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Frost Risk

1. Introduction

The first cold air survey of the wine-growing regions in Hesse was carried out by the agricultural meteorological research stations in Giessen and Geisenheim in 1956/57. The survey was commissioned by the former State Department for Geological Research of Hesse. The area covered the whole of the Rheingau from Wiesbaden to Lorchhausen, the Maingau from Kostheim to Wicker-Massenheim and parts of the Hessische Bergstrasse.

The field measurements were carried out from March to November 1956 and over the same period in 1957.

The results were first presented in 1 : 5.000 scale maps, which formed the basis for creating individual regional 1 : 25.000 scale maps.

2. General principles

The critical limits for growing grapes are primarily determined by the temperature regime. Vines are frost-sensitive plants. The green parts are easily damaged by frost since they cannot tolerate ice formation within the tissue. The woody tissue however, can survive temperatures below – 20 °C during dormancy. Vine resistance to frost also varies between varieties and depends on the age of the woody tissue. Mature wood is rich on reserve substances especially sugars and starch and the water content is relatively low.

The degree of frost damage also depends on site conditions. Frost cannot penetrate as deep into light, well-aerated soils as into soils with high clay or silt contents. However, ground level-air cools much more rapidly above light soils, which results in a higher frost risk.

Vine frost resistance also depends on the degree of hardening and the extent of dormancy. Late or spring frosts can cause serious losses and may even lead to total loss. The critical air temperature lies between –1.5 °C and –2 °C. A temperature of –3 °C may already suffice to cause total loss. According to current general survey guidelines of the National Meteorological Service (Deutsche Wetterdienst, DWD) a frost event is recorded when the air temperature at a point 70 cm above ground attains a temperature below freezing point. The defined measuring height was lowered to 50 cm above ground for the initial cold air survey of the Rheingau. Thus a frost event correlates to a measuring height of 70 cm. Frosts are generally categorized according to the temperature and time of year as well as meteorological cause (Schnelle 1965).

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- Classifying frost according to temperature:
  Light frost = Frost at temperatures between –0.1 °C and –2.0 °C
  Moderate frost = Frost at temperatures between –2.1 °C and –4.0 °C
  Severe frost = Frost at temperatures of –4.1 °C and below
- Classifying frost according to time of year:
  Winter frost = frost during winter, during dormancy
  Spring frost = late frosts = during spring after onset of vegetation period until mid June
  Autumn frost = early frost = frost occurring from beginning of September onwards until the end of the vegetation period
- Classifying frost according to meteorological origin:
  Advection frost (wind frost)
  Radiation frost

While the first two classifications provide a clear distinction between frost categories, it is not always possible to distinguish between the two meteorological categories. Although both advection and radiation can each cause frost, both conditions can occur simultaneously to produce a frost event. The appearance of frost during the vegetation period between April and October is usually preceded by advection of colder air from northern latitudes. The occurrence of late frosts in spring is particularly important for assessing frost risk in wine-growing regions. These frosts damage buds and expanding leaves, which can lead to substantial economic losses. Although this damage is offset to a certain degree when secondary buds begin to break, the shorter vegetation period has a substantial negative effect on quality and yield.

Site conditions have a pronounced effect on the occurrence of radiation frosts and much less on that of advection frosts. This is the reason why frost frequency counts were limited to clear nights. These are defined as nights with a cloud cover $<3/8$, limited air movement and wind speeds <1.5 m /s. These conditions are required to produce the characteristic layering and distribution of temperatures in the evening, which also depends on the topography of the site. The appearance of radiation frosts depends on several factors. Level or slightly inclined sites, cold and weed-covered soils facilitate radiation frosts. The heat transfer from deeper horizons is interrupted in freshly tilled soils further enhancing local cold air formation. Valley floors and depressions where cold air can accumulate are especially at risk.

3. Evaluation and presentation of the results

Only moderate to severe frosts are considered. The basic criterion for the present frost risk survey is the minimum temperature defined in the previous two-year study. The results were compared to the long-term temperature measurements from the meteorological station Geisenheim. Frost risk is graded according to frost probability, meaning frost frequency.

The risk of frost over a given period of time (30 years) is defined as follows: the percentile proportion of years in which temperatures 0.5 m above ground fall below –2 °C at least once during the vegetation period for moderate frosts and below –4 °C for severe frosts. The results are combined into risk zones as defined in Table 1 and presented in a map.

