellation (A.O.C.) provides many examples for this. The most famous example is the evaluation of the Bordeaux wines in 1855. Brokers from the Bordeaux region evaluated the wines according to the soil, reputation of the vineyards and price. Although soil and climatic aspects vary little over time, changing ownership can have a profound effect on quality and therefore price. The classification has been revised several times since then.

In Germany, there is a tendency towards selecting a scientific approach. The Digital Atlas of the Wine-Growing Regions of Hesse is the result of a scientific approach. The importance of the soil for evaluating the suitability of a location for wine-growing varies considerably in different regions. While some regions have focused on implementing the terroir concept, others have reduced the importance of the soil to a few properties such as water budget, nutrient supply and pH.

In the northern wine-growing regions, the term terroir signifies much more than just the evaluation of the soil with respect to its viticultural suitability. In the Rheingau region, there has been a notable shift of emphasis from the soil to the climatic conditions when compared to the French terroir. Climate plays an important role in determining wine quality along the northern boundary of wine production. The noticeable differences between vintages and locations are a persuasive example of the effects of climate on grape quality. Temperature and radiation are less important in the Mediterranean regions, where water budget has the greatest effect. Here soil factors are important in determining quality. A description of the natural conditions helps the winegrower to obtain the optimum quality for his vineyard. For this, he can use the Vineyard Site Atlas as a decision making tool in vineyard management (selecting variety, canopy management, pruning, yield control etc.).

7. Summary

The present set of maps provides the winegrower with the fundamental knowledge for decisions in the vineyard with respect to:

- selection of vine and rootstock varieties,
- vine training and canopy management,
- soil management and fertilization,
- qualitative evaluation of the vineyard.

Obviously, a differentiated analysis of the vineyard leads to an optimal management practice. Thus, the leaves of vines growing on lower sites with deep soils and affected by cold winds will require more frequent trimming than those on drier locations. In contrast, the latter will require a more intense yield control and a good soil management system. The site maps enable a better assessment of the potential risks that may incur by changing the soil management system. The necessary modifications for reducing potential nitrate leaching and erosion are presented for the whole area. Individual sites may be evaluated using the maps or by implementing the described assessment and evaluation procedures.

Because of the low precipitation in the Rheingau region, not all sites are suitable for permanent cover-cropping. In these cases, the winegrower will need to introduce alternative measures to reduce erosion and nitrate leaching.

8. References

BECKER, N.J. (1967): Beiträge zur Standortforschung an Reben (Vitis Vinifera L.). Ergebnisse einer Erhebungsuntersuchung im Rheingau. – Diss. Univ. Gießen.

BERTHOLD, G. (1991): Untersuchungen zur N-Dynamik weinbaulich genutzter Flächen unter besonderer Berücksichtigung der Bewirtschaftungsform. – Geisenheimer Ber., **7**; Geisenheim.

BETTNER, W. (1979): Der Wasserhaushalt der Rebe. - Die Weinwissenschaft, **30**: 1–20; Mainz.

Brandtner, E. (1973): Die Bewertung geländeklimatologischer Verhältnisse in Weinbaulagen. - Deutscher Wetterdienst; Offenbach.

CHRISTOPH, N., BAUER-CHRISTOPH, C., GESSNER, M. & KÖHLER, H.J. (1995): Die „Untypische Alterungsnote“ im Wein, Teil 1: Untersuchungen zum Auftreten und zur sensorischen Charakterisierung der „Untypischen Alterungsnote“. – Rebe und Wein, **9**: 350–356; Weinsberg.

CURRLE, O., BAUER, O., HOFÄCKER, W., SCHUMANN, F. & FRISCH, W. (1983): Biologie der Rebe. – Neustadt an der Weinstraße (Meininger).

EMDE, K. (1992): Experimentelle Untersuchungen zu Oberflächenabfluß und Bodenaustrag in Verbindung mit Starkregen bei verschiedenen Bewirtschaftungssystemen in Weinbergsarealen des Oberen Rheingaues. – Geisenheimer Ber., **12**: 248 S.; Geisenheim.

GRIEBEL, T. (1996): Untersuchungen über die Anteile der Transpiration der Rebe und der Evaporation in begrünten Rebbeständen an der Gesamtverdunstung. – Geisenheimer Ber., **28**; Geisenheim.

GUROVICH, L.A., HERNÁNDEZ, A. & PSZCZÓLKOWSKI, P. (1996): Deficit Irrigation as a Strategy to Modify Wine Characteristics. – 76th General Assembly of O.I.V., 10.–18.11.1996; Cape Town/South Africa.

HOFMANN, B. (1996): Zeitliche und räumliche Einflüsse bei einer flächenhaften Abschätzung des Trockenstressrisikos von Rebanlagen. – Tagungsband des XI. Kolloquiums des internat. Arbeitskreises „Begrünung im Weinbau“, 18.–31.08.1996: 35–40; Kaltern.

