United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Conservation Buffers to Reduce Pesticide Losses

March 2000

Issued March 2000

Conservation Buffers to Reduce Pesticide Losses is a joint product of the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) National Water and Climate Center and the United States Environmental Protection Agency (USEPA) Office of Pesticide Programs. It was conceived by an ad hoc joint committee formed in 1994. Participants were Joe Bagdon, USDA-NRCS National Water and Climate Center, Ron Parker, USEPA Office of Pesticide Programs, Tom Gilding, American Crop Protection Association, Nick Poletika, Dow AgroSciences LLC, and Dick Fawcett, Fawcett Consulting. The committee would like to express its thanks to reviewers from the following organizations for comments on and additions to the publication:

Iowa State University - Department of Agricultural Engineering

Michigan Agricultural Cooperative Marketing Association

New York State Department of Environmental Conservation

Rachel Carson Council, Inc.

United States Geological Survey

USDA Agricultural Research Service

USDA-NRCS Science and Technology Consortium and National Headquarters

USEPA Regional Offices

USEPA Office of Water

Virginia Polytechnic Institute - Dept. of Biological Systems Engineering

The committee hopes that the production of this document will demonstrate the opportunities for intergovernmental as well as public - private cooperation in furthering goals of common interest. While all of the above mentioned organizations share the common goal of reducing pesticide losses, not all items in the publication necessarily represent the official policy of each organization. The cooperation of the Federal agencies does not imply endorsement of any commercial product or service mentioned in this publication.

Executive Summary

Conservation buffers are areas or strips of land maintained in permanent vegetation. These buffers can be used in a systems approach to manage soil, water, nutrients, and pesticides for sustainable agricultural production, while minimizing environmental impact. This publication summarizes recent research investigating the ability of conservation buffers to trap and degrade pesticides carried in field runoff. It is designed to be used by change agents, such as NRCS field staff, Extension agents, certified crop advisors, land use planners, and agrichemical sales and support personnel. When used in conjunction with local and regional research and information sources, such as the NRCS Field Office Technical Guide (FOTG), this publication should help planners design, install, and maintain buffers for optimal pesticide trapping, while gaining other buffer benefits, such as erosion control, nutrient and sediment trapping, wildlife habitat, and streambank protection.

Some pesticides are highly adsorbed to soil particles. Because properly designed buffers are effective in trapping eroded sediment, runoff losses of this kind of pesticide have been consistently reduced by buffers. However, a number of modern pesticides are only moderately adsorbed to soil particles and are carried with runoff from fields primarily in the dissolved phase. To be effective in trapping this type of pesticide, buffers must slow runoff and increase infiltration so that pesticides can be trapped and degraded in buffer soil and vegetation. Many studies have demonstrated pesticide trapping efficiencies of 50 percent or more for this type of pesticide, provided that sheet flow, not concentrated flow, occurs. Concentrated flow is the nemesis of pesticide trapping by buffers. Techniques to encourage shallow sheetflow across buffers are described. Maintenance of buffers is critical. Trapped sediment can change the profile of buffers, increasing concentrated flow, and will need to be removed or leveled to maintain buffer function. Soil conservation practices used above buffers will prolong their effectiveness. Buffer location, size, and vegetation species selection are described.

Conservation buffers are not a substitute for careful pesticide selection and use. They are a tool to further improve water quality and produce additional environmental benefits when used along with other practices described in the text.

Conservation Buffers to Reduce Pesticide Losses

Introduction

Conservation buffers are areas or strips of land maintained in permanent vegetation to help control pollutants and manage other environmental problems. These buffers can be used in a systems approach to help manage soils, water, nutrients, and pesticides for sustainable agricultural production while minimizing environmental impact. Buffers have long been a staple in conservation systems designed to prevent erosion and trap sediment and nutrients from field runoff. They also provide other benefits, such as wildlife habitat improvement, streambank protection, and farming safety. Many studies have been conducted to document these benefits and to provide guidance in designing buffers for these purposes. But do buffers work to reduce pesticide losses?

Rainfall or irrigation can cause pesticides to run off the surface of treated fields. Edge-of-field losses can range from less than 1 percent of the amount applied to as much as 10 percent (Wauchope, 1978; Baker, 1983). Losses are greatest when severe rainstorms occur soon after pesticide application. Edge-of-field concentrations of pesticides in surface runoff can range from less than 1 part per billion (ppb) or 1 microgram per liter (μ/L) to 1 part per million (ppm) or 1 milligram per liter (mg/L) or more.

Soil erosion runoff

Until recently, few studies had been conducted to measure the effectiveness of buffers in trapping pesticides in runoff. Physical and chemical properties of pesticides affect pesticide behavior and transport. Some pesticides are highly adsorbed to soil particles and are carried primarily adsorbed to eroded sediment. Buffers trap these pesticides in the same way they trap sediment. However, some pesticides are only moderately adsorbed to soil particles and are carried off fields primarily dissolved in water. For buffers to be effective in trapping this type of pesticide, either water must infiltrate into the buffer, carrying the chemical into the soil, or chemicals must be removed from solution flowing over the soil surface by contact with soil or vegetation. Most studies indicate that an increase in water infiltration is the most important factor in trapping these pesticides.

This booklet examines current knowledge of how conservation buffers can be most effectively used to reduce pesticide losses to water. Studies specifically measuring pesticide trapping by buffers will be reported, as well as relevant studies on effectiveness of buffers in trapping sediment and increasing water infiltration. The effectiveness of buffers in reducing pesticide losses depends on the properties of the specific pesticide, the design and maintenance of the buffer, and local climate, weather, and soil conditions. When combined with specific local input from such sources as the Natural Resources Conservation Service (NRCS), Soil and Water Conservation Districts, and the Extension Service, this booklet will provide guidance to those advising and assisting farmers and landowners installing conservation buffers. Other Best Management Practices (BMPs) which improve management and reduce losses of pesticides and can be used in combination with buffers, will also be described. This publication does not comprehensively examine buffer impacts on nutrient losses to water. However, buffer impacts on nitrate loss are briefly described and contrasted to impacts on pesticide loss.

Literature Reviews

Gilliam, J.W., et al. 1997. Selected agricultural best management practices to control nitrogen in the Neuse River Basin, North Carolina State University Technical Bulletin 311, Raleigh, NC.

Lowrance, R., et al. 1995. Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. U.S. EPA Publication EPA 903-R-95-004.

Bibliographies

Vegetated stream riparian zones: their effect on stream nutrients, sediments, and toxic substances. Smithsonian Environmental Research Center, Edgewater, MA. http://www.serc.si.edu/documents/ripzone.html

Function and design of vegetation filter strips: an annotated bibliography. Texas State Soil and Water Conservation Board, Temple, TX. http://waterhome.tamu.edu/tsswcb/Projects/bibliography/index.html

NRCS Websites

National Handbook of Conservation Practices and Buffer Job Sheets:
http://www.ncg.nrcs.usda.gov/nhcp_2.html

Natural Resources Conservation Service Homepage:
http://www.nrcs.usda.gov

Types of Buffers

Water buffers within fields

Grassed waterway—a natural or constructed vegetated channel that is shaped and graded to carry surface water at a nonerosive velocity to a stable outlet. Because of concentrated flow that normally occurs in waterways, sediment trapping and water infiltration can be minimal with large runoff events, but substantial with smaller events. Waterways are most effective in trapping sediment and dissolved chemicals when designed to spread concentrated waterflow over a vegetated filter adjacent to streams.

Contour buffer strips— strips of perennial vegetation alternated with wider cultivated strips that are farmed on the contour. Buffers are most effective in trapping pesticides when runoff enters uniformly as sheetflow. Contour buffer strips are one of the most effective buffers to trap pesticides. There is less chance for concentrated flow and smaller areas of cultivated field deliver runoff directly to each strip within a relatively short distance compared to some edge-of-field buffers.

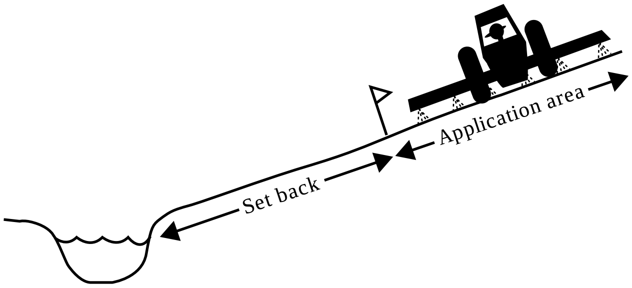
Vegetative barriers—narrow, permanent strips of stiff stemmed, erect, tall, dense, perennial vegetation established in parallel rows and perpendicular to the dominant slope of the field. These barriers function similar to contour buffer strips and may be especially effective in dispersing concentrated flow, thus increasing sediment trapping and water infiltration.

Terrace tile inlet buffer—setbacks surrounding inlets to tile-outlet terrace systems. Some herbicide labels describe leaving untreated setbacks around these inlets when tiles draining terraces outlet directly into streams. These terraces are designed to cause water to pond over areas adjacent to inlets following runoff. Therefore, buffers may not increase sediment trapping or water infiltration compared to cropped areas, but only reduce total areas treated with pesticide.

Edge-of-field

Field borders—a band or strip of perennial vegetation established on the edge of a cropland field. This buffer reduces pesticide runoff only when runoff flows over the strip. Even when no water flows over the strip, some water quality benefit may be gained because spraying operations are physically separated from adjacent areas, reducing drift and direct application to riparian areas.

