Geologische Abhandlungen von Hessen 2004, 114, 105-115 (Engl. translation 2010)

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The Map of Potential Must Weights as an Objective Basis for Characterizing Vineyards in the Rheingau Wine-Growing Region

1. Introduction

Although vineyard location has been a traditional and important aspect of German viticulture for a long time, it is not included as a quality-determining factor in current Wine Directives. In the wake of current endeavors to harmonize the regulatory framework within the EU, German legislation is expected to take into consideration the importance of geographical position for differentiating wine quality.

Solar radiation and temperature are the limiting climatic factors along the northern margin of the wine production zone. The water budget in a vineyard also has an effect on quality in years with long dry periods. In areas with less than 550 mm annual precipitation, the proportion of dry years can increase to about 40 %. The basic data was collected in a long-term site-monitoring program published by ZAKOSEK et al. (1967). Current geographic information system (GIS) technology can be implemented to obtain spatial distribution patterns of the climatic and pedological factors affecting must weight. The map of potential must weights of the Rheingau establishes specific areas where soil and climatic conditions enable the production of high-quality wines. The calculated must weights only apply for Riesling grapes.

2. Methods

The basic data required for the validation of the must weight model was collected in long-term surveys carried out between 1960 and 1984 (HOPPMANN 1988). The analysis only takes those sites into account for which must weights have been recorded for at least 10 years. Such datasets are available for 123 test lots. Must weights were determined at the start of the main grape harvest. A regression model from the BMDP-Statistics program packet was used to validate the influence of soil and climate on must weights. The calculations cover the period between 1960 and 1991. The model uses climatic variables (temperature, sunshine hours, relative humidity, wind speed and precipitation) as well as derived agricultural meteorological variables such as potential evaporation, climatic water budget and calculated direct solar radiation. The influence of climate on growth and ripening of the grapes depends on the developmental stage. Consequently, all estimates of the site-specific variable also take life-cycle events (BBCH-Code) into consideration (HOPPMANN & JAGOUTZ 1986). The climatic conditions at the site are derived from models of the basic data gathered from the climate station network of the meteorological service. All site variables known to have an effect on quality are listed in Table 1. The temperature

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Tab. 1. Climatic and pedological differentiation of vineyard sites

Topography	Soil	Climate
Slope gradient	Soil class	direct solar radiation
Aspect	Soil type	potential evaporation and water budget
Elevation above sea level	plant available soil water (AWC)	Temperature (elevation, aspect, slope)
Elevation above valley floor	Heat budget	cold air risk and wind risk

function enables the calculation of the real temperature conditions for each location at different elevations and types of terrain.

The computed temperatures as well as the water budget and evaporation estimates help to validate the relationship between site variables and observed must weights. The new edition of the Digital Atlas of the Wine-Growing Regions of Hesse also includes a map of available water contents (AWC) (ZIMMER 1996).

The geographic information system (GIS) of the Institute for Geography at the University of Mainz integrates all site variables. The digitalized elevation model (DEM) created and made available by the State Survey Office of Hesse forms the basis of the GIS. The resolution of the elevation values is 20×20 m, which also allows the calculation of gradient and exposure. In addition to the basic variables coordinates, elevation, gradient and exposure, each grid point is also allocated specific values for cold air and wind risk, radiation, temperature and available water content.

3. Results

The first part of the investigation focuses on identifying the effect of changing the variables during specific grape developmental stages on must weights. Table 2 summarizes how a divergence by one standard deviation affects must weights. The results indicate that the most sensitive event is the onset of flowering, followed by evaporation during the cell division stage, precipitation during ripening etc. The sequence, however, says nothing about the scale of the influence. This can only be estimated using the regression coefficient and standard deviation (column 2 and 3 in Table 2).

