Long-term trapping efficiency of a vegetated filter strip under agricultural use

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Dedicated to Prof. Dr. U. Schwertmann on the occasion of his 65th birthday

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Summary - Zusammenfassung

In a hops-producing area long-term average trapping effectiveness of a grassed filterstrip under agricultural use was measured. Copper, applied as fungicide, was used to identify the colluvium in a meadow below a hop garden. 9.5 t material were trapped during 17 years per m width of the filterstrip. This annual accumulation of 540 kg/m width represents a trapping efficiency of 55 % of the computed annual soil loss of the hop garden. The results agree with other publications which report the trapping efficiency for a longer period, whereas the reported results of short-term experiments largely overestimate the efficiency.

Langfristige Filterwirkung eines Grasfilterstreifens unter landwirtschaftlicher Nutzung


Introduction

Soil erosion pollutes aquatic ecosystems by sediment and nutrient input, which also increase the cost of stream maintenance. To protect the streams, grassed filter-strips along the streams are recommended. The strips should reduce runoff reaching the stream because of their higher infiltrability, as well as reduce transport capacity and flow velocity because of higher friction coefficients (Hayes and Barfield, 1982). Both cause sedimentation. To reduce sediment to a given value, the literature recommends different necessary filter-lengths. Neibling and Alberts (1979) found, that a filter of 2.44 m length can remove about 95 % of sediment, while Barfield and Albrecht (1982) demand 40 m for an effectiveness of 75 %. This difference can be explained by different ages of the studied filter systems. While Neibling and Alberts (1979) examined new filters, Barfield and Albrecht (1982) measured over a period of 9 months. During this time, the effectiveness dropped from 99 to 75 %. Neither study determined the long-term effectiveness, and none of the examined filter-systems were located on productive land. Because the optimized conditions of test plots cannot be maintained under field conditions, we determined the long-term effectiveness of a filter-stripe under normal agricultural use, using copper as a tracer. Copper is applied as a fungicide in hops production. It accumulates with increasing cultivation length, because it adsorbs strongly to soils (McBride, 1981). It is only exported in association with soil material (Rieder and Schwertmann, 1972). The loss of Cu was used by Schwertmann and Huiih (1975) to quantify the average erosion rate during the cultivation period of hops. For this study, we used Cu as a tracer in the area of deposition. It allows the differentiation of sediment that was accumulated since the beginning of usage of Cu on the field upslope from older colluvial sediments. Because the time, over which Cu is used, is known, the average annual deposition rate can be quantified.

Material and Methods

Test site: On a field about 30 km northwest of Freising / Bavaria, hops were grown for 17 years and frequently treated with Cu-containing fungicides. These treatments increased the EDTA-extractable Cu content from the native value of 5 mg/kg soil to 35 mg/kg soil. The hops were planted in direction of slope. The slope steepness of the 176 m long field varied between 5 and 13 %. During the last three years,
intercrops were cultivated to reduce erosion. Soil texture varied from clay loam on the upper slope to sandy loam downslope. Soil type is a brown earth (Eutrochrept) derived from loessial loam. Average annual temperature of the region is 7.8°C, annual rainfall is 800 mm.

Grassland extended 35 m to the river Prambach downslope the hop garden. This direction is called the filter-length. The slope of the filter-area varied between 5 and 12%, with an average of 8% (Fig. 1). For 12 years, it was used as a meadow. During the last 5 years, it was cut 3 times a year. The vegetation consisted of 10% herbs, 60% tall grass and 30% short grass. This causes a seasonal variation of soil cover. The tall grasses suppress the short grasses at the beginning of the growing season. At this time, the soil surface between the plants is not covered. After the first cut, short grasses and herbs can grow up and cover almost the entire surface.

Soil sampling: The colluviation was studied along 4 transects that were 4.8 m apart and covered a width of 19.2 m of the grass-filter. Along each transect 10 locations with a distance of about 3.3 m were sampled with an auger (40 sampling points). One meter deep soil cores were taken, divided into 5 cm increments (800 samples) and analyzed for Cu. At one transect, grain size distribution was analyzed as well.