Filter strips—areas of grass or other permanent vegetation used to reduce sediment, organics, nutrients, pesticides, and other contaminants in runoff and to maintain or improve water quality. Filter strips are located between crop fields and waterbodies. More pesticides can be removed by encouraging as much sheetflow as possible across the strip and minimizing concentrated flow. This may be accomplished by combining filter strips with other conservation practices that control concentrated flow, such as vegetative barriers, level spreaders, or water bars.



Setbacks—untreated areas where surface runoff enters streams. Some herbicide labels describe leaving these areas untreated. Seeding these areas to perennial grass improves herbicide trapping compared to trapping with untreated row crop.

Riparian forest buffer—an area of trees and shrubs located adjacent to streams, lakes, ponds, and wetlands. Forest buffers are often combined with perennial grass buffers. Woody vegetation provides food and cover for wildlife, helps lower water temperatures by shading the waterbody, contributes energy sources to aquatic communities, protects streambanks, and slows out-of-bank flood flows. Deep tree roots may intercept nitrate entering streams in shallow subsurface flow and provide soil carbon for microbial energy. Microbes can degrade pesticides and denitrify nitrate.

Constructed wetlands

While pesticides are usually carried to streams in surface runoff, most nitrate is carried to streams in subsurface flow. Subsurface flow may also carry low concentrations of pesticides. Riparian buffers can intercept shallow subsurface flow and cause either uptake of nitrate and utilization by plants or encourage denitrification. Drainage tiles bypass buffers and deliver subsurface drainage directly to streams. Wetlands constructed at tile outlets or as part of a riparian buffer system can effectively degrade pesticides and denitrify nitrate.

Wind buffers

Windbreak/shelterbelts—plantings of single or multiple rows of trees established for environmental purposes. The primary purpose of such buffers is to protect leeward areas from troublesome winds. They may also separate spraying operations from adjacent areas, reduce drift resulting from lowered wind speed, and intercept spray drift. Taller plantings provide the most drift protection.

Cross Wind Trap Strips—areas of herbaceous vegetation, resistant to wind erosion, and grown in strips perpendicular to the prevailing wind direction. These strips trap wind-borne sediment and nutrients and pesticides carried by sediment.

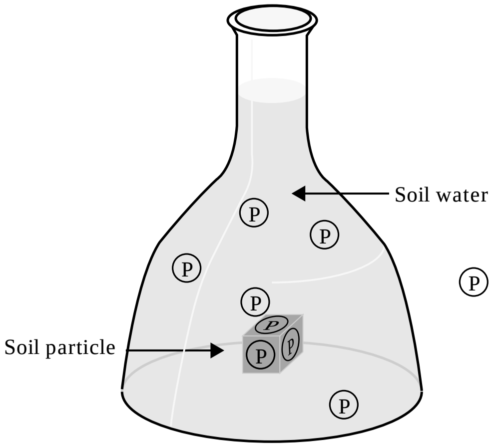
Herbaceous Wind Barriers—tall grasses, up to 5 feet, and other non-woody plants established in 1- to 2-row, narrow strips spaced across the field perpendicular to the normal wind direction. These barriers reduce wind speed and wind erosion and intercept wind-borne soil particles that may carry pesticides and nutrients.

Other Barriers—other types of perennial vegetation on the landscape can serve as a buffer. These barriers include CRP fields, wood lots, terrace back slopes, ditchbanks, and wildlife plantings.

Pesticide Trapping

Pesticides may be held on the surface of material, such as soil particles. This phenomenon is called adsorption. Pesticides may also be taken inside a material, such as being taken up by a plant. This process is called absorption. The term sorption is sometimes used to refer to both processes. Pesticide interaction with soil is primarily an adsorption process.

Pesticides vary in how tightly they are adsorbed to soil particles. Degree of soil binding is measured by binding coefficients, or **K** values. K_{oc} (K of organic carbon) is a measure of adsorption to the organic matter or carbon content of soil, with higher values indicating more binding. While pesticides are also bound to clay particles, binding to organic matter is a useful predictor of pesticide behavior and movement in soil. K_{oc} values can be used to predict whether a specific pesticide will be carried primarily in the sediment or dissolved phase of field runoff. Example K_{oc} values for specific pesticides range from 2 for dicamba (which is held loosely in the soil) to 1 million for paraquat (which is bound tightly to soil). K_{oc} values greater than 1,000 indicate that pesticides are highly adsorbed to soil. These pesticides tend to be carried off fields on eroded soil particles. Thus, if conservation buffers are effective in trapping the sediment particle sizes that transport the pesticides, they effectively trap this type of pesticide. Pesticides with lower K_{oc} values (generally less than 500) tend to move more in water than on sediment. Concentrations carried on sediment are higher than concentrations in water, but because water quantities running off fields are so much greater than eroded soil quantities, water accounts for the majority of chemicals leaving fields. To trap low K_{oc} pesticides effectively, buffers need to increase water infiltration and maximize runoff contact with soil and vegetation that may adsorb pesticides.



$$K_d = \frac{\text{Conc. pesticide on soil}}{\text{Conc. pesticide in } H_2O}$$

In contrast to most pesticides, nitrate is water-soluble and not readily adsorbed by soil particles. Usually nitrate is not in runoff because in enters the soil quickly. Rather, nitrate that is not taken up by plants may leach to ground water and be carried to streams by subsurface flow. (Significant losses of nitrate in surface runoff can occur in certain situations, such as heavy rainfall after surface application of nitrogen fertilizer or manure.) To trap nitrate effectively, roots of conservation buffer plants need to intercept this subsurface flow. Conditions for denitrification present in this biologically active zone also reduce nitrate reaching streams. Similarly, some weakly adsorbed pesticides may leach to shallow ground water in small amounts. Although subsurface flow may carry small quantities of pesticides to streams, quantities present in surface runoff are usually much greater. The NRCS maintains a current Pesticide Property data base and can provide K_{oc} values for specific pesticides.

Study Results

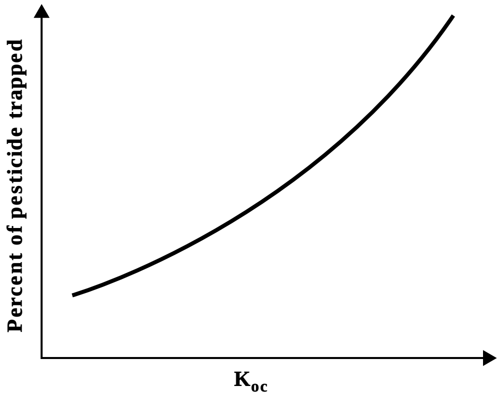
One of the earliest studies of the impact of buffers on pesticide runoff investigated pesticide retention by grassed waterways (Asmussen, et al., 1977). When runoff from a small plot was directed into an 80-foot-long grassed waterway, 70 percent of the weakly adsorbed herbicide, 2,4-D, was trapped. In a similar study (Rohde, et al., 1980), 96 percent of the strongly adsorbed trifluralin was trapped when the waterway was dry before runoff, and 86 percent was trapped when the waterway was wet before runoff occurred.

Hall, et al. (1983) studied the impact of strip cropping on atrazine runoff in Pennsylvania. Seventy-two-foot-long plots were constructed up and down a 14 percent slope with a 19.7-foot-wide area at the base of the slope seeded to oats (*Avena sativa* L.). Runoff of atrazine applied to corn was measured throughout the season, which included a severe, once-in-100-year frequency storm in June. The oats strip trapped 91 percent of atrazine in runoff when the herbicide was applied at a rate of 2 pounds per acre.

Results of these early studies surprised some scientists who assumed that buffers would have minimal impact on runoff of moderately adsorbed pesticides like atrazine and 2,4-D. However, significant infiltration of runoff water into buffers was identified in these studies as the primary mechanism of pesticide removal.

In Mississippi, Webster and Shaw (1996) measured runoff of metolachlor and metribuzin from soybean plots with and without tall fescue (*Festuca arundinacea* Schreb.) filter strips. Plots were 13 by 72 feet with 3 percent slope. Filter strips were either 13 or 6.5 feet wide. Width of the filter strip did not affect herbicide trapping efficiency. Over 3 years, metolachlor loss was reduced 55 to 74 percent by the filter strips, compared to plots without filter strips, while metribuzin loss was reduced by 50 to 76 percent. Much of the herbicide trapping could be attributed to infiltration of runoff into the filter strips. Using similar techniques in a later study (Rankins, et al., 1998), tall fescue buffers reduced runoff of fluormeturon and norfluorazon applied to cotton by at least 60 and 65 percent, respectively.

Several studies in Iowa have investigated herbicide trapping by smooth bromegrass (*Bromus inermis* Leysser) filter strips using either simulated or natural runoff. In some studies field runoff was simulated by adding known concentrations of herbicide to water released above filter strips while rainfall was simulated (Mickelson and Baker, 1993). Simulated runoff solution representing runoff from a 150-foot-long area was applied to the top of 15- and 30-foot-long filter strips (thus representing source area to buffer ratios of 10:1 and 5:1). The 15-foot strip reduced atrazine runoff by 35 percent, while the 30-foot strip reduced atrazine runoff by 59 percent.



