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Agroforestry Buffers for Nonpoint Source Pollution Reductions from Agricultural Watersheds

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Despite increased attention and demand for the adoption of agroforestry practices throughout the world, rigorous long-term scientific studies confirming environmental benefits from the use of agroforestry practices are limited. The objective was to examine nonpoint-source pollution (NPSP) reduction as influenced by agroforestry buffers in watersheds under grazing and row crop management. The grazing study consists of six watersheds in the Central Mississippi Valley wooded slopes and the row crop study site consists of three watersheds in a paired watershed design in Central Claypan areas. Runoff water samples were analyzed for sediment, total nitrogen (TN), and total phosphorus (TP) for the 2004 to 2008 period. Results indicate that agroforestry and grass buffers on grazed and row crop management sites significantly reduce runoff, sediment, TN, and TP losses to streams. Buffers in association with grazing and row crop management reduced runoff by 49 and 19%, respectively, during the study period as compared with respective control treatments. Average sediment loss for grazing and row crop management systems was 13.8 and 17.9 kg ha^{-1} yr^{-1}, respectively. On average, grass and agroforestry buffers reduced sediment, TN, and TP losses by 32, 42, and 46% compared with the control treatments. Buffers were more effective in the grazing management practice than row crop management practice. These differences could in part be attributed to the differences in soils, management, and landscape features. Results from this study strongly indicate that agroforestry and grass buffers can be designed to improve water quality while minimizing the amount of land taken out of production.

Three decades after the implementation of the Clean Water Act in the 1970s, nonpoint-source pollution (NPSP) remains a major challenge in protecting and restoring water quality. Despite improvements in soil conservation practices, crop rotation, and nutrient management programs, significant concerns still exist regarding soil erosion and nutrient runoff from agriculture (Udawatta et al., 2006b). Agricultural practices of row cropping and grazing are often blamed for adverse effects on the quality of surface and ground waters. The USEPA (2009) noted that agriculture is the leading cause of water pollution, which has impacted 44, 64, and 30% of evaluated river, lake, and estuary areas, respectively. The most common pollutants to water bodies were sediment, nutrients, pathogens, and organic enrichments.

Kohn (2004) and Jones et al. (2004) suggested that the proportion of forest to agricultural land cover can be a good indicator of NPSP moving to streams and lakes. For example, Omernik et al. (1981) observed that total nitrogen (TN) concentrations were nearly nine times greater downstream from agricultural lands than downstream from forested areas, with the highest concentration in the Corn Belt states. Although many of our current agricultural practices negatively affect water and soil quality, improved management practices have the potential to reverse these negative effects. Studying a 360-km^2 agricultural basin in Wisconsin with 140 yr of data, Trimble (1999) noticed decreased sediment loss with improved soil conservation practices.

Establishment of perennial vegetation on agricultural watersheds as upland buffers and streamside riparian buffers has been shown to improve water quality parameters (Udawatta et al., 2002; Schultz et al., 2009). This is because incorporation of permanent vegetation on row crop and pastured watersheds improves soil physical and biological properties compared with row crop management alone (Mungai et al., 2005; Seobi et al., 2005; Kumar et al., 2008). Strategically positioned buffers can enhance environmental benefits by filtering nutrients and reducing sediment losses more effectively. This strategy might include conversion of sensitive areas, such as variable source areas or areas with greater runoff potential to perennial vegetation or

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Abbreviations: HARC, Horticulture and Agroforestry Research Center; NPSP, nonpoint-source pollution; TN, total nitrogen; TP, total phosphorus.

wetlands (Schmitt, 1999; Qui, 2003). In support of this concept, Omernik et al. (1981) concluded that land-use patterns across the entire watershed are more important in determining water quality than a single practice on a selected location. His review was based on nutrient outputs of >80 large watersheds (average area 40 km^2). Numerous studies suggest that a holistic approach that addresses landscape parameters, soil properties, and management provides the best protection of watersheds.

Agroforestry practices have been recognized as a measure to address many issues related to water and soil quality (Udawatta et al., 2002, 2009; Schultz et al., 2009; Jose, 2009). Implementation of water quality protection may include establishing vegetative buffers, protecting streams and stream banks, and managing grazing. Zaimes et al. (2004) showed that vegetative buffers reduce significant quantities of nutrients in runoff from grazed pastures and row-cropped fields. Trees with deep root systems function as an efficient safety net to capture nutrients that are lost from the crop or pasture root zone. On the soil surface, tree roots, fallen branches, and litter material reduce flow velocity and thereby enhance sedimentation. Moreover, they help reduce loss of sediment-bound nutrients.

The general public desires and deserves environmentally acceptable management strategies from agricultural operations. Landowners, state agencies, and other regulatory authorities need scientifically proven, practical, and biologically acceptable buffer development guidelines for the protection of water resources. Although agroforestry practices improve environmental quality, studies comparing the effectiveness of agroforestry buffers on water quality within ecoregions or land uses are largely missing from the literature (Loveall and Sullivan, 2006). This paper examines the effects of agroforestry and grass buffers on discharge of water, sediment, and nutrients from two long-term studies under conditions of grazing and row crop management.

