Agroforestry and grass buffer effects on water quality in grazed pastures

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Abstract Conservation practices including agroforestry and grass buffers are believed to reduce nonpoint source pollution (NPSP) from pastured watersheds. Agroforestry, a land management practice that intersperses agricultural crops with trees, has recently received increased attention in the temperate zone due to its environmental and economic benefits. However, studies are limited that have examined buffer effects on the quality of water from grazed pastures. Six treatment areas, two with agroforestry buffers, two with grass buffers, and two control treatments were used to test the hypothesis that agroforestry and grass buffers can be used to effectively reduce NPSP from pastured watersheds. Vegetation in grass buffer and pasture areas includes red clover (*Trifolium pretense* L.) and lespedeza (*Kummerowia stipulacea* Maxim.) planted into fescue (*Festuca arundinacea* Schreb.). Eastern cottonwood trees (*Populus deltoides* Bortr. ex Marsh.) were planted into fescue in agroforestry buffers. Soils at the site are mostly Menfro silt loam (fine-silty, mixed, superactive, mesic Typic Hapludalfs). Treatments were instrumented with two-foot H flumes, water samplers, and flow measuring devices in 2001. Composite water samples were analyzed for sediment and total nitrogen after each runoff event to compare treatment differences. Treatments with agroforestry and grass buffers had significantly lower runoff volumes as compared to the control. The loss of sediment and total nitrogen were smaller for the buffered treatments. The results of this study suggest that establishment of agroforestry and grass buffers help reduce NPSP pollution from pastured watersheds. It is anticipated as trees grow and roots occupy more soil volume, the reduction in N in runoff will increase on the agroforestry watershed.

Keywords HARC · Menfro soil ·
Nitrogen · Phosphorus · Runoff · Sediment

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Introduction

Agricultural management practices including grazing are often blamed for having adverse effects on the quality of surface and ground waters. The U.S. Environmental Protection Agency (2000) noted that the most common pollutants to rivers and streams

from livestock grazing include pathogens, siltation, organic enrichment, and nutrients. A 500-kg dairy cow produces 43 kg manure d^{-1} (Hubbard et al. 2004). Each ton of manure produced by a cow contains approximately 4.5 kg N, 2.3 kg P_2O_5, and 3.6 kg of K_2O. A grazing cow returns 79% of the N, 66% of the P, and 92% of the K consumed back to the soil. In some regions, watersheds under poor grazing management discharge 5–10 times more nutrients than those under cropland and forest production (Hubbard et al. 2004). Poor grazing management practices not only increase contamination of surface and ground waters but reduce farm income. These pollutants enter the water bodies through surface flow and/or subsurface flow.

Although surface and subsurface losses from grazed pastures are related to rainfall amounts (Campbell and Allen-Diaz 1997), these losses vary with soil type. For example, in the unglaciated plains of Ohio, 20–75% of the loss occurs in base flow (Owens et al. 1991) while on highly permeable soils in the mid-Atlantic coastal Plains, 43–75% of the loss occurs in subsurface or groundwater flow (Volk et al. 2006). These changes can be partially attributed to decreased infiltration, porosity, pasture growth and increased bulk density due to cattle management (McDowell et al. 2003; Drewry et al. 2000). Therefore, highly permeable soils as found in areas similar to the current study site need conservation measures that reduce water contamination from grazing management.

Control of NPSP from grazing is important in order to improve water quality (Agouridis et al. 2005). Grazing management practices can be improved to protect water quality while maintaining farm profitability and grass production. According to a review by Dahlin et al. (2005), nutrient loss can be reduced and production can be improved through proper management of grazing animals and pastures. A recent study in New York demonstrated that careful management can help reduce soil-phosphorus build-up and losses at field and watershed scale (Ghebremichael et al. 2008). Adoption of alternative practices that improve soil and water quality and farm income are essential for the sustainability of small family livestock operations.

Implementation of water quality protection may include establishing upland vegetative buffers, riparian buffers, protecting streams and streambanks, and

managing grazing. Russell (2006) showed that vegetative buffers reduce significant quantities of nutrients and runoff. Studies conducted on pastured watersheds have shown that establishment of buffers at the field edge improves soil physical properties (Wood et al. 1989; Kumar et al. 2008). 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. These barriers are effective during small runoff events, however, concentrated flow might remove significant quantities of NPSP from watersheds through buffers. Moreover, they help reduce loss of sediment-bound nutrients. Establishment of buffers may also help reverse adverse effects such as increased bulk density and reduced porosity (Daniel et al. 2002; Wheeler et al. 2002; Kumar et al. 2008). Kumar observed significantly lower bulk density in upland buffer areas as compared to rotationally and continuously grazed areas. Increased bulk density and reduced porosity were attributed to cattle trampling in the grazed areas and improved soil properties in the buffer areas to roots of the perennial vegetation.