Other similar studies with smooth bromegrass buffers (Misra, et al., 1996) showed less difference between buffer sizes. When comparing 15:1 and 30:1 source area to buffer ratios, atrazine removal was 31.2 and 26.4 percent, respectively. Herbicide concentrations in simulated runoff were applied at either 0.1 ppm or 1.0 ppm. A higher percentage of herbicide was trapped by buffers when inflow had higher concentrations. When inflow had 1.0 ppm herbicide, 15:1 area ratio buffers trapped 50, 47, and 47 percent of atrazine, metolachlor, and cyanazine, respectively. When inflow concentrations were 0.1 ppm, these buffers trapped 31, 32, and 30 percent of atrazine, metolachlor, and cyanazine, respectively. Infiltration of runoff water into buffers accounted for most herbicide trapping.

In other studies, natural runoff from a treated area was collected and distributed to replicated smooth bromegrass buffers 66 feet long (Arora, et al., 1996). Runoff was distributed to represent source area to buffer area ratios of 15:1 and 30:1. Efficiency of herbicide trapping was determined for six runoff events over a 2-year period. Trapping of atrazine, cyanazine, and metolachlor ranged from a low of 8 percent to a high of 100 percent, depending largely on the timing and intensity of rainfall and antecedent soil moisture conditions. Herbicide trapping was least efficient when soil was saturated from previous rains. For most events there were only small differences in herbicide trapping efficiency between area ratios. Averaging results for all herbicides and area ratios over the six events, 62 percent of herbicides contained in runoff was trapped by buffers. Infiltration of runoff into buffers was determined to be the major mechanism of herbicide removal. While sediment retention ranged from 40 to 100 percent, only about 5 percent of total herbicide retention resulted from sediment trapping.

Analysis of soil within the buffer strips confirmed that herbicides were being trapped and held by soil within the strips (Fawcett, et al., 1995). Concentrations declined during the growing season, presumably because of degradation. No phytotoxicity was observed on buffer grasses.

Bermudagrass (*Coynodon dactylon* L.) and wheat (*Triticum aestivum* L.) contour buffers were studied in Texas (Hoffman, 1995). Three 30-foot-wide buffers were equally spaced within a 435-foot-wide watershed planted to corn. Hydrologic data showed that water runoff was reduced 57 percent by bermudagrass and 50 percent by wheat. Total atrazine loss was reduced 30 percent by bermudagrass and 57 percent by wheat in 1 year, and by 44 to 50 percent by all buffers in another year.

Patty, et al. (1997) studied ryegrass (*Lolium perenne* L.) buffers in France under natural rainfall conditions. Buffer widths varied from 20 to 59 feet Runoff volume was reduced by 43 to 99.9 percent, suspended solids by 87 to 100 percent, lindane losses by 72 to 100 percent, atrazine and metabolite losses by 44 to 100 percent, isoproturon losses by 99 percent, and diflufenican losses by 97 percent.

The ability of bermudagrass buffers to trap runoff of turf pesticides was studied in Oklahoma (Cole, et al., 1997). Buffers 16 feet wide trapped from 90 to 100 percent of dicamba, from 89 to 98 percent of 2,4-D, from 89 to 95 percent of mecroprop, and from 62 to 99 percent of chlorpyrifos in runoff. In most instances buffer mowing height (3.3 or 9.7 inches), buffer length (7.9 or 16 feet), and tine aeration did not significantly affect pesticide trapping efficiency.

The effectiveness of a three-zone riparian buffer in trapping herbicide runoff was studied in Georgia (Lowrance, et al., 1997). Total buffer width was 164 feet, with a 26-foot-wide grass buffer adjacent to the crop field, a managed pine forest downslope from the grass, and a narrow hardwood forest containing the stream channel. More than 90 percent of atrazine and alachlor in field runoff was trapped by the buffer. Most herbicide was trapped by the grass strip, with 60 to 70 percent of herbicide in runoff trapped. Grass was a mixture of bahiagrass (*Paspalum notatum* Flugge), bermudagrass, and perennial ryegrass.

The impact of untreated setbacks around tile inlets in tile-outlet terrace systems was studied in Iowa, Nebraska, and Missouri (Mickelson, et al., 1998; Franti, et al., 1998). In all studies setbacks provided no reductions in herbicide runoff into inlets beyond what would be expected because of reduced area treated. This result is not surprising since these terraces are designed to pond water around inlets, causing sediment to settle and increasing water infiltration. Much of the untreated setback area is under water during runoff events and cannot be expected to increase infiltration or sediment trapping beyond that caused by normal functioning of the terrace system. The studies' authors concluded that alternative BMPs, such as herbicide incorporation and no-till production, were more effective in reducing herbicide runoff into inlets. Based on this research, USEPA allowed label changes on atrazine-and cyanazine-containing products. Three alternative BMPs are now described on these labels for use in tile-outlet terrace systems: (1) 66-foot untreated setback around inlet, or (2) incorporation of herbicide in areas draining to inlet, or (3) no-till production with high crop residue levels in areas draining to inlet.

The importance of water infiltration as a mechanism of trapping moderately adsorbed pesticides is illustrated by some studies that have shown that buffers do little to reduce concentrations of moderately adsorbed pesticide in runoff. In Nebraska (Yonts, et al., 1996), smooth bromegrass or intermediate wheatgrass buffers did not significantly reduce concentrations of alachlor, cyanazine, 2,4-D, or atrazine present in furrow irrigation runoff water, although concentrations of the strongly adsorbed chlorpyrifos were reduced.

In contrast, some studies have shown significant reductions in concentrations of moderately adsorbed pesticides caused by buffers. In Mississippi (Tingle, et al., 1998), tall fescue buffers as narrow as 1.6 feet at the base of 72-foot plots reduced concentrations of metolachlor and metribuzin in runoff by almost 50 percent.

Biological and physical conditions, which develop in buffers planted to grasses and/or trees, favor increased water infiltration and subsequent attenuation of nutrients and attenuation and degradation of pesticides. Bharati (1997) compared infiltration and soil properties under a multispecies riparian buffer in Iowa to adjacent cultivated fields and a grazed pasture. Average cumulative water infiltration was five times greater under the buffer than that under the cultivated field and pasture sites. Soil bulk density was also consistently lower under the buffer. Wood (1977) compared hydrologic characteristics of forested land to adjacent sugarcane, pineapple, or pastureland of the same soil series at 15 sites in the Hawaiian Islands. Infiltration rates were higher under forest cover at 14 of the 15 sites. Mean weight diameters of the surface soil aggregates were larger for forested soils.

The extensive root growth in buffers and superior soil structure most likely explain observed water infiltration increases. This root growth also increases biological activity by supplying an organic carbon energy source to soil micro-organisms. These micro-organisms in turn are responsible for degrading pesticides and denitrifying nitrate. Such untilled areas also attenuate atmospheric carbon dioxide through carbon sequestration in tree and grass vegetation and soil organic matter. Tillage and crop production often deplete soil organic matter (Reicosky, et al., 1995), releasing carbon dioxide to the atmosphere. Increased soil organic matter in buffers serves to better adsorb pesticides in runoff. Nutrients are taken up by vegetation and stored in living tissue. Periodic harvest may be desirable to prevent later release. Pesticides are also taken up by roots and may be metabolized in plants. In addition, vegetation at the soil surface adsorbs pesticides during runoff events. In Iowa (Fawcett, et al., 1995), atrazine concentrations in plant residue collected in buffers ranged from 80 ppb to 740 ppb, depending on collection date, and were similar to concentrations found in surface buffer soil.

Few studies have investigated pesticide trapping by constructed wetlands. Some pesticides are relatively short-lived in water and will degrade while sequestered in wetlands, therby reducing contaminants reaching streams. Wetlands can also serve to attenuate pulses of concentrated runoff before it enters streams. Some pesticides are relatively persistent once they reach water. However, the high organic matter content of wetland sediment binds these pesticides, removing them from water. Matter (1993) used intact freshwater wetland sediment microcosms to study the behavior of atrazine. Atrazine was removed from the overlying water column at a rate of 15.8 percent per day for 3 days after introduction. After 10 months, 88 percent of the applied atrazine was unextractable from sediment and none was recovered from the overlying water.

Considering buffer research to date, buffers have been effective under controlled conditions, in trapping highly adsorbed and moderately adsorbed pesticides. Table 1 summaries buffer studies showing trapping efficiency for specific pesticides and pesticide K_{oc} values. Highly adsorbed pesticides were trapped at rates of from 62 to 100 percent. Trapping of moderately adsorbed pesticides was more variable and ranged from 8 to 100 percent. Buffers retained the lowest percent of pesticide when buffer soil was saturated from previous rains. Many studies found pesticide trapping efficiencies of 50 percent or more.

Do results of these controlled studies predict what will happen in the real world? Nearly all of these studies (with the exception of early grassed waterway studies) were designed to encourage sheetflow across buffers. Therefore, they represent the maximum trapping that can be expected. In the real world, concentrated flow often occurs across buffers, reducing their effectiveness. To maximize trapping of sediment-adsorbed and dissolved pesticides, sheetflow needs to be encouraged through proper buffer design and maintenance.

Dillaha, et al. (1989) analyzed 33 existing buffers in Virginia for sediment trapping efficiency. They found sediment trapping was often poor because of either concentrated flow where topography was hilly or sediment that accumulated in the buffer, causing runoff to flow parallel to the buffer until a low point was reached where concentrated flow occurred.