Materials and Methods

Watersheds Studied and Management

The mini watersheds located at the Horticulture and Agroforestry Research Center (HARC), New Franklin, MO (39°01′05″ N, 92°45′34″ W, 195 m above mean sea level; Fig. 1A and 1B; Udawatta et al., 2010), were monitored during the 2004 to 2008 period. Treatments were agroforestry buffers, grass buffers, and a control (no buffer), with two replications of each. All treatment watersheds were created on slopes of 12% by establishing a soil berm around 0.8-ha area and subsequently compressing the berms with a tractor. Each treatment unit is 107 m long and 75 m wide. For the agroforestry and grass buffer treatments, the width is divided into a 60-m grazing area and a 15-m buffer area. These buffer areas were fenced and not grazed, and occupy 20% of a watershed area. The entire 75-m width was grazed on the control treatment. The groundcover vegetation in the buffer and grazed areas is the same—consisting of tall fescue [*Schedonorus phoenix* (Scop.) Holub] red clover (*Trifolium pratense* L.), and lespedeza (*Lespedeza* Michx). Four rows of eastern cottonwood trees (*Populus deltoides* Bortr. ex Marsh.) were planted in 2001 at a 3-m spacing between and within rows to create the agroforestry buffers. The average tree diameter at the end of the 2008 growing season was 13 cm at breast height (1.4 m above ground). Grass buffers were maintained unmanaged.

Soils in the watersheds are Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs) with 30% slope. The long-term mean precipitation (1956–2007) for the study area is 970 mm (http://mrcc.isws.illinois.edu). Of this precipitation, approximately 64% falls in April through September. The mean temperature in July is 31.7°C and mean temperature in January is −7.6°C.

Watersheds were managed with no cattle for 4 yr and cattle were introduced in 2005. Each year since grazing began, three, 450- to 490-kg beef cows were placed in each grazing area for

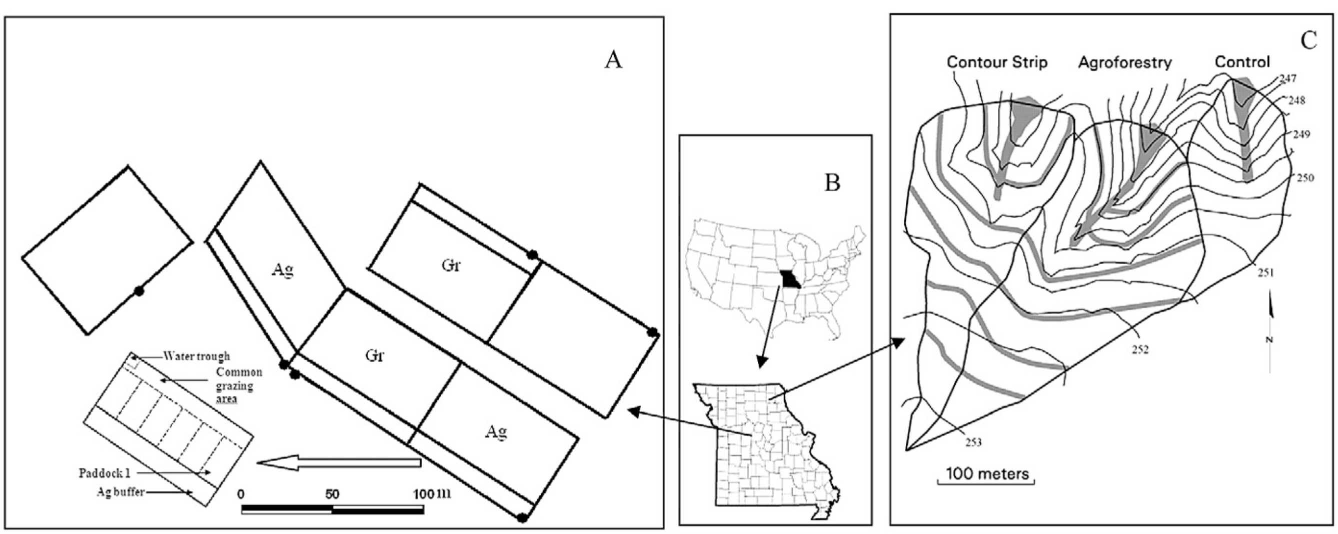

Fig. 1. (A) The six study watersheds were located at the Horticulture and Agroforestry Research Center (HARC), New Franklin, Howard County, MO (Udawatta et al., 2010). Narrow strips on four watersheds represent agroforestry (Ag) and grass (Gr) buffers. Black circles represent water sampler assembly and location of H flumes. (B) The inset map shows approximate location of HARC and Greenley Center in Missouri. (C) Three watersheds of the paired watershed study at Greenley Research Center, Novelty, Knox County, MO (Udawatta et al., 2002). Wide gray bands represent grass buffers on the contour grass strip watersheds, agroforestry buffers (tree + grass) on the agroforestry watershed, and grass waterways (three perpendicular bands) on all three watersheds. Narrow lines represent 0.5-m interval contour lines.

approximately 215 d between March and November. A four-wire, high-tensile electric fence prevented cattle access to buffer areas. The grazing area within each unit was divided into six equal-sized paddocks for rotational grazing. Cattle were grazed on a paddock for 3.5 d and the paddock was rested for 17.5 d. Additional information about cattle management and the study site can be found in Kumar et al. (2008).