A seven day delay of the onset of flowering (plus one standard deviation) causes a decrease of the must weight by 5.9 °Oechsle. Similar results are obtained for the other influencing factors: an increase in evaporation by 27 mm and climatic water budget by 51 mm during the cell division phase causes an increase in must weight by 7.2 ° and 5.2 °Oechsle respectively. A change in the combined variable “precipitation and water budget” during grape ripening will reduce quality by 2.3 °Oechsle if precipitation and water budget increase by 23 and 31 mm respectively. In the vineyard, quality is also influenced by exposure and gradient. The well-known observation that quality decreases with increasing elevation is the result of the decreasing temperature

Tab. 2. Influence of phenological development and climate on must weight

Phenology/climatic factor	Change (standard deviation)	Quality loss/ increase [°Oe]
Date Full blossom	+7 days	–5,9
Evaporation (BBCH 65 to 73)	+27 mm	+7,2
Precipitation (BBCH 85 to 89)	+21 mm	–2,0
Max-temperature (BBCH 73 to 81)	+0.9 °C	+3,7
Precipitation and water budget (BBCH 81 to 85)	+23 mm a. +31 mm	–2,3
Water budget (BBCH 65 to 73)	+51 mm	+5,2
Max-temperature (BBCH 85 to 89)	+1,8 °C	+2,2

at higher elevations. However, this decrease also depends on overall weather conditions. Wind and cloud cover form the basis for classifying weather conditions.

Each point in the terrain is assigned the nightly temperature minimum and mean daylight temperature calculated in correlation to cold air and wind risk, elevation, direct solar radiation and prevailing wind direction (HOPPMANN 1988).

The temperature calculations take into consideration the cold air risk values available for the whole Rheingau.

Cold air risk is presented in Figure 1. The vineyard slopes of the Rheingau are less at risk than other wine-growing regions. There are nine possible risk classes. However, the two highest do

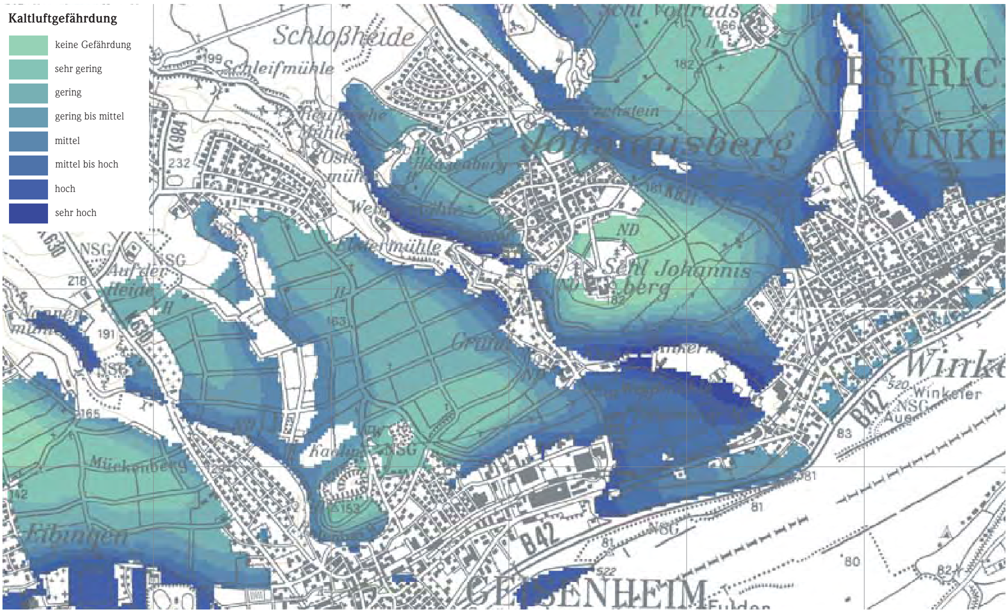

Fig. 1. Example of cold air risk.