Excessive sediment load in runoff may not only change flow patterns caused by accumulation in buffers, but may also reduce water infiltration, making buffers less effective in trapping dissolved pesticides. In an Iowa simulation study (Misra, 1994), runoff with and without suspended sediment was introduced into buffers. In absence of sediment, buffers removed over 80 percent of atrazine, cyanazine, and metolachlor. When sediment at 10,000 mg/L was included in runoff, trapping of the three herbicides fell to about 50 percent. Accumulation of sediment apparently caused soil surface sealing, reducing total water infiltration from 83 percent, in the absence of sediment, to 30 percent with sediment. It is thus critical that soil conservation methods be used above conservation buffers to reduce the amount of sediment entering buffers.

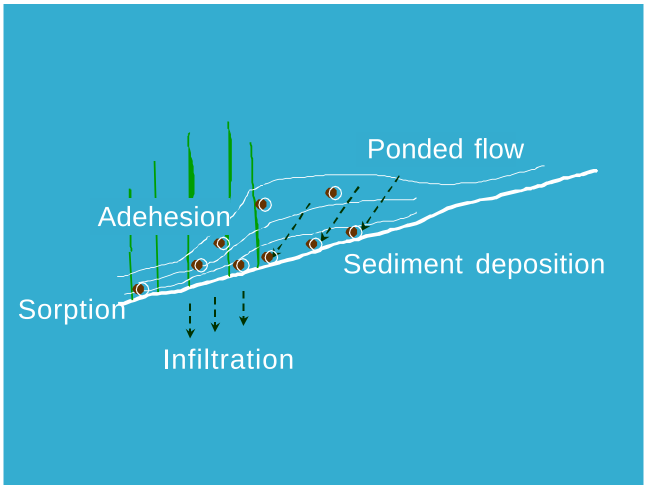
Table 1 Summary of buffer studies measuring trapping efficiencies for specific pesticides. K_{oc} values listed for each pesticide are from the NRCS Field Office Technical Guide, Section II Pesticide Property data base.

Pesticide	K_{oc}	Study reference	Percent pesticide trapped
Highly adsorbed pesticides			
Chlorpyrifos	6,070	Boyd, et al., 1999	57–79
		Cole, et al., 1997	62–99
Diflufenican	1,990	Patty, et al., 1997	97
Lindane	1,100	Patty, et al., 1997	72–100
Trifluralin	8,000	Rhode, et al., 1980	86–96
Moderately adsorbed pesticides			
Acetochlor	150	Boyd, et al., 1999	56–67
Alachlor	170	Lowrance, et al., 1997	91
Atrazine	100	Arora, et al., 1996	11–100
		Boyd, et al., 1999	52–69
		Hall, et al., 1983	91
		Hoffman 1995	30–57
		Lowrance, et al., 1997	97
		Mickelson and Baker 1993	35–60
		Misra, et al., 1996	26–50
		Patty, et al., 1997	44–100
Cyanazine	190	Arora, et al., 1996	80–100
		Misra, et al., 1996	30–47
2,4-D	20	Asmussen, et al., 1977	70
		Cole, et al., 1997	89–98
Dicamba	2	Cole, et al., 1997	90–100
Fluormeturon	100	Rankins, et al., 1998	60
Isoproturon	120	Patty, et al., 1997	99
Mecoprop	20	Cole, et al., 1997	89–95
Metolachlor	200	Arora, et al., 1996	16–100
		Misra, et al., 1996	32–47
		Webster and Shaw 1996	55–74
		Tingle, et al., 1998	67–97
Metribuzin	60	Webster and Shaw 1996	50–76
		Tingle, et al., 1998	73–97
Norflurazon	600	Rankins, et al., 1998	65

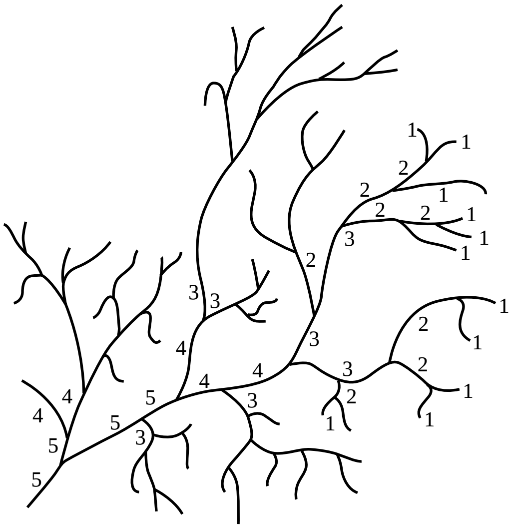
Designing Buffers for Maximum Pesticide Trapping Efficiency

Location

All buffers can provide some protection of waterbodies if they are sited between pesticide-treated fields and water. Physical separation of spraying operations and water reduces the chances for direct application to water where spray booms overhang water when turning at field ends. It can also reduce spray drift into water. However, to trap the pesticides in runoff and drift, buffers must be sited so that water runs over, or wind passes through, the buffer area. Concentrated flow is often prevalent by the time field runoff reaches streambanks. Natural berms may develop along banks, preventing overland flow into streams. This phenomenon was illustrated by a study in Nebraska, where water runoff patterns were characterized between field edges of watersheds and streams (Eisenhauer, et al., 1997). In one watershed, about 51 percent of the area had runoff pathways that experienced sheetflow, but only 22 percent of the area had sheetflow distances of more than 10 feet. Thus, buffers adjacent to water may be limited in their ability to trap pesticides unless land can be shaped to encourage sheetflow or spreader devices are incorporated into the design.



Buffers are most effective in trapping pesticides when located as close to treated fields as possible. Contour buffer strips and vegetative barriers are most effective because they are located within fields and are on the contour, thus maximizing sheetflow across the buffer. Herbaceous wind barriers and cross wind trap strips located close to treated fields trap wind eroded particles containing adsorbed pesticides. Typically, the ratio of runoff source areas to buffers is smaller for this type of buffer than most edge-of-field buffers, which also increases trapping efficiency. Grassed waterways intercept both sheet and concentrated flow from fields and also can intercept pesticides close to the source. Wider grass strips encourage more sheetflow and infiltration as runoff enters the edges of waterways.

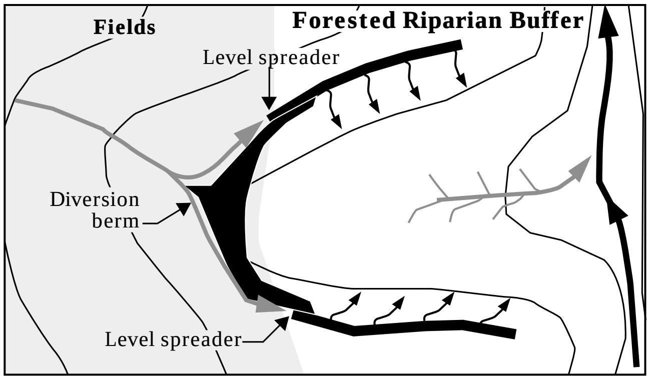


Numbering system of stream orders

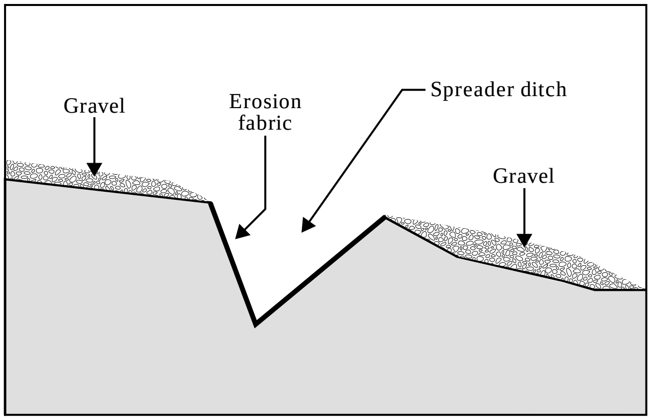
Stream networks are designated by using stream orders. First order streams have no tributaries. A second-order stream starts at the confluence of two first-order streams. The confluence of two second-order streams is a third-order stream, and so on. Most experts conclude that streamside conservation buffers are most effective on first- and second-order streams at the “top” of watersheds. The greatest volume of runoff water, and therefore pollutant volume, enters most stream systems from these small streams. Thus, intermittent as well as first- and second-order perennial streams require more vegetative buffer protection. Little “new” water enters third- and fourth-order streams over banks. Conservation buffers along these larger streams provide other benefits, such as wildlife habitat and streambank protection, but have less opportunity to intercept pesticides and improve water quality. In watershed planning, likely sources of pesticides can be identified based on cropping patterns. This information can be used to prioritize placement of conservation buffers.

Concentrated flow through a grass buffer

Concentrated flow is the nemesis of pesticide trapping by buffers. Natural berms often develop along field edges from deposition of sediment. Such berms become barriers to sheet flow off fields and should be removed by leveling when possible. Land can also be shaped to encourage broad, shallow sheet flow. New techniques have been developed to disperse concentrated flow. For example, level spreaders are constructed to laterally disperse runoff uniformly across a slope. They consist of a long, narrow trench with an outlet lip of uniform elevation constructed in stable, undisturbed soil. The outlet area should have uniform slope and be well-vegetated. Small berms, or “water bars” may be constructed to break up concentrated flow and redirect it as sheet flow across buffers. Strategically located vegetative barriers perpendicular to the flow can serve the same purpose to slow runoff velocity and redirect runoff across an associated grass buffer as shallow sheetflow.



Design of level spreader used for dispersing agricultural runoff through a forested riparian buffer



Detailed cross-section of level spreader trench for dispersing runoff along the contour

How wide is wide enough?

