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ADVANCING INTELLIGENT MITIGATION

VEGETATIVE BUFFER STRIPS

A Proven Field Mitigation Measure to Reduce Pesticide Runoff from Agricultural Fields

In this short summary paper the current knowledge about the effectiveness of vegetative buffer strips for the mitigation of pesticide transport via surface-runoff from agricultural fields is summarized.

Edge-of-field vegetative buffer strips

Literature Reviews on the Effectiveness of Vegetative Buffer Strips

In a recent comprehensive paper about mitigation strategies to reduce diffuse source pollution of ground and surface water with pesticides, Reichenberger et al. (2007) reviewed 180 relevant publications in this area and used the data from 16 studies for quantitative evaluation of buffer strip effectiveness versus run-off transport of pesticides. In general, potential practices to mitigate run-off transport of pesticides from fields were grouped into the following six basic options:

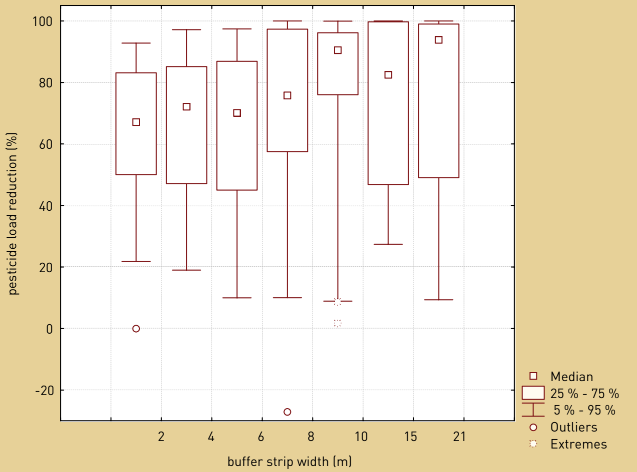
- Edge-of-field vegetative buffer strips (or vegetative filter strips (VFS))
- Riparian buffer zones
- Grassed waterways in areas of concentrated surface flow
- Constructed wetlands to retain surface run-off water
- In-field farming measures (conservational tillage, mulching, cover-crops, contour ploughing, grass strips between vineyard rows)
- Change of application methods (reduction of application rate, band spraying, use of micro encapsulated formulations, soil incorporation, optimisation of application timing).

Edge-of-field buffer strips and riparian buffer zones are also an essential part of the toolbox to mitigate drift to surface water bodies.

Factors Driving the Efficiency of Vegetative Buffer Strips

Reichenberger et al. (2007) conclude that the general effectiveness of edge-of-field buffer strips to reduce run-off transport of pesticides has been proven, but that their efficacy in reducing runoff during an individual rain event varies among individual rain events and also depends upon site conditions (e.g. precipitation rate, antecedent soil moisture). The buffer width was identified as only one factor among others that affects reduction efficiency; its influence seems to be clearer when average reduction rates are considered, but less so on the range of reduction values observed for a specific filter strip system. For the 16 studies investigated in detail, the authors report an average pesticide run-off reduction value ranging from 65 % with buffers up to 2 m in width to 95 % for buffers about 18 m in width; the 25th percentile of the reduction efficiency is in the range of 45 to 75 %. The authors concluded that, at least for buffer strip widths greater than 8 m, load reduction efficiencies tended to be larger for pesticides with the major portion transported in the sediment phase than for pesticides predominantly transported in the water phase and **that "on average" buffer strip efficiencies are "roughly comparable" to a "50 % reduction for 5 m width, a 90 % for 10 m width, and 97.5 % for 20 m width" for all pesticides, run-off volume and sediment.**

The authors stress that **buffer strips show low pesticide removal when concentrated flow enters** their upper boundary and that under these conditions reduction efficiency will be greatly overestimated using the average values reported above. Consequently, **the exclusive use of riparian buffer strips will lead to less run-off mitigation, when compared with a combination of riparian and edge-of-field buffer strips**, due to the higher probability of concentrated runoff forming on the catchment slopes before entering the buffer strip. However, riparian buffer strips are highly effective for drift reduction and also play an important ecological role. Besides the installation of buffer strips, **in-field farming measures are seen as key to reduce the probability of surface-runoff**.



