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REDUCTION IN SEDIMENT AND CHEMICAL LOAD IN AGRICULTURAL FIELD RUNOFF BY VEGETATIVE FILTER STRIPS

by

John E. Parsons[1], R. B. Daniels[2], J. W. Gilliam[2] and T. A. Dillaha[3]

Department of Biological and Agricultural Engineering[1]
Department of Soil Science[2]
College of Agriculture and Life Sciences
North Carolina State University
Raleigh, NC 27695-7625

Agricultural Engineering Department[3]
Virginia Polytechnic Institute and State University
Blacksburg, VA

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ABSTRACT

This project was instrumental in developing two field projects for collecting water quality data on the effectiveness of grass and riparian filters for mitigating agricultural surface runoff. The project areas were located in the Coastal Plain and Piedmont physiographic regions of North Carolina. Replicate grass buffers of 4 m and 8 m were monitored during natural rainfall events and compared to water quality data from agricultural fields and runoff filtered by two riparian buffers of 4 m and 8 m lengths. The monitoring and comparisons consisted of surface runoff, sediment yields and nitrogen and phosphorus during 1990 and 1991. Other measurements included the amount of sediment trapped in each filter along with chemical analysis of filter vegetation and soils. Results of the collected data are reported and analyzed. Although, the results are of a preliminary nature, they provide a good starting point to evaluate the effectiveness of planted grass filters versus natural riparian buffer for trapping surface runoff, sediment and nutrients. These results are discussed and initial conclusions are presented.

SUMMARY AND CONCLUSIONS

At both the Piedmont and Coastal Plain sites, runoff volumes from the field edge collectors were generally reduced as they passed thorough the grass buffers. In fact, several small rainfall events produced flow from the field which never reached the end of the buffers. The natural grass (mostly crab grass) initially present on the buffers were not as effective in reducing runoff volume as the fescue sod planted later. The riparian vegetation plots reduced runoff volumes for most of the smaller storm events. However, for the larger storm events the runoff volumes from the riparian areas were often large and comparable to the field edge runoff.

All filters were effective in removing sediment from the agricultural runoff. For most storms, this reduction was 80 to 90%. Although the riparian areas were less effective in reducing total runoff volume than the grass filters, in almost all cases, the sediment load from the riparian plots was small. The sediment filtration capacity of the riparian plots is comparable to the grass buffers. However, we did find that the riparian plots were much more fragile and susceptible to channelization and concentrated flow.

Comparison of chemical loads from the grass filters did not yield as consistent results as the sediment yields. The reductions in chemical loads were dependent on time of year and site. Neither the grass buffers nor the riparian areas were very effective in removing phosphorus in solution (orthophosphate). Removal of total phosphorus and total Kjeldahl nitrogen was very variable between storms and between plots. However, approximately 50% of these constituents was removed in the 4 m filters. Generally the 8 m filters were more effective in removing all potential contaminants from the runoff water but doubling the filter length almost never doubled the grass or riparian filter effectiveness for removal of any constituent.

RECOMMENDATIONS

Although the collected database does provide a starting point for evaluating the effectiveness of grass and riparian filters, it does not provide enough information to provide definitive answers for the original objectives of this WRRI research project or such questions as:

1) What length of grass filter is required for a given source area?
2) Can natural riparian zones be as effective as planted grass filters?
3) How often should the grass filters be leveled and re-seeded?

The third question is often discussed but few grass filters are installed with definite plans for maintenance. Our data indicates that grass buffers can be very effective, but there are also indications that the effectiveness may be lost if they are not maintained. As the filters accumulate more and more sediment, the chances are greatly increased that water will accumulate at the edge of the filter and create channels as it breaks through the sediment barrier.

While definitive answers to these questions require additional information, some tentative recommendations can be made. Because the natural vegetative riparian areas we studied seem more fragile and susceptible to channelization than the planted grass filters, an ideal buffer would seem to include both grass and trees. The grass filter would slow and spread the initial runoff and remove coarse sediments. This area can also be reworked as necessary. The runoff from the grass filters would have lower transport capacity, velocity, and probably more readily infiltrate in the forested filter. The forested area provides long term stability to the area and may be more effective in removal of nitrate from the subsurface flows. Although exact widths cannot be recommended from this report, an 8 m grass buffer with an 8 m forested buffer is a good starting point.

INTRODUCTION

Because of concerns about agricultural sources of pollution, much research has been conducted on best management practices (BMPs) for nonpoint source pollution control. One of the most promoted BMPs is vegetative filter strips (VFSs). VFSs are being promoted by many state and federal programs. The U. S. Department of Agriculture - Soil Conservation Service (USDA-SCS) has guidelines for VFS installation, but they have little data on their effectiveness for sediment and nutrient removal. Research by Dillaha et al. (1987) shows that VFS are ineffective under certain conditions. In many cases, it appears that VFSs are being installed in areas with soils and geomorphic conditions where they are ineffective.

In addition to constructed VFS, naturally vegetated or riparian areas are found adjacent to many streams. In the early 1980's three groups in the United States independently initiated work on the removal of nitrogen (N) from shallow groundwater by riparian vegetation. The results obtained were amazingly similar for field research conducted in three different states. Jacobs and Gilliam (1985) observed in the North Carolina Coastal Plain that nitrate in subsurface water decreased from levels greater than 10 mg-N/L to less than 1 mg-N/L while passing through a 50 m riparian zone. They estimated that of the 35 kg-N/ha/yr entering the riparian zone only 5 kg-N/ha/yr left the watershed in stream flow. Lowrance et al. (1984), working in the Georgia Coastal Plain, found that of the 52 kg/ha/yr of N entering a riparian ecosystem, only 13 kg/ha/yr left in stream flow. Peterjohn and Correll (1984) estimated the removal of 45 kg/ha/yr of nitrate-N from subsurface flow through a riparian zone in Maryland. Similar observations were reported for pastureland in New Zealand (Cooke and Cooper, 1988).

When riparian areas are present in a watershed, much of the sediment leaving agricultural fields is removed from the surface flows. Cooper et al. (1987) estimated that approximately 90% of the sediment leaving agricultural fields in a North Carolina watershed was deposited in the riparian zones. Most of the sediment was deposited within 100 m of the field edge indicating that relatively narrow buffers adjacent to streams may be effective for sediment removal. Lowrance et al. (1986) also measured sediment accumulation in a riparian zone in Georgia and concluded that riparian ecosystems are important sinks for sediments.

Phosphorus (P) is also removed in riparian zones but apparently less effectively than either N or sediment. Cooper and Gilliam (1987) estimated that only about 50% of the P entering riparian areas they studied was trapped. Lowrance et al. (1984) measured lower retention of P in their riparian areas than for other elements studied. Phosphorus removal in the riparian areas of the New Zealand watersheds (Cooke, 1988) was also less than N removal. Although riparian areas may be less effective in removing P than other potential contaminants, P trapping is still very important because P is generally the limiting nutrient in freshwater bodies.

Research on grass VFSs has reported high sediment trapping efficiencies as long as flow is shallow and the VFSs are not inundated with sediment. However, trapping efficiency decreases dramatically at higher runoff rates (Barfield et al., 1979). Several short-term experimental studies have quantified the effectiveness of grass VFSs in reducing sediment, nutrients and other contaminants in runoff (Dillaha et al., 1987; Dillaha et al., 1988; Magette et al., 1989; Young et al., 1980). These short-term studies reported that VFSs were effective for sediment and sediment-bound pollutant removal with trapping efficiencies exceeding 50% if flow was shallow. Reports on this project by Parsons et al. (1990 and 1991) have found similar results for grass buffers. Dissolved nutrients, however, were not removed as effectively and several studies reported higher dissolved nutrient concentrations in VFS effluents than in the influent runoff (Dillaha et al., 1989; Magette et al., 1989). This was attributed to the limited assimilative capacity of VFSs for some nutrients. VFS plots with concentrated flow, similar to that expected under field conditions, were reported to be much less effective than the experimental shallow flow plots used in most VFS research (Dillaha et al., 1989).

Existing grass VFS on 18 farms in Virginia were studied and found to be extremely variable in their VFS effectiveness for sediment removal (Dillaha et al., 1989). Most VFSs in hilly areas were ineffective because runoff usually crossed the VFSs as concentrated flow. In flatter regions, VFS were more effective because slopes were more uniform, and more runoff entered the VFSs as shallow dispersed flow.

PURPOSE AND OBJECTIVES

This study was initiated to provide quantitative data on the effectiveness of VFSs on removing sediment and nutrients as influenced by: (1) soil and geomorphic conditions, (2) type of vegetation, and (3) hydrologic features of site and various runoff events.

The original objectives of this project were very ambitious. These include:

1. To test the effectiveness of selected VFS for the removal of sediments and nutrients (primarily N and P) from agricultural runoff water.
2. To determine if plant type (grass or trees) influences the effectiveness of the VFS.
3. To determine the influence of soil and geomorphic features on effectiveness of VFS.
4. To determine if existing models can be used or modified to predict effectiveness of VFS under a range of conditions.

In this report, we have considered the following modified objectives:

1. A description of the experimental setup to monitor effects of natural and planted vegetative filter strips on the reduction of sediment and nutrients from agricultural surface runoff.
2. A comparison of the performance natural vegetative buffers versus planted grass buffers for filtering sediment and nutrients.
3. Some data showing the fate of sediment and nutrients in natural and planted filter strips.

The analysis in this project report includes experimental data from 1990-1991.

METHODS

Site Locations and Properties

The vegetated filter research was conducted in both the Piedmont and Coastal Plain of North Carolina. These sites are representative of not only the two major agricultural areas of North Carolina and many Atlantic Coastal states but also areas where most urban nonpoint source contaminants originate. The Piedmont site is in Wake County on NCSU Research Farm Unit 9 which has topography and soils typical of the lower Piedmont. The Coastal Plain site is on the Cunningham Research Farm near Kinston, North Carolina. This site has topography and Norfolk-Rains Soil Association typical of the middle and lower Atlantic Coastal Plain.

Both sites occupy gentle valley slopes that grade downward to a concave foot-slope in a riparian area. Figure 1 shows a cross-section for the Coastal Plain site from the field area through the riparian buffer. The soils at the Piedmont site are on a dissected high terrace and are within the State Soil Series. At the Coastal Plain site, the soils in the cultivated area are within Norfolk and Goldsboro Soil Series. The soils in alluvium in the Coastal Plain riparian filters are within the range of the Myatt series. Descriptions of soils at both sites are in Appendix I.

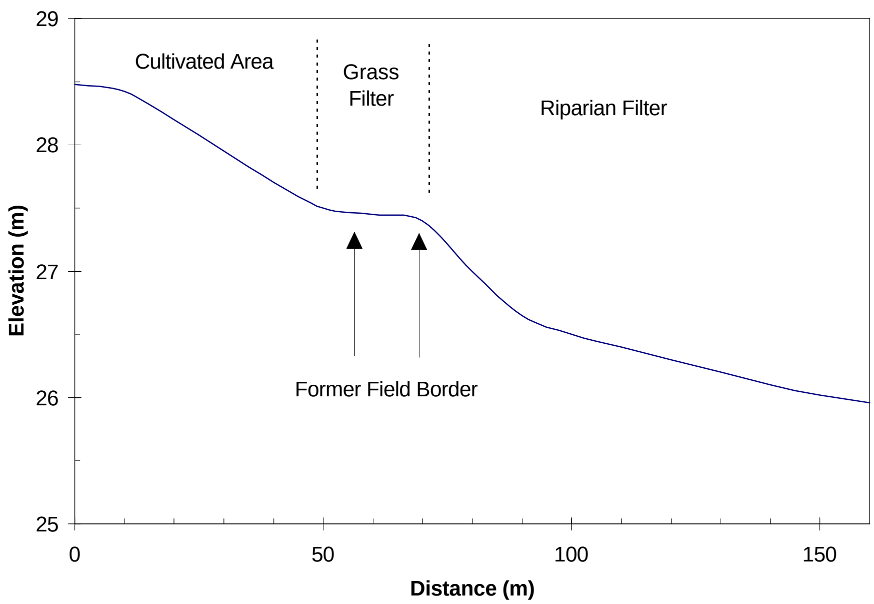


Figure 1. Cross-section of Coastal Plain site showing the relative slopes in the cultivated, grass filter and riparian filters. The Piedmont site is similar except slopes in the forested filter plots are about 12%.

Plot Characteristics

The Piedmont site occupies a gentle linear slope with an average slope of 3.6% in the cultivated areas and slightly steeper slopes in the grass filters (Table 1). The wooded filter plots are very steep. This increase in slope from the cultivated areas to the vegetated buffers is common in the North Carolina Piedmont. The grass filters in the Piedmont site were a field border that received runoff and sediment from higher cultivated areas.

The Coastal Plain site occupies a gentle linear to concave head slope. The cultivated area has an average slope of 1.9 percent (Table 1). The grass filters have slopes less than 1.5% and slopes in the riparian filters are less than 1%. The sharp increase in slope between the grass filter and the riparian area in Figure 1 is post-settlement alluvium deposited at a field border. The grass filter area was part of the cultivated field, and the old field border is about the end of the 8.4 m plots.

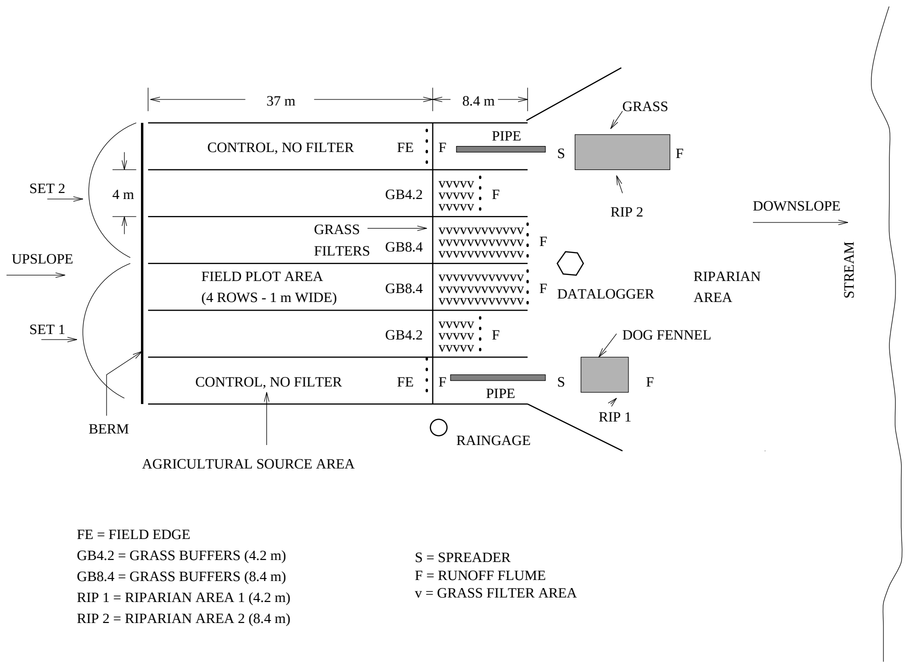
Both the Piedmont and Coastal Plain study areas have a sloping cultivated area 27.4 m wide and 36.6 m long. A 9 m traffic area borders the sides and top. A ridge and furrow on the upslope edge of the plots prevents addition of surface water from higher areas. A 9 to 12 m lower border includes the grass filter strips. There are two sets of plots and each set contains a field edge collector and 4.2 m and 8.4 m grass filter plots. The riparian buffer plots in the Piedmont study area were on a forested slope and the Coastal Plain area has a cut-over forest riparian area. Figure 2a shows the plan view of the cultivated area, filter strips and sampling devices for the Coastal Plain study area. The Piedmont study area layout was similar and is shown in Figure 2b.