In the second long-term study, watersheds located at the University of Missouri's Greenley Memorial Research Center in Knox County, MO (40°01′52″ N, 92°11′14″ W; Fig. 1B and 1C), have been monitored since 1991 to evaluate the influence of "in-field" buffers on water quality in row crop watersheds. This study used a paired watershed approach with three adjacent north-facing watersheds designated as "east," "center," and "west," with land areas of 1.65, 4.44, and 3.16 ha, respectively. No treatments were established between 1991 and 1997, but water samples were collected and analyzed for water quality parameters. The time period between 1991 and 1997 is called the "calibration period."

Agroforestry (oak trees + grass) and grass-legume buffer treatments were established in 1997 on the center and west watersheds, respectively. The grass-legume combination planted throughout the buffer strips included redtop (*Agrostis gigantea* Roth), smooth bromegrass (*Bromus inermis* L.), and birdsfoot trefoil (*Lotus corniculatus* L.). Pin oak (*Quercus palustris* Münchh.), bur oak (*Q. macrocarpa* Michx.), and swamp white oak (*Q. bicolor* Willd.) were alternately planted in the center of the buffer strips at a 3-m spacing to create agroforestry buffers on the center watershed. Grass waterways on the three watersheds consist of 'Kentucky 31' tall fescue.

The three watersheds were maintained in a corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] rotation under no-till management. Corn was planted in 2004, 2006, and 2008, during the 5-yr period. The watersheds are underlain by glacial and loess material. Soils are mapped as Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs), Kilwinning silt loam (fine, smectitic, mesic Vertic Epiaqualfs), and Armstrong loam (fine, smectitic, mesic Aquertic Hapludalfs). Thirty-year mean (1961–1990) annual precipitation in the region is 920 mm, of which >66% falls from April through September (Owenby and Ezell, 1992). Details on watershed management, parent material, soils, experimental design, and climatic data can be found elsewhere (Udawatta et al., 2002).

Water Sampling and Sample Analysis

The watersheds at the Greenley Center and the six experimental watersheds at HARC were instrumented with concrete approach sections, H-flumes, bubbler flow-measuring devices, and water sampling units (ISCO Inc., Lincoln, NE). Flumes at the grazing study site are 0.61 m (2 ft), whereas flumes at the paired watershed site are 1.07 m (3.5 ft) and 1.22 m (4 ft). ISCO bubbler flow-measuring devices record flow rate, water level, sampling time, and control ISCO water samplers, which collect water samples. All nine units are on flow-paced sampling, i.e., sampling is conducted after a set amount of water passed through the H-flume. These units were removed from the watersheds during the third week of December when the water in the stilling well was frozen. Thus, the sample collection period extended from February–March to late December each year. Runoff samples were collected after each measurable runoff event. Water samples were transported from the field to the laboratory and composite samples were analyzed for sediment, total phosphorus (TP), and TN. Unprocessed samples were refrigerated at 4°C until analysis.

A known volume (varies with sediment concentration) of a well-mixed sample was filtered through a preweighed glass microfiber filter (934–AH), using a vacuum pump to estimate suspended sediment weight. These filters were dried at 105°C to a constant weight. Differences between the tare weights and sample volume were used to estimate the weight of suspended sediment.

Total P and TN were determined on a Lachat Quickchem Automated Ion Analyzer (HACH Company, Loveland, CO). Total P in unfiltered samples was determined through ammonium peroxydisulfate digestion and analysis using an ascorbic acid–molybdate procedure (Liao and Marten, 2000). The detection limit for the method was 0.9 μg P L^{-1}. Total N was determined using Cd reduction on unfiltered samples, following potassium perusulfate digestion (Pitzlaff, 1999). The detection limit for the TN method is 0.002 mg N L^{-1}. Quality control for the Lachat analyzer was maintained by randomly positioning three control standards with differing concentrations, three duplicate samples, and one quality control sample in each 90-sample tray.

Statistical analysis of data was performed using SAS (SAS Institute, 1999). Random variables, runoff, sediment loss, and nutrient loss were analyzed as a split-plot in time. The main plot consisted of management and the subplots consisted of year and interaction of management × year. The fixed effects were management, year, and the interaction of management × year. Differences were declared to be significant at $\alpha = 0.05$ level (SAS Institute, 1999).

The paired watershed analysis procedures were used to examine treatment differences in the row crop trial (USEPA, 1993). In brief, runoff, sediment, N, and P losses during the calibration period (1991–1997) were used to develop regression relationships among the three watersheds. For example, runoff on the contour strip watershed (m^3 ha^{-1}) = 0.999 × runoff on the control watershed (m^3 ha^{-1}); $r^2 = 0.97$. Calibration relationships and losses on the control watershed were used to predict runoff and other losses on treatment watersheds during the treatment period, i.e., if treatments were not established, treatment watersheds would have lost predicted amounts. The treatment effect was estimated by predicted loss minus observed loss by runoff event.