States are now required to implement water quality criteria, based on USEPA guidelines or by using other scientifically defensible methods (Ice and Binkly 2003). Landowners, state agencies and other regulatory authorities need scientifically supported, practically realistic, and biologically acceptable buffer development guidelines for the protection of water resources. Use of agroforestry buffers and riparian buffers to reduce NPSP from pastured watersheds seems advantageous from economic and practical perspectives. Unfortunately, experimental studies comparing the effectiveness of these buffers by ecoregions or landuses are largely missing from the literature. There is a need for more information on the effects of buffers on water quality, to enable farmers to adopt the most suitable practice for their farm. This paper examines (1) the effects of agroforestry and grass buffers on discharge of water, sediment, and nutrients, and (2) the effects of precipitation distribution on runoff, sediment and nutrient loss on pastured watersheds. The results reported here are part of a long-term study to evaluate soil and water quality as influenced by agroforestry and grass buffers on pastured watersheds.

Materials and methods

### Study watershed and management

Six treatment areas located at the Horticulture and Agroforestry Research Center, New Franklin, Missouri, USA (39°02′ N and 92°46′ W, 195 m above mean sea level), were studied during the 2000–2008 period (Fig. 1). Treatment areas were created by installing soil berms around each treatment for containment. Soil berms were subsequently compressed with a tractor. The treatments represent two conservation management practices and a control treatment. Two treatment areas have agroforestry buffers and two treatments have grass buffers. The remaining two treatments have no buffers (i.e., controls). The vegetation in the buffers and grazing areas consists of tall fescue (*Festuca arundinacea* Schreb), red clover (*Trifolium pratense* L.), and lespedeza (*Kummerowia stipulacea* Maxim.). Four rows of eastern cottonwood trees (*Populus deltoides* Bortr. ex Marsh.) were planted in 2001 at 3 m between and within row spacings to create the agroforestry buffers. The grazing area is 107 m long and 60 m wide. The buffer area at the lower landscape position is 107 m long and 15 m wide. The average tree diameter at the end of the 2008 growing season was 13 cm at breast height (1.4 m above ground).

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, about 64% falls in April through September. The mean temperature in July is 31.7°C and mean temperature in January is −7.6°C.

Treatment areas were managed with no cattle for 4 years and cattle were introduced in 2005. Each year since grazing began, 450–490 kg beef cows (3 cows) have been placed in each grazing area for approximately 215 days between March and November. In brief, a four-wire fence was installed around the treatment area and between the grazing and buffer areas. The grazing area within each treatment was divided into six paddocks with electric fences and the cattle were rotated to the adjoining paddock after 3.5 days of grazing. Thus each paddock is rested for 17.5 days. Additional information about cattle management and the study site can be found in Kumar et al. (2008).

Sample collection and analysis

Each treatment is instrumented with a 2-foot H flume, ISCO water sampler (Lincoln, NE, USA), and an ISCO bubbler flow measuring device to record flow rate, water level, sampling time and to collect water
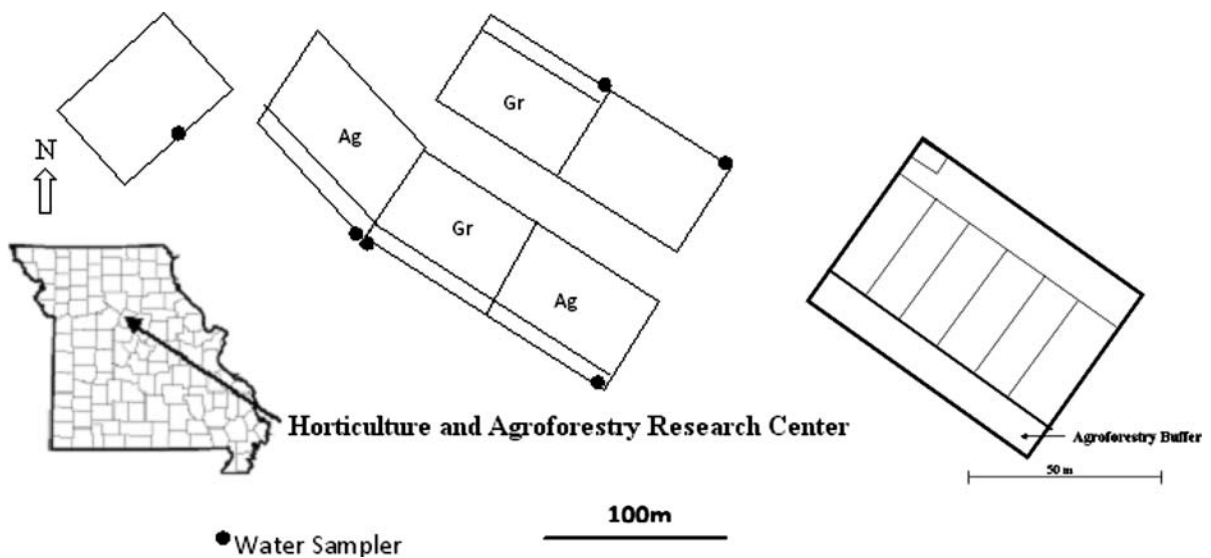
Fig. 1 The six studied treatment areas at the Horticulture and Agroforestry Research Center (HARC), New Franklin, Howard County, Missouri. Narrow strips on four treatment areas represent agroforestry (Ag) and grass (Gr) buffers. The inset map shows approximate location of the HARC Center and six Paddocks within the grazing area