Table 1: Average Slope of Cultivated and Filter Plots at the Piedmont and Coastal Plain Sites

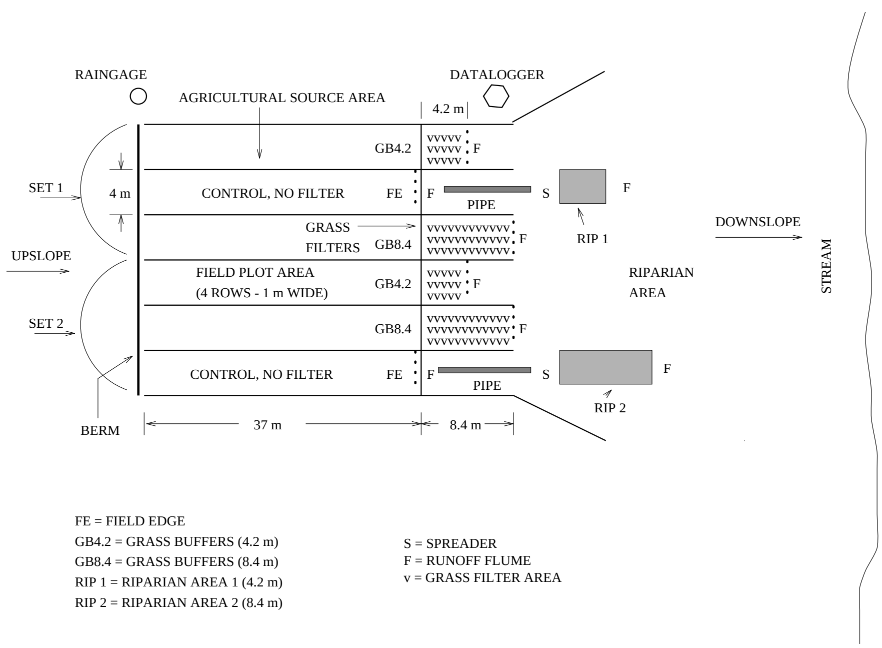
Plots	% Slope	
	Piedmont	Coastal Plain
Cultivated Plot	3.6	1.9
Grass Filter (Length in m)		
4.2 (Set 1)	6.3	0.8
4.2 (Set 2)	4.2	1.4
8.4 (Set 1)	5.2	0.7
8.4 (Set 2)	4.8	1.1
Riparian Filters (Length in m)		
4.2	12.4	0.8
8.4	16.4	0.7

The 27.4 m width of the cultivated area allowed four cultivated rows for each of six runoff plots. Two buffer rows were on the outside of the cultivated plot area. The crop rows were planted up and down hill and bedded to prevent runoff from crossing from one cultivated plot to the next. Soil preparations and bedding were done just before planting to prevent winter runoff from crossing plot boundaries. Plastic edging prevented runoff from crossing over in the lower 3 m of the cultivated part and throughout the grass or riparian filter.

Plastic rain gutters were installed to collect runoff from two cultivated plots at the field edge, and at the end of two 4.2 m and 8.4 m grass filters. Pipes carried the runoff to HS flumes (see Chapter 2 in Brakensiek et al. 1979) for volume measurement and sampling. Plywood spreaders delivered the runoff to the upslope portion of the two riparian plots (Figure 3) Gutters at the downslope end of the riparian plots collected the runoff. HS flumes measured the runoff volume and samplers collected runoff for water quality measurements.



a. Coastal Plain site.



b. Piedmont site

Figure 2. Schematics showing the runoff plots, flumes and samplers and filters.

We had the option to route any combination of direct field runoff or runoff filtered by the 4.2 and 8.4 m buffer plots through the riparian areas. This enabled quantifying both the water quality and quantity of the surface water entering and exiting the riparian plots. Figure 3 shows the layout for the grass filters and Figure 4 for the riparian plots.

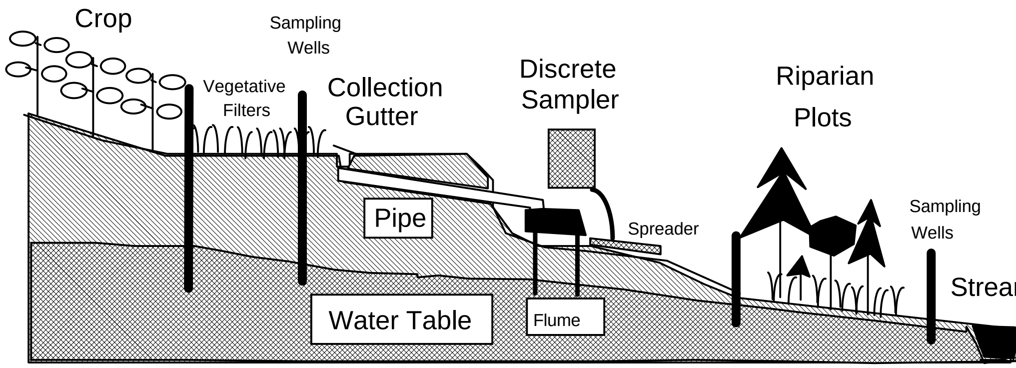


Figure 3. Schematic of surface water quality collection system from the grass filters and the field edge.

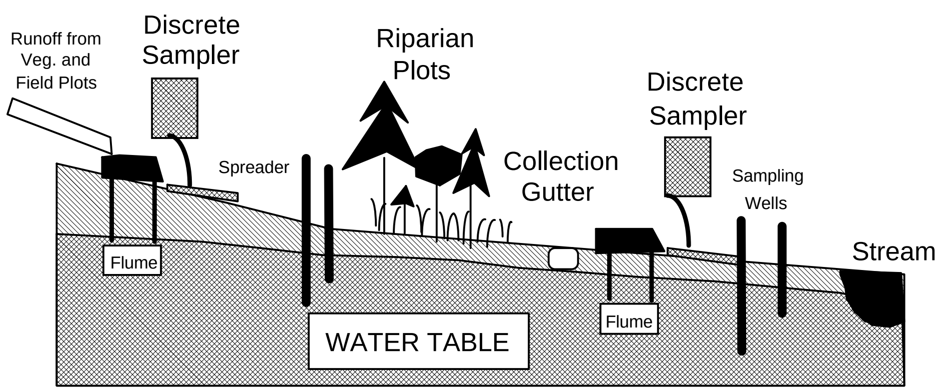


Figure 4. Details of surface water collection system in the riparian areas.

Instrumentation

A Campbell Scientific CR10 portable datalogger at each site monitored rainfall, surface runoff and activated the water samplers. An on-site tipping bucket rain gage continuously monitored by the datalogger records rainfall totals and 5 minute intensities. Passive rainfall collectors at the same site served as backup for the tipping bucket rain gage.

HS flumes (0.15 m (0.5 ft) depth) were used to measure the quantity of runoff from each plot. A potentiometer - float assembly (Figure 5) was used to monitor water levels in the HS flumes. A bridge circuit with a 2 volts DC excitation was used with the potentiometers to convert water levels in the flumes to voltages between 0 and 2 volts DC (Figure 6).

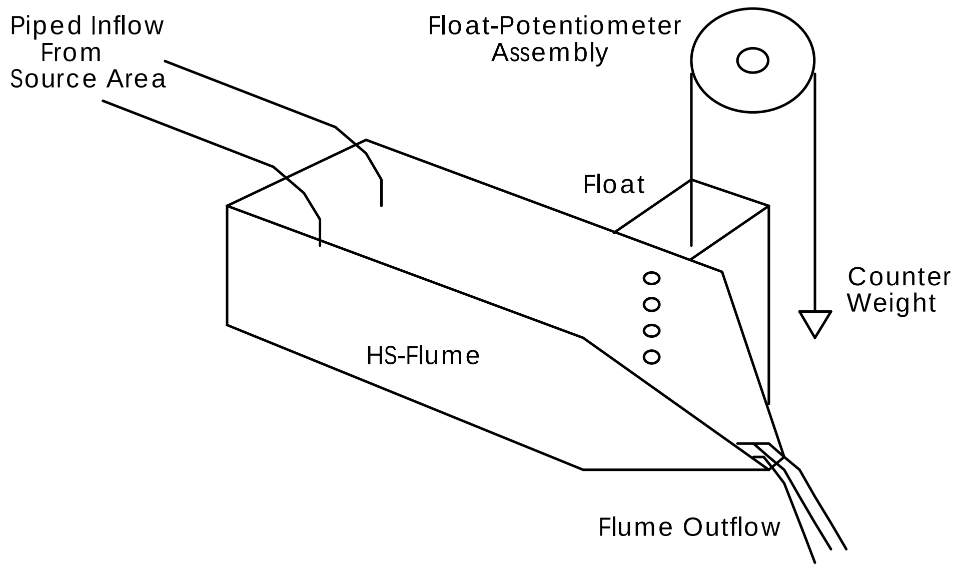


Figure 5. Flume showing the potentiometer-float measurement assembly.

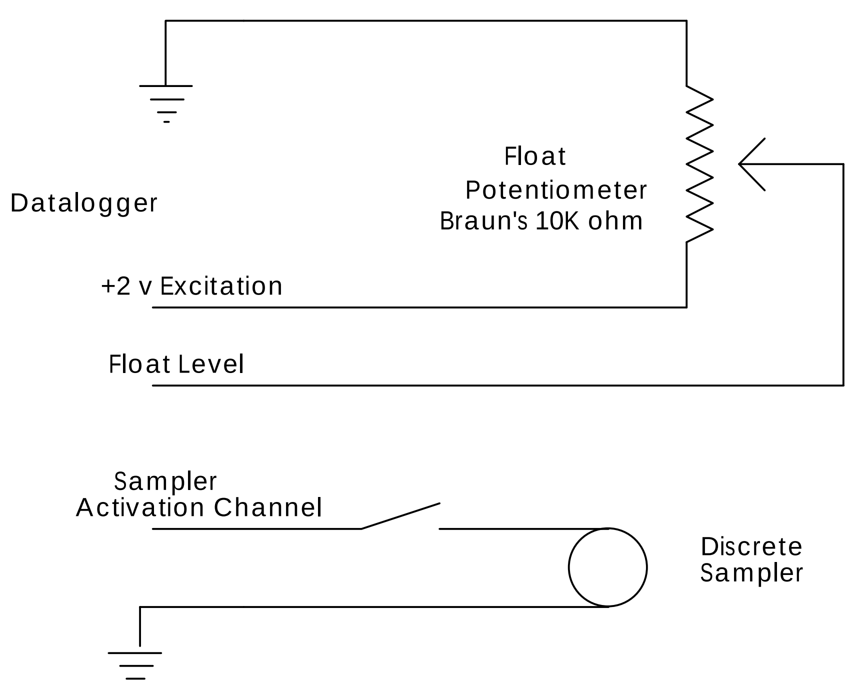


Figure 6. Details of Datalogger hookup for float measurements and sampler activation.

The datalogger monitored the potentiometer voltages at 30 second intervals. Using calibrations for each flume the voltages were converted to flume water levels. Recorded flume stage levels were converted to flow rates using laboratory measured stage-discharge relationships for each flume. During a runoff event, these changes trigger the discrete samplers (American Sigma Designs Model Streamline Portable Sampler) to pump a 500 ml sample from the flume outflow for water quality analysis. The samplers could take up to 24 discrete samples during the rainfall-runoff event at a maximum frequency of 1.5 min. The trigger from the datalogger activated an incoming pulse to the sampler to initiate a sample from the outflow of the flume.

Sample Handling and Analyses

Removal of samples from the field was as soon as possible after each runoff event. The sample bottles were numbered and stored in a cooler at 35 degrees C until analyzed. All samples had total sediment measured, but sediment chemistry was only determined for major events with a suite of samples from each plot. The events sampled for chemical analyses represented critical periods such as a major storm, or runoff after planting and fertilization. If possible, sediment chemistry was determined monthly during the growing season. About one-third of the samples from selected runoff events had total silt + clay, Kjeldahl nitrogen (TKN), NH_4, NO_3, total phosphorus (TP), $P0_4$-P in solution (orthophosphorus) and Cl measured. The samples for chemistry analysis were selected based on the runoff hydrograph. Those selected were the first measured point with a sample, some on the rising limb of the hydrograph, at the hydrograph peak, and those on the falling limb. If the hydrograph had more than one peak, all peaks were sampled using the same criteria.

Runoff samples collected in the field were transported to the laboratory within 18 hours of each run-off event and stored at 4^o C until analysis. Unpublished data here have shown insignificant changes in NO_3-N and NH_4-N concentrations in runoff samples placed in a refrigerator within 24 hours of runoff event.

The sample was poured through sieves to separate the sand from silt and clay after gentle hand shaking for 15 seconds for dispersion. Total sample weight less total sediment determined volume of water. An aliquot of the sieved mixture was dried and weighed to determine amount of silt + clay. The dried sand fraction included varying amounts of silt + clay that was not water dispersable.

Runoff samples were filtered through Whatman no. 42 filter paper which gave a clear filtrate on which NO_3-N, NH_4-N and PO_4-P were determined. The procedure of Lowe and Hamilton (1967) was used for nitrate, ammonium was determined using the procedure of Smith (1980) and orthophosphate was determined by the Murphy and Riley (1962) method. An aliquot of stirred whole sample was taken for digestion by Kjeldahl procedure. Digestion was in a solution of H_2SO_4, K_2SO_4 and $CuSO_4$ at 350^o C for 6 hours after solution cleared (total digestion time approx. 10 hours). Digest was brought to a volume of 100 mL and an aliquot was taken for determination of total P using same colorimetric method described above. Ammonium was distilled from another aliquot, collected in boric acid and titrated to obtain total Kjeldahl nitrogen (TKN) of runoff sample.

Cropping Patterns and Filter Vegetation

The rotations in the plots were corn and soybeans planted on beds with the rows parallel to the slope. Bedding and fertilization was done at standard rates just before planting. Harvesting was by combine starting at the top of the plots and going to the grass filters. The combine backed to the upper border area before moving to the next unharvested strip. This procedure retained the runoff integrity of the beds throughout the winter months.

Filter vegetative cover in the grass filter area during the summer and fall of 1990 was largely crabgrass (about 90% cover) at both sites. Renovation of both sites consisted of aerating the filters and seeding with Kentucky 31 Fescue was done in the fall of 1990. The grass cover has been near 100% since replanting. Reseeding of small areas was done each fall as needed. The grass was cut periodically to about 15 cm to prevent lodging.