Laboratory analysis: Bulk density in 5-10 cm depth was measured with randomized collected core samples. Density was 1.2 g/cm³ in the hop garden and 1.59 g/cm³ in the filter. For grain size distribution, the fractions >100 and 63-100 μm were sieved; the smaller fractions were determined by sedimentation after ultrasonic dispersion of 10 g air-dried soil in Na₂P₂O₇-solution. Cu was extracted from 2 g air-dried soil with 50 ml 0.05 M EDTA during 2 hours and measured with AAS. EDTA was used to extract mainly fungicide Cu and only a small amount of native Cu and thus improving identification of the colluvial material from the hop garden.

Results

1. Soil loss in the hop garden

To calculate the effectiveness of a filter system, the sediment input has to be known. It was calculated for an irregular slope with the dUSLE (Auerwald et al., 1988) for the hop garden, using a R factor of 68, a K factor of 0.35-0.42 (determined for 20 m segments), a C factor of 0.78, a slope length of 176 m, and a slope steepness of 5-13% according to Schwertmann et al. (1987). The calculated average annual soil loss is 55.5 t/ha. 18.7 t/ha/a enter the filter over the studied width of 19.2 m. Per m width an average annual sediment input of 975 kg can be expected.

2. Copper content in the filter

The concentration of EDTA-extractable Cu in the topsoils varied between 10 and 60 mg/kg soil. It decreased with depth to the native concentration of 5 mg/kg (Figure 1), indicating the sedimentation of eroded material from the hop garden. The depth-functions of the four sampling points across the slope were very similar, whereas they changed with increasing filter-length (Figure 1). At the 4 sampling points, situated close to the stream, concentration did not decrease down to a depth of 60 cm. We suspect that Cu-containing material was sedimented during flooding of the river Prambach or was excavated during the maintenance of the stream. This indicates, that the material does not originate from the examined hop garden. Therefore, these sampling points were excluded from further calculations.

The Cu concentration decreases linearly with depth during the first 6 m filter-length. The slope of the regression represents the annual increase of Cu concentration of incoming sediment, caused by an increasing accumulation of Cu in the hop garden. From the slope of the depth-function an annual increase of about 2.5 mg/kg/a can be computed. This increase can also be calculated by the formula of Schwertmann and Huith (1975):

\[
a = \frac{k \cdot k_i}{\Sigma(1-x/b)^a}
\]

(Eq 1)

where

\[\begin{align*}
    & a \quad \text{annual increase of Cu concentration (mg/kg)} \\
    & k \quad \text{present Cu concentration (mg/kg)} \\
    & k_i \quad \text{initial Cu concentration (mg/kg)}
\end{align*}\]

35.9

5

Figure 1: Depth function of Cu concentration with increasing filter-length

Abbildun 1: Cu-Tiefenfunktion bei zunehmender Filterlänge
x annual soil loss (cm) 0,46
b depth of tillage (cm) 16
n duration of Cu application (a) 17

The calculated annual increase is 2,34 mg/kg. An enrichment of Cu by a factor of 1,09 can be expected in the sediment for the average soil loss of the hop garden according to Auerswald (1989). The calculated annual increase of Cu concentration in the sediment of 2,55 mg/kg (2,34 x 1,09) is very close to the measured increase (2,5 mg/kg). Therefore no important distortion by burrowing animals should have taken place in the first 6 m of the filter.

With increasing length of the filter, the slope of the regression Cu content/depth increases, and the Cu concentration at the surface decreases slowly (Figure 1). Because there is no change in clay content along the filter-length, the Cu concentration at the surface of the filter should remain equal. The decreasing Cu content at the surface can be attributed to a mixing of younger, Cu-containing deposits with untreated older deposits, caused by earthworms and livestock trampling. Because the accumulation of sediment becomes thinner, the mixing becomes more intensive at the lower part of the filter, leading to lower concentrations at the soil surface.

3. Calculation of sediment thickness

To calculate the original thickness, the influence of mixing subsoil into the sediment has to be eliminated. The mean concentration of the first two sampling points is 48,8 mg/kg soil. Almost the same value (48,3 mg/kg) can be expected from the annual increase of Cu, length of Cu application and geogenetic background. With this suspected copper content at the surface (48 mg/kg) and the Cu content of each profile, the true depth was calculated. If this mixing is not taken into account, the total trapping efficiency would be 24 % higher.