samples. These units are removed during the third week of December when the water in the stilling well is frozen. Thus, the sample collection period extends from February/March to late-December each year.

Flow measuring devices control the sampler to collect water samples. A 125-ml sample was collected after each 5 m^3 flow, and samples were composited. Water samples were transferred from the field to the laboratory and analyzed for sediment and total nitrogen (TN). Unprocessed samples were refrigerated at 4°C until analysis. After a runoff event, flow rate, water level, and sample intake time data were downloaded to a laptop computer.

A known volume of a well-mixed sample was filtered through a pre-weighed glass microfiber filter (934-AH) using a vacuum pump (maximum vacuum 7 lbs in^{-2} above ambient) to estimate 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.

A Lachat Quick-Chem 8000 Analyzer (Lachat Instruments, Loveland, CO) was used to determine TN concentrations. Total nitrogen was determined using cadmium reduction on unfiltered samples following potassium persulfate digestion (QuikChem Method # 10-107-04-1-C; Pritzlaff 1999). The detection limits for the TN method is 0.002 mg l^{-1}.

Statistical analysis of data was performed using SAS (SAS Inst. 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 are management, year, and the interaction of management*year. Mean differences were determined using Fisher Least Significance (LSD) and were calculated using a LSMeans statement within the Proc Mixed procedure. The variance-covariance matrix was investigated using AIC coefficient to determine the most suitable mean separation procedure.

## Results and discussion

Precipitation

The study area received 15 and 48% more precipitation in 2004 and 2008, respectively, than the long-term mean (970 mm; Fig. 2). The precipitation amounts
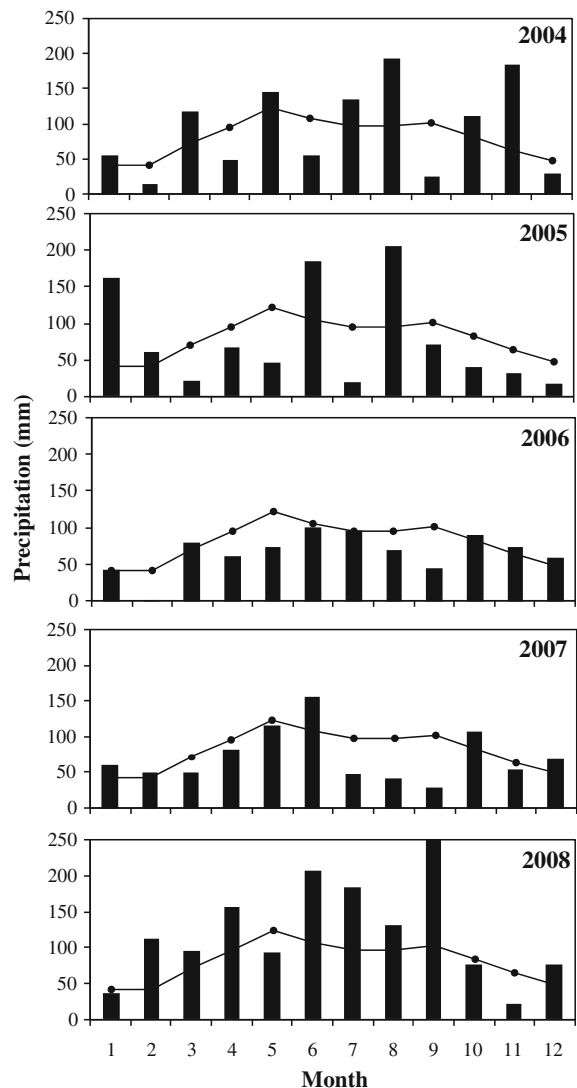
Fig. 2 Monthly precipitation (*bars*) and long-term mean (*line*) for the study site from 2004 to 2008