The riparian buffers at the Piedmont site were located in an established mixed hardwood-pine stand. The understory can be characterized by a dense litter layer with volunteer vines (such as poison ivy) and small saplings. At the Coastal Plain site, the riparian area was typical of Coastal Plain clear-cut area four years later. The 4.2 m riparian filter has a natural cover of dog fennel, an early pioneer vegetation in cut-over areas. However the 8.4 m Coastal Plain riparian filter had a fescue cover because of plot disturbances during project installation and land leveling to allow even distribution of the runoff through the plot.

Filter Area Measurements and Sampling

Bimonthly biomass samples were taken to determine biomass production along with the uptake of nitrogen and phosphorus over the year by the filter vegetation. Changes in nutrient levels within the filters and the lower portion of the cultivated field area were determined with soil samples from the filters and cultivated plots. These samples were taken to be representative of sediment deposition in the top 5 cm of the soil profile.

The amount and location of changes in the filters from sediment deposition were determined by detailed topographic surveys of the plots. The amount of sediment deposited was calculated from the elevation changes in the plot. Spring and fall measurements of 54 ground elevations in six rows from the 4 meter filter and 90 from 10 rows in the 8 meter filter were used to quantify elevation changes. Similar grid densities were used to record elevations in the lower 3 m of each plot in the cultivated area in the spring and fall. Each elevation measurement point was assumed to represent the area around the point. From this area and the change in elevation, a volume of deposited sediment was computed.

RESULTS AND DISCUSSION

Sediment Properties in Field and Filter

Soil sampling in the spring of 1992 showed distinct changes in phosphorus and nitrogen within the cultivated and filter areas (Tables 2 and 3). Soil nitrogen and phosphorus decrease from the upper to the middle of the Coastal Plain plots before increasing through the grass filters. The large nutrient increase at 7.5 meters in the grass filters was located near the boundary of the old field. Considerable accumulation of nutrients occurred in the borders. There was some evidence of nutrient accumulation in the filters after only a year of filtering runoff. The Coastal Plain riparian filters had moderate to high nitrogen content but low phosphorus compared to the background.

Table 2: Coastal Plain Site Soil Sample Data. Sampled 3/2/92.

Location	Total Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorus
	mg/g		
upper plot row	0.48	0.52	0.41
upper plot track	0.46	0.46	0.41
middle row	0.50	0.49	0.23
middle track	0.38	0.35	0.18
lower row	0.55	0.47	0.24
lower track	0.77	0.76	0.32
grass filter 1m	0.83	0.81	0.35
grass filter 3.5 m	0.88	0.91	0.39
grass filter 7.5 m	1.28	1.14	0.62
grass no add. 0-6 m[a]	0.64	0.62	0.28
Grass no add. 8-12 m[a]	1.24	1.33	0.53
riparian 4 m	1.87	2.00	0.16
riparian 8 m	1.80	1.88	0.33
riparian background	2.16	2.95	0.63

a. No runoff added to area from field rows.

Both nitrogen and phosphorus were relatively uniform throughout the Piedmont cultivated area but increased sharply 1 m into the filter (Table 3). There was little change in phosphorus through the grass filters, but nitrogen increased with distance from the field edge. The nitrogen content of the filters was higher than the adjacent grass area of the old field border that did not receive field runoff. Apparently, there was considerable increase in nitrogen after two years of filtering agricultural runoff. The wooded slopes and riparian foot-slope sites had moderate phosphorus contents. These areas had received sediment from the higher fields for some time prior to the initiation of this experiment yielding one possible explanation.

Table 3: Piedmont Site Soil Sample Data, Sampled 3/2/92.

Location	Total Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorus
	mg/g		
upper plot	0.64	0.57	0.38
middle plot	0.61	0.62	0.36
lower plot	0.58	0.58	0.32
lower track	0.60	0.60	0.33
grass filter 1 m	1.03	1.06	0.50
grass filter 3.5 m	1.50	1.60	0.61
grass filter 7.5 m	2.13	2.22	0.58
grass 0-6 m[a]	1.27	1.16	0.51
grass 8-12 m[a]	1.56	1.64	0.50
wooded slope 4 m	1.23	1.30	0.31
wooded slope 8 m	1.79	1.83	0.28
wooded slope check	1.56	1.56	0.27
riparian foot slope	1.87	1.79	0.31

a. No runoff added to area from field rows.

Sediment Deposition in Filters

Figure 7 shows the sediment deposition in both sets of grass filter plots (Figure 2). Deposition in the Piedmont site ranged from about 0.4 m^3 in the 8 m grass filter in set 1 to about 0.7 m^3 in the 8 m grass filter in set 2. There was little relationship to length of filter. Deposition at the Coastal Plain site was less than the Piedmont site. This may be attributed to the sandy soils at the Coastal Plain site and that the slope is less than the Piedmont site. The deposition was not uniform across the plot, although the largest amount of sediment usually was within 2 m of the field edge (Figure 8). The major exceptions were the 8 m filters at the Coastal Plain site where major amounts of sediment accumulated between 5 and 7 m from the field edge.

The spring and fall elevation measurements in the lower 3 m of the cultivated area above the plots show sediment accumulation. Bedding equipment started at the field edge and moved upslope. This partially redistributed the sediment that was accumulated during the previous year. Cultivation from 1990 to the spring of 1992 has moved more material upslope than subsequent erosion deposited in the lower 3 m of the Coastal Plain site. At the Piedmont site there was a gain in the lower 2.5 m of the field (Table 4). There was a gain in sediment in the lower 2.5 m across the six plots, but a net loss by removal of material from the 3.5 m segment. While these data give some indication of the processes operating at the lower part of the runoff plots, the variability is large and major conclusions are risky. Table 4 is evidence, however, that sediment accumulates at and upslope from the field edge in appreciable amounts. The accumulations should increase in time because the filters are accumulating sediment and act as a rising base level.

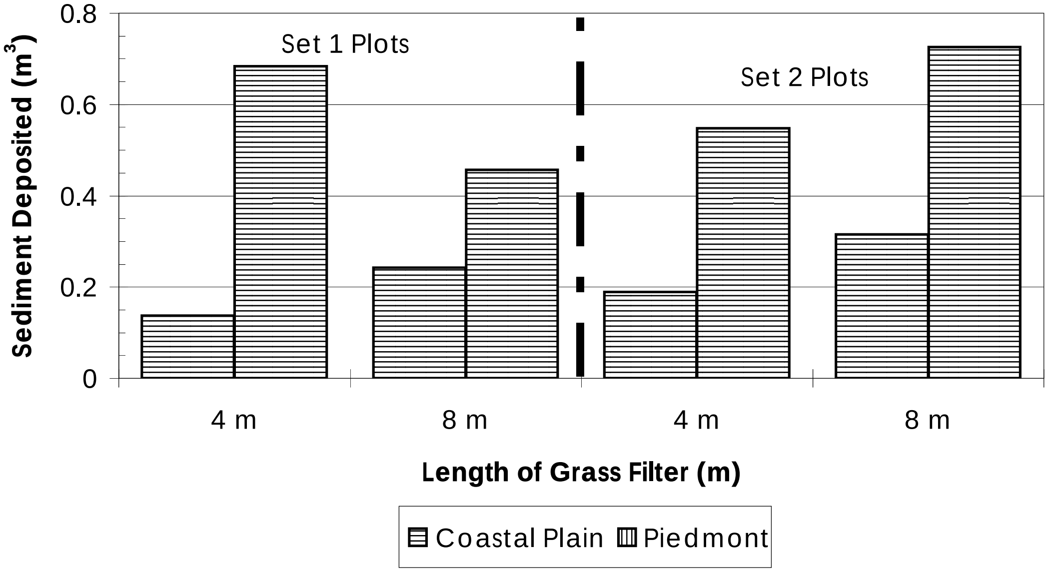


Figure 7. Sediment deposition in the grass filters. The Piedmont site deposition is in 1990 and 1991 and the Coastal Plain site deposition in late summer 1990 and summer of 1991.

Table 4: Sedimentation in the lower 3 m of the Cultivated Plots at the Piedmont Site from 5-90 to 12-91.

Distance Upslope From Field Edge m	Sediment Accumulation m^3
0.5	0.11
1	0.17
1.5	0.12
2	0.02
2.5	0.04
3	0.03
3.5	-0.84
Total	-0.35

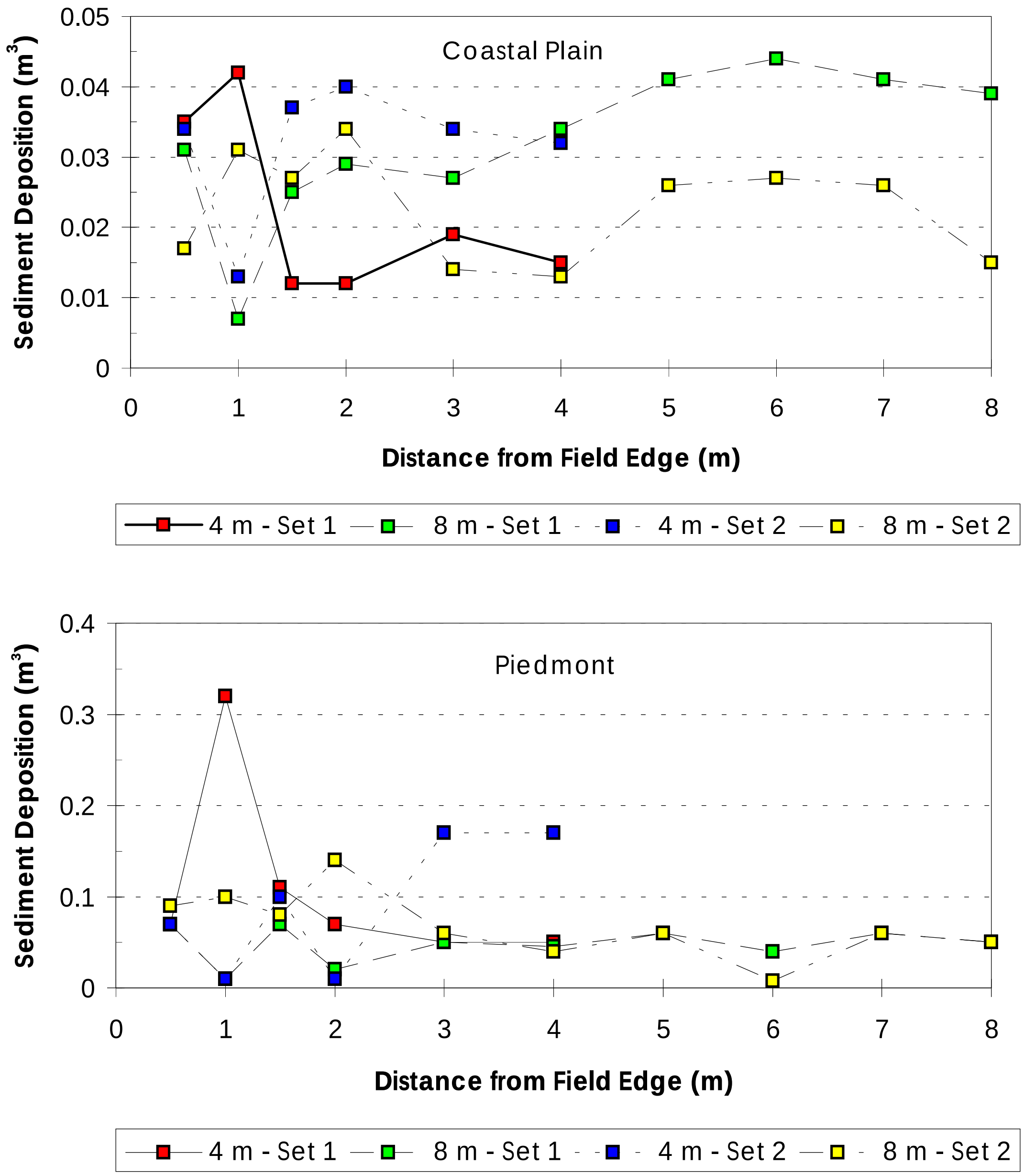


Figure 8. Sediment deposition in a 4 and 8 meter filters by distance from the field edge in Coastal Plain and Piedmont sites. The solid markers represent plots 2 and 3 in Coastal Plain and 1 and 2 in Piedmont. The open markers are plots 4 and 5 in Coastal Plain and 4 and 5 in Piedmont.

Filter Biomass and Nutrient Accumulation

Five sets of biomass samples from the grass filter areas were taken in 1992. The samples were at 1.0, 3.5 and 7.5 m from the field edge for each filter plot. All samples were cut at 7 cm above ground level. The Coastal Plain 4 m riparian plot had dog fennel as the vegetation and the 8 m riparian plot had fescue. Samples were analyzed for nitrogen and phosphorus.

Biomass production was about equal on the grass filters receiving runoff at both Coastal Plain and Piedmont (Figures 9 and 10). At the Piedmont site, the grass not receiving runoff produced slightly more biomass than the filter areas. This is not unexpected because this site was a field border receiving runoff for several years before being converted to a research plot.

At the Coastal Plain site, the increase in production at 7.5 m corresponds with the old field border. There is a distinct difference, however, between the grass and dog fennel riparian filters. The grass riparian filter, even though disturbed, produced more biomass than the grass filters near the field. The dog fennel biomass was double the production of the grass filters.

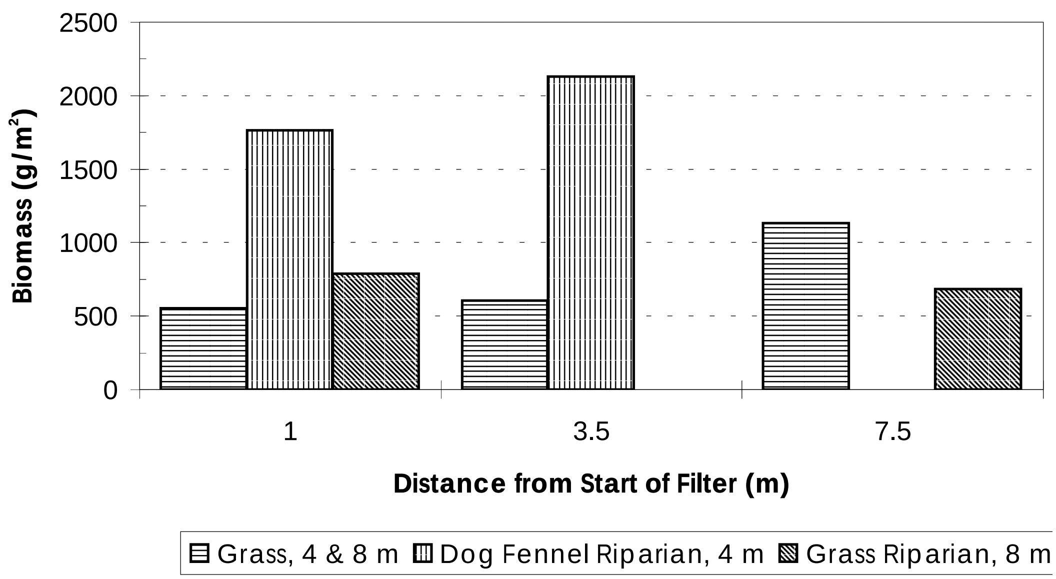


Figure 9. Annual biomass production for grass and riparian filters at Coastal Plain site.