Results

Precipitation

Monthly rainfall amounts and long-term means were different for the two study sites (Fig. 2). The long-term annual precipitation means for HARC and the Greenley Center are 970 and 920 mm, respectively. At HARC, precipitation was above normal in 2004 and 2008, when precipitation was 115 and 148%, respectively, of the long-term mean. Rainfall amounts were 102 and 156%, respectively, of the long-term mean for the Greenley Center in these same years. On average, precipitation amounts were 10, 10, and 5% below the long-term mean

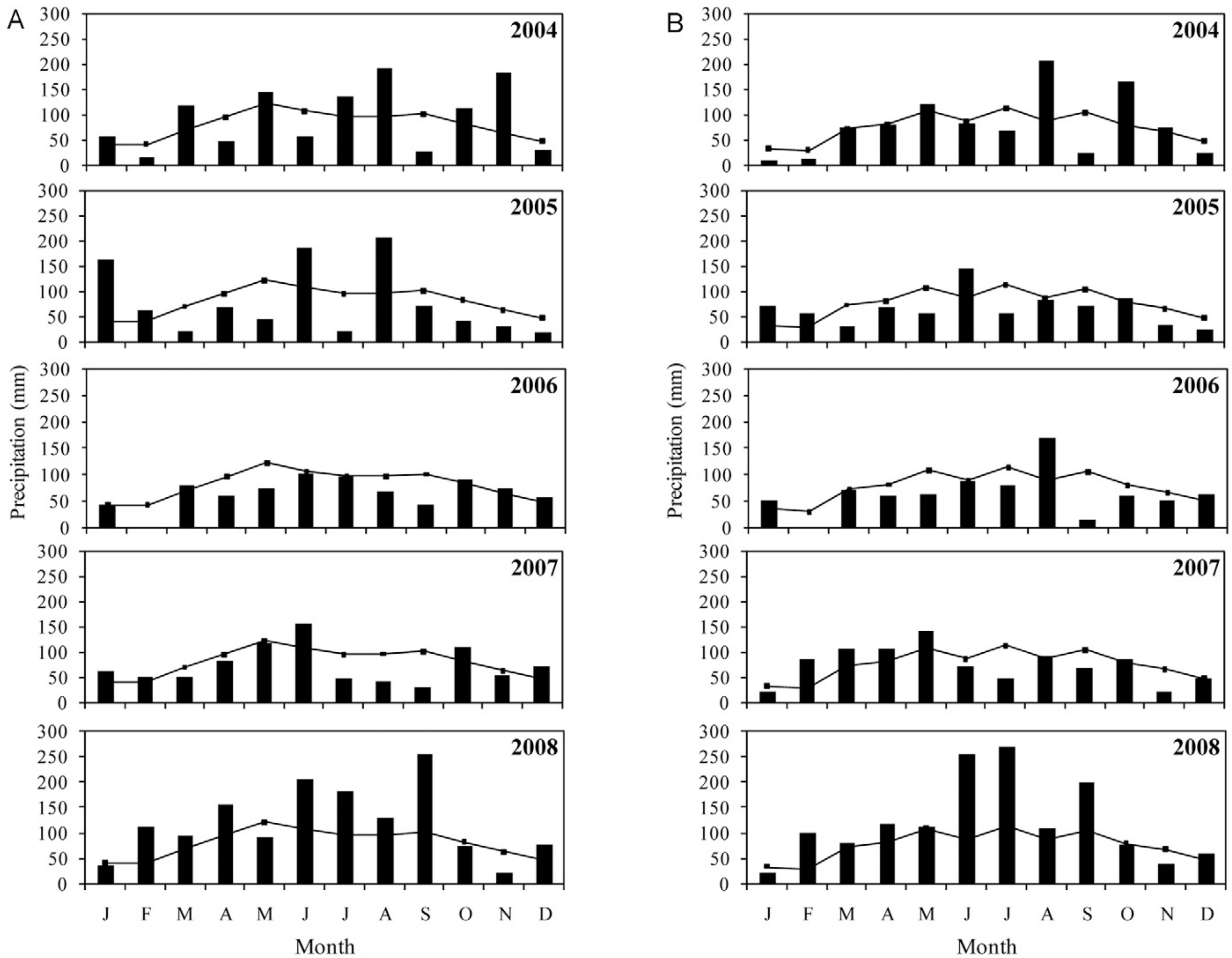

Fig. 2. Monthly precipitation (bars) and long-term mean (line) from 2004 to 2008 for (A) Agroforestry and Horticulture Research Center and (B) Greenley Research Center.

in 2005, 2006, and 2007, respectively, for the two study sites. Although the study sites recorded three drier years than the normal, average precipitation was 1.6% greater than normal for the entire study period.

There was no runoff in 2006, which was the driest year of the study. All nine units (six for grazing and three for row crop) produced the highest number of runoff events in 2008. The watersheds at HARC and Greenley produced 27 and 24 measurable runoff events during the study period, respectively.

Runoff

Despite differences in study approaches, both the grazing and row crop management sites showed significant reductions in runoff as influenced by buffers. However, annual discharge of water per area varied greatly among treatments and years. Runoff volumes closely follow the precipitation distribution. For example, study areas received above normal precipitation in 2004 and 2008, and runoff volumes were larger in all treatments as compared with the period between 2005 and 2007. There was no runoff during the driest year in the study.