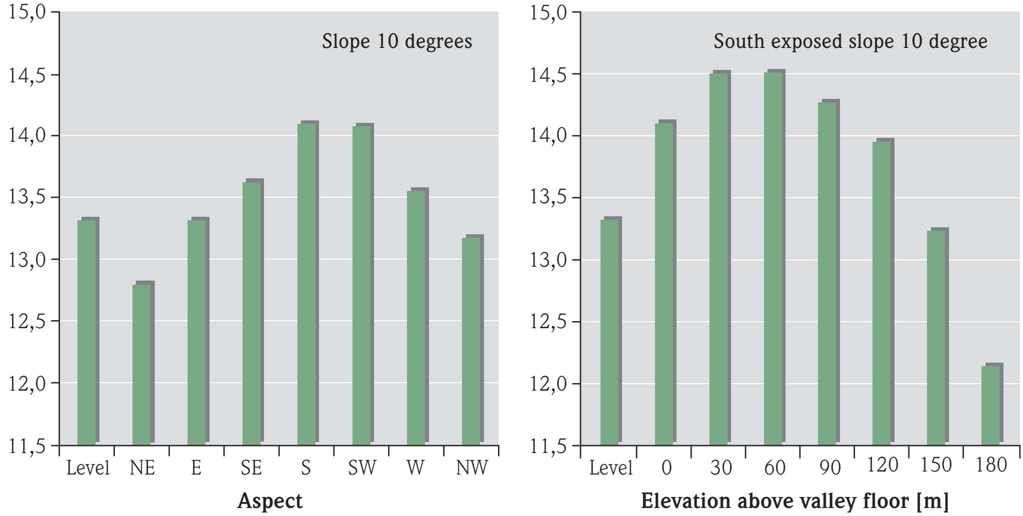

Fig. 2. Mean daylight temperatures from veraison to harvest.

not occur in the Rheingau. In a similar manner, wind risk has been divided into 5 classes for cartographic presentation. The variability of mean daylight temperature during the period between onset of ripening and harvest is presented in Figure 2. The left diagram shows the influence of aspect. The results indicate that optimum temperatures are found on S to SW-facing slopes and that temperatures are higher on SW-facing than on SE facing slopes. The right diagram depicts the influence of elevation on daylight temperatures and indicates that optimum temperatures occur on lower elevations between 30 and 60 m. Temperatures drop significantly above the 120 m contour line.

Evaporation from the land surface depends on slope aspect and gradient. The records show negative water budgets for most years in the Rheingau (Hoppmann 1988). Usually vines will depend on water stored in the soil. Thus, available water contents (AWC) plays a key role in site evaluation. Details on this topic have been published by several authors (for example Hüster 1993). A complete set of AWC values for the Rheingau was available for the new edition of the Atlas for the Wine-Growing Regions of Hesse. An example of the AWC values is depicted in Figure 3 (Zimmer 1996).

The must weight model is based on the minimum nighttime temperatures, daylight temperatures, evaporation and water budget during the phenological periods as well as the AWC values. Table 3 lists those site variables that have a statistically significant effect on must weight. The results indicate that 51 % of the must weight variability can be related to the effect of mean daylight temperature during grape ripening. Plant available water content (AWC) accounts for 15 % of the recorded variability. 5.3 % and 4.2 % can be explained by variations in nighttime temperature minima and evaporation between bud break and full bloom respectively. The must weight model can explain a total of 76 % of the variability between the investigated sites.

Table 4 clarifies the effect of site variables on must weights. Each variable is increased by one standard deviation. The climatic data comprise the mean values recorded during the phenological period. The resulting changes are presented in Table 4. For example, raising mean daytime