Average concentration of phosphorus in the biomass at the Coastal Plain site varied little across the various filters (Figure 11). The nitrogen concentrations were more variable, ranging from 1.5 to about 2.5 mg/g (Figure 12). Both the grass and dog fennel riparian filters have a higher nitrogen concentration in the biomass than the grass filters receiving runoff from the field. The riparian filters receive direct runoff from the field. The differences in nitrogen biomass concentrations were probably related to the relative high soil nitrogen content in these filters (Table 2). The nitrogen and phosphorus concentrations in the biomass at the Piedmont site were similar to those at Coastal Plain (Figure 13).

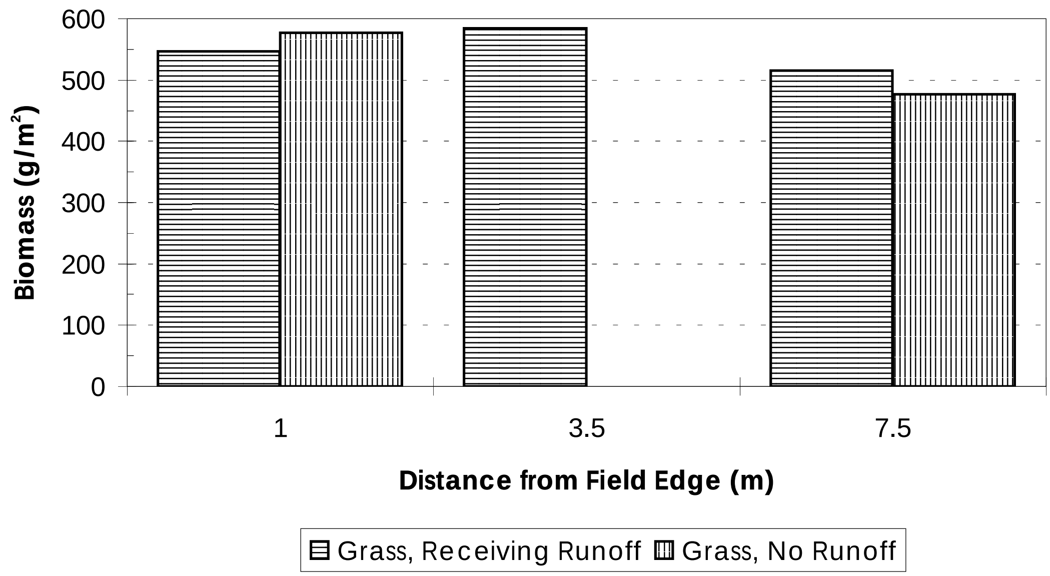


Figure 10. Annual biomass production for grass filters and grass area receiving no runoff at the Piedmont site.

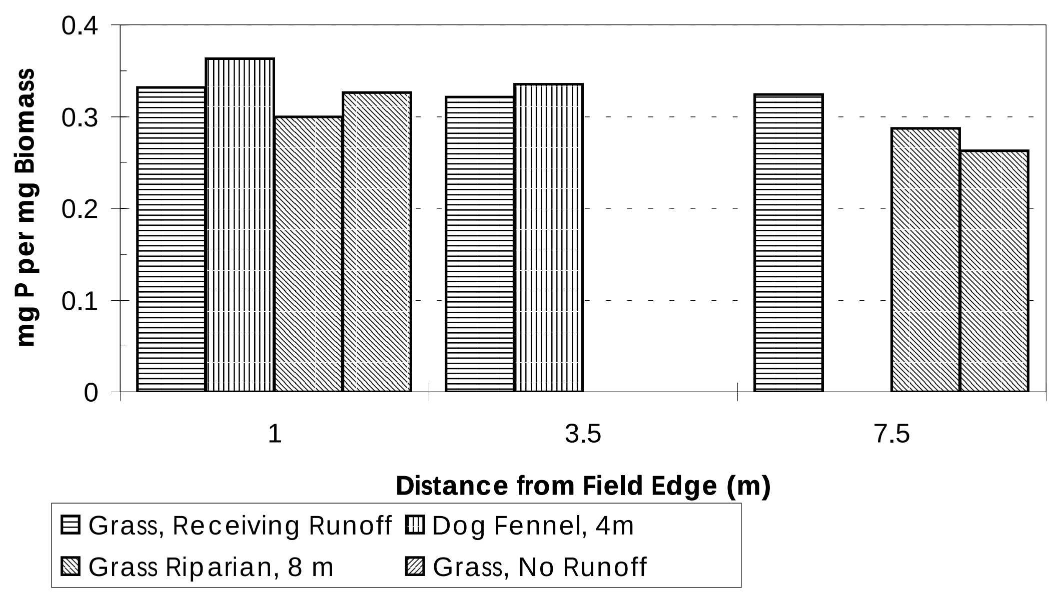


Figure 11. Average concentration of phosphorus in the biomass in the Coastal Plain filters.

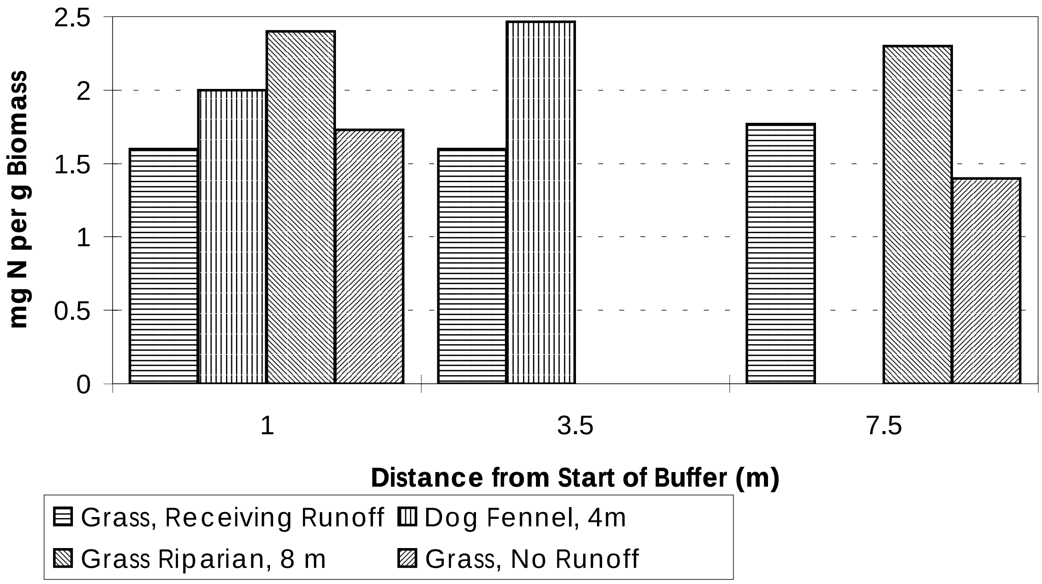


Figure 12. Average concentration of nitrogen in biomass in the Coastal Plain filters.

The weight of nitrogen and phosphorus in the total biomass sampled at the Coastal Plain site is given in Figure 14. Nitrogen values ranged from 7 to 13 Kg/ha for the 4 and 8 m grass filters. The phosphorus accumulation was from 1 to 3 Kg/ha. Figure 13 shows that the longer filters accumulated more nutrients than the shorter filters. The concentration data (Figures 11 and 12) suggests this should occur. These data indicate that the harvested grass biomass accumulated a moderate amount of nutrients.

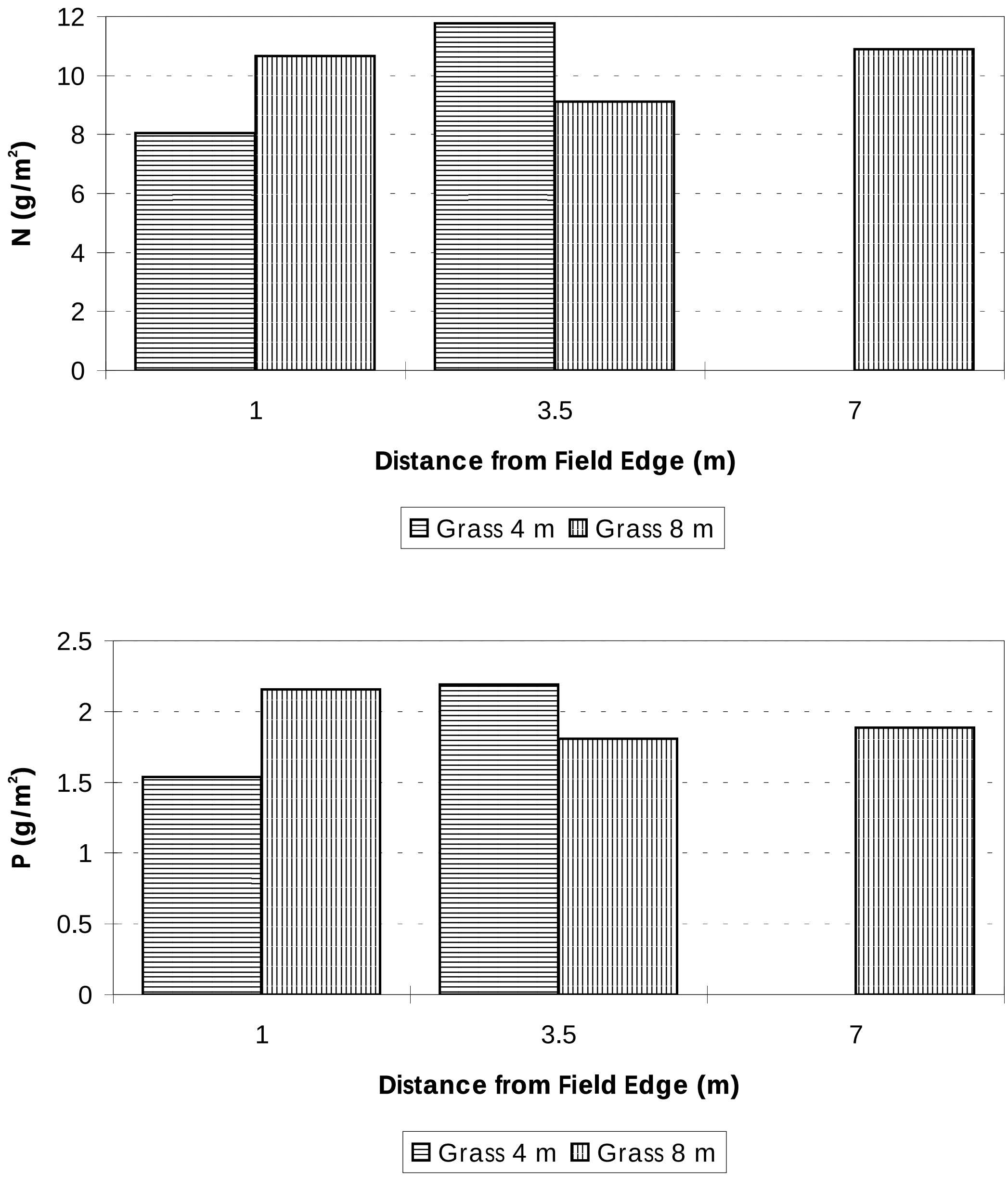


Figure 13. Average concentration of nitrogen and phosphorus in biomass of the Piedmont filters.

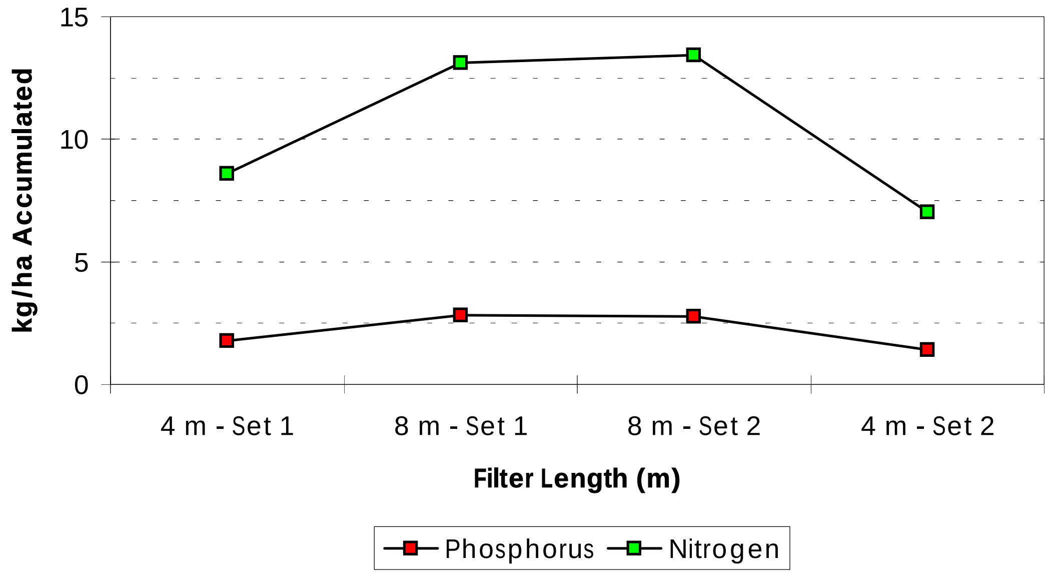


Figure 14. Nitrogen and phosphorus accumulated by the harvested biomass in the grass filters at Coastal Plain during 1992. The length of each plot in meters is shown as (4). The numerals on the X axis are the plot number.

Storm Results

Initial data collection was in June 1990 at the Piedmont site and August 1990 at the Coastal Plain site. At this time, filters were a combination of fescue, weeds and crab grass in the old field borders, although both areas were seeded to fescue the previous fall. This vegetation was sparse and short, consisting mostly of crab and wire grass. Thus, the early results from both study areas reflect the original sparse grass and weed stands. The riparian filters at the Coastal Plain site consisted of dense weed growth and some volunteer pines. This area had been clear-cut in 1987. In contrast, the wooded slopes at the Piedmont site are hardwood and pine with a moderately thick duff.

During 1990 the riparian plots at both the Coastal Plain and Piedmont sites received runoff from the 4 and 8 m grass filters. In 1991, the riparian plots were changed to receive runoff from the field edge collectors at both sites.

During fall of 1990, the grass filters were reseeded at both sites, so the data during these periods do not represent typical managed grass filter strips. During 1990 and 1991, data were collected on a number of rainfall events at both sites. At the Coastal Plain site, daily rainfall totals ranged from trace amounts to 53 and 42 mm on day 219 and 220 in 1990. During 1991, the daily rainfall was as high as 72 mm on day 88. The wettest period at the Coastal Plain site was from day 207-211 with a total rainfall of 110 mm. Daily rainfall amounts for the 1990and 1991 monitoring period at the Coastal Plain site are presented in Appendix 2 (Tables 1 and 2).

