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# Nitrate Leaching Potential in the Wine-Growing Regions of Hesse

The nitrate concentrations in most potable water wells in the wine-growing regions of Hesse have risen continuously since the 1970s. In the meantime, concentrations exceed the upper limit of 50 mg nitrate/l specified in the Potable Water Regulation. Occasionally over 200 mg nitrate have been measured (Berthold 1991, Schaller et al. 1994).

Most nitrates polluting the groundwater originate from fertilizer application on cultivated land, including viticultural land. For this reason, the Soil Science and Plant Nutrition department of the Geisenheim Research Centre and the agricultural meteorological service of the National Meteorological Service (Deutscher Wetterdienst) in Geisenheim have cooperated to study nitrate leaching potentials of vineyard soils (Berthold 1991, Schaller et al. 1994).

As an anion, nitrate is not significantly adsorbed in the soil and is easily transported from the rooting zone to deeper parts of the profile by percolating water. Therefore, the nitrate leaching risk increases with higher unsaturated flow rates, which depend on the annual water budget excess. The risk decreases with increasing water retention times in the soil since this allows the plant roots to take up more nitrates. Water retention time closely correlates with field capacity (FC) or the capacity of the soil to store water. Field capacity is determined from the particle size distribution curve, stoniness, humus content and the bulk density of the soil. However, only a specific part of this water can be taken up by plant roots – this is the available water content (AWC, Zimmer 2004).

## 1. Methods

The methodological approach is based on the following relationship:

$$\text{potenial nitrate leaching risk} = \frac{\text{moisture surplus (mm)}}{\text{field capacity (mm/dm)} \times \text{rooting zone depth (dm)}}$$

The data for field capacity and rooting zone depth were obtained from the large-scale soil maps and the study results by Zimmer (2004).

Unsaturated flow is usually inferred from the "average annual sum of the climatic water budget" (CWBa) – the balance between annual precipitation and potential evaporation. This method is based on the assumption that the water balance is positive and surplus water will percolate down the soil profile. However, the records of the National Meteorological Service for Geisenheim between 1951 and 1980 show a clear negative CWBa. Therefore, without water percolating down the profile there should be no nitrate

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leaching. This contradiction points to a methodological "error" since water balance calculations for the whole of Germany are standardized and do not take into account site-specific conditions. More realistic estimates of moisture surplus take into account actual evapotranspiration in relation to site exposure and vegetation cover. This study uses a model developed by HOFMANN (2004) for calculating soil moisture conditions in relation to vine development stage to simulate soil moisture surplus in open vineyards for the period between 1961 and 1990. This model takes into account precipitation and actual evapotranspiration (evaporation from soil and vegetation) in relation to different slope gradients and aspects, as well as surface runoff.

Locations with a very low water storage capacity and high soil moisture surplus are suspected of having a high nitrate leaching potential. Tables 1 and 2 document the moisture surplus for soils with low field capacities from various locations within the wine-growing regions in relation to exposure and slope gradient. As expected, soil moisture surplus decreases with increasing slope gradient (surface runoff, evaporation, lower precipitation density) and with increasing exposure towards the south (evaporation due to solar radiation).

**Tab. 1.** Moisture surplus (in mm) for soils with low available water capacity (100 mm) at different stations in the Rheingau-region

| | **Lorch** | | | | **Geisenheim** | | | |
|---|---|---|---|---|---|---|---|---|
| **Aspect** | **Slope** | | | | **Slope** | | | |
| | 0 < 10° | 10–20° | 20–30° | > 30° | 0<10° | 10–20° | 20–30° | > 30° |
| **South** | 236 | 208 | 166 | 123 | 188 | 163 | 131 | 96 |
| **SW/SE** | 236 | 212 | 173 | 130 | 188 | 167 | 137 | 103 |
| **West** | 236 | 226 | 198 | 161 | 188 | 180 | 159 | 132 |

| | **Wiesbaden-Biebrich** | | | | **Hochheim** | | | |
|---|---|---|---|---|---|---|---|---|
| **Aspect** | **Slope** | | | | **Slope** | | | |
| | 0 < 10° | 10–20° | 20–30° | > 30° | 0 < 10° | 10–20° | 20–30° | > 30° |
| **South** | 241 | 212 | 173 | 132 | 221 | 193 | 155 | 115 |
| **SW/SE** | 241 | 216 | 180 | 140 | 221 | 197 | 161 | 122 |
| **West** | 241 | 230 | 205 | 172 | 221 | 210 | 185 | 152 |

**Tab. 2.** Moisture surplus (in mm) for soils with low available water capacity (100 mm) at different stations in the Bergstrasse region

| | **Gross Umstadt** | | | | **Bensheim** | | | |
|---|---|---|---|---|---|---|---|---|
| **Aspect** | **Slope** | | | | **Slope** | | | |
| | 0 < 10° | 10–20° | 20–30° | > 30° | 0<10° | 10–20° | 20–30° | > 30° |
| **South** | 321 | 289 | 244 | 193 | 422 | 382 | 321 | 254 |
| **SW/SE** | 321 | 294 | 252 | 202 | 422 | 387 | 329 | 263 |
| **West** | 321 | 309 | 280 | 239 | 422 | 404 | 361 | 303 |

