NM1591

VEGETATIVE FILTER STRIPS

Reduce Feedlot Runoff Pollutants

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What are Vegetative Filter Strips?

Due to rapid growth of small and medium-size animal feeding operations, the major issue facing animal agriculture is managing nutrients and pathogen runoff from land application of manure and feedlot areas. According to Koelsch et al. (2006), runoff from feedlots can be a major contributor to surface and groundwater impairment. Thus, establishing a treatment system that effectively contains or reduces runoff pollutants from feedlots and manure storage areas and during land application of manure is important. Vegetative filter strips/vegetative treatment systems have become an important best management practice to minimize runoff from feedlots (Gilley et al. 2008; Woodbury et al., 2003; Andersen et al., 2009) and land application (Sanderson et al., 2001; Duchemin and Hogue, 2009).

According to the U.S. Department of Agriculture's Natural Resources Conservation Service, vegetative filter strips (VFSs), also known as vegetative buffer strips, buffer strips or buffers, are areas of permanent vegetation established to intercept sediments, nutrients, pesticides and other pollutants from runoff before the runoff reaches a water body. VFSs are installed at the end of an agricultural field, alongside any surface water body or anywhere downstream of a diffused pollutant source.

Many different VFS designs exist. A typical vegetative treatment system consists of a settling basin for the collection of solids and a vegetative area for utilizing nutrients from runoff. They are effective in reducing nonpoint and point sources of pollution that affect surface water and ground water quality. However, to eliminate the settling basin, a new VFS design has been developed, as shown in Figure 1. It allows runoff from the feedlot to pass through the VFSs and maximize pollutant retention, then be dispersed evenly throughout the water-spreading area.

Many processes are involved in pollutant-reduction systems, including sedimentation, infiltration, sorption, plant uptake, dilution, volatilization, precipitation and decomposition.

When runoff flows through the VFSs, the velocity is decreased, and, consequently, the sediment-carrying capacity of the runoff decreases and particles settle. As a result, nutrients attached to sediment particles are retained in the VFSs, and, thus, downstream discharge of pollutants is reduced. As velocity decreases, runoff would have longer time to infiltrate into soil, and soluble nutrients will be removed with infiltrated water.

Vegetation also helps nutrient removal from the VFSs by taking up nutrients for their metabolism, as well as by adsorption on the plant surfaces and soil particles. However, the effectiveness of the VFSs varies widely depending on the vegetation types, buffer physical properties, hydrology and pollutant properties. The effectiveness of a VFS is further explained in this publication.

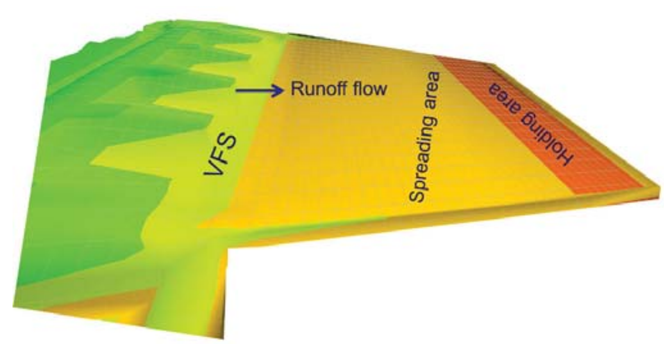

Figure 1. Layout of a feedlot's vegetative filter strips and water-spreading area (Source: Jim Hicks, Natural Resources Conservation Service, Fargo, N.D.)

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Factors Influencing Vegetative Filter Strip Performance

Pollutant type

Pollutants in runoff can be classified broadly in two categories: particulate-bound and soluble. Both can be removed from the runoff by using VFSs through different pollution-reducing processes. For instances, particulate-bound pollutants are removed by sedimentation, infiltration, sorption and other physical processes, but soluble fractions are removed through infiltration, sorption and other chemical processes.

The removal effectiveness of a particular fraction depends on the predominant mechanisms that occur in the VFSs. In most cases, sedimentation is a predominant mechanism. Pollutant reduction in terms of mass and concentration is greatest for sediment, followed by sediment-bound and soluble pollutants. Dillaha et al. (1988) suggested that soluble P (phosphorus) flows in solution (that is, independent of suspended sediment) and, therefore, transport is difficult to control.