Appropriate widths for conservation buffers are debatable. Widths are defined here as flow length across the buffer. Buffer per unit area is affected by runoff flow rate and depth as well as by conditions within the buffer, such as soil type and antecedent moisture, that affect water infiltration. Amount of runoff is affected by source area size and properties as well as rainfall intensity and quantity. Selecting an appropriate buffer size often involves consideration of several desired functions, site conditions, and what is economically or politically practical.

Many studies have investigated sediment trapping efficiency of grass buffers. Dillaha, et al. (1989) found that 30- and 15-foot strips of orchardgrass trapped 84 and 70 percent of incoming solids, respectively. The source area of runoff was 60 feet, or 4 times as wide as the 15-foot buffers. Magette, et al. (1989) found that 30- and 15-foot strips of fescue trapped 75 and 52 percent of incoming solids, respectively. The source area was 72 feet deep, or 4.8 times as wide as the 15-foot buffers. Castelle, et al., (1994) reviewed literature on buffer size requirements and concluded that a range of buffer widths from 10 to 650 feet was effective, depending on site-specific conditions. A buffer width of at least 50 feet was necessary to protect wetlands and streams under most conditions.

Width and Length Used in Conservation Buffers

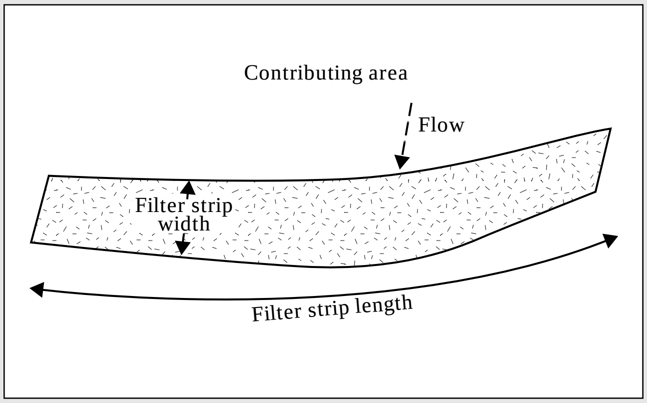
The width is measured in the direction of flow. Since conservation buffers are placed along the contour or perpendicular to the prevailing wind direction as feasible as possible, their direction at the narrow point is called width. This is analogous to the width of a cultivated area in stripcropping or width of a contour strip. The flow of water moves parallel with the width. (The same is the case of other conservation practices, such as cross wind trap strips, which have movement of the wind across the width.) The length of a conservation buffer is the longitudinal distance across the landscape that the strip occupies perpendicular to the direction of flow. Other terms, such as flow length, may be used to depict the direction of flow (see insert figure).

The slope of the buffer and soil in the buffer area impact the overall buffer performance. Steeper slopes in the conservation buffer strips increase flow velocity and shorten the time the contaminant material carried in the runoff water, both particulate and soluble, has to interact with the vegetation and soil in the buffer area. The soil is an important parameter in judging buffer effectiveness. Hydrologic soil groups (A, B, C, and D) are indicative of the infiltration and runoff potential of the soil. Soil groups A and B have higher infiltration potential; therefore, less runoff than groups C and D. Buffer strips located on hydrologic soil groups C and D are less effective in treating run-on than buffer areas on A and B soils. The soil drainage class also determines the extent of soil moisture conditions and water storage available in a soil.

With most conservation buffers, the greater flow length (width) of buffer area provides the greater entrapment and removal of contaminants. However, an optimal length or area is soon reached where further distance does not result in proportionally greater efficiency. A buffer strip that achieves 100 percent removal of contaminants or completely reduces the water discharge to zero would be difficult and impractical to design and maintain. Most practical designs are based on contaminant removals of at least 50 to 60 percent (up to 80 percent for sediment) and at the same time allow some discharge at the end of the buffer.

Type and density of vegetation also influence buffer effectiveness. A large number of vegetative stems (usually greater than 50 per square foot for most grasses) is required to retard water and wind flows and provide enough surface area for attachment of contaminate material passing through the buffer strip. Stems should stand upright during runoff and wind events.

The width of a conservation buffer strip depends on a number of factors. The purpose of the buffer strip must be defined. Buffers to entrap and deposit sediment are not required to be as wide (only at least 20 feet) as buffers used to remove soluble compounds, such as nitrate nitrogen or pesticides (as wide as 100 feet or longer). It takes more surface area and longer flow paths to adsorb and infiltrate soluble material than to entrap solid material. Climate conditions and storm events anticipated during the expected runoff events influence the effectiveness of the buffer to retard flow and remove pollutants. At times, conditions such as frozen and snow covered soil, saturated soil, and crusted soil surfaces, severely reduce the function and effectiveness of buffer strips.



Adequate buffer widths depend on field slopes and source areas. A draft NRCS Conservation Practice Standard for Filter Strips requires a minimum flow length of 30 feet for the purpose of reducing sediment and sediment-adsorbed contaminant loadings. It also sets ratios of filter strip area to field area based on Universal Soil Loss Equation R factor values (rainfall amount and intensity) of regions: "The ratio of the field or disturbed area to the filter strip area shall be less than 70:1 in regions with USLE R factor values 0 to 35, less than 60:1 in regions with USLE R factor values 35 to 175, and less than 50:1 in regions with USLE R factor values of more than 175." Consult the local NRCS Field Office Technical Guide for filter strip standards because these criteria vary depending on local conditions. Additional criteria may apply to reduce dissolved contaminants in runoff. The draft national standard states: "Filter strip flow length required to reduce dissolved contaminants in runoff shall be based on management objectives, contaminants of concern, and the volume of runoff from the filter strip drainage area compared with the filter strip's area and infiltration capacity."

Several site characteristics may dictate wider buffers, especially when trying to maximize water infiltration and trapping of dissolved pesticides. For example, fine-textured soils generally have lower water infiltration rates; or a high water-table underlying buffers may limit infiltration. Iowa studies found that water infiltration and trapping of dissolved herbicides by buffers was least effective when previous rains saturated soils. Vegetation within the buffer improves surface soil conditions, improving infiltration rates and internal soil drainage.

Narrow buffers have sometimes trapped pesticides effectively. The specific pesticide studies cited in this publication found that buffers as narrow as 1.6 feet could be effective in trapping significant quantities of pesticides. Increasing buffer width did not always significantly improve pesticide trapping. Tingle, et al. (1998) compared tall fescue buffers measuring 1.6, 3.2, 6.6, 9.8, and 13.1 feet wide placed below 72-foot-long soybean plots. No significant differences in pesticide trapping efficiencies were found between buffer widths. Runoff loss of metribuzin was reduced by at least 73 percent, and runoff loss of metolachlor was reduced at least 67 percent by all buffer widths.

While site characteristics, such as large source areas or slow permeability soils, may dictate larger buffers for high pesticide trapping efficiency, relatively small buffers should provide significant water quality benefits. Typical buffer widths of about 50 feet can be effective in reducing pesticide runoff by at least 50 percent if sheet flow is maintained, depending on a number of factors as described previously. Wider buffers may provide greater protection than narrow buffers in many settings, but where space or cost considerations limit buffer widths, a narrow buffer is better than no buffer at all.

For more information

Section IV of the NRCS Field Office Technical Guide in each state contains Conservation Practice Standards developed for that state. These state standards are based on national standards in the NRCS National Handbook of Conservation Practices. National standards establish minimum requirements for state standards, which are specifically tailored to each state's local conditions. Conservation Practice Standards include a practice definition, purposes of the practice, conditions where the practice applies, criteria for applying the practice, special considerations in applying the practice, practice plans and specifications, and practice operation and maintenance requirements. All applicable conservation buffer practices have standards in the local Field Office Technical Guide which include required buffer widths.

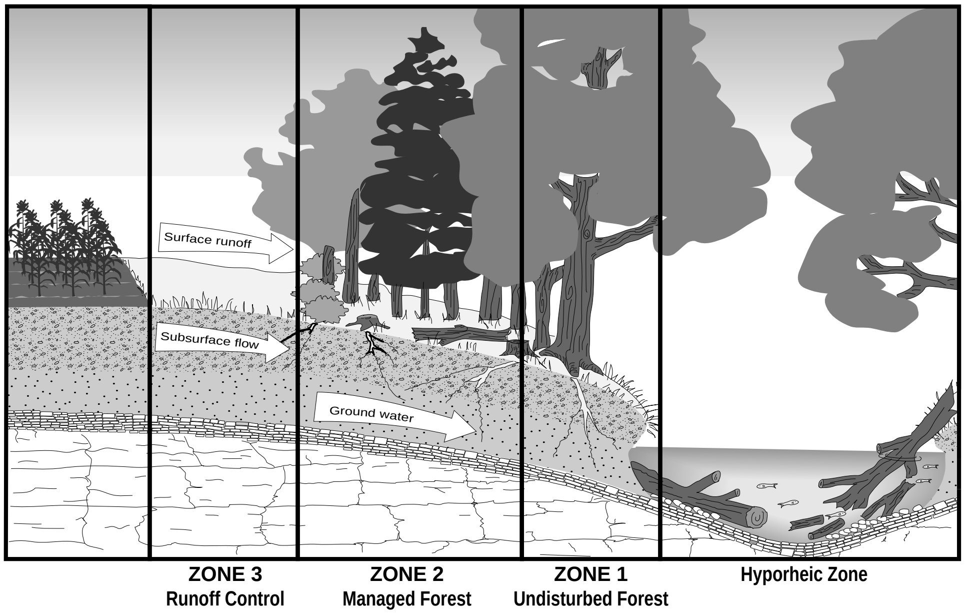
Information on selecting and sizing buffer practices for the conservation buffer initiative is available at:

http://www.ftw.nrcs.usda.gov/tpham/buffer/akey.htm

Species selection

Conservation buffers can be planted to perennial grasses, legumes and forbs, woody plants, or a combination of the three. When available and able to perform the desired functions of specific buffer types, native plant species are preferred. Some annually harvested crops, such as small grains or legume-grass forages, can serve the purpose of buffers, either when planted adjacent to watercourses or in stripcropping systems–alternating strips of row crop and densely planted crops. In Texas (Hoffman, 1995), wheat was more effective in trapping herbicides than bermudagrass when planted in contour strips below a corn field.