Under row crop management, watersheds with agroforestry and grass buffers had significantly smaller runoff volumes than the control. The average runoff volumes during the study period were 145 and 112 m^3 ha^{-1} for the control and buffer treatments, respectively. The treatment watersheds yielded less runoff than the predicted volumes, except for three runoff events. The difference, observed minus predicted, ranged from +5 to −73 m^3 ha^{-1}, as compared with the predicted loss (Fig. 3). The positive differences occurred when rain continued for an extended period—causing greater antecedent moisture level in the soil than normal rain events. On average, the grass-buffered and agroforestry-buffered watersheds yielded reduced runoff volumes that were 23 and 15% less than the predicted volumes during the study. During the 1997 to 1999 period, the grass-buffered watershed reduced runoff by 10% as compared with 1% on the agroforestry-buffered watershed.

On average, runoff from the two buffer treatments on the grazing management site yielded only 30 and 59% of the runoff observed for the control treatment in 2004 and 2008, respectively. In contrast, the differences between the buffer and control treatments were small in years with relatively few runoff events. Among the study years, the difference between buffers and the control was significant in 2004 and 2008. During the 4-yr study period, agroforestry and grass buffer treatments reduced runoff by 52 and 45%, respectively, compared with the control treatment in the grazing system.

Sediment Loss

Soil loss on watershed sites was significantly affected by buffer treatments. Soil loss in runoff water generally paralleled rainfall amounts and runoff. Sediment losses were greater in years with more runoff and were lower in years with less runoff and precipitation. In the row crop management practice, agroforestry, grass buffer, and control treatments had sediment losses of 76, 82, and 110 kg ha^{-1}, respectively, during the study. On average, the control watershed lost 7.36 kg sediment ha^{-1} in each runoff event and 22 kg sediment ha^{-1} yr^{-1} for the study period. The average sediment losses were 5.04 and 5.46 kg ha^{-1} in each runoff event for watersheds with agroforestry and grass buffers, respectively. Agroforestry and grass buffer treatments reduced sediment losses by 30 and 28%, respectively, during the 2004 to 2008 period when analyzed using the paired watershed approach (Fig. 4; Table 1).

The three grazing treatments lost a total of 47, 70, and 91 kg sediment ha^{-1} during the 5-yr study from the agroforestry, grass buffer, and control treatment areas, respectively. The average annual sediment loss for grazing management was 13.8 kg ha^{-1}. Sediment losses during the 5 yr were 48 and 23% lower in the agroforestry and grass buffer treatments, respectively, compared with the control (Table 1). Buffers in association with grazed areas helped reduce sediment loss by 36% during the study.

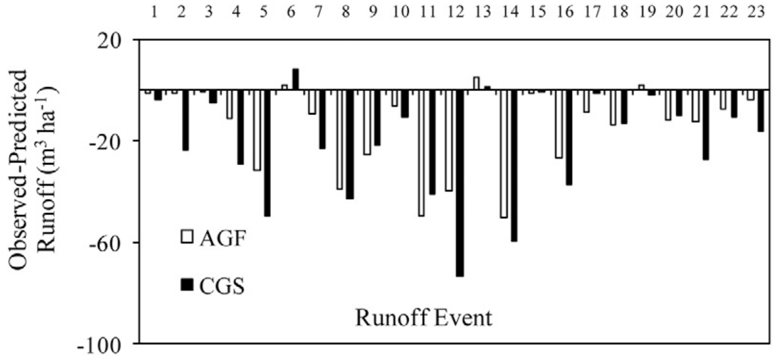

Fig. 3. Observed minus predicted runoff volumes for agroforestry (AGF) and grass buffer (CGS) watersheds at the Greenley Research Center from 2004 to 2008.

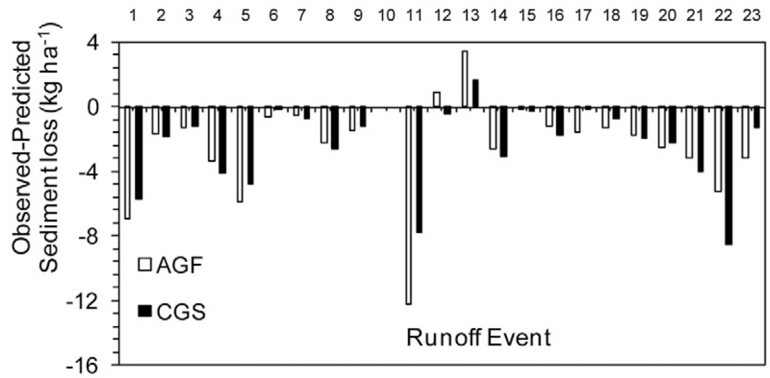

Fig. 4. Observed minus predicted sediment loss for agroforestry (AGF) and grass buffer (CGS) watersheds at the Greenley Research Center from 2004 to 2008.

Nitrogen Loss

In the row crop management study, TN loss was reduced by 11 and 13% by the agroforestry and grass buffer treatments, respectively, compared with the predicted losses based on calibration equations. The agroforestry, grass buffer, and control treatments lost 14, 16.8, and 24.8 kg TN ha^{-1}, respectively, during the treatment period. Annual losses were 2.8, 3.3, and 4.96 kg ha^{-1} yr^{-1}, respectively, on the treatments.