were 5, 17, and 10% below the long-term mean in 2005, 2006, and 2007, respectively. There was no runoff in 2006 during the driest year of the study. Measurable runoff events produced by the various treatments generally followed precipitation (Figs. 2 and 3). The highest number of runoff events was reported in 2008. Watersheds produced 7, 2, 2, and 13 runoff events in 2004, 2005, 2007, and 2008, respectively. All six treatments produced the same number of runoff events each year although the volumes were different.

In a 10-yr study with three adjacent corn-soybean rotational watersheds in northeast Missouri and another study that used riparian buffers and Conservation
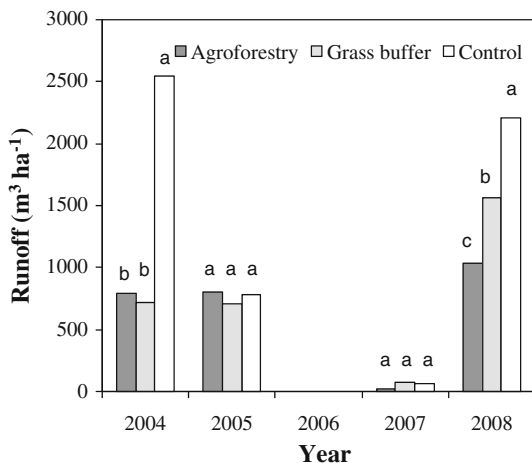
Fig. 3 Annual runoff volumes for agroforestry buffer, grass buffer, and control treatments from 2004 to 2008. *Bars* with different lower case letters denote significant differences among treatments at the α = 0.05 within the year

Reserve Program lands in northern Missouri, Udawatta et al. (2002, 2006) observed more runoff events when precipitation was greater than normal and fewer events when precipitation was normal or below normal. The current study site is different from the latter two sites, because it has deep and well-drained soils and produces little runoff as compared to soils with restrictive horizons as found in northern Missouri. Furthermore, yearly, seasonal and within growing season variation in the frequency and intensity of precipitation also influence the number of runoff events.

Runoff

The annual discharge of water per area differed greatly among treatments and years, ranging from $0 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ (2006) to $2548 \text{ m}^3 \text{ ha}^{-1} \text{ year}^{-1}$ (2004 on the control). During the study period, agroforestry, grass buffer, and control treatments produced a total of 2655, 3067, and $5598 \text{ m}^3 \text{ ha}^{-1}$ runoff, respectively, between 2004 and 2008. On average, buffer treatments produced only 30 and 59% of the runoff of the control treatment in 2004 and 2008, respectively (Fig. 3). In years with a very small number of runoff events, the difference between the buffer and control treatments was small and differences were not significant. The total runoff on agroforestry versus grass buffer treatments was not significant in 2004, 2005, and 2007. The total runoff was significantly

different in 2008 between the two buffer treatments. The control treatment produced significantly more runoff during 2004, a year with 115% precipitation of the long-term mean, than during any other study year.

Trees and undisturbed grass buffer vegetation improve infiltration and water holding capacity of soils. Studying soil physical properties, Kumar et al. (2008) showed that saturated hydraulic conductivity was 16.7 times greater in buffer areas compared to grazed areas on this same study site. Trees reduce runoff, soil erosion and nutrient loss from watersheds and improve infiltration (Gilliam 1994). In France, 5.7 and 11.1 m-wide grassed filter strips reduced runoff by 8–89% and 37–91%, respectively (Patty et al. 1997). In this study, 15-m wide buffers effectively controlled runoff during years with above normal precipitation. Although large runoff events remove significant amounts of NPSP from watersheds (Morgan et al. 1986; Robinson et al. 1996; Udawatta et al. 2004), smaller events that occur more frequently account for a greater proportion of total nutrient loss than infrequent large events (Quinton et al. 2001; Udawatta et al. 2004). Therefore, a well-established buffer, including upland buffers, is essential to control NPSP in runoff from more frequent small events and infrequent large events.