From thickness and bulk density, the average sediment was computed as the mean of the four sampling points with the same distance from beginning of the filter. In total, 540 kg/a/m width were found (Figure 2). The sedimented soil per m² decreases with filter-length. While about 60 kg/m² are trapped annually at the beginning of the filter, after 15 m only 10, and after 30 m only 6 kg/m² are applied (Figure 2). The deposition per m filter-length can be calculated by:

\[
\ln Y = 5,01 - 0,94 \cdot \ln X; \\
\text{r}^2 = 0,961^{***}; \ n = 9
\]

(Eq 2)

\[X = \text{Filter-length (m)}; \ Y = \text{Deposition rate (kg/a/m width)}\]

While the effectiveness of the filter decreases with filter-length, the total deposition increases (Fig. 2):

\[
Y = -304 + 369 \cdot X^{0,25}; \\
\text{r}^2 = 0,999^{***}; \ n = 9
\]

(Eq 3)

\[X = \text{Filter-length}; \ Y = \text{cumulative Deposition (kg/a)}\]

4. Grain size

All grain size fractions are sedimented from the beginning of the filter (Figure 3). Especially the clay content remains constant during the first 25 m (average = 16,7 %; std.dev = 1,3). This indicates, that a large part of sediment is deposited as aggregates. Also sand can be found over all the distance, what may be caused by erosion events of varying severity.

Nevertheless, there is a distinct sorting of sizes along the filter. At the first 13 m, sand is predominantly trapped, but it is assumed that also large aggregates are deposited over
this length. With increasing filter-length, the size of the deposited aggregates and primary particles becomes smaller; the silt fraction increases. After 20 m, also the silt fraction begins to decrease slowly, while clay increases. The sharp decrease in trapping efficiency over the first 10 m (Fig. 2) can be explained by this size sorting. The quick-settling sand-sized particles are removed from the sediment after this distance. For the removal of smaller particles, the transporting capacity has to be lowered by increasing infiltration or decreasing slope. Therefore, only a small amount (< 2 % per m) of the remaining sediment will continue to be deposited. The mixing of older deposits with deposits from the hop garden was not considered in the grain size distribution. The field upslope the filter was already cultivated before it was used as a hop garden. Therefore, the old and young colluvium should have a similar grain size distribution.

Discussion

As an average, 540 kg/a/m width are trapped. For a calculated input of 975 kg/a/m width, almost 60 % of the eroded soil will remain in the filter. In spite of a 30 m filter-strip, about 400 kg soil/a/m enter the stream. This high percentage of untrapped sediment is reasonable because even at the end of the filter, deposition could be detected and the riverbed contained Cu-bearing sediments. Also, the good agreement of Cu enrichment, that was predicted from the calculated soil loss and the measured Cu enrichment, indicates a correct calculation of the soil lost.

A shortening of the filter would increase the input into the stream. In Germany, filter-lengths of 5 or 10 m are discussed (Schultz-Wildau et al.; 1990). At this length, the examined filter would catch 260 or 380 kg soil/a/m. This corresponds to approximately 26 or 39 % of incoming material.

The filter, studied by Barfield et al. (1982), trapped 75 % of incoming material at a length of 40 m (slope 17 %). This is similar to our measurement. The effectiveness of our filter at a length of 40 m, extrapolated with Eq 3, is 64 %. The difference can be explained by a shorter measuring period of their plot, the optimum maintenance of their filter (no agricultural use) and the lack of clay in the incoming sediment. As Wilson (1967) showed, there is an inverse relationship between the filter-length necessary to reach a desired effectiveness, and the diameter of particle size. He found increasing clay content up to 120 m. This value can be calculated for our filter, too, if the length with an expected effectiveness of 100 % is calculated by Eq 3.

The low efficiency of filter strips demands two conditions in land use to protect stream water quality. First, soil erosion on cultivated land has to be reduced as far as possible. Efficient methods, like mulch tillage, are available to accomplish this (Schwertmann et al., 1989). Second, the wide riparian areas, that increasingly have been put under corn in the last decades, should be returned to meadow to ensure sufficient long filter-paths.

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Literature


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