Total N loss was significantly reduced by all buffer treatments (Table 1). The agroforestry and grass buffer treatments within the grazing system reduced TN losses by 75 and 68%, respectively, compared with the control. Total N losses were 1.85, 2.34, and 7.47 kg ha^{-1} from the agroforestry, grass buffer, and control treatment sites, respectively, during the study. The differences were significant among the three treatments. The control treatment lost 4 and 3.2 times more TN than the agroforestry and grass buffer treatments, respectively.

Phosphorus Loss

Row crop management at the Greenley Center also showed a reduction in TP loss as influenced by buffers. The reductions in TP loss on the agroforestry and grass buffer watersheds were 26 and 22%, respectively, based on the calibration equation. Annual TP losses from the control, agroforestry, and contour grass buffered watersheds averaged 0.03, 0.02, and 0.03 kg ha^{-1}, respectively. During the study period, watersheds with buffers lost 0.16 kg ha^{-1} compared with 0.20 kg ha^{-1} for the control watershed.

Buffers had a significant effect on reducing P in runoff from grazed and row-cropped watersheds. Under grazing management, the agroforestry buffer, grass buffer, and control treatments lost 273, 305, and 924 g ha^{-1}, respectively, during the 5 yr. Compared with the control treatment, the two buffer treatments on average reduced the TP loss by 68%.

Discussion

Research in other regions has shown that buffers with trees and/or grass help reduce NPSP loss from row crop watersheds (Bharati et al., 2002; Abu-Zreig et al., 2003; Dosskey et al., 2007; Schultz et al., 2009). However, most of the studies were either short term or small plot scale, as compared with these two studies. Results reported in these two long-term studies show significant reductions in TN and TP where buffers were implemented. For example, TN and TP losses on the same

Table 1. Percent reduction of sediment, total N, and total P losses on grazing and row crop management practices with agroforestry and grass buffers compared with the respective control treatment.

Parameter	Managements and treatments			
	Grazing management		Row crop management	
	Agroforestry	Grass buffer	Agroforestry	Contour grass
	%			
Sediment	48	23	30	28
Total N	75	68	11	13
Total P	70	67	26	22

three row crop watersheds before buffers were installed during the calibration period were 16 and 1.36 kg ha^{-1} yr^{-1} compared with 3.05 and 0.16 kg ha^{-1} yr^{-1} after buffers were installed (Udawatta et al., 2004, 2006b).

Grass and trees + grass buffers improved infiltration, water holding capacity, bulk density, and soil porosity (Seobi et al., 2005; Kumar et al., 2008; Udawatta and Anderson, 2008). Studying soil physical properties, Kumar et al. (2008) showed that saturated hydraulic conductivity was 16.7 times greater in buffer areas compared with the grazed areas on our grazed study site. On the row crop watersheds, saturated hydraulic conductivity was 14 times greater in the buffer areas than in crop areas (Seobi et al., 2005). Bulk density values were significantly lower in buffer areas than in crop areas (Seobi et al., 2005; Kumar et al., 2008). In addition, permanent vegetation in buffer areas use soil water before the crop is established—helping reduce runoff potential (Anderson et al., 2009). And, Anderson et al. (2009) found that soil water content was significantly lower throughout the growing season, except for recharge periods and thereby reducing the antecedent moisture, which in turn increases total water holding capacity over time. Other research has shown that establishment of buffers improves soil biological parameters and C sequestration (Mungai et al., 2005; Udawatta et al., 2009). These soil physical and biological improvements, as well as use of soil water by the permanent vegetation, were obvious factors in helping reduce NPSP losses in grazing and row crop agriculture in our studies.

The results of the current study (2004–2008) show greater reduction in runoff on both buffer treatments as compared with the initial 3 yr. These differences could be attributed to maturity of buffers, greater transpiration in the buffer areas, lower soil water content (Anderson et al., 2009), expansion of above- and below-ground biomass (Udawatta et al., 2005), and soil quality improvements (Udawatta et al., 2009). This also emphasizes the long-term environmental benefits of buffers and protection of buffers for enhanced water quality improvements.

A comparison between the grazing and row crop management showed that buffers resulted in greater reductions in NPSP in the grazing study than under row crop management. The grazing treatment is established in soils formed from loess material. Deeper soils without a restrictive horizon and greater water use by the pasture vegetation may have contributed to the benefits observed as compared with the effects on the row crop soils. Soils with a restrictive horizon, such as a claypan with extremely low saturated hydraulic conductivity values typical of those of the row crop site, reduce water infiltration and promote surface runoff (Blanco-Canqui et al., 2002). For example, saturated hydraulic conductivity values were 192 mm h^{-1} and 1.8 to 2.2 μm h^{-1} for surface to 10 cm and 55- to 75-cm soils, respectively (Blanco-Canqui et al., 2002). In addition, vegetation begins to transpire earlier and continues until late November or early December in the pasture study as compared with the cropped site. The trees in the grazing site are cottonwood, a fast-growing tree spp, whereas tree buffers on the row crop site consist of slow-growing oak spp. Differences in soils, management, and vegetation may have contributed to greater NPSP reductions in the grazing site as compared with the row crop site.