Basically, soluble pollutants are less affected by the VFSs. The principle mechanism of soluble pollutant reduction is infiltration, so the removal effectiveness decreases with the duration of flow. Some soluble pollutants also are removed by sorption on soil particles (Schmitt et al., 1999; Mersie et al., 2003) and soil organic matter.

To increase the buffer strips' effectiveness in removing dissolved pollutants, soil amendment can be used. For example, Watt and Torbert (2009) applied gypsum in buffer strips as a soil amendment at a rate of 223 pounds/acre to reduce the transport of soluble phosphorous and found higher soluble phosphorous reduction (32 to 40 percent) as compared with an untreated plot (18 percent). However, calcium (Ca) may be needed in conjunction with the gypsum to reduce dissolved reactive P levels.

Other options are adjusting the soil pH to increase soluble phosphorus removal effectiveness. At higher pH levels, soluble P is bound with Ca and precipitates as Ca-phosphates and no longer is soluble. However, at a lower pH, Ca-phosphates are soluble in soil solution.

Soil type

Because soil is an important component of vegetative filter strip design and reduction capabilities, the performance of VFSs obviously will be affected largely by the soil's physical, chemical and biological properties. One of the major mechanisms of VFS effectiveness is infiltration, which is determined by the type of soil. Buffers established on sandy-loam soil will have less runoff volume compared with a clay soil.

Researchers found in a simulation study that a filter strip length of 3 to 13 feet is required for sandy clay soil, whereas 26 to 145 feet of filter length is required for clay soil to achieve similar sediment-trapping efficiency (Munoz-Carpena and Parsons, 2004).

Because the soluble portion of nutrients from runoff is removed by infiltration, soil type plays an important role in soluble nutrient transport reduction. Moreover, some pollutants are adsorbed on the soil particles' exchange sites. Thus, soil types with higher exchange sites play a significant role in pollutant removal.

Vegetation type

Generally, dense, standing vegetation is required for efficient filtration effect. Vegetation may increase surface roughness, resulting in reduced surface runoff velocity, thereby increasing deposition of sediment and decreasing transport of particulate-bound nutrients. Sediment and some nutrients are adsorbed on leaves and stems. Nutrient uptake by vegetation and its removal as biomass is also an important way to manage nutrients, which are released and transported from the concentrated animal feeding operations. Canopy density, root distribution and nutrient uptake are all affected by vegetation types.

Several studies have been conducted to identify the suitable species for establishing a VFS. These studies have shown that effective buffer species varied widely from region to region. In one study, researchers used different grasses (for example, perennial ryegrass, Kentucky bluegrass as sod, mixed grass species and no vegetation) to retain pollutants from mixed slurry, and they found that sod grass (Kentucky bluegrass) was the most effective to retain particulate-bound nutrients, followed by the perennial rye and mixed grasses, respectively.

However, sod and mixed grasses were equally effective in reducing the transportation of total suspended solids (TSS). Similarly, other researchers found that a warm-season forb (perennial sunflower) and warm-season grasses (switchgrass) were most effective in reducing P from runoff, followed by coastal Bermuda and cool-season grasses, while, switchgrass had higher effectiveness for longer periods of time than cool-season grasses due to uniform distribution of grasses and litter and a stiff stem. Similarly, crested wheatgrass and bromegrass are the most effective due to high basal areas and biomass yield.

Researchers agreed that plant density of a VFS is an important performance factor for selecting a suitable plant

Figure 2. Vegetative filter at the end of pen surfaces to treat runoff. (Shafiqur Rahman, NDSU)

species for a buffer. Similarly, nutrient uptake, especially P, by plants is another important selection criterion for selecting a buffer species.

One study suggested that the native grass in Elora, Ontario, Canada, was more effective in reducing P than ryegrass and red fescue. The study also showed that coastal Bermuda grass was more effective than sorghum and wheat. In addition, a mix of grass and trees also can be established as a VFS, and their effectiveness varies widely as well.

Under North Dakota climatic conditions, cool-season grass would be more suited to VFSs because it grows earlier in the spring and also has high water and nutrient use. Therefore, the selection of a vegetation type is very important, and it has to be done based on local management practices.

■ Buffer length and width

The effectiveness of VFSs depends on the length of the strips. In general, the longer the length, the higher the trapping efficiency. Greater widths also increase the opportunity for infiltration and sorption to vegetation and organic matter. Researchers observed that the effectiveness of a buffer strip enhanced as the length of the strips increased. However, the effectiveness decreased as the runoff event and pollutant loading rate increased.