Tab. 1. Classification of risk zones

Zone 0	no risk	very rare
Zone 1	low risk	1–2 times in a lifetime
Zone 2	moderate risk	1–2 times in a decade
Zone 3	high risk	very often

3.1 Frost risk in the Rheingau area

a) Frost probability –2 °C (late frost)

As expected, the risk of frost decreases with increasing elevation, with some local exceptions.

The sites with negligible risk of frosts up to –2 °C (Zone 0) are situated above the 200 m contour line from east of Johannisberg to the Rauenthal. In the central region of the Rheingau, between Johannisberg and Rüdesheim, this rare frost zone is located below the 200 m contour line. Near the Niederwald this zone even extends below the 100 m contour almost reaching the Rhine Valley. This most favored zone is not found between Assmannshausen and Lorchhausen and beyond. This region is strongly influenced by cold air advection from the Wisper Valley towards the Rhine.

The low risk zone (Zone 1) is located below the 200 m contour line in the eastern part of the Rheingau. In the central Rheingau this zone extends beyond the 200 m contour but may also descend to below the 100 m contour. Downriver from Assmannshausen this zone extends from the 200 m contour to the forested zone above.

Zone 2 extends to approximately the 140 m contour line and is also found below the railway line and settlements to the Rhine riverbank. This apparent abnormal distribution of cold air is only found in the immediate vicinity of the Rhine riverbank. The Rhine remains relatively warm during clear nights and elevates the air temperature in a narrow strip alongside the riverbank. This zoning can be found in the whole Rheingau.

The areas most likely to experience frosts (High frost risk, Zone 3) are located from below the 140 m contour to the railway embankment, which acts as cold air barrier. Areas with high frost risk are also found in depressions above the 140 m contour on slightly inclined slopes and in narrow strips along the valley floors, which extend upwards to the forest edge.

In clear nights, cold air streams downhill from the Rheingau Mountains towards the Rhine Valley. The spatial extent of these narrow, local advection currents are symbolized on the map by arrows.

b) Frost probability – 4 °C (late frost)

The distribution of risk zones corresponding to the probability of frost below –4 °C shows an increased prevalence of the negligible risk zone. This zone extends to the 160 m contour. The remaining area is almost entirely classified as Zone 1 except for the real cold air pockets near the railway embankment and in solitary localities along the 120 m contour. These unfavorable sites are classified as Zone 2. High risk zones do not appear on this map.

c) Early frosts

The early frosts usually extend to higher elevations than late frosts in the Rheingau. Frosts up to –2 °C can be expected in all locations up to an elevation of at least 280 m. Frosts colder than –4 °C only occur once or twice during a human lifespan in areas higher than 280 m. Such frosts can be expected once or twice a decade in elevations between 180 and 280 m. The lower areas are designated as Zone 3, with a high risk of frost. The general distribution of zones shows that the Niederwald area is especially favored. While Zone 3 does not occur here, Zone 0 can be found at elevations between 220 and 270 m. Small areas with favorable conditions can also be found in extremely good locations upstream and downstream.

3.2 Frost risk in the map section Kostheim –Hochheim –Wicker–Massenheim

a) Frost probability –2 °C (late frost)

The only low risk zones for late frosts up to –2 °C are located on the Hochheimer Berg in the parish of Kostheim and Hochheim, south of Hochheim beneath the location Domdechanei as well as in the district of Wicker on the Herrenberg. The locations on the Hochheimer Berg and Herrenberg are characterized by slightly steeper slopes. The location south of Hochheim is protected by the town itself.

Moderate risk zones are located on the slopes above Kostheim between the 100 and 120 m contour lines. A similar situation is found in Hochheim although the zone actually extends to the 130 m contour east of the town. The zone is interrupted by a depression west of Hochheim, which serves as a channel for cold air originating from the grasslands above the vineyards. A second cold air channel is located east of the town between Victoriaberg and Falkenberg. A narrow moderate risk zone stretches from the Falkenberg to south of the town between the railway line and Main river bank. This zone clearly benefits from the warming effect of the River Main.

The moderate risk zones in the area around Wicker-Massenheim are all located between the 140 m and 120 m contour. All other parts of this district belong to Zone 3, which means that the risk of late frosts up to –2 °C are very high.