Perennial grasses—Many buffer studies have used common forage grass species, such as bromegrass, orchardgrass, fescue, and bermudagrass. While these species have performed satisfactorily, researchers are investigating other species including native warm-season grasses. To date, few studies have compared the effectiveness of grass species in trapping pesticides. Rankins, et al. (1998) compared giant reed (*Arundo donax* L.), eastern gammagrass (*Tripsacum dactyloides* L.), big bluestem (*Andropogon gerardii* Vitman), Alamo switchgrass (*Panicum virgatum* L.), and tall fescue planted in filter strips below cotton treated with fluormeturon and norflurazon. All species were similar in effectiveness.



A three-zone riparian forest buffer

The native warm-season grass (switchgrass), was compared to cool-season grasses (bromegrass), timothy (*Phleum pratense* L.), and fescue in ability to trap sediment and nutrients in Iowa (Lee, 1997). Switchgrass filter strips removed significantly more sediment, total N, nitrate-N, total P, and PO4-P than cool-season grass filter strips.

Ideally, buffer grasses should produce dense vegetation with stiff, upright stems near ground level. Species that form sods rather than clumps provide more uniform coverage. Because increased infiltration and percolation of water into buffers is an important pesticide removal mechanism, species with deeper rooting patterns may also be more effective. Upright growth and stiff stems can slow runoff velocity and increase sediment deposition and infiltration. Weak-stemmed species may be pushed over by runoff, mat on the soil surface, and decrease infiltration. Because buffers trap considerable quantities of sediment, buffer species should be able to tolerate deposition of sediment over crowns.

Stiff-stemmed grass species have received recent attention for use as narrow hedges. Meyer, et al., (1995) found that a 19-inch-wide hedge of switchgrass or vetiver [*Vetiveria zizanioides* (L.) Nash.] ponded runoff to a depth of 10 inches and trapped more than 90 percent of sediment coarser than 125 mm (fine sands and coarser). Such hedges can be used in contour strips. Over time, trapped sediment forms natural terraces. Short hedges can also be integrated with other buffers to break up concentrated flow and direct it across buffers. Vetiver is not winter-hardy, but switchgrass is adapted to northern and southern climates and is widely used for conservation buffer and grass hedge applications. Warm-season grasses, such as switchgrass and big bluestem, are also tolerant to triazine herbicides that may be present in field runoff.

Conservation buffer grass species and varieties should be adapted to local conditions. Check local information sources, such as NRCS and Extension, before making selections. These sources can also recommend seeding rates and procedures. Some cost sharing programs may also have specific seeding requirements.

Woody species—Trees and shrubs can also trap sediment, nutrients, and pesticides, as well as provide wildlife habitat and streambank protection. The deep roots of trees also help to intercept subsurface water-flow containing nitrate and introduce organic matter deep into the soil, facilitating denitrification and acting as a carbon source for pesticide-degrading micro-organisms.

Trees and shrubs are often used in combination with a grass buffer located adjacent to crop fields. Schultz, et al. (1995) describe a three-zone buffer with a 23-foot-wide strip of perennial grass (switchgrass preferred) adjacent to the crop field, two rows of shrubs next downgradient, and four or five rows of trees adjacent to the stream, for a total width of 66 feet. Gilliam, et al. (1997) describe a 50-foot-wide buffer with half in perennial grass and half forest species. Welsch (1991) describes a three-zone riparian buffer, where zone 1 is permanent woody vegetation immediately adjacent to the streambank, zone 2 is managed forest occupying a strip upslope from zone 1, and zone 3 is an herbaceous filter strip upslope from zone 2. (See figure above.)

Selection of appropriate shrubs and trees for three-zone riparian buffers depends highly on the following factors:

- climate
- site conditions, including soil type and depth to water table
- intended uses (possible harvest)
- species of wildlife desired
- tolerance of the vegetation species to the pesticides contained in the runoff

For more information contact the local Soil and Water Conservation District office. Additional information:

- Banks and Buffers, A Guide to Selecting Native Plants for Streambanks and Shorelines. Available on CD-ROM from Tennessee Valley Authority. Call 423-751-7338.
- Plants for Conservation Buffers. USDA, NRCS.

Economic considerations

When planning installation of a buffer, consider the cost of installation and maintenance and the economic consequences of taking land out of crop production. Proper design and installation can increase the expected life span of a buffer and reduce maintenance costs. Payments from Federal, State, and private sources can help to offset reductions in income and cover installation costs. Some states allow a real estate tax exemption for the area of a farm planted to a permanent conservation buffer. Some income may be generated from buffers if haying or tree harvest is allowed, helping to offset loss of income from the traditional crop.

Cost-sharing programs often have specific design criteria that vary with locality. Local input is essential to ensure that buffers are properly designed and installed so that they qualify for payments. Installation costs vary, depending on species and design. A typical riparian forest buffer with mixed hardwood seedlings and a switchgrass strip can cost about $400 per acre to install (USDA-NRCS, 1999). Cost-share funds contributing 50 to 75 percent or more of the cost of practice installation are widely available.

Maintenance

Sediment removal—Conservation buffers must be intensively managed to maintain pesticide-trapping efficiency. Sediment trapped by buffers changes land shape and may cause runoff to flow parallel to buffers, rather than across them. Similarly, sediment trapped in the center of grassed waterways may cause runoff to flow along the edge of waterways, eroding gullies and increasing concentrated flow. Sediment must be removed periodically from these areas, and vegetation reestablished when necessary. It is critical that sediment loads flowing across buffers be limited as much as possible by soil conservation practices applied to source fields. The draft NRCS Conservation Practice Standard for Filter Strips requires that average sheet and rill erosion above the filter strip be less than 10 tons per acre per year.

Mowing—Buffers may require mowing for weed control or aesthetic reasons. Mowing can both positively and negatively affect pesticide trapping efficiency. It can encourage some grass species to tiller and produce denser vegetation at the soil surface. Mowing too short, especially with stiff-stemmed species, may reduce the flow retardance of the vegetation and injure the grass. Actively growing vegetation is more biologically active, taking up and degrading pesticides, and supplying carbon for microbial degradation.

Harvest of grass or trees—One function of conservation buffers is to trap nutrients, such as nitrogen and phosphorus. Periodic harvest of buffer vegetation removes trapped nutrients from the system, preventing eventual release to the soil and potential movement to water.

Impact of trapped herbicides—Herbicides trapped by buffers are degraded in the soil by microbial and chemical processes. Some herbicide may be taken up by buffer plants either by roots or through foliage and metabolized. However, excessive loads of certain

herbicides can injure buffer vegetation. Some preemergence herbicides have little impact on established plants. However, a few, such as the triazines, can injure grasses if present in high enough concentrations. Most buffer studies have reported either no injury to buffer grasses, or only slight injury. In Iowa, bromegrass in buffers grew most vigorously nearest source areas, apparently because of nutrients trapped by the buffer (Arora, et al., 1996). Atrazine, cyanazine, and metolachlor trapped by the buffers did not harm the grass. Grass seedlings are most sensitive to herbicides in runoff. Thus, the greatest chance for harmful impact of herbicides in runoff would occur during buffer establishment. Warm-season grasses, such as switchgrass, big bluestem, and bermudagrass, tolerate triazine herbicides well and would not be injured by runoff.

Avoid overspray—While buffers usually tolerate herbicide concentrations in runoff, direct application or drift of some herbicides can harm grasses and woody plants. Nonselective herbicides used as burndown treatments in no-till production systems and on some herbicide-tolerant crop varieties can be especially damaging to buffer vegetation. Care should be taken to turn off spray booms and use control drip nozzles when driving over buffers, or if booms extend over buffers when turning. Squaring up cropland areas by varying buffer widths along irregular streams or field borders makes application of herbicides easier, with fewer “point rows” and chances for overspray over buffers.

Turning on buffers—While buffers at the edge of fields make convenient turning areas, driving heavy equipment on buffers can cause damage, compacting soil and reducing water infiltration, and causing ruts when soil is wet. Ruts may then encourage concentrated flow that bypasses filtering ability of the buffer. Avoid driving on buffers as much as possible, especially under wet soil conditions.

Livestock grazing—Grazing reduces buffer efficiency by compacting soil and reducing grass heights. Woody species may also be injured. Livestock can cause significant streambank degradation and directly contaminate water. Some livestock producers would like to graze livestock in fields adjacent to buffers for limited times without having to fence buffers, for example, to allow gleaning of waste grain following harvest. Plan a grazing system to allow quick, intensive foraging under good soil moisture conditions. Remove livestock when soils are wet to reduce potential damage to buffers.

Weed control—Buffers may harbor weeds requiring control. Vigorous grass growth prevents growth of many annual weeds, but some perennial weeds may require either mowing or spot treatment with herbicides. Noxious weeds must be controlled in the buffer.