**Tab. 3.** Moisture surplus of the same soils with low available water capacity (100mm) on level sites at different locations

| | avg. | median | max. | min. | st.-dev. | coef.-var. | max. moisture surplus in % of years | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 10 | 25 | 50 | 75 | 90 |
| **Lorch** | 236 | 255 | 466 | 26 | 120 | 50,8 | 64 | 150 | 255 | 340 | 376 |
| **Geisen-heim** | 188 | 181 | 386 | 20 | 97 | 51,5 | 52 | 109 | 181 | 250 | 301 |
| **Wiesbaden-Biebrich** | 241 | 242 | 413 | 32 | 92 | 38 | 130 | 172 | 242 | 318 | 358 |
| **Hochheim** | 221 | 208 | 473 | 34 | 112 | 50,7 | 70 | 149 | 208 | 300 | 380 |
| **Bensheim** | 422 | 410 | 698 | 172 | 157 | 37,3 | 213 | 300 | 410 | 567 | 652 |

Average soil moisture surplus values from long-term observations obscure the effects of annual fluctuations and intensities. This is exemplified in Table 3, which shows the distribution of calculated values around the average value and the expected annual soil moisture surplus for very shallow soils.

According to these values, the probability that annual soil moisture surplus will not exceed 64 mm in the Lower Rheingau is 10 %. Furthermore, there is a 25 % probability that annual soil moisture surplus will attain a value up to 150 mm.

A maximum of 109 mm annual soil moisture surplus can beexpected in 25 % of the years for the area around Geisenheim. In contrast, the probability of a maximum annual soil moisture surplus of 130 mm is 10 % for the area around Wiesbaden.

In the Bergstrasse region, the annual soil moisture surplus may reach 213 mm in 10 % of the years and even 300 mm in 25 % of the years.

## 2. The map of nitrate leaching potential

To facilitate the task of evaluating such a large volume of data, the leaching potential was differentiated into 8 available water content (AWC) classes.

The evaluation is based on the AWC of the soils. The leaching potential of waterlogged soils is offset by potential denitrification, longer retention times (therefore increased plant uptake) and a non-quantifiable lateral nitrate input and output due to interflow.

| Class | soil water surplus | Leaching potential |
|---|---|---|
| Class 1 | <100 mm | very low |
| Class 2 | 100–<150 mm | low |
| Class 3 | 150–<200 mm | low to intermidate |
| Class 4 | 200–<250 mm | intermediate to high |
| Class 5 | 250–<300 mm | high |
| Class 6 | 300–<350 mm | high to very high |
| Class 7 | 350–<400 mm | very high |
| Class 8 | >400 mm | extremely high |

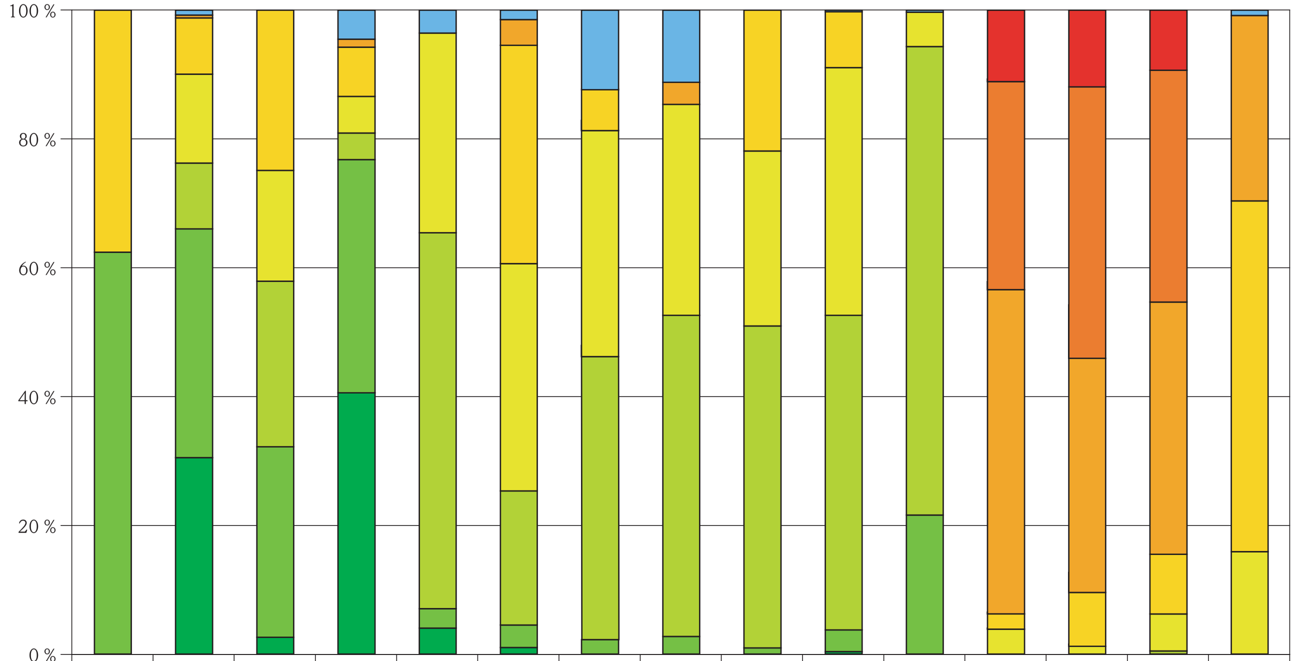
Similar problems were encountered with groundwater-influenced soils. Because of the fluctuating groundwater levels, the water budget of these soils is not only determined by precipitation and evaporation. These locations were always downgraded by a single class regardless of the calculated category (higher risk of translocation). In contrast to the simplified method based on the annual average climatic water budget, the present evaluation procedure also shows that the nitrate leaching potential can be significant even in regions with low-precipitation. The map of nitrate leaching potentials verifies that high precipitation rates in the Bergstrasse region exacerbate the risk of nitrate leaching. However, the high water retention capacity of the loess-dominated soils and similar locations can limit the risk. According to the distribution of these soils, the risk is limited on the lower slopes but high in the middle and top slope locations with their coarse and shallow soils.