Pesticide load reduction efficiencies of edge-of-field buffer strips vs classified buffer strip width

From: Reichenberger S., Bach M., Skitschak A. & Frede H.-G. (2006). State-of-the-art review on mitigation strategies and their effectiveness. Report DL#7 of the FP6 EU-funded FOOTPRINT project [www.eu-footprint.org], 76p.

Conservation tillage, contour ploughing, and cover crops play a particularly important role; these practices are also proven effective anti-erosion measures. In heavy soils and landscape positions prone to frequent water logging, sub-surface drains are an effective tool to reduce surface-runoff from saturated soil surfaces, although pesticides can also be transported to surface water via drainage water.

If required by the topography of a catchment, **grassed waterways can be a highly effective measure** to stop or reduce concentrated surface-runoff in channel-like landscape positions. **Constructed wetlands/infiltration ponds have proven to be highly effective** in retaining surface run-off water in riparian landscape positions where surface-runoff occurs; however, construction and maintenance costs are required to implement these measures.

In some circumstances, **changes in application timing** (avoiding periods of heavy rainfall) and treatment method (e.g. soil incorporation, banded application) can further **reduce the run-off transport of pesticides** to surface waters.

Importance of Pesticide Properties

Another recent review paper of Arora et al. (J. Environ. Qual., submitted) evaluated the results of 38 studies, including most of the studies reviewed by Reichenberger et al. (2007), to quantify the retention efficiency of buffer strips for pesticides. The main process that mitigates the run-off transport of pesticides from fields is the retention of run-off water and sediment mass in the filter strips. Over the wide range of conditions and filter strip widths in these studies, on average the volume of run-off water and sediment mass was reduced by 45 % and 76 %, respectively. The overall average retention of weakly adsorbing pesticides ($K_{OC}<100$) was 62 % (range: 0-100 %), of moderately adsorbing pesticides ($100<K_{OC}<1000$) was 63 % (0-100), and of strongly sorbing pesticides ($K_{OC}>1000$) was 76 % (53 to 100 %). Because more data were available to quantify run-off volume and sediment mass retention than pesticide retention, **the authors used these data to estimate that the average pesticide retention was 46, 51, and 70 % for the three sorption classes** ($K_{OC}<100$, $100<K_{OC}<1000$, and $K_{OC}>1000$, respectively).

Lower field length to VFS ratios generally reduce the amount of run-off water entering the filter strip and therefore increase its effectiveness for water retention. To be practical and effective the field length to VFS ratios should lie between 10 and ≤50.

Riparian vegetative buffer strip

The variability of pesticide retention results is mainly the result of the variability of the experimental events, and some of the extreme events most likely represent conditions seldom encountered in real field conditions. Arora et al. conclude that average pesticide retention of the reported data would be expected to more closely represent the true performance characteristics of buffer strips. Buffer width is more important for retention of strongly adsorbing pesticides than for weakly to moderately adsorbing pesticides, as the retention efficiency for sediment mass is more closely correlated with buffer width.

Both reviews identify that it is practically impossible to evaluate, on field scale, all combinations of site and hydrologic factors and pesticide properties to establish the optimal pesticide retention by buffer strips and Arora et al. conclude that a model that can analyse these combinations needs to be developed and validated.

A Mechanistic Model to Predict the Efficiency of Vegetative Buffer Strips

A mechanistic filter strip model (VFSMOD-W) has recently been developed by Sabbagh et al. (2009). The authors used data from five experimental studies to test the hydrological/sedimentological VFS simulation model (VFSMOD; Munoz-Carpena et al., 1999; Munoz-Carpena and Parsons, 2004) for its use as prediction tool for pesticide retention in VFS. The main processes influencing pesticide trapping efficiency in this model are phase partitioning of pesticides and the subsequent retention of surface run-off water and sediment in the VFS. In the studied experiments (a subset of high quality studies reviewed by Arora et al., submitted, and also included in Reichenberger et al., 2007), the buffer strip width ranged from 0.5 to 20.1 m, minimum reduction of water volume ranged from 4 to 85 %, and maximum reduction from 73 to 100 %; for reduction of sediment mass transport the minimum and maximum ranges were 41 to 100 % and 93 to 100 %, respectively. Consequently, the overall minimum reduction of pesticide runoff from VFS ranged from 8 to 98 % and the maximum reduction from 98 to 100 % for the evaluated studies.