Typically, greater width means higher trapping efficiency. However, about the first 16 feet of a buffer are more effective in reducing sediment and particulate-bound nutrients than the remaining buffer length. Basically, larger particles settle quickly in the first few feet of buffer strips, whereas smaller particles take a longer time to settle and travel longer distance. This means that filter length needs to be longer if pollutant removal, especially soluble nutrients, has to be maximized from runoff water.

Similarly, area ratio (defined as the ratio of the vegetated buffer area to the area that contributes runoff containing pollutants to the buffer area) also is an important factor to increase buffer effectiveness. A smaller area ratio results in an increased volume of runoff onto VFSs and reduces the VFSs' effectiveness. On the other hand, greater area ratio provides a longer runoff treatment time, leading to an increased opportunity for infiltration, and prolongs contact time for adsorption and an eventually increased VFS effectiveness. A 1-to-1 area ratio shows best performance (Webber et al., 2009).

■ VFS slopes

Slope has a predominant effect on the velocity of flow. As the slope increases, the velocity of flow increases, resulting in a low retention time for sufficient infiltration and sorption. Land slope also is a factor for the state of runoff flow, determining if it is overland sheet flow or concentrated channel flow, through the buffer and land areas.

Overland sheet flow is an essential prerequisite for effective buffer strip performance. This type of flow occurs on mild and uniform slopes; however, concentrated channel flow occurs in plots with steeper slopes.

VFS slope and soil types determine the lengths of VFSs. A longer VFS length is required on steep slopes and fine-textured soil. Typically, 0 to 10 percent slope can optimize the sediment-trapping capability of a vegetated buffer regardless of area ratio. However, if buffer is longer, a steeper slope may be required, which might cause soil erosion.

■ State of flow

The state of flow is a critical factor for buffer strip performance. Flow through the VFS may be overland sheet flow or concentrated channel flow. When the concentrated channel type flows occur, the VFS effectiveness is reduced compared with shallow overland flow. In shallow overland sheet flow, high flow resistance and reduced flow velocity likely would reduce the transportation of sediment and particulate-bound pollutants by sedimentation and provide more time for adsorption and infiltration.

On the other hand, in concentrated flow, runoff might flow through a small fraction of the total VFS area, which is likely to decrease infiltration volume, resulting in reduced VFS effectiveness. Concentrated flows sometimes submerge vegetation, causing reduced hydraulic resistance to flow and resulting in decreased effectiveness.

■ Time after establishment

With time and runoff events, changes in soil properties and vegetation occur within vegetative buffers. Through time, vegetation composition and density change and plant biomass decomposes and turns into soil organic matter, which affect buffer filtering and adsorption capacity. Decomposing vegetation on soil surfaces and plant roots in soil matrices may affect infiltration by creating preferential flow paths into soil, which can have a negative effect on VFS effectiveness.

Also through time, organic matter improves soil structure, increases aeration and augments activities of microorganisms. For instance, Duchemin and Hogue (2009) reported low effectiveness of vegetative filter systems in the first year after establishment due to limited vegetation cover. Similarly, Dosskey et al. (2007) found that buffer strip performance improved through time and reached full effectiveness within three growing seasons after establishment, and infiltration played a dominant role in pollutant attenuation.

With time, P and N removal efficiency decreases within the first few meters of filter strips as sediment and nutrients build up from prior runoff events (Dillaha et al. 1988). As a result, through time, buffer strips may become nutrient rich, and, subsequently, these nutrients may be released into future runoff events if sediment buildup is allowed.

Case Study

The performance of a vegetative filter strip at the down-slope end of a beef feedlot was evaluated under North Dakota climatic conditions. The average annual rainfall in the study area is 18.72 inches. The soil type is sandy loam and classified as hydrologic soil group A with a weighted curve number of 49. This feedlot was designed for 500 head of beef cattle with two pens, but only one pen was operational, and runoff was collected from that pen only. The pen was 250 feet long and 205 feet wide. An overall aggregate slope of 5.3 percent was achieved by incorporating mounds in the pen, with a perception that liquid would be separated quickly from solids at a steeper slope and buffer effectiveness would be increased as a result.