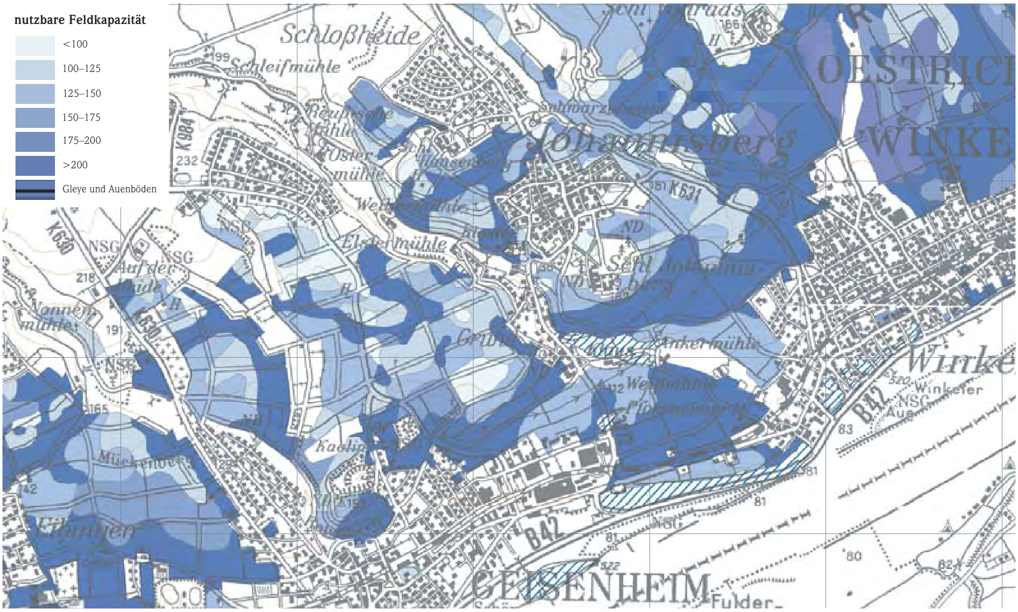

Fig. 3. Example of AWC values.

temperature by 0.6 °C causes an increase in must weight by 2.8 °Oechsle (Fig. 4). The difference was found to be only slightly larger in three sites. The discrepancy of ±5 °Oechsle accounts for the remaining 24 % not explained by the must weight model.

The cartographic representation of potential must weights must take into account the observed variability between measured and calculated values. The present results show that a value

Tab. 3. Regression results of the fluctuations of mean must weights from 123 lots in the Middle Rheingau

Factor	Single correlat.	F - Value	Regression coeff	Increase effect	P-Value
Mean daylight temperatures (veraison - harvest)	0.714	158.03	4.641	51.0 %	0.001
plant available soil water (Site map)	0.508	53.83	0.0394	15.5 %	0.001
Nighttime temperature minimum (full blossom – veraison)	–0.328	33.09	–5.244	5.3 %	0.001
Potent. evaporation (budding – flowering)	0.309	20.63	20.034	4.2 %	0.001
coefficient of determination				**76.0 %**	
Note	**The factors are significant when P-value <0.05**				

Tab. 4. Influence of site factors on long-term average must weights of 123 locations

Climate factor	Change (standard deviation)	Quality loss/ increase [°Oe]
Mean daylight temperatures (veraison - harvest)	+0.6 °C	+2.8
plant available soil water (Site map)	+40 mm	+1.4
Nighttime temperature minimum (full blossom – veraison)	+0.3 °C	–1.6
Potent. evaporation (budding – flowering)	+0.05 mm per day	+1.0

of ±5 °Oechsle must be added to each calculated value. This supplement means that it is not possible to obtain a higher must weight on any particular site than predicted by the must weight model. Since the observed scatter is related to differences in vineyard management (crop protection, fertilization, canopy management), the supplement also presupposes that the vineyard and the crop are managed optimally. This is the reason why this value is specified as the potential must weight.