In 1990, data collection at the Piedmont site began in June. The largest storm in 1990 yielded a total rainfall of 72 mm on day 228. This was preceded by a wet period from day 218-223 (total rainfall 39 mm) and 42 mm on day 226. In 1991, days 170 and 171 yielded the only event with rainfall in excess of 55 mm (72 mm total rainfall). Tables of daily rainfall amounts for the 1990, 1991 and 1992 storms are presented in Appendix 2 (Tables 3- 5).

For all storm events, flume water levels were monitored every 30 s throughout the storm. The flume water level data was used to calculate flow rates. The flow rates are weighted by time and integrated to provide a volume of outflow from the respective plots. The water samplers can collect up to 24 samples during each runoff event. The sediment and chemical concentrations for each sample collected during the event were used to compute outflow loads.

Concentrations of sediment and nutrients multiplied by the outflow volume and integrated over the storm event to provide the outflow loads for the storm. During periods of constant or nearly constant flow rates, concentrations were estimated by interpolating between the concentration before the period and the one after the period. These data are presented in two sets of tables in Appendix 3. One set of tables contain the outflow loads and the other set contains the runoff volume weighted average concentration of the contaminant; either sediment or the particular chemical constituent.

The grass filter plots were organized in two sets (Figure 1, Table 5). Due to the difficulty in providing replication of this type of data, we assumed these sets of plots were replicates. However, these are not true replicates and thus our interpretation of the data reflects this. We also assumed that data collected at the field edge from each set was representative the surface runoff that arrived at the entrance for each of the grass filters within that set. Therefore, our comparisons and reductions due to the grass filters are referenced to the field edge runoff from the plot within the respective set. For the riparian plots, the runoff entering the upslope portion was the runoff from the field edge plot for the 1991 data from the set upslope from the plot (Figure 1). This runoff was measured and then spread across the entrance to the riparian buffer as explained in the methods section. We assumed that little or no loss occurred during the sampling and spreading. This was confirmed by field observations after a number of storms. Thus, the data reported from the riparian collectors was directly compared to the field edge data. There were no replicate plots for the riparian buffers.

Table 5: Definition of the Treatments.

Treatment	Definition
field-1	field edge collector, replicate 1
field-2	field edge collector, replicate 2
grass4-1	grass buffer, 4.2 m length, replicate 1
grass4-2	grass buffer, 4.2 m length, replicate 2
grass8-1	grass buffer, 8.4 m length, replicate 1
grass8-2	grass buffer, 8.4 m length, replicate 2
riparian-1	riparian buffer, 4.2 m length
riparian-2	riparian buffer, 8.3 m length

Coastal Plain Site

Summaries of the storm data for the Coastal Plain site are presented in Appendix 3, Tables 1- 8. The data are organized by year and amount of data collected on each storm. During 1990, we collected hydrograph data on four storms with sediment and nutrient data for one storm. As was indicated earlier, these storms occurred shortly after the installation and during the establishment of grass in the filter strips. The filtering effect of the Coastal Plain grass filters was minimal in 1990 because the vegetation was sparse. Little reduction of flow or sediments and chemicals was seen for the two events during these periods. Other events after installation and prior to reseeding showed reductions of water flow through the grass filters from 10-25% of that from the field edge collectors for rainfall events ranging from 28 mm - 103 mm.

Storm data collected in 1991 at the Coastal Plain site reflected the new stand of fescue. The stand was dense and healthy. Figures 15 and 16 show runoff and sediment data for the storm on day 171, 1990.   Runoff volumes from all the grass filters were smaller than the field edge plots. The first riparian plot, 4.2 m, produced the largest runoff volume which is data we cannot explain. Runoff volumes from the second field edge plot was larger than the volumes from either of the grass filters and also the second riparian filter (8.4 m). There was very little difference between the runoff volumes from the grass filters.

The sediment loads from all filtered plots were much smaller than the yield from the field edge plot (Figure 16). Sediment yields from the riparian plots were nearly zero.

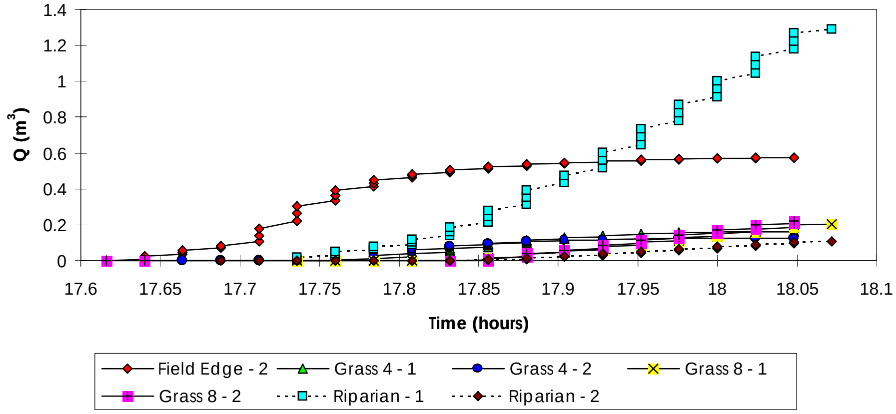


Figure 15. Runoff volumes for day 171, 1991, at the Coastal Plain site (Rain=38 mm).

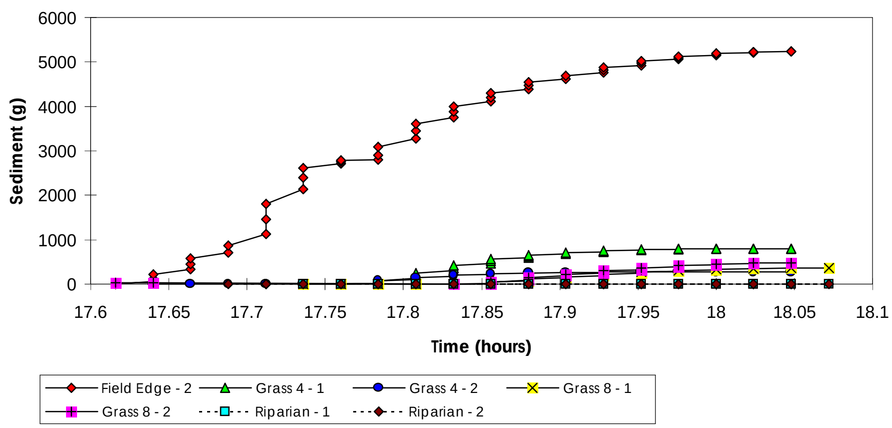


Figure 16. Sediment yield for the Coastal Plain site, day 171, 1991.

Figures 17 and 18 show similar results for the storm on day 221, 1991. Runoff volumes from the riparian plot plots exceeded the volumes from the field edge plots for this storm (Figure 17). For all grass filter plots the runoff volume was 50% or less of the volumes from the field edge plots.

Sediment losses were measured for the second field edge plot (Figure 18) and the two of the grass filters (4.3 m and 8.5 m plots). Both grass filters reduced sediment losses in excess of 90% over those measured from the field edge collector.

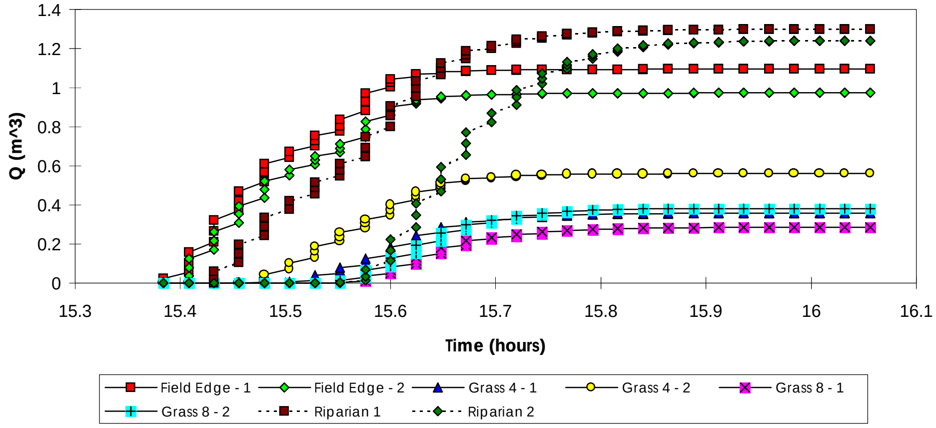


Figure 17. Runoff volumes for the Coastal Plain site, day 221, 1991 (Rainfall=14 mm)

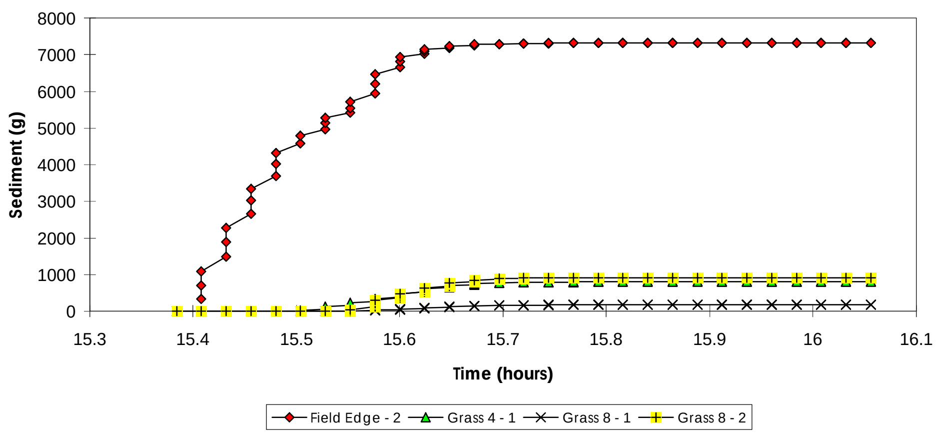


Figure 18. Sediment yield for the Coastal Plain site, day 221, 1991.

Table 6: Sediment Concentration for day 171, 1991.

Treatment	Sediment(g/l)
field-2	8.19
grass4-1	1.13
grass4-2	2.2
grass8-1	0.66
grass8-2	1.8

Table 7: Chemical Concentrations for Day 221, 1991

Treatment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
field-2	4.38	0.71	0.0	2.31	0.92	0.13	0.04
grass4-1	1.08	-[a]	-	-	-	-	-
grass4-2	2.94	0.6	0.0	0.96	0.61	0.35	1.04
grass8-1	1.35	-	-	-	-	-	-
grass8-2	2.28	3.21	0.24	3.81	1.90	1.55	6.9

a. Data not measured or missing.

Figures 19 - 25 show the runoff volumes and sediment and chemical loads for the storm on day 263, 1991 at the Coastal Plain site. Runoff volumes were largest for the field edge plots (Figure 19). For this storm, no measurements were done for the second riparian filter. The first riparian filter yielded runoff volumes comparable to the second field edge collector. Runoff volumes from all of the grass filters were 90% or less than those from the field edge collectors.

Sediment yields from all of the plots on day 263, 1991 are shown in Figure 20. The yields measured from the grass filters were 75% or less than those measured from the field edge. The first riparian strip (4.3 m length) yielded more sediment than the grass filters. However, the reduction from the field edge sediment loads was greater than 50%.

Table 8: Sediment and Chemical Concentrations for day 263, 1991.

Treatment	Sed	NO_3-N	TKN	TP	OP	CL
	(g/l)	(mg/l)				
field-1	5.42	1.51	6.4	5.65	0.38	0.19
field-2	5.52	1.77	8.35	2.53	0.51	0.25
grass4-1	0.0	0.0	0.0	0.0	0.0	0.0
grass4-2	0.0	0.0	0.0	0.0	0.0	0.0
grass8-1	3.04	1.15	1.15	1.15	0.0	0.0
grass8-2	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	2.76	1.83	3.93	1.83	0.52	0.26
riparian-2	0.90	0.97	2.91	0.97	0.97	0.97

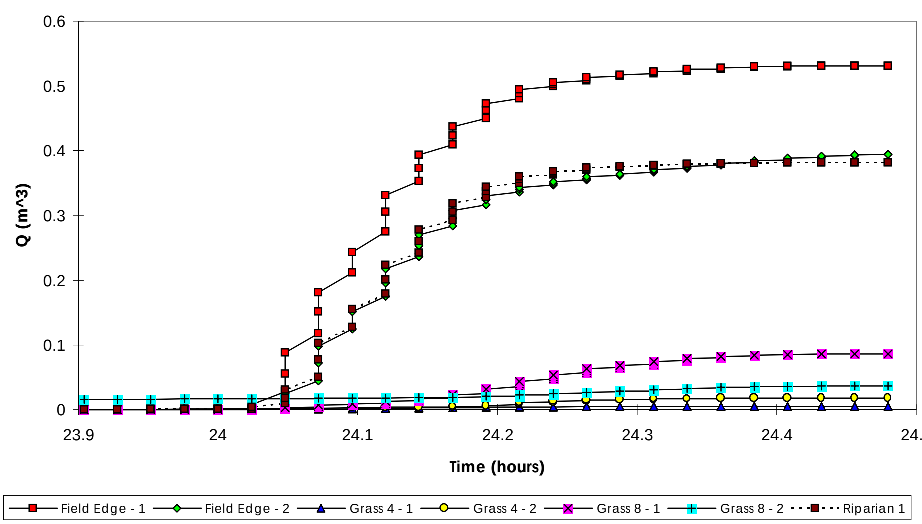


Figure 19. Runoff volumes for the Coastal Plain site, day 263, 1991 (Rainfall=20 mm).

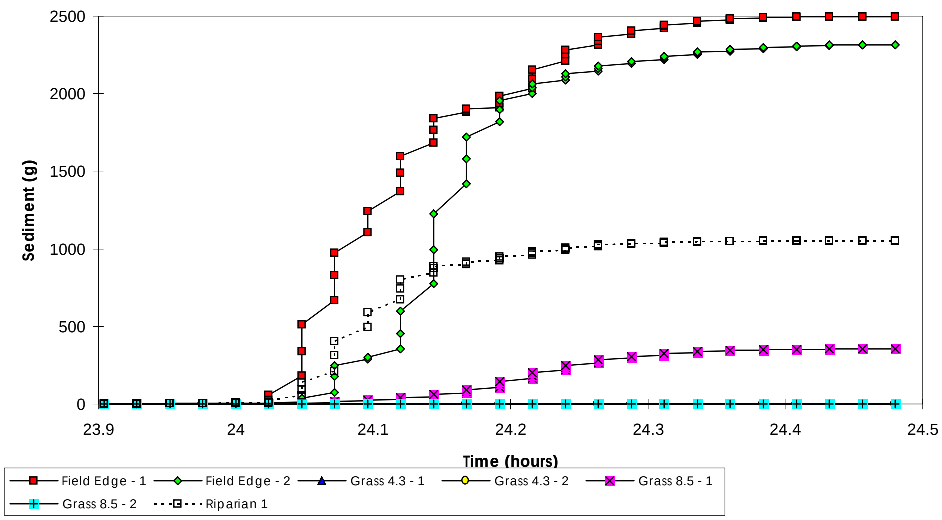


Figure 20. Sediment yield for the Coastal Plain site, day 263, 1991.