Sabbagh et al. (2009) identified that soil moisture status of the buffer is an important factor affecting its performance in retaining pesticides. The overall retention of water in a buffer strip (expressed as a percentage of the water entering the buffer strip) decreases with increasing rainfall intensity and decreasing buffer width. As the retention of water and sediment by a specific VFS is also a function of the rainfall event (rate and quantity) and the antecedent soil moisture, the percent of pesticide removal for a specific buffer strip can vary significantly from event to event. Since pesticide retention is dependent on the antecedent moisture content of the buffer soil (infiltration of water decreases with increasing soil moisture content), VFSs are generally not very effective when the soil is saturated. The results showed that **VFSMOD-W provides significantly improved pesticide trapping predictions compared to approaches based solely on field slope and VFS width**.

In an experimental study, Poletika et al. (2009) tested the influence of different run-off situations (variation of run-off volume and flow concentration) on pesticide retention in a VFS with a width of 4.6 m. The study was also used to test the predictive power of VFSMOD-W for the provided experimental conditions. The results showed that the effect of VFS on run-off volume and sediment trapping efficiency was reduced when concentrated flow (channelled over 10 % of the filter strip area) entered the filter

Grassed path

strip (runoff: average 16 %, range: 5 to 27 %; sediment: 31 %; range: 11 to 54 %), as compared to uniform flow (runoff: 59 %, range: 43 to 77 %; sediment: 88 %; range: 79 to 94 %). These values were not significantly different for field length to VFS ratios of 15:1 and 30:1. **VFSMOD-W was able to predict the run-off water, sediment, and pesticide trapping efficiencies adequately for uniform and concentrated flow conditions for this field study**.

Using VFSMOD, Dosskey et al. (2008) simulated the influence of slope, slope length, soil texture, and crop/soil management (USLE C factor) to determine the effectiveness of VFS for run-off water and sediment trapping efficiency. The authors then derived sets of graphical curves as a decision-making tool showing the relationship between buffer strip widths and trapping efficiencies. **In summary, a trapping efficiency of 60 % for run-off water and sediment can be achieved for most soil types, when slope ≤2 %, C factor ≤0.50, and slope length ≤200 m, using a buffer strip of 8 to 10 m width**. Under more unfavourable conditions (finer soil texture, higher slope, longer slope length, higher C factor), the length of the slope must be reduced, or the filter strip width increased appropriately. Equally, a narrower strip can be effective, when better crop/soil management is practiced, the slope is lower, or the length of the slope is smaller.

Application of Vegetative Buffer Strips in Practice

A recent document (USDA, 2000) providing guidance on buffers established in the U.S. to reduce pesticide run-off losses draws the following conclusions:

1. **Vegetative buffer strips are an effective tool to reduce pesticide losses to water. Many studies found pesticide trapping efficiencies for VFS of 50 % and more.**
2. **A maximum buffer strip width of 50 feet (about 15 m) is adequate for most cases; a minimum width of 30 feet (about 9 m) is recommended by USDA- However, no significant correlation between buffer width and pesticide entrapment efficiency was found: where space and costs are crucial, "a narrow buffer is better than no buffer at all"**. Additional work by USDA (Williams et al., 2009), has shown that the uppermost portion of the buffer provides the most retention of pesticides per unit length.
3. **According to NRCS, field to VFS ratio should be <70 for less endangered fields, and <50 for highly endangered fields.**
4. **For optimum effectiveness, VFS need to be used in conjunction with other BMPs** (best management practices), such as integrated pest management, banded applications, optimizing pesticide application time, reducing pesticide availability for run-off transport (soil incorporation, if feasible), and minimizing runoff from fields (conservation tillage, contour planting, strip cropping, terraces, compaction reduction, irrigation timing, subsurface drainage).
5. **Vegetative buffer maintenance is critical for their effectiveness:** removal of sediment, reestablishment of vegetation (if necessary), mowing, and avoiding compaction (no tractor turning on VFS) are important in this respect.
6. Perennial grasses with stiff, upright stems near ground level that form sods (instead of clumps) are preferred vegetation in VFS.

As mentioned earlier, a critical factor for successful prevention of pesticides movement to surface water is avoiding concentrated flow and this should be reflected in the placement of VFS by considering the flow regime of surface water in a catchment. Optimally, VFS should be preferentially positioned at locations near the origin of any runoff.