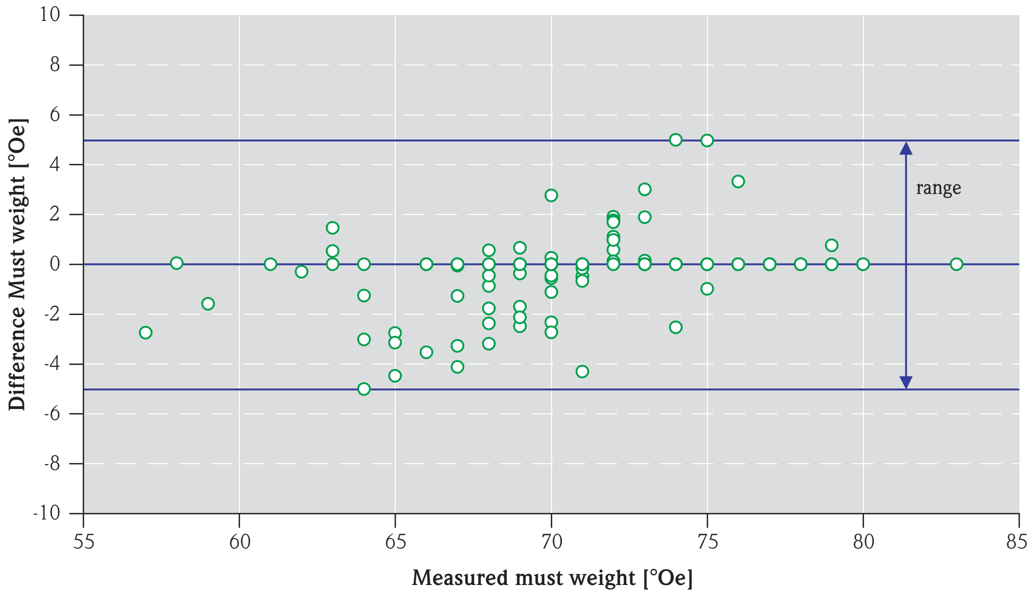

Fig. 4. Difference between measured and calculated must weight.

4. Individual map description

A seamless map of the potential must weights is available for the Rheingau region. The CD-ROM also includes 7 printable individual DIN A3, 1: 25 000 scale maps of the following regions:

Lorchhausen to Bodenthal
Assmannshausen to Geisenheim
Geisenheim to Oestrich-Winkel
Oestrich-Winkel bis Hattenheim
Hattenheim to Walluf
Walluf to Wiesbaden-Neroberg
Hochheim to Flörsheim-Wicker

Each zone is assigned to one of 12 classes, each representing a class interval of 2 °Oechsle. Thus the class “79 – 80” includes the value range between 78.5–80.4 °Oechsle. The lowest (<68.5) and highest (>88.4) values have been consolidated into individual classes. Orange to red zones indicate very high quality locations, yellow hues represent good quality locations and dark green zones are only suitable for early ripening grape varieties.

The individual maps and regional outstanding features are described in the following sub-sections. The percentage distribution of must weights has also been determined for each location.

In some cases, different collective vineyards may share an individual vineyard or a single vineyard may belong to different districts. In these instances, the vineyard will appear in each of the relevant sub-sections.

The region between Lorchhausen and Bodenthal

The conditions for solar radiation for the vineyards on the SW facing slopes are excellent. Cold air from the Wisper Valley flows over the vineyards at the foot of the slopes near Lorch. The general thermal conditions for wine production deteriorate with increasing elevation. The higher vineyards are also more exposed to wind. The soil water supply is a limiting factor in some parts of the vineyards “Pfaffenwies” and “Bodenthal-Steinberg”. The map reveals the correlation between site conditions and quality. The vineyards with the highest potential must weights are the “Kapellenberg”, followed by “Bodenthal-Steinberg” and “Pfaffenwies”.

The region between Assmannshausen and Geisenheim

The quality of the vineyards in Assmannshausen is slightly lower than those around Lorch. Cold air from the higher agricultural regions reduces quality near the valley. In addition to this, the aspect of the slopes is highly variable and the larger proportion of NW facing slopes also reduces the average solar radiation in the vineyard. The higher areas are also more exposed to wind. However, the lower parts near the valley floor of the vineyards “Höllenberg” and “Frankenthal” achieve a very high quality rating. Locally occurring soil water supply deficiencies diminish the quality of the “Frankenthal” vineyard. The landscape changes somewhat between Assmannshausen and Rüdesheim, the majority of slopes now facing SW and S. The favorable climate is also less affected by downhill streams of cold air. However, local low plant available soil water contents will reduce the possibility of achieving very high must weights in dry years. The potential must weight generally decreases with increasing elevation. The best qualities are usually confined to the zone between the 80 and 180 m above sea level.

Wind exposure increases with elevation. The potential must weights reflect the influence of climate and soil. The vineyards “Rosengarten”, “Schlossberg” and “Berg Rottland” are noteworthy in this context as are the lower parts of the vineyard “Magdalenenkreuz” in Eibingen. These sites profit from a better water supply.

Towards Geisenheim, the S-facing slopes fall less steep towards the Rhine, except for two very steep vineyards "Rothenberg" and "Kläuser Weg" located east of the town. The vineyard "Fuchsberg" is an outstanding location in Geisenheim. The site is protected from wind, not affected by cold air streams and the soil has very good properties. As a consequence large areas of this vineyard attain highest quality ratings. The quality falls towards "Mäuerchen" where the influence of the wind increases and the soils cannot provide an adequate water supply in dry years. A similar situation is found in smaller parts of the vineyards "Rothenberg" and "Kläuserweg". Large masses of cold air stream down the Blaubach Valley towards Geisenheim. As a result, the potential must weights attained on the areas at the foot of the slopes of the "Mönchspfad" vineyard are slightly lower. The upper parts of the same vineyard are near level so that only about 20 % of the area may achieve must weights above 80 °Oechsle. The order of sequence in Geisenheim with respect to quality is "Fuchsberg", "Rothenberg" and "Kläuserweg".