Sediment loss

cSoil loss on treatments was significantly affected by treatments. Soil loss in runoff water generally paralleled rainfall amounts. It varied between 47 and 91 kg ha^{-1} during the 5-year study period (Fig. 4). Grazed treatment with agroforestry buffers lost only 51% of the sediment lost on the control treatment. The control treatment without buffers lost 36% more soil than the average for the agroforestry and grass buffer treatments.

Permanent vegetation, including the trees and undisturbed grass in the buffer areas of our treatments, may have utilized more water, thus runoff and erosion losses were less than in a watershed with no buffers. Research also shows that most of the sediment and nutrients are retained within the first 4–7.5 m of the strip and thereafter, increasing the width results in only marginal increases in retention of pollutants (Robinson et al. 1996; Schmitt et al. 1999). The observed reduction in sediment loss in this study was achieved by 25% of the buffer area as compared to the total treatment area. There is some concern that shading reduces grass growth and filtration capacity of a buffer
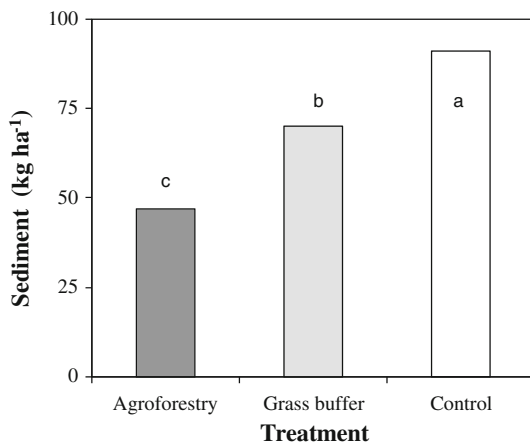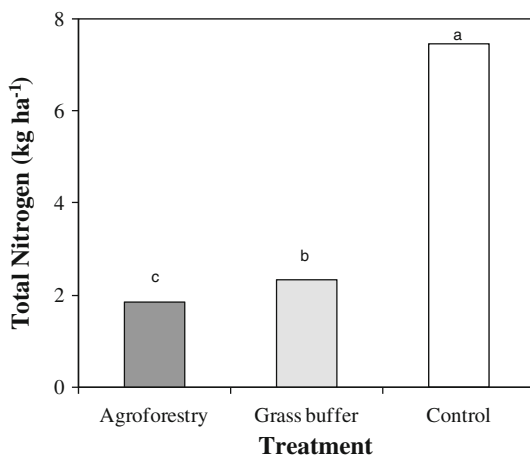
Fig. 4 Total soil loss on agroforestry buffer, grass buffer, and control treatments from 2004 to 2008. *Bars* with different lower case letters denote significant differences among treatments at the $\alpha = 0.05$

as canopy closure occurs. Results of this study demonstrate that buffers with trees may be more effective than grass alone, probably due to improved soil properties and greater resistance to surface flow.

Nitrogen loss

Total nitrogen (TN) loss was significantly affected by treatments (Fig. 5). It ranged from 1.85 kg ha^{-1} in

Fig. 5 Total nitrogen loss on agroforestry buffer, grass buffer, and control treatments from 2004 to 2008. *Bars* with different lower case letters denote significant differences among treatments at the $\alpha = 0.05$

the agroforestry treatment to 7.47 kg ha^{-1} in the control treatment. The difference was significant among the three treatments. The control treatment lost 4 and 3.2 times more TN than the agroforestry and grass buffer treatments, respectively.

Total nitrogen losses reported in this study clearly demonstrate that agroforestry and grass buffers can be used to significantly reduce nitrogen in runoff from pastures. When cattle were allowed to graze without some form of buffer between the pastured area and the flume approach area, soil and nutrient losses were greatly increased. This observation strongly supports the need for no access buffer strips along streams in pastured watersheds.

Conclusions

This study was designed to examine the effects of agroforestry and grass buffers on NPSP loss from pastured watersheds. Results indicate that watersheds with buffers have significantly reduced runoff volume and loss of sediment and nutrients compared to watersheds without buffers. However, the difference in runoff volume among the three treatments was found to be significant only during years with above average precipitation. Results of this study suggest that greater emphasis should be placed on management strategies that minimize runoff and NPSP losses. Upland buffers, as a protective measure, can clearly help reduce soil erosion and nutrient losses from pastured land and thereby protect water quality.

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