One non-technical factor for the successful adoption of VFS is the existence of an appropriate regulatory framework and economic incentives. Past experience has shown reasonable acceptance of VFS when coupled with farmer compensation schemes related to production or environmental benefits (VFS also have benefits related to enhancing biodiversity and reducing nutrient losses).

Overall Conclusions

Between-rows grass strips

1. The effectiveness of vegetative buffer strips to reduce the loss of pesticides via surface-runoff from agricultural fields has been shown beyond reasonable doubt. Although the timing and intensity of rain events and site conditions influence the effectiveness of buffer strips, average reduction values of ≥50 % for 5 m buffer strips and ≥90 % for 10 m buffer strips can reasonably be expected for all pesticides. For lipophilic pesticides (KOC>1000) a reduction of ≥75 % can be expected for 5-m buffer strips, due to the higher reduction efficiency of VFS for sediment mass than for run-off water volume. Particularly on the catchment level, such average reduction values can reasonably be assumed to be valid, because individual site conditions and rain events within a catchment mirror the variability observed in the different field studies with VFS.

2. An understanding of the soil hydrology is critical for a prediction of vegetative buffer strip performance on a rain event basis. The removal efficiency for pesticides is strongly related to the size of the storm event and the antecedent soil moisture conditions in the VFS. Consequently, VFS efficiency for pesticide removal is substantially reduced when the soil is approaching saturation. Critical parameters affecting pesticide removal are the amount of sediment and run-off water retained in the VFS.

3. The average removal efficiency of vegetative filter strips for pesticides is also significantly reduced when surface-runoff does not uniformly flow through buffer zones (sheet flow conditions), but instead flows in channels through the buffer zone. Such concentrated flow needs to be minimized through in-field BMPs for soil and vegetation cover management (e.g. contour planting, conservational tillage), as well as by adequate maintenance of VFS (sediment removal, regular mowing, avoiding compaction).

4. Edge-of-field vegetative buffer strips are, in addition to riparian buffer strips, necessary to minimize the concentrated surface-runoff on the catchment level. The field length to VFS ratio should be adapted to slope and soil texture conditions and not be >50.

5. If required by the topography of the catchment, grassed waterways (for slope channels) and constructed wetlands (for riparian areas with highly probable to inevitable surface-runoff) should be considered.

6. VFSMOD-W is a valuable and validated tool to predict the effectiveness of VFS for reduction of pesticide runoff via run-off water and sediment on an event-by-event basis and support the design of vegetative filter strips in practical risk management applications. VFSMOD-W can be used to quantitatively estimate the impact of VFS in risk assessments based on the FOCUS step 3 runoff scenarios.

While buffer strips of greater width are more effective than narrower ones, the width of the buffer strip in the field should be primarily determined by site conditions and economic evaluations. Positioning the buffer zone nearest to the vulnerable field is usually the most effective, as flowing run-off water tends to coalesce into concentrated flow as it passes downhill. As a result of this coalescence, a buffer twice as wide is not usually twice as effective. Nevertheless, the field length to VFS ratio is an important factor to consider, because it directly affects the amount of water entering the buffer strip when surface-runoff occurs in a field. While the USDA-NRCS recommends a minimum width of 9 m for VFS, this statement must be considered with caution, since the typical rainfall intensity and size of fields in the U.S. are, in many instances greater than in most areas of Europe. Studies conducted under European conditions have shown that buffer strips of 5 m are effective tools for pesticide retention in many situations. The use of the process-based model VFSMOD-W has potential to aid the design of buffers across a range of scenarios throughout Europe and to quantify their impact in risk assessments performed during product registration.

Although recommendations for implementing buffer strips exists in the USA and selected EU member states (e.g. France -CORPEN, 2007), no EU guidance has yet been developed. Within the ECPA-funded AIM project, blueprint EU BMPs for implementation and maintenance of riparian and edge-of-field buffer strips are currently being developed. In a second step, the proposed ECPA project PROWADIS (Protecting Water from Diffuse Pollution; submitted for EU Life+ project funding) will integrate these BMPs into a toolbox of mitigation measures against diffuse pollution, using catchment- and field-level audit and diagnosis tools.

Constructed wetland

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