The region between Geisenheim and Oestrich-Winkel

The outstanding vineyards in Johannisberg are "Schlossberg", "Hölle" and "Mittelhölle", each located on steep S to SW-facing slopes. However, not every vineyard can boast plant available water content over 150 mm. In such cases, high solar radiation can have a negative effect in dry years. The climatic conditions of the vineyards close to the Elsterbach Valley near Castle Johannisberg ("Klaus") and further east in Winkel (fringes of "Gutenberg") are affected by cold drainage winds. In the same area the vineyard "Hasensprung" benefits from the S-facing slopes of the location. Further down the slopes, in proximity of the Rhine, is a narrow strip of excellent vineyards, the "Jesuitengarten" and "St. Nikolaus" in Mittelheim. Just like the "Fuchsberg", these vineyards lie protected from the wind and are mostly well supplied with water. Among other factors, the meager soils of the green areas of the "Dachsberg" vineyard near Castle Johannisberg and Castle Vollrads above the 220 m contour diminish the quality of the locations. The vineyard "Edelmann" in Mittelheim is less favorable than "St. Nikolaus". The quality of the vineyard "Schönhell" in Hallgarten is lower than those vineyards at lower elevations. The quality is less than expected since the higher wind exposure at higher elevation offsets the positive effect of higher solar radiation due to the favorable aspect of these slopes. Plant available water is also a limiting factor in some parts of this vineyard.

The vineyards "Oestricher Lenchen" on the eastern side of the Gottesthal Valley and "Doosberg" further east benefit from more favorable climatic conditions. The best vineyards of the region in terms of potential must weight are:

Mittelhölle
Schloß Johannisberg
Teile des Hasensprung
Jesuitengarten
St. Nikolaus
Lenchen
Doosberg

Apart from the vineyard "Lenchen" and parts of "Doosberg" all vineyards with very high must weights in Oestrich-Winkel are located in proximity of the Rhine.

The region between Oestrich-Winkel and Erbach

The vineyards east and west of Hallgarten are less affected by cold air streaming down the slopes than other areas of the Rheingau region. Even the valley of the Kisselbach is relatively little affected by cold air. The higher vineyards between Oestrich-Winkel and Erbach are affected by the higher elevations. This effect is exacerbated by a higher wind exposure along the SE and E-facing slopes. Some parts of the vineyard "Klosterberg", "Würzgarten" and "Hendelberg" are therefore only suitable for early ripening grape varieties. The best vineyards are located close to the Rhine along the railway line. The string of excellent sites begins west of Hattenheim with the vineyards “Schützenhaus“ and “Pfaffenberg“, followed in easterly direction by the vineyards “Engelmannsberg“, “Mannberg“ and “Nussbrunnen“. The row continues towards Erbach and the locations of the famous vineyards “Marcobrunn“, “Wisselbrunnen“ as well as “Siegelsberg“ and “Michelmark“. The quality produced in these vineyards does not diminish even in dry, high radiation years, due to the excellent soil water supply. The frost and wind risk is very low for these vineyards. Small areas along the SW-facing slopes of the vineyards “Schützenhaus” and “Steinberg” to the north of Hattenheim are also capable of producing good qualities. The plant available water content of large parts of the soil of the vineyard “Steinberg” is less than 125 mm.