Moreover, in the control treatment on the grazing management site, cattle can reach the edge of the concrete approach section of the flume. Thus, additional disturbance in this area, due to trampling and manure accumulation, may have contributed to the large differences found between treatments and the control as compared with the differences observed under row crop management. This would also strongly indicate that direct cattle access to water bodies or adjacent areas should be regulated to protect water quality. On the row crop management site, water passes through a grass waterway before it reaches the concrete approach section on the three watersheds studied. The grass waterways likely serve to further reduce NPSP leaving all three watersheds, especially during small runoff events (Schultz et al., 2009; Udawatta et al., 2006a). These factors may have caused a smaller difference between the control and treatments on the row-cropped site as compared with grazing site.

Historical data show that buffers wider than 7 m produce marginal increase in terms of NPSP removal in runoff (Robinson et al., 1996; Schmitt et al., 1999). Buffers in the row-cropped site are 3 to 4 m wide, whereas buffers in the grazed site are 15 m wide. The upland buffers on the row crop watershed appear to help retain nutrients and sediments on the site, whereas buffers at the edge of the field representing riparian conditions serve as the final defense on the grazing site. In the current study, NPSP removal rates appear to be smaller as compared with plot scale studies where 85 to 97% removals have been observed (Patty et al., 1997; Edwards and Owens, 1991). As trees mature and occupy more soil volume, these sites may also filter more NPSP in runoff.

Upland buffers reduce slope length and slope steepness. In addition, upland buffers serve to keep nutrients on site within a watershed, although they have the disadvantage of taking productive land out of production (Schultz et al., 2009). Landowners and farmers prefer field-edge to within-field buffers due to their comparative practicality, easy maintenance, and cost effectiveness. In these studies, buffers occupy 10% of the within-land area in the row crop trial and 20% of the area as field edge in the grazing trial. Although these areas are taken out of production, we show that an allocation of only 10 to 20% of the land area to buffers can significantly reduce NPSP losses. At the Greenley Center, location of the row crop site, buffers are mowed and hayed. The hay can provide an additional income source to land owners and farmers. Moreover, research shows that buffers accumulate more C and nutrients than crop areas, especially when deeper-rooted vegetation is incorporated (Udawatta et al., 2009; Mungai et al., 2005). Thus, they may also indirectly help mitigate global warming while improving water quality. Establishment of buffers on critical areas may also provide ecosystem services as they improve water and soil quality, and have the potential to generate extra income in addition to wildlife benefits.

Conclusions and Implications

Despite differences in approaches and management systems, results support the hypothesis that agroforestry and grass buffers significantly reduce NPSP losses from grazed and row-cropped sites. Runoff, sediment, TN, and TP losses were significantly reduced by establishment of buffers under grazing and row crop management practices. In addition to improvements in water quality, in-field upland buffers serve to help retain soil and soil nutrients in the field as contrasted to field-edge buffers. Removal of NPSP by vegetative buffers appears to be more efficient in a grazing system with deep soils than in a row crop management system on a claypan soil. This variance, in part, can be attributed to landscape, restrictive horizons, grass waterways, and tree species differences. It is assumed that beneficial effects from buffers will increase with time, as the permanent vegetation occupies larger soil volumes and improves soil physical and biological properties. Results of these studies suggest that management strategies designed to minimize runoff and NPSP losses should include strategic placement of in-field buffers.

Acknowledgments

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References

Abu-Zreig, M., R.P. Rudra, H.R. Whiteley, M.N. Lalonde, and N.K. Kaushik. 2003. Phosphorus removal in vegetated filter strips. J. Environ. Qual. 32:613–619.

Anderson, S.H., R.P. Udawatta, T. Seobi, and H.E. Garrett. 2009. Soil water content and infiltration in agroforestry buffer strips. Agrofor. Syst. 75:5–16.

Bharati, L., K.H. Lee, T.M. Isenhart, and R.C. Schultz. 2002. Soil-water infiltration under crops, pasture, and established riparian buffer in Midwest USA. Agrofor. Syst. 56:249–257.

Blanco-Canqui, H., C.J. Gantzer, S.H. Anderson, E.E. Alberts, and F. Ghidey. 2002. Saturated hydraulic conductivity and its impact on simulated runoff for claypan soils. Soil Sci. Soc. Am. J. 66:1596–1602.

Dosskey, M.G., K.D. Hoagland, and J.R. Brandle. 2007. Change in filter strip performance over ten years. J. Soil Water Conserv. 62:21–32.

Edwards, W.M., and L.B. Owens. 1991. Large storm effects on total soil erosion. J. Soil Water Conserv. 46:75–78.

Jones, J.R., M.F. Knowlton, D.V. Obrecht, and E.A. Cook. 2004. Importance of landscape variables and morphology on nutrients in Missouri reservoirs. Can. J. Fish. Aquat. Sci. 61:1503–1512.

Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: An overview. Agrofor. Syst. 76:1–10.

Kohn, R.A. 2004. Use of animal nutrition to manage nitrogen emissions from animal agriculture. p. 25–30. *In* Proc. of the Mid-Atlantic Nutrition Conf., Timonium, MD. 24–25 Mar. 2004. Maryland Feed Industry Council, Inc., College Park, MD.

Kumar, S., S.H. Anderson, L.G. Bricknell, and R.P. Udawatta. 2008. Soil hydraulic properties influenced by agroforestry and grass buffers for grazed pasture systems. J. Soil Water Conserv. 63:224–232.