Insect concerns—Buffers may harbor insect pests that move into crop fields. In some cases, such grassy areas are sprayed with insecticides to prevent damage to adjacent crops. If necessary, such treatments should be selected considering potential risks to adjacent aquatic ecosystems. Buffers also can be a safe harbor for beneficial insects. Populations of these insects can build up within buffer areas and stay outside the cropland area treated with insecticides. Tailor vegetation and buffer maintenance to promote beneficial insect populations within buffer areas.

Regional considerations in buffer design and maintenance

Appropriate buffer design depends on many local factors including climate, soils, hydrology, and farming practices. Buffer species need to be adapted to the region and appropriate for other functions, such as wildlife habitat. Climate can greatly affect buffer function. For example, winter rains on frozen soil in northern areas produce runoff that cannot be processed by buffers. Rainfed agriculture produces different runoff patterns than agriculture dominated by irrigation. For these reasons, planners must get local input to benefit from local experience and research. In addition, specific buffer design specifications are often required to qualify for cost-sharing programs.

Local NRCS and soil and water conservation district offices can provide design specifications for your area. Extension is also a source of expertise and information. Many State Extension Services have developed publications on buffer design and maintenance.

Example of Extension publications:

- Buffer Strip Design, Establishment, and Maintenance. Publication Pm-1626b, Iowa State University Extension.
- Landowner's Guide to Managing Streams in the Eastern United States. Publication 420-141, Virginia Cooperative Extension.
- Vegetative Filter Strips: Application, Installation, and Maintenance. Publication AEX-467-94, Ohio State University Extension.

Impact of Buffers on Leaching of Pesticides and Nitrate

Because buffers increase water infiltration, concern has been expressed that leaching of pesticides and nitrate might be increased, possibly to shallow ground water. When examining this possibility, consider the properties of pollutants normally present in field runoff. Because nitrate is water soluble and rarely adsorbed to soil particles, it quickly moves into the soil with rainfall. In most settings surface runoff contains little nitrate. As described previously, nitrate is carried to surface water primarily by subsurface flow. Similarly, weakly adsorbed pesticides (which would have the greatest leaching risk) often are not detected at significant concentrations in runoff, as they quickly move into the soil. Pesticides detected in runoff are primarily strongly adsorbed compounds attached to suspended sediment and moderately adsorbed compounds both adsorbed to sediment and dissolved in water.

Strongly adsorbed pesticides have very low leaching potential because of adsorption to soil. Moderately adsorbed pesticides can sometimes leach below the root zone in small concentrations. However, quantities leached are normally as much as 1,000 times smaller than quantities carried off fields in surface runoff. Parts per million concentrations of some products can be detected in runoff at the field edge, while concentrations detected in shallow ground water are often only a few parts per billion, if detected at all. Because many buffers are located near streams, pesticides or nitrate leaching into buffers would most likely be carried by subsurface flow to streams. Movement of runoff through the root zone soil of buffers before discharge to streams by subsurface flow is much better than allowing surface runoff to directly enter streams. Pesticides can be adsorbed and degraded and nitrate taken up by plants or denitrified within buffers.

Because of relatively low concentrations of pesticide trapped in buffers, leaching risk from buffers should be much less than that from source fields. For example, in an Iowa study, atrazine concentrations in a source corn field were 4,800 ppb in the surface 2 cm of soil after the first runoff event of the season (Fawcett, et al., 1995). Atrazine concentrations in the buffer strip were 750 ppb. Using BMPs to reduce pesticide runoff from source fields not only reduces pesticide loads ultimately reaching surface water, but also reduces loads trapped by buffers. Conservation buffers have been shown to degrade pesticides and to attenuate pesticide concentrations in subsurface water-flow. In Iowa (Schultz, et al., 1997), atrazine concentrations in soil water 2 feet below a corn field were 13 ppb. Atrazine concentrations beneath an adjacent grass and woody vegetation buffer were only 0.2 ppb. In a Georgia study (Lowrance, et al., 1997), no atrazine was detected in shallow ground water beneath a 3-zone buffer for the first 2 years of the study. In the third year, a large rain event soon after herbicide application resulted in atrazine detection in monitoring wells 6.6 feet deep. A concentration of 6 ppb was detected at the field edge. At the downslope edge of a 26-foot-wide grass strip adjacent to the field, atrazine concentrations declined to 2 ppb. At the downslope edge of the tree strip at the stream edge, atrazine was detected at only 0.2 ppb.

Considering the relatively small load of pesticide intercepted by buffers compared to that applied to crop fields, and the adsorption and degradation of pesticides by soil and vegetation in buffers, increased leaching of pesticides does not appear to be a significant risk from conservation buffers.

Integrating Buffers with BMPs

Conservation buffers can trap and degrade part of the pesticides that run off fields either adsorbed to sediment or dissolved in water. However, buffers seldom trap all pesticides in runoff. Buffers have been described as “the last line of defense” or as acting to “polish” runoff after it has been treated by other practices. Other BMPs are needed in a systems approach to adequately protect water quality. Many practices can be used to reduce offsite movement of pesticides, and can be selected and integrated into cropping systems where appropriate and effective. Although not an exhaustive list, some common pesticide BMPs and descriptions are listed below.

Integrated Pest Management (IPM)—IPM systems utilize pesticides in concert with nonchemical pest management techniques. Pest populations are determined and pesticides or other techniques are used only when pest populations exceed economic thresholds. The lowest effective pesticide rate is used, and pesticide products are selected to target specific pests and protect nontarget organisms.

Pesticide selection—Pesticides applied at low rates reduce amounts available to run-off. Products that are strongly adsorbed are less likely to move off fields dissolved in runoff.

Pesticide application timing—Risk of pesticide runoff is greatest when heavy rains closely follow pesticide application. Avoid applying pesticides if heavy rain is imminent. Sometimes long-term weather records can indicate application times when heavy rains are less likely. Post-emergence applications result in less runoff than soil applications, as the crop and weeds behave similar to a buffer, increasing infiltration and pesticide adsorption by soil and foliage.

Banded application—Application of herbicides in bands over crop rows, combined with cultivation to control weeds between rows, reduces total amounts of chemical applied compared to broadcast applications.

Soil incorporation—Some herbicides and insecticides are effective when mechanically incorporated into the soil (in the case of herbicides) or placed in crop furrows (in the case of insecticides). Placing some of the applied chemical below the soil surface protects it from surface runoff. Because tillage performed to incorporate pesticides buries surface crop residue, it may increase erosion risk.

Conservation tillage—Surface crop residue reduces erosion and often increases water infiltration, reducing pesticide runoff (Fawcett, et al., 1994). No-till, especially after having been practiced for several years, has sometimes dramatically reduced pesticide runoff, although pesticides intercepted by surface crop residue may be subject to runoff if heavy rains follow application.

Nutrient management—Supplying the amount, selecting the form, and determining the timing and placement of crop nutrients provide adequate soil fertility for food, fiber, and forage production while at the same time protect against any detrimental environmental risk.

Contour planting—Contour rows reduce erosion, slow runoff, and increase infiltration. Orientation of rows adjacent to buffers may need to be adjusted to direct runoff as sheetflow across buffers.

Stripcropping—When strips of densely planted crops, such as forages or small grains, are alternated with strips of row crops, the densely planted crop acts as a buffer. When the strips are planted on the contour, runoff and erosion are reduced and more runoff water enters the soil.

Crop rotation—Rotation of crops can disrupt life cycles of insects, diseases, and weeds, and reduce the necessity for pesticide treatments. Pesticides can be rotated as the crop is rotated, thus reducing the amount of any one pesticide used on that field.

Terraces/detention ponds—These structures shorten slope length, trap sediment, and increase water infiltration, reducing pesticide runoff.

Irrigation timing—Irrigation after application of soil-applied herbicides moves the chemical into the soil profile, improving weed control and protecting the chemical from later rainfall-runoff events. Use of polyacrylamide (PAM), which reduces irrigation-induced erosion, also improves water infiltration, thereby reducing pesticide runoff.

Irrigation water management—Improved management of the rate and amount of irrigation water can reduce deep percolation, tailwater, and erosion losses.

Compaction reduction—Correcting compaction problems encourages water infiltration and reduces runoff.

Subsurface drainage—A high water table can result in excessive runoff and pesticide loss. Improving drainage increases water infiltration and reduces pesticide runoff. As subsurface drainage carries nitrate to streams, treatment of tile effluent in a constructed wetland or buffer area may be desirable.

Summary

Conservation buffers are an effective tool to reduce pesticides losses to water when used in conjunction with other BMPs. Pesticide trapping is most efficient when sheetflow, rather than concentrated flow, occurs across buffers. Sheetflow can be encouraged by proper buffer design, including such innovations as level spreaders, water bars, and stiff-grass hedges. As sediment is trapped, waterflow patterns are changed. Thus, buffer maintenance is critical. Sediment must be periodically removed and buffers reshaped to maintain effectiveness. Other soil conservation practices must be used in conjunction with buffers to prolong the effective buffer life.

Conservation buffers provide many other benefits, including trapping sediment and nutrients, providing wildlife habitat, protecting streambanks, and increasing farming safety. By varying buffer width along irregular streams or field borders, the cropped areas can be "squared up," reducing sprayer overlaps and making fields more compatible with Global Positioning Systems controls used in precision farming. Many buffer types can be selected to match site conditions and desired benefits. Appropriate buffer plant species should be selected to match local conditions. Research into buffer effectiveness in pesticide trapping is a relatively new field. As research continues, buffer designs and maintenance procedures will undoubtedly be refined to maximize their effectiveness.