HOPPMANN, D. (1978): Standortuntersuchungen im Rheingau und in Baden. – Weinberg und Keller, **25**: 66–92; Frankfurt am Main.

HOPPMANN, D. (1979): Das Kleinklima am Steilhang und Möglichkeiten seiner Verbesserung. – In: BECKER, H.: Weinbau am Steilhang: 13–26; Münster-Hiltrup.

HOPPMANN, D. (1988): Der Einfluss von Jahreswitterung und Standort auf die Mostgewichte der Rebsorten Riesling und Müller-Thurgau (Vitis vinifera L.). – Berichte des Deutschen Wetterdienstes, **176**: 213 S.; Offenbach.

HOPPMANN, D. (1999): Die Karte des potentiellen Mostgewichtes für das Weinbaugebiet Rheingau als objektive Grundlage zur Charakterisierung der Weinlagen. – 24. Weltkongreß für Rebe und Wein, Sektion 1: Methoden des Rebanbaus. 5.–9.07.1999 Mainz. Kongreßbd. BMELF: 176–183; Mainz.

HOPPMANN, D. & SCHALLER, K. (1981): Der Einfluß verschiedener Standortfaktoren auf Qualität und Quantität der Reben.

1. Mitteilung: Entwicklung der Qualität in geringen und mittleren Jahrgängen. – Die Weinwissenschaft, **36**(5): 299–319; Mainz.

2. Mitteilung: Entwicklung der Qualität in guten und besten Jahrgängen und im 11jährigen Mittel. – Die Weinwissenschaft, **36**(6): 371–377; Mainz.

HOPPMANN, D., BETTNER, W. & BETTNER, L. (1987): Untersuchungen des Leistungsverhaltens sowie des Bestandsklimas bei unterschiedlichen Standweiten an der Rebsorte Riesling. – Die Weinwissenschaft, **42**(3): 147–178; Mainz.

HOPPMANN, D. & LÖHNERTZ, O. (1996): Die Standortkarte der Hess. Weinbaugebiete unter besonderer Berücksichtigung der Begrünungsmöglichkeiten der Weinberge. – Tagungsband des XI. Kolloquiums des internat. Arbeitskreises „Begrünung im Weinbau“, 28.–31.08.1996: 56–73; Kaltern.

HÜSTER, H. (1993): A long-term simulation of the soil water budget in tilled and gras covered vineyards. –Die Weinwissenschaft, **48**: 127–129; Mainz.

LÖHNERTZ, O., PRIOR, B., BLESER, M. & LINSENMEIER, A. (1998) Influence of N-supply and Soil Management on the Nitrogen Composition of Grapes – Proceedings of the XXV International Horticultural Congress (Part 2): Mineral Nutrition and Grape/Wine Quality, Mineral Management to Optimize Fruit Quality. – Acta Horticulturae **512**: 55–64; Brussels.

MÜLLER-THURGAU, H. (1892): Die Transpirationsgröße der Pflanzen als Maßstab ihrer Anbaufähigkeit. –Mitt. Thurgauische Naturforsch. Ges., **10**; Thurgau.

RAPP, A., VERSINI, G. & ULLEMEYER, H. (1993): 2-Aminoacetophenon: Verursachende Komponente der „untypischen Alterungsnote" („Naphthalinton", „Hybridton") bei Wein. – Vitis, **32**: 61–62; Siebeldingen

SCHALLER, K., JAGOUTZ, H., BERTHOLD, G., EMDE, K., LÖHNERTZ, O. & HOPPMANN, D. (1994): Bewirtschaftungssystem und Nitratbildung bei Rebflächen: Teil 1 Grundlagen für die Erarbeitung eines Simulationsmodells; Teil 2 Parameterschätzung und Umsetzung zu einem Düngerberatungsmodell. – Geisenheimer Ber., **16a** u. **16b**; Geisenheim.

SCHMID, J. (1997): Xylemflußmessungen an Reben. - Diss. Univ. Bonn. – Geisenheimer Ber., **33**; Geisenheim.

SMART, R.E. (1984): Some aspects of climate, canopy, microclimate, vine physiology and vine quality. – In: Proceeding of the Internat. Symposium on cool climate Viticulture and Enology. – Oregon State University Agricult. Experiment. Station, Techn. Publication **7628**: 1–19; Oregon.

STEINBERG, B. (1988): Auswirkungen der Bodenpflege in Abhängigkeit von der Jahreswitterung auf die Ertragsleistung der Rebe im Standort „Geisenheimer Mäuerchen". – Die Weinwissenschaft, **43**: 237–260; Mainz.

ZAKOSEK, H., KREUTZ, W., BAUER, W., BECKER, H. & SCHRÖDER, E. (1967): Die Standortkartierung der hessischen Weinbaugebiete. – Abh. hess. L.-Amt Bodenforsch., **50**; Wiesbaden.