Nitrate-N loads from the plots were also the largest for the field edge plots (Figure 21). Nitrate-N was also large for replicate 1 of the riparian plots. It should be remembered that these data are for surface runoff water. Nitrate reduction in grass and riparian buffers occurs mainly in subsurface flows.

The loads of total Kjeldahl nitrogen (TKN) were largest in the field edge plots with the first replicate of the riparian plot next (Figure 22). TKN load from the 8.4 m grass buffer was small. Orthophosphate-P (OP) in solution and total P (TP) followed similar trends. Both field edge plots yielded the largest loads with both riparian plots next (Figures 23 and 24). Loads from the 8.4 m grass filter were small. Figure 25 shows similar results for chlorides (CL).

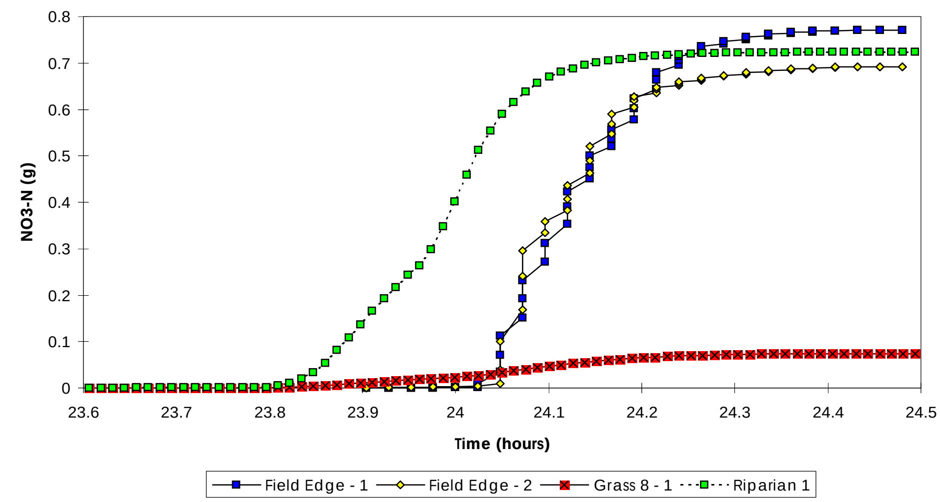


Figure 21. Nitrate-N (NO_3-N) load for the Coastal Plain site, day 263, 1991.

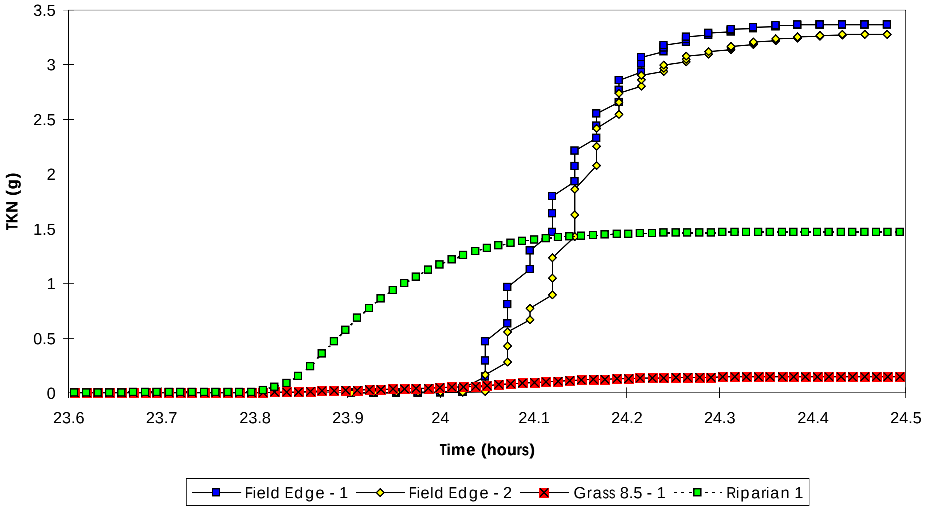


Figure 22. TKN load for the Coastal Plain site, day 263, 1991.

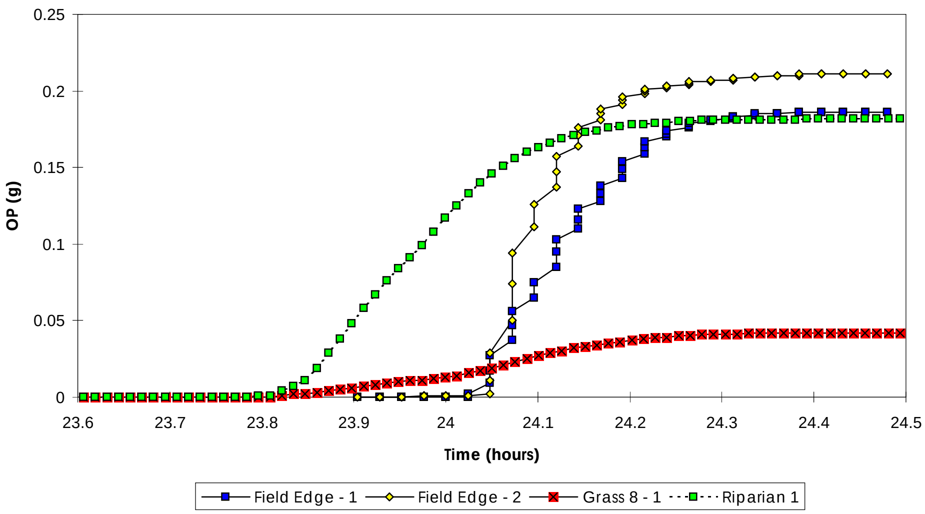


Figure 23. Ortho-P load for the Coastal Plain site, day 263, 1991.

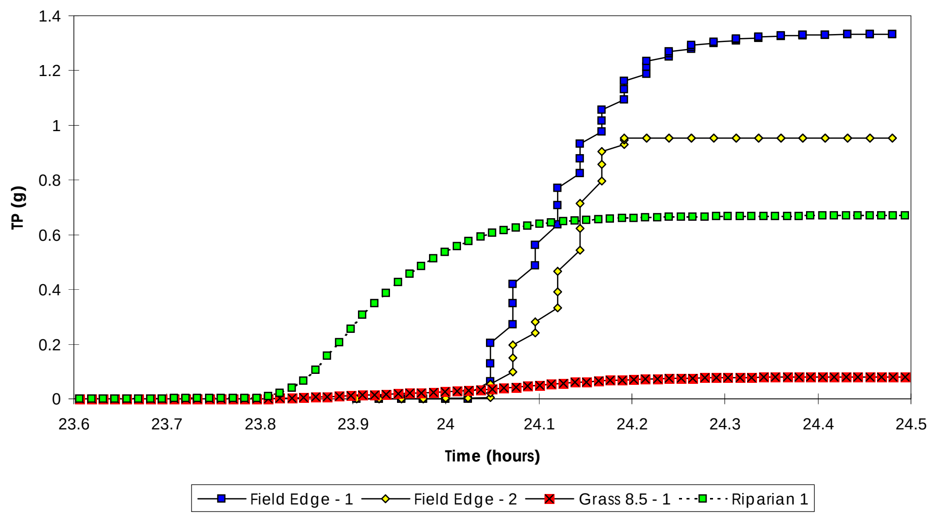


Figure 24. Total P load for the Coastal Plain site, day 263, 1991.

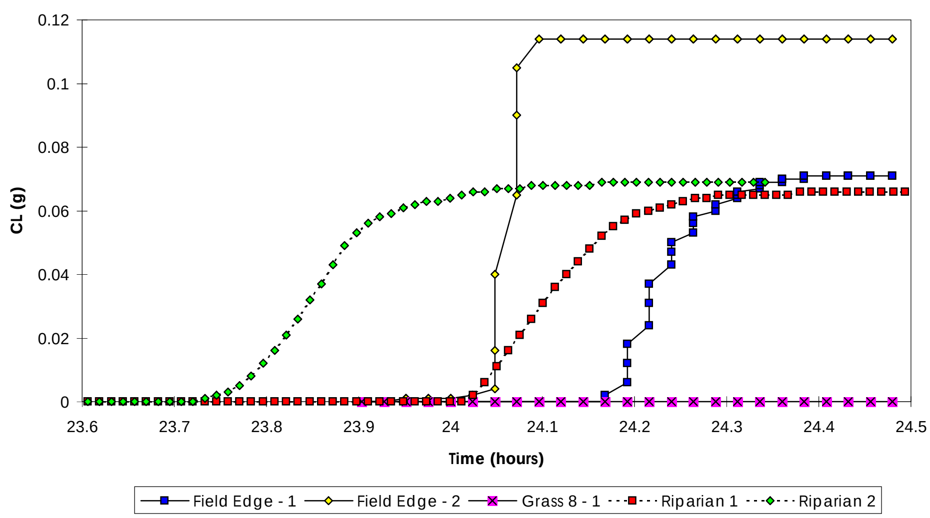


Figure 25. Chloride load for the Coastal Plain site, day 263, 1991.

Piedmont Site

In 1990, the grass buffer strips were the natural field borders which was mostly crab grass. These were reseeded with fescue in the fall of 1990. Summaries of the storm data are in Appendix 3, Tables 9-18.

Figures 26 - 33 give details for the storm on day 228, 1990. Even though this storm occurred prior to reseeding the grass buffers, the filters did reduce sediment loads. There was little difference between filters and field edge runoff volumes (Figure 26). Sediment and chemistry were measured on the samples from the first field edge and grass filter plots. Sediment yields from the grass filters were much smaller than the loads from the agricultural source areas (field edge collectors) (Figures 27). Average sediment concentrations also declined with increasing grass filter length (Table 9).

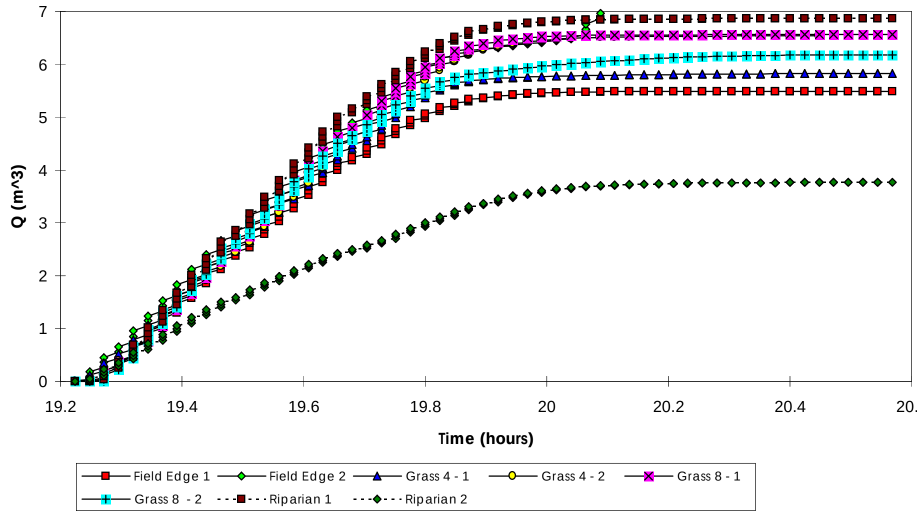


Figure 26. Runoff volumes for the Piedmont site, day 228, 1990 (Rainfall=72 mm).

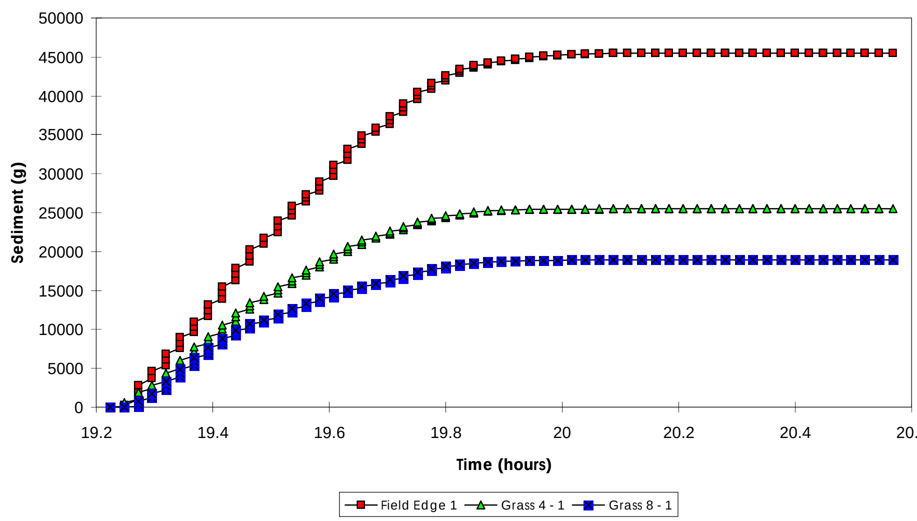


Figure 27. Sediment yield for the Piedmont site, day 228, 1990.

Table 9: Average Sediment and Chemical Concentrations for day 228, 1990.

Treatment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
field-1	8.29	3.70	0.22	13.16	4.99	0.67	4.52
grass4-1	4.38	1.99	0.07	7.49	4.12	0.48	1.63
grass8-1	2.88	1.59	0.02	5.29	3.14	0.41	1.97

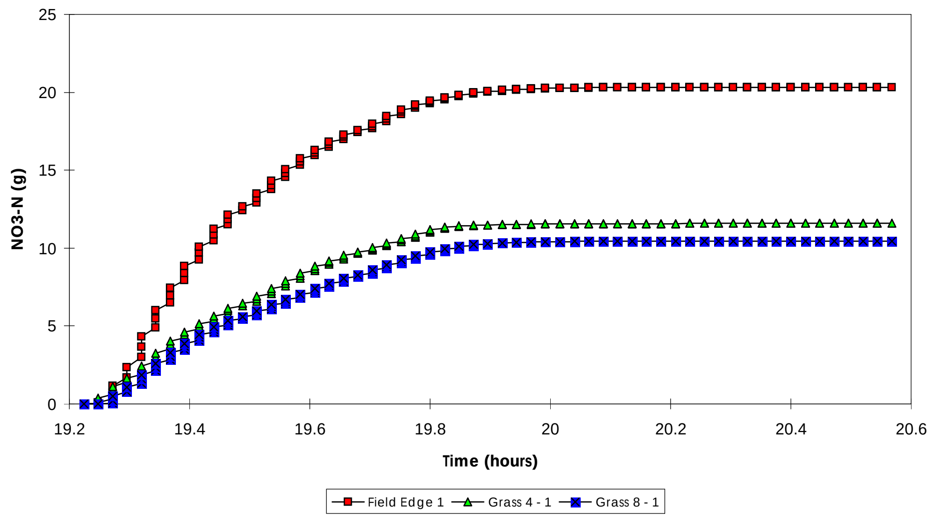


Figure 28. NO_3-N load for the Piedmont site, day 228, 1990.

Nutrient loads followed a similar trend as the sediment for day 228 (Figures 28 - 33). For example, nitrate-N loads from the grass filters were nearly 50% less than those measured in the field edge collector and nitrate-N loads from the shorter grass filter were larger than those from the longer grass filter (Figure 28). Reductions in ammonium-N from the grass filters were greater than 80% over the loads from the field edge (Figure 29). Average concentrations of nitrate-N and ammonium-N showed similar trends (Table 9).