Liao, N., and S. Marten. 2000. Determination of total phosphorus by flow injection analysis colorimetry (acid perusulfate digestion method; 10-115-01-1-F). Zellweger Analytics, Lachat Instruments, Milwaukee, WI.

Loveall, S.T., and W.C. Sullivan. 2006. Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. Agric. Ecosyst. Environ. 112:249–260.

Mungai, N.W., P.P. Motavalli, R.J. Kremer, and K.A. Nelson. 2005. Spatial variation of soil enzyme activities and microbial functional diversity in temperate alley cropping systems. Biol. Fertil. Soils 42:129–136.

Omernik, J.M., A.R. Abernathy, and L.M. Male. 1981. Stream nutrient levels and proximity of agricultural and forest lands to streams: Some relationships. J. Soil Water Conserv. 36:227–231.

Owenby, J.R., and D.S. Ezell. 1992. Monthly station normals of temperature, precipitation, and heating and cooling degree days 1961–90. Climatography of the United States no. 81. Natl. Climatic Data Center, Ashville, NC.

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

Pitzlaff, D. 1999. Determination of nitrate/nitrite in surface and wastewater by flow injection analysis (10-107-04-1-C). Zellweger Analytics, Lachat Instruments, Milwaukee, WI.

Qui, Z. 2003. A VSA-based strategy for placing conservation buffers in agricultural watersheds. Environ. Manage. 32:299–311.

Robinson, C.A., M. Ghaffarzadeh, and R.M. Cruse. 1996. Vegetative filter strip effects on sediment concentration in cropland runoff. J. Soil Water Conserv. 50:227–230.

SAS Institute. 1999. SAS user's guide: Statistics. SAS Inst., Cary, NC.

Schmitt, S.J. 1999. Application of a flow source mixing model and remote sensing to the hydrology and water quality of two small watersheds in Northern Missouri. MS Thesis, Univ. of Missouri, Columbia, MO.

Schmitt, T.J., M.G. Dosskey, and K.D. Hoagland. 1999. Filter strip performance and processes for different vegetation, widths, and contaminants. J. Environ. Qual. 28:1479–1489.

Schultz, R.C., T.M. Isenhart, J.P. Colletti, W.W. Simpkins, R.P. Udawatta, and P.L. Schultz. 2009. Riparian and upland buffer practices. p. 163–218. *In* H.E. Garrett (ed.) North American agroforestry: An integrated science and practice. ASA, Madison, WI.

Seobi, T., S.H. Anderson, R.P. Udawatta, and C.J. Gantzer. 2005. Influence of grass and agroforestry buffer strips on soil hydraulic properties for an Albaqualf. Soil Sci. Soc. Am. J. 69:893–901.

Trimble, S.W. 1999. Decreased rates of alluvial sediment storage in the Coon Creek Basin, Wisconsin, 1975–1993. Science 285:1244–1246.

Udawatta, R.P., and S.H. Anderson. 2008. CT-measured pore characteristics of surface and subsurface soils influenced by agroforestry and grass buffers. Geoderma 145:381–389.

Udawatta, R.P., H.E. Garrett, and R.L. Kallenbach. 2010. Agroforestry and grass buffer effects on water quality in grazed pastures. Agrofor. Syst. 79:81–87 doi:10.1007/s10457-010-9288-9.

Udawatta, R.P., G.S. Henderson, J.R. Jones, and R.D. Hammer. 2006a. Runoff and sediment from row-crop, row-crop with grass strips, pasture, and forested watersheds. J. Water Sci. 19:137–149.

Udawatta, R.P., R.J. Kremer, H.E. Garrett, and S.H. Anderson. 2009. Soil enzyme activities and physical properties in a watershed managed under agroforestry and row-crop systems. Agric. Ecosyst. Environ. 131:98–104.

Udawatta, R.P., J.J. Krstansky, G.S. Henderson, and H.E. Garrett. 2002. Agroforestry practices, runoff, and nutrient loss: A paired watershed comparison. J. Environ. Qual. 31:1214–1225.

Udawatta, R.P., P.P. Motavalli, and H.E. Garrett. 2004. Phosphorus loss and runoff characteristics in three adjacent agricultural watersheds with claypan soils. J. Environ. Qual. 33:1709–1719.

Udawatta, R.P., P.P. Motavalli, and H.E. Garrett. 2006b. Nitrogen losses in runoff from three adjacent agricultural watersheds with claypan soils. Agric. Ecosyst. Environ. 117:39–48.

Udawatta, R.P., P.O. Nygren, and H.E. Garrett. 2005. Growth of three oak species during establishment in an agroforestry practice for watershed protection. Can. J. For. Res. 35:602–609.

USEPA. 1993. Paired watershed study design 841-F-93-009. Office of Water, USEPA, Washington, DC.

USEPA. 2009. National Water Quality Inventory: Report to Congress, 2004 reporting cycle: Findings. Available at http://www.epa.gov/305b (verified 5 Jan. 2011).

Zaimes, G.N., R.C. Schultz, and T.M. Isenhart. 2004. Stream bank erosion adjacent to riparian forest buffers, row-cropped fields, and continuously-grazed pastures along Bear Creek in central Iowa. J. Soil Water Conserv. 59:19–27.