The high railway embankment in the Hochheim area acts as a barrier for cold air streaming downhill from the slopes. Therefore, the risk of frost in the strip immediately alongside the embankment is a high.

b) Frost probability – 4 °C (late frost)

The risk of frost below – 4 °C during the vegetation period is limited to a few solitary locations within the wine-growing region Wicker–Massenheim. Such severe frosts occur in the vicinity of the high railway embankment SW of Hochheim where cold air accumulates. These areas should not be used for growing wine.

c) Early frost

Early mid-October frosts up to –2 °C towards the end of the vegetation period must be expected in all districts of this wine-growing region. The only areas not at risk from early severe frosts below –4 °C are located within Zone 0.

3.3 Frost risk in the map section Bergstrasse

The distribution of frost risk zones in the Bergstrasse region conforms to the expected pattern. The risk increases with decreasing elevation from the top of the slope towards the Rhine valley plain. Cold air accumulates in the narrow zone between the bottom of the slope (Bergstrasse) and the railway embankment. Cold air also accumulates in the wider area beyond the embankment towards the Rhine valley plains.

As in the other wine-growing regions in Hesse, the extent of the risk zones depends on the relief of the land, barring a few exceptions. The areas most likely to experience frost are the deeply incised valleys of the western Odenwald and depressions in the landscape. The risk is even higher where these areas are located down slope from cold air production areas such as grasslands, fields, deforested areas or bare land. The critical cold air currents are marked with blue arrows in the map.

The zone designation depends not only on elevation but also on slope. The results also indicate that cold air advection from areas located behind the first row of mountains is impeded. This means that the boundaries between individual zones move upslope in valleys where cold air is trapped behind a protruding mountainside.

a) Frost probability –2 °C (late frost)

In the area Heppenheim, Erbach and Hambach Zone 0 is located between the 180 m and 200 m contour depending on slope inclination. This area includes locations above Mittlerer Eckweg south of Heppenheim, Maiberg, Schlossberg, and the locations above Rebmuttergarten and the higher locations on the east side of Hambach. The low risk Zone 1 is located between the 180 m and 170 m contour. This is followed by moderate risk Zone 2 which extends to the 140 m contour. All lower locations including the valleys have been assigned to high risk Zone 3.

The distribution of zones in the area between Bensheim and Zwingenberg indicates that the area assigned to Zone 0 is severely restricted. The following locations, all lying within the elevation range described above, are not threatened by late frosts up to –2 °C: Hopberg including Streichling, Kalkgasse and Kirchberg, parts of Herrenwingert, Schönberg and Rod, the favorably exposed locations beneath Auerbach Castle as well as the steep, upper south exposed slopes near Zwingenberg.

The greater part of the aforementioned districts has been assigned to low frost risk zone 1. L arge parts of these districts, located between the 140 m and 150 m contour line, are classified as Zone 2 (moderate frost risk). The risk of experiencing late frosts up to –2 °C is high in the areas below the 140 m contour line and extending to the lower slopes and the Rhine valley plain.

b) Frost probability – 4 °C (late frost)

Most locations in the Bergstrasse are not threatened by severe frost below –4 °C. This survey included all areas along the slopes of the Bergstrasse independent of use. Low and modarate risk locations (Zones 1 and 2) are found nearer the foot of the slopes. One solitary location at the foot of the slope between Heppenheim and Bensheim is classified as high risk (Zone 3). This wine location lies below the 100 m contour behind the railway embankment. The remaining high risk areas alongside the embankment are negligible.

c) Early frost

Early frosts up to –2 °C are to be expected in all orchards and vineyards of the Bergstrasse region. The risk of severe early frosts below –4 °C is high up to the 170 m contour line. This contrasts with the observed late severe frost risk where Zone 3 only extends to the 100 m contour line. The 170 m contour line coincides with the limits of zones 1 and 2 for late frosts up to

–2 °C. Clearly, the risk of early frosts at a given elevation is significantly higher than that of late frosts. The low risk zone for early frosts begins above the 200 m contour line in the Bergstrasse.

4. References

Schnelle, F. (1965): Frostschutz im Pflanzenbau. – Bayerischer Landwirtschaftsverlag GmbH; München.