The nitrate leaching risk in the remaining wine-growing areas tends to be lower due to reduced precipitation rates. The Middle Rhine Valley wine-growing region must be mentioned in this context since it is characterized by a small-scale variability of habitat conditions. Coarse soils of the steep slopes with low water retention capacities are located next to lower slope locations with high AWCs. Precipitation rates in the Rheingau gradually increase between Rüdesheim and Wiesbaden.

This has a concomitant effect on the nitrate leaching potential. The low precipitation rates of the Maingau and wide-spread occurrence of soils with a high water retention capacity result in low to moderate nitrate leaching potentials. Figure 1 presents a statistical overview of the nitrate leaching risk.

## 3. Summary

In contrast to previous methods for analyzing nitrate leaching potential, the present survey of the wine-growing regions of Hesse takes into account actual evaporation from conventional clean-cultivated sites under vine. This survey shows that the most important factor is the spatial and temporal distribution of precipitation. The high nitrate leaching potential calculated for the vineyards of the Bergstrasse is largely determined by the high precipitation rates in the region. Some leaching is also to be expected in the Rheingau and Maingau, despite lower precipitation rates. The reasons for this are the geographical position of the soils (exposure, slope) and their inherent poor water retention capacities.




| | no collective vineyard | Burgweg | Steil | Ernte-bringer | Gottesthal | Mehrhölz-chen | Deutels-berg | Honigberg | Heiligen-stock | Stein-mächer | Daubhaus | Rott | Wolfs-magen | Schloßberg | no collective vineyard Groß-Umstadt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rheingau | | | | | | | | | Maingau | Hess. Bergstraße | | | |
| extremly high GWS | | 5,6 | | 33,0 | 10,4 | 5,1 | 39,0 | 28,4 | | 2,0 | 1,4 | | | | 0,9 |
| extremly high | | | | | | | | | | | | 19,3 | 19,5 | 32,0 | |
| very high | | | | | | | | | | | | 56,0 | 68,7 | 123,2 | |
| high | | 3,3 | | 9,0 | | 14,0 | 0,2 | | | | | 87,2 | 59,3 | 134,0 | 33,4 |
| middle to high | 1,6 | 64,3 | 22,8 | 56,1 | | 119,1 | 20,5 | 8,7 | 49,0 | 62,8 | | 4,1 | 13,6 | 31,8 | 62,7 |
| middle | | 102,0 | 15,8 | 41,7 | 91,1 | 124,0 | 111,4 | 83,1 | 61,0 | 279,1 | 22,7 | 6,8 | 2,0 | 19,6 | 18,2 |
| low to middle | | 75,4 | 23,5 | 30,2 | 171,4 | 73,1 | 139,6 | 126,4 | 112,0 | 354,3 | 308,2 | | | 1,6 | |
| low | 2,7 | 261,8 | 27,1 | 265,1 | 8,9 | 12,3 | 7,2 | 6,9 | 2,2 | 24,4 | 91,5 | | | | |
| very low | | 225,0 | 2,4 | 296,9 | 11,8 | 3,6 | | | | 2,9 | | | | | |

**Fig. 1.** Area proportion of potential nitrate leaching risk classes in collective vineyards (Proportion in the collective vineyard - Graphic; Area in ha - Table).

## 4. References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