The region between Hattenheim and Walluf

Cold air streaming down the Sulzbach valley affects the lower parts of the vineyards “Baiken“ and “Taubenberg“. Another strong cold air stream from the Taunus Mountains flows down the Walluf Valley, around the Nussberg hill in the east towards Schierstein where it finally accumulates in the trough between Niederwalluf and Schierstein. Many slopes along the eastern parts of the area between Erbach and Walluf face SE and E. In general, these sites are more affected by wind, which results in a slight reduction of must weights. This particularly applies to the vineyards along the Hühnerberg and Sonnenberg to the east. In contrast, the SW-facing slopes along the valleys of the Kisselbach, Kiedricher Bach, Sulzbach and Walluf benefit from more favorable climatic conditions. The exceptional vineyards are located in close proximity to the Rhine, south of the railway line between Eltville and Walluf. The previously described climatic conditions are reflected in the potential must weights. Beginning in the west, the notable vineyards in this specific location are:

Hohenrain
Schlossberg
Steinmorgen
Wasserros
Gräfenberg
Rheinberg
Sonnenberg
Sandgrub
Kalbspflicht
Baiken
Langenstück
Langenberg
Vitusberg
Walkenberg

This group includes several outstanding vineyards: “Schlossberg“, “Rheinberg“, “Sonnenberg“, “Baiken“ and “Walkenberg“.

The region between Walluf and Wiesbaden-Neroberg

The area between Walluf and Schierstein is mostly used for agriculture and fruit orchards. However, several vineyards are located in this area, in particular near Frauenstein and in the district of Schierstein and Dotzheim. The fruit orchards planted near the valley, in the zone below 140 m are an effective barrier against cold air streaming down these gradual slopes. However, this only affects small areas of the vineyards “Herrnberg“, “Marschall“, “Homberg“, “Dachsberg“ and “Hölle“ in the vicinity of the small side valleys. Since these vineyards are generally situated on SW-facing slopes they are less exposed to wind. Consequently, large areas of the vineyards “Herrnberg“ and “Hölle” are capable of producing very high must weights. The lower qualities found in other parts of these vineyards are mainly due to unfavorable soil conditions.

Small vineyards are also located within the urban area of Wiesbaden. The quality is not especially good.

The region between Hochheim and Flörsheim-Wicker

In contrast to the highly differentiated terrain structure of the Lower and Middle Rheingau, the elevation of the area between Hochheim and

Flörsheim only varies by 40 m. The vineyards cover the area between the banks of the Main and the generally level river terrace at 140 m above sea level. The S and SW-facing slopes are characterized by very good radiation conditions. The majority of sites close to the valley bottom are not used for growing wine since these are affected by cold air. The S and SW-facing slopes are well protected against wind. These favorable climatic conditions are reflected in the very high potential must weights. The overall soil conditions are good. Only small areas are affected by low plant available water content (AWC) below 125 mm. Consequently, a high percentage of the total vineyard area of this region attains very high potential must weights.

The first-class locations begin in the west with the vineyards “Weiss Erd“ and “Reichesthal“. The sequence continue eastwards with the vineyards “Stielweg“, “Domdechaney“, “Kirchenstück“, “Hölle“, “Königin Victoriaberg“ and “Stein“ and end in the east with the favored locations “Herrnberg“, “Nonnberg“ and “König-Wilhelmsberg“. The superior vineyards “Domdechaney“, “Kirchenstück“ and “Königin Victoriaberg“ stand out from this group of good to very good locations.

5. Summary and conclusions

The Rheingau is the first wine growing region in the world, which was classified on the basis of scientific information. Wine quality not only depends on must weights – flavor and composition are affected by the various stages of wine production from the management of the vineyards to the work of the winemaker. The map confirms in a most remarkable fashion that the Rheingau is an outstanding region in terms of climate and soil. Thus, an average of 50 % of the vineyard area can achieve must weights in excess of 80° Oechsle during a 30-year period. Only 14 % of the vineyard area attains potential must weights of less than 75 ° Oechsle.

The favorable climate is determined by various factors:

- S and SW facing slopes intercept high levels of solar radiation. Less than 5 % of the slopes face an unfavorable direction.
- The higher regions of the Rheingau are covered with forest. In contrast to fields and meadows, these forests block the nighttime downward flow of cold air towards the lower vineyards. There are only a few side valleys in the Rheingau, thus only a small area is affected by drainage winds from higher elevations.
- The soils provide best conditions for growing vines. The amount of precipitation in dry years is often too low to ensure an adequate supply of water to the vines. Over two-thirds of the soils in the Rheingau are capable of storing more than 150 l/m^2 during the winter half-year for the summer.

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