Total Kjeldahl nitrogen trends were similar to those of nitrate-N (Figure 30). Soluble Ortho-P and total P loads from the grass buffers were smaller than the loads from the field edge plots (Figures 31 and 32). However, the loads from the grass filters were 60% and 80% of the field edger soluble ortho-P and total P loads, respectively.

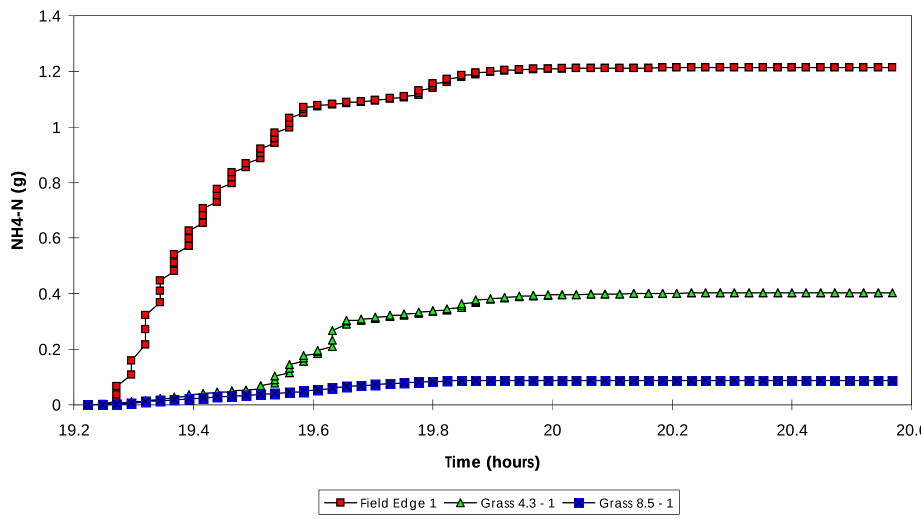


Figure 29. NH_4-N load for the Piedmont site, day 228, 1990.

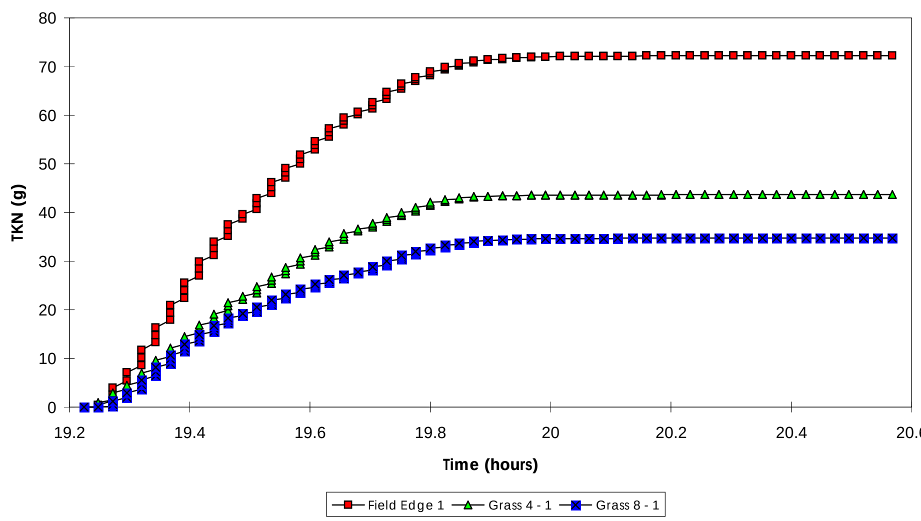


Figure 30. TKN load for the Piedmont site, day 228, 1990.

For the storm on day 228, 1990 at the Piedmont site, chloride loads from the grass filters were less than 50% of those from the field edge collector (Figure 33). Average concentrations of chloride are shown in Table 9.

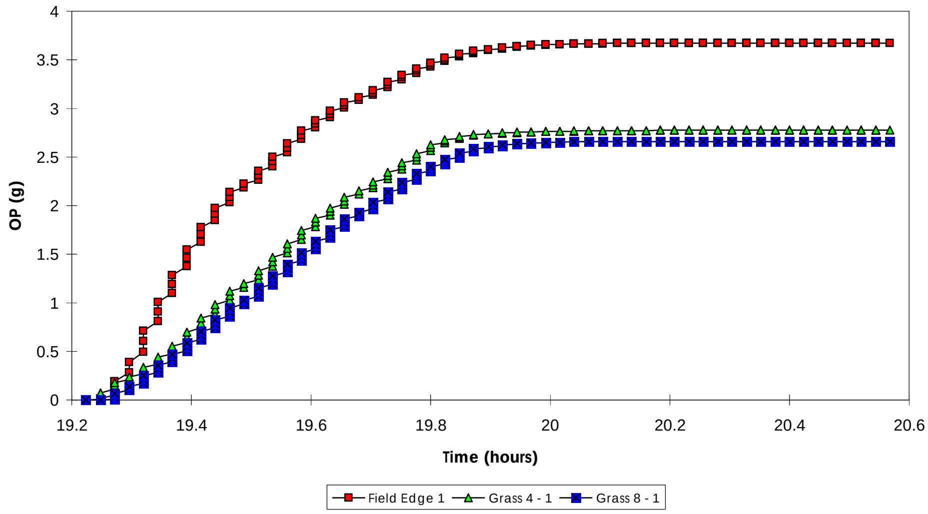


Figure 31. Ortho-P load for the Piedmont site, day 228, 1990.

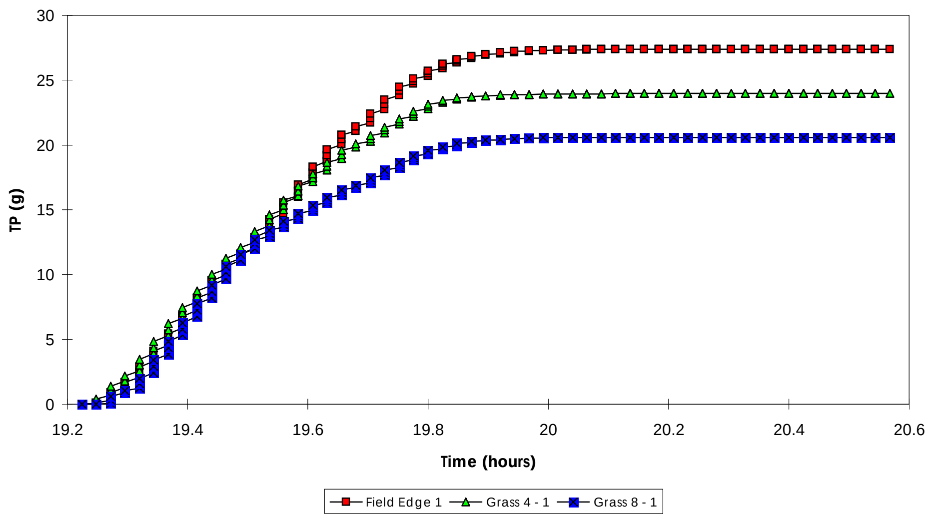


Figure 32. Total P load for the Piedmont site, day 228, 1990.

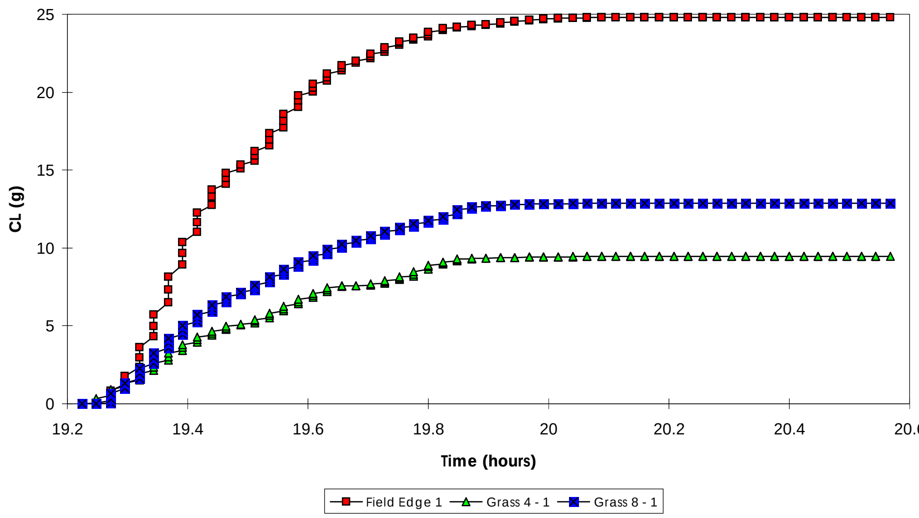


Figure 33. Chloride load for the Piedmont site, day 228, 1990.

In 1991, we began sampling all plots at the Piedmont site. The stand of fescue was healthy and thick. Summaries of sediment and chemical loads and concentrations for the monitored storms are presented in Appendix 3 (Tables 13 - 16). Discussions of the events on days 170, 183, and 262 are presented below.

Figures 34 - 39 give the runoff volume, sediment and chemical loads for the storm on day 170. Runoff volume and sediment loads were largest for the field edge collectors (Figures 34 and 35). The start of runoff from the grass and riparian filters was delayed by as much as 0.2 hour. The runoff from the first and second riparian filters were comparable until hour 17.6. At this time, the runoff from the shorter riparian filter (Riparian -1) increased and yielded greater runoff volumes than either of the grass filters in set 1 (Figure 34). This was probably due to the runoff concentrating versus sheet flow. Also, the longer grass filter in set 2 (8.3 m) yielded more runoff than the shorter grass filter which we cannot explain. Other comparisons of runoff volumes followed the trend we expected, for example, in the first set of plots, field edge runoff was greater than runoff from the 4.3 m grass filter which was greater than runoff from the 8.5 m grass filter.

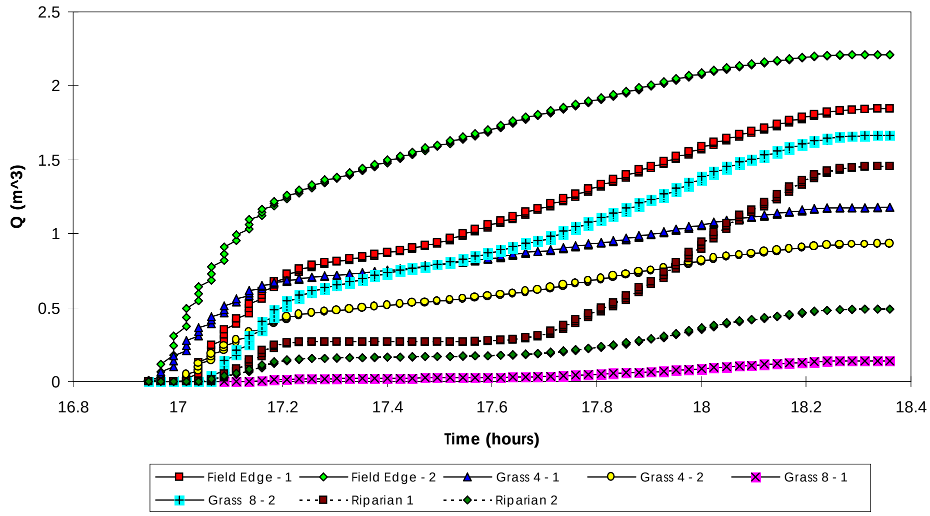


Figure 34. Runoff volumes for the Piedmont site, day 170, 1991 (Rainfall=72 mm).

Sediment loads from the plots are compared in Figure 35. The second field edge collector yielded the largest sediment load. This sediment load was in excess of 25,000 g as compared to about 5,000 g from the first field edge collector. This shows that even though both sets of plots were selected to be comparable there was considerable variability. Even with this, the sediment yields from the grass and riparian filters were substantially less than those from either field edge collector. Sediment filtration was greater than 75% for all of the filters. Average sediment concentrations showed similar trends (Table 10). The average sediment concentration from the second field edge plot was greater than 11 g/l indicating that a large portion of the sediment arrived as bed load. As expected, this was filtered out quickly as indicated by average sediment concentrations of less than 2 g/l in either of the filters.

Table 10: Sediment and Chemical Concentrations for Day 171, 1991.

Treatment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
field-1	3.53	4.11	0.0	6.77	3.14	0.32	4.17
field-2	11.41	1.04	0.0	12.26	5.84	0.1	0.72
grass4-1	1.95	3.74	0.0	4.93	3.31	1.44	4.76
grass4-2	1.22	3.23	0.0	4.41	3.12	1.08	3.33
grass8-1	0.12	2.14	0.0	1.43	1.43	2.14	1.43
grass8-2	0.78	1.85	0.0	1.61	1.67	1.32	2.09
riparian-1	0.2	2.06	0.0	1.3	1.03	0.55	2.4

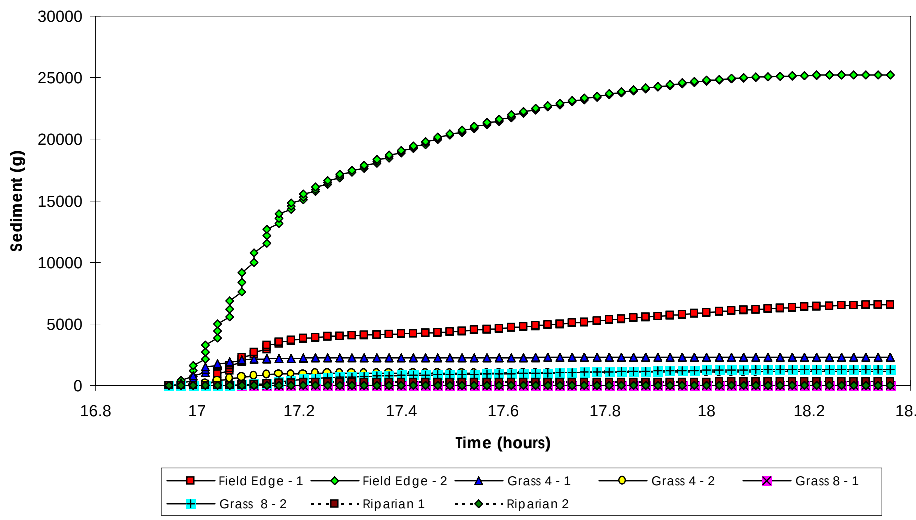


Figure 35. Sediment yield for the Piedmont site, day 170, 1991.

Nitrate-N loads were largest for replicate 1 of the field edge collector with some differences between the replicates (Figure 36). The load from the field edge collector for set 1 was nearly 8 g while the set 2 field edge collector yielded approximately 2 g. For set 1, the shorter grass buffer (4.3 m) yielded approximately 4 g for a reduction of approximately 50% from the field edge collector.