Literature Cited

Arora, K., S.K. Mickelson, J.L. Baker, D.P. Tierney, and C.J. Peter. 1996. Herbicide retention by vegetative buffer strips from runoff under natural rainfall. Trans of the ASAE 30(6):2155-2162.

Arora, K., S.K. Mickelson, and J.L. Baker. 1995. Evaluating vegetative buffer strips for herbicide retention. Paper No. 95-2699. American Society of Agricultural Engineers, St. Joseph, MI.

Arora, K., J.L. Baker, S.K. Mickelson, and D.P. Tierney. 1993. Evaluating herbicide removal by buffer strips under natural rainfall. Paper No. 93-2593. American Society of Agricultural Engineers, St. Joseph, MI 49085.

Asmussen, L.E., A.W. White Jr., E.W. Hauser, and J.M. Sheridan. 1977. Reduction of 2,4-D load in surface runoff down a grassed waterway. J. Environ. Qual. 6(2):159-162.

Baker, J.L. 1983. Agricultural areas as nonpoint sources of pollution. *In* M.R. Overcash and J.M. Davidson (eds.) Environmental Impacts of Nonpoint Source Pollution. Ann Arbor Sci. Publ., Inc., Ann Arbor, MI. pp. 275-310.

Bharati, Luna. 1997. Infiltration in a Coland clay loam under a six-year old multi-species riparian buffer strip, cultivated row crops and continually grazed pasture. M.S. Dissertation, Iowa State Univ., Ames, IA.

Boyd, P.M., L.W. Wulf, J.L. Baker, and S.K. Mickelson, 1999. Pesticide transport over and through the soil profile of a vegetative filter strip. American Society of Agricultural Engineers. ASAE Paper no. 992077

Castelle, A.J., A.W. Johnson, and C.Conolly. 1994. Wetland and stream buffer size requirements - a review. J. Environ. Qual. 23:878-882.

Cole, J.T., J.H. Baird, N.T. Basta, R.L. Huhnke, D.E. Storm, G.V. Johnson, M.E. Payton, M.D. Smolen, D.L. Martin, and J.C. Cole. 1997. Influence of buffers on pesticide and nutrient runoff from bermudagrass turf. J. Environ. Qual. 26:1589-1598.

Dillaha, T.A., R.B. Reneau, S. Mostaghimi, and D. Lee. 1989. Vegetative filter strips for agricultural nonpoint source pollution control. Trans. of the ASAE 32(2):513-519.

Eisenhaurer, Dean, Thomas Franti, Mike Dosskey, and Kyle Hoagland. 1997. Field assessment of surface runoff patterns into riparian areas. Proceedings Vegetative Filter Strip and Riparian Buffer Research Symposium, Dec. 17, 1997. University of Nebraska, Lincoln.

Fawcett, Richard S., Brian R. Christensen, and Dennis P. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: a review and analysis. J. Soil and Water Cons. 49(2):126-135.

Fawcett, R.S., D.P. Tierney, C.J. Peter, J.L. Baker, S.K. Mickelson, J.L. Hatfield, D.W. Hoffman, and T.G. Franti. 1995. Protecting aquatic ecosystems with vegetative filter strips and conservation tillage. Proceedings of the National Agricultural Ecosystem Management Conference. New Orleans, LA, December 13-15, 1995. Conservation Technology Information Center, West Lafayette, IN.

Franti, T.G., C.J. Peter, D.P. Tierney, R.S. Fawcett, and S.A. Meyers. 1998. Reducing herbicide losses from tile-outlet terraces. J. Soil and Water Cons. 53(1):25-31.

Gilliam, J.W., D.L. Osmond, and R.O. Evans. 1997. Selected agricultural best management practices to control nitrogen in the Neuse River Basin, North Carolina State University Technical Bulletin 311, Raleigh, NC.

Hall, J.K., N.L. Hartwig, and L.D. Hoffman. 1983. Application mode and alternate cropping effects on atrazine losses from a hillside. J. Environ. Qual. 12(3):336-340.

Hoffman, Dennis W. 1995. Use of contour grass and wheat filter strips to reduce runoff losses of herbicides. Proc. Austin Water Quality Meeting, Texas A & M Univ., Temple, TX.

Lee, Kye-Han. 1997. Nutrient and sediment removal by switchgrass and cool-season grass filter strips. Proceedings Vegetative Filter Strip and Riparian Buffer Research Symposium, Dec. 17, 1997, University of Nebraska, Lincoln.

Lowrance, R., L.S. Altier, J.D. Newbold, R.R. Schnabel, P.M. Groffman, J.M. Denver, D.L. Correll, J.W. Gilliam, J.L. Robinson, R.S. Brinsfield, K.W. Staver, W. Lucas, and A.H. Todd. 1995. Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. EPA 903-R-95-004.

Lowrance, R., G. Vellidis, R.D. Wauchope, P. Gay, and D.D. Bosch. 1997. Herbicide transport in a managed riparian forest buffer system. Trans. of the ASAE 40(4):1047-1057.

Magette, William L., Russel B. Brinsfield, Robert E. Palmer, and James D. Wood. 1989. Nutrient and sediment removal by vegetated filter strips. Trans. of the ASAE 32(2):663-667.

Matter, Michael Patrick. 1993. Sorption kinetics of atrazine and hydroxyatrazine in freshwater wetlands. M.S. Dissertation, Iowa State Univ., Ames, IA.

Meyer, L.D., S.M. Dabney, and W.C. Harmon. 1995. Sediment-trapping effectiveness of stiff-grass hedge. Trans. of the ASAE 38(3):809-815.

Mickelson, S.K., J.L. Baker, S.W. Melvin, R.S. Fawcett, D.P. Tierney, and C.J. Peter. 1998. Effects of soil incorporation and setbacks on herbicide runoff from a tile-outlet terraced field. J. Soil and Water Cons. 53(1):18-25.

Mickelson, S.K. and J.L. Baker. 1993. Buffer strips for controlling herbicide runoff losses. Paper No. 932084. American Society of Agricultural Engineers, St. Joseph, MI.

Misra, Akhilesh Kumar. 1994. Effectiveness of vegetative buffer strips in reducing herbicide transport with surface runoff under simulated rainfall. Ph.D. Dissertation, Iowa State Univ., Ames, IA.

Misra, A., J.L. Baker, S.K. Mickelson, and H. Shang. 1996. Contributing area and concentration effects on herbicide removal by vegetative buffer systems. Trans. of the ASAE 39(6):2105-2111.

Misra, A., J.L. Baker, S.K. Mickelson, and H. Shang. 1994. Effectiveness of vegetative buffer strips in reducing herbicide transport with surface runoff under simulated rainfall. Paper No. 942146. American Society of Agricultural Engineers, St. Joseph, MI.

Patty, L., B. Real, and J.J. Gril. 1997. The use of grassed buffer strips to remove pesticides, nitrate and soluble phosphorous compounds from runoff water. Pesticide Sci. 49:243-251.

Rankins, A., Jr., D.R. Shaw, M. Boyette, and S.M. Seifert. 1998. Minimizing herbicide and sediment losses in runoff with vegetative filter strip. Abstracts Weed Sci. Soc. Am. 38:59.

Reicosky, D.C., W.D. Kemper, G.W. Langdale, C.L. Douglas, Jr., and P.E. Rasmussen. 1995. Soil organic matter changes resulting from tillage and biomass production. J. Soil and Water Cons. 50:253-261.

Rohde, W.A., L.E. Asmussen, E.W. Hauser, R.D. Wauchope, and H.D. Allison. 1980. Trifluralin movement in runoff from a small agricultural watershed. J. Environ. Qual. 9(1):37-42.

Schultz, R.C., J.P. Colletti, T.M. Isenhart, W.W. Simpkins, C.W. Mize, and M.L. Thompson. 1995. Design and placement of a multi-species riparian buffer strip system. Agroforestry Syst. 29:201-226.

Schultz, Richard C., Amy Kuehl, Joe P. Colletti, Paul Wray, Tom Isenhart, and Laura Miller. 1997. Riparian buffer systems. Iowa State University Publication Pm-1626a, Ames, IA.

Tingle, C.H., D.R. Shaw, M. Boyette, and G.P. Murphy. 1998. Metolachlor and metribuzin losses in runoff as affected by width of vegetative filter strips. Weed Sci. 46:475-479.

USDA-NRCS. CORE4 Conservation Practices. The Common Sense Approach to Natural Resource Conservation. Natural Resources Conservation Service. Fort Worth, Texas. 385 pp.

Wauchope, R.D. 1978. The pesticide content of surface water draining from agricultural fields – a review. J. Environ. Qual. 7:459-472.

Webster, E.P. and D.R. Shaw. 1996. Impact of vegetative filter strips on herbicide loss in runoff from soybean (Glycine max). Weed Sci. 44:662-671.

Welsch, D.J. 1991. Riparian Forest Buffers. USDA-FS Pub. No. NA-PR-07-91. USDA-FS, Radnor, PA.

Wood, H.B. 1977. Hydrologic differences between selected forested and agricultural soils in Hawaii. Soil Sci. Soc. Am. J. 41:132-136.

Yonts, C.D., R.G. Wilson, and G.L. Hein. 1996. Control of pesticides and nitrates in surface irrigation runoff water. Paper No. 96-1041. American Society of Agricultural Engineers, St. Joseph, MI.