A 40-foot grass buffer strip was installed down slope of the feedlot with an assumption that runoff from the feedlot would pass through the buffer strip and maximize pollutant retention and then be dispersed evenly throughout the water-spreading area. The water-spreading area was graded with a slope of 0.53 percent for the first 289 feet and 0.47 percent for the remaining 288 feet. The wastewater was contained in a holding area within a dike system (Figure 1). The VFS area had a uniform slope of 2 percent.

Results indicated that, on average, the VFS was very effective in reducing the concentration of total solids (TS) by 33.7 percent, total suspended solids (TSS) by 68 percent, total phosphorous (TP) by 29.9 percent, ortho-phosphorous (OP) by 19.3 percent, ammonium nitrogen (NH_4-N) by 31.8 percent, total Kjeldahl nitrogen (TKN) by 35.6 percent and potassium (K) by 19.8 percent. Nitrate nitrogen (NO_3-N) concentrations at the outlet samples increased as expected. The buffer was not effective in reducing soluble nutrients. Some of the findings are shown in Figures 3-5.

Summary

The major issue facing animal agriculture is managing nutrients and pathogen runoff from the land application of manure and feedlot areas. Vegetative filter strips /vegetative treatment systems have become an important best management practice to minimize runoff from feedlots and land application. Performance of the VFS case study indicated that a VFS can be used for reducing runoff pollution that comes directly from a feedlot into a VFS without passing through a settling basin. Therefore, the selection of a vegetation type is very important and has to be based on management intention.

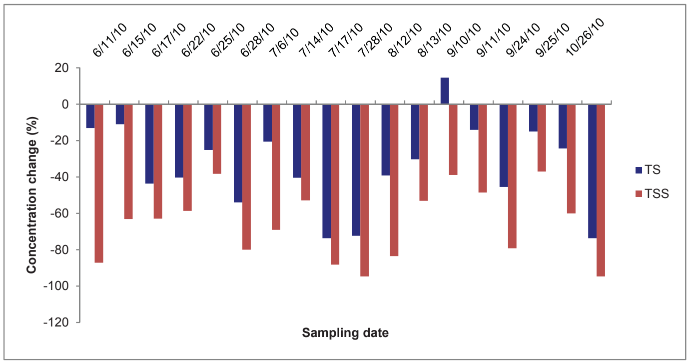

Figure 3. Transport reductions of runoff total solids (TS) and total suspended solids (TSS) during different runoff events (negative sign indicates reduction).

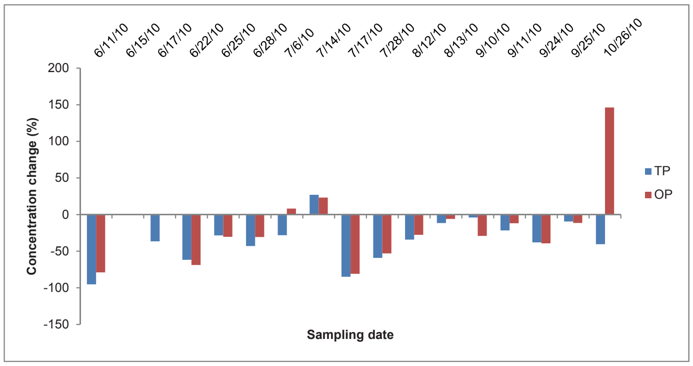

Figure 4. Variation in total phosphorus (TP) and ortho-phosphorus (OP) concentration reduction averaged from each sampling event (negative sign indicates reduction).

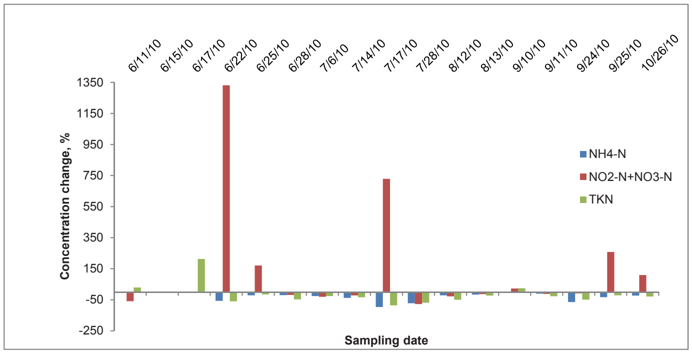

Figure 5. Concentration reductions of ammonium nitrogen (NH_4-N), nitrite-nitrate-nitrogen (NO_2-N + NO_3-N) and TKN during different sampling events (negative sign indicates reduction).

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