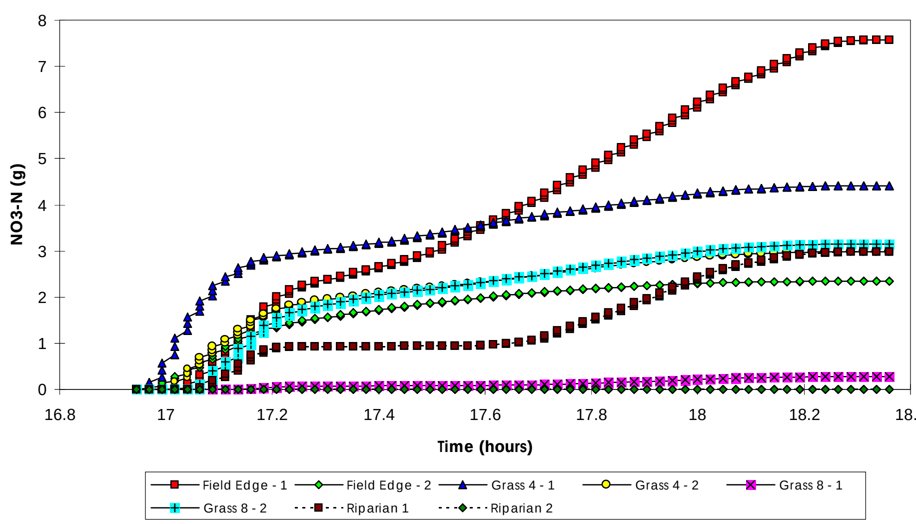


Figure 36. Nitrate-N load for the Piedmont site, day 170, 1991.

Soluble P (Ortho-P) loads were largest for the grass buffers; replicate 2 of the 8.4 grass buffer was the largest followed by replicate 1 of the 4.2 m grass filter (Figure 37). The loads from both field edge collectors were less that 0.5 g. This indicates that soluble P was probably being released from P that had been stored in the grass buffers from earlier storms.

Total P loads from the field edge collectors were larger than those from the grass buffers (Figure 38). The total P load from the second field edge collector was nearly 14 g compared to total P loads of approximately 2 g from both set 2 grass filters. Even though, the total P load from the first field edge collector was about 5 g, both grass filters in set 1 showed reductions in total P loads greater than 30%. The total P from the longer grass filter is set 1 was nearly 0. Total P loads from both riparian filters were less than the loads from both field edge collectors.

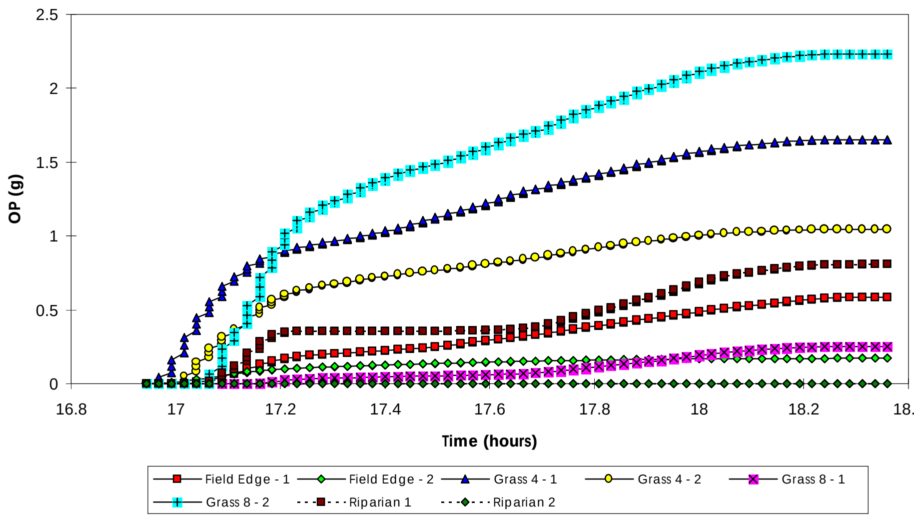


Figure 37. Ortho-P load for the Piedmont site, day 170, 1991.

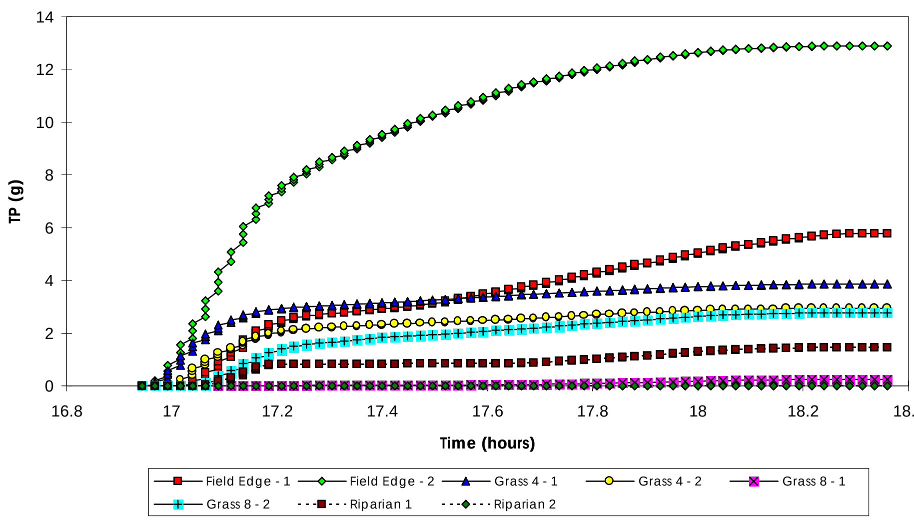


Figure 38. Total P load for the Piedmont site, day170, 1991.

Chloride loads presented in Figure 39 show that the replicate 1 of the field edge collector resulted in the largest final loads. The trends in chloride were similar to those seen in the nitrate-N comparisons in Figure 36.

Average concentrations of nitrate-N, total Kjeldahl N and total P were reduced by the grass and riparian filters for the storm on day 170, 1991 (Table 10). However, for soluble P (ortho-P), the average concentrations from the filtered runoff were higher than from the field edge.

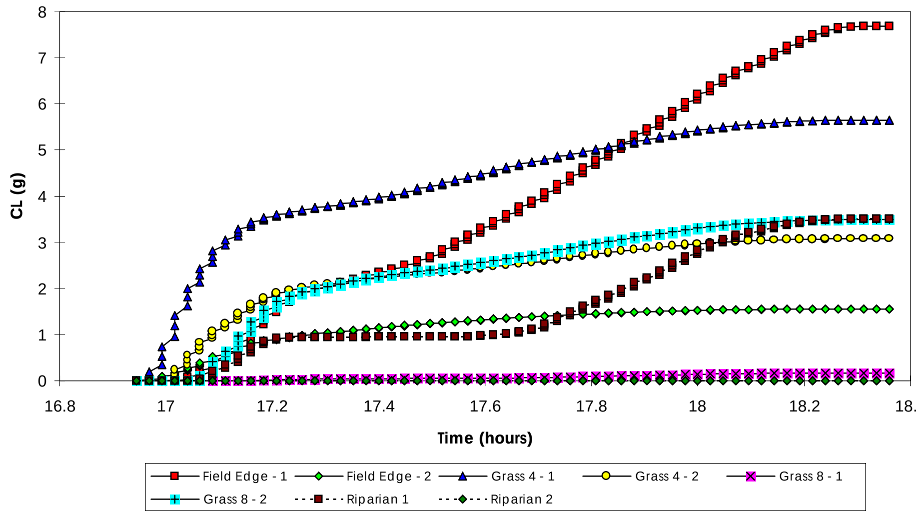


Figure 39. Chloride load for the Piedmont site, day 170, 1991.

Figures 40 - 42 give data on runoff volume, sediment and nitrogen loads from the storm on day 183, 1991. Runoff volume was largest from the second field edge plot (Figure 40). For this storm runoff from the first field edge plots was less than the volume from the shorter grass filter in set 1. Again, this can be attributed to variability in the runoff source area and the filters. Runoff volumes from both riparian filters were less than the volumes from their respective field edge sources.

Figure 41 shows the relationship between sediment loads for each filter and the field edge collectors. Even though runoff volumes were variable, sediment loads from the grass and riparian filters were much smaller (nearly 0) than those from the field edge collectors.

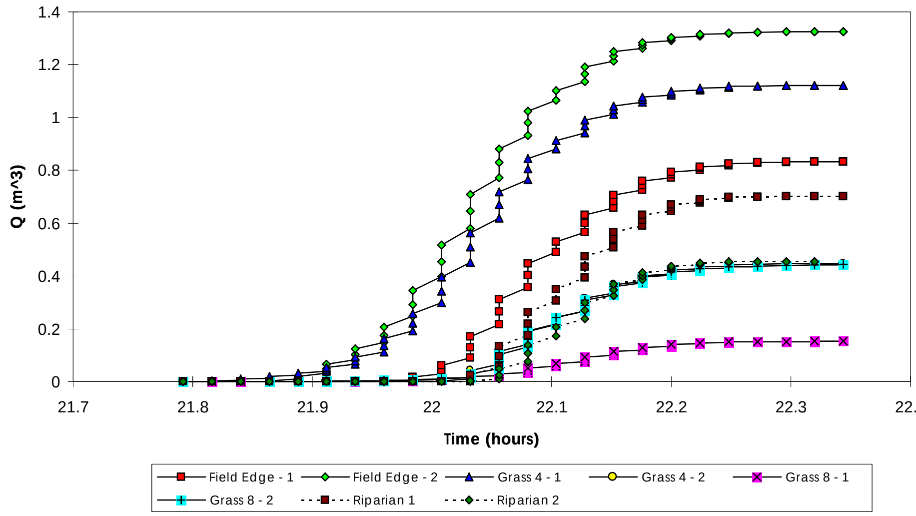


Figure 40. Runoff volumes for the Piedmont site, day 183, 1991 (Rainfall=27 mm).

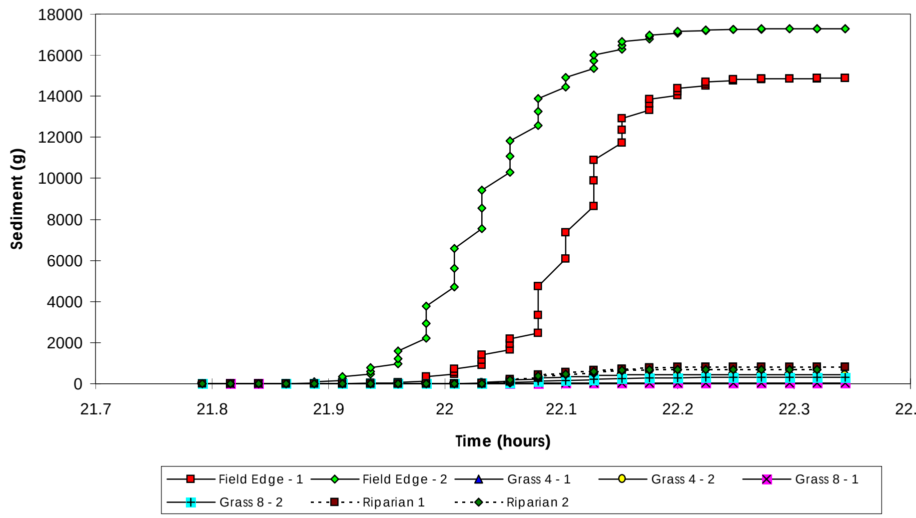


Figure 41. Sediment yield for the Piedmont site, day 183, 1991.

Figures 42 and 43 show the relationships between nitrate-N and ammonium-N and all plots for the storm on day 183, 1991. For both nitrate-N and ammonium-N, the field edge loads were the largest. Both riparian filters yielded comparable nitrate-N and ammonium-N loads and these were less than 50% of the loads measured for the field edge collectors. The longer grass filters in both sets had the smallest loads of both forms of nitrogen.

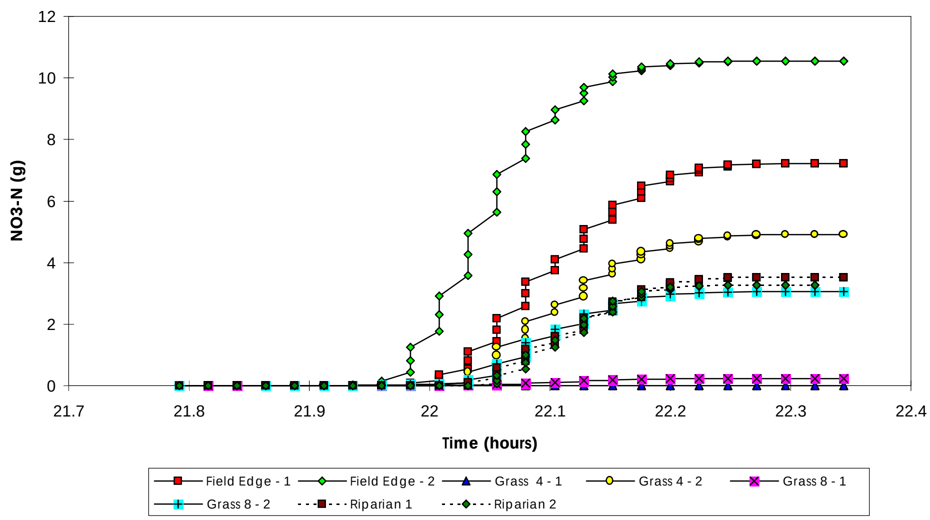


Figure 42. Nitrate-N load for the Piedmont site, day 183, 1991.

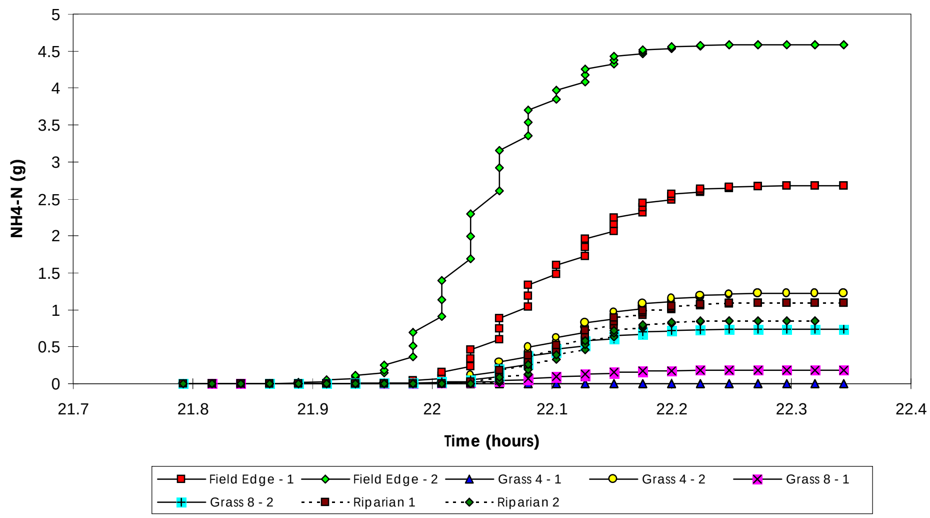


Figure 43. NH4 - N load for the Piedmont site, day 183, 1991.

Average concentrations of sediment on day 183 were reduced from in excess of 10 g/l for the field edge plots to 1 g/l or less by the grass filters and 1 and 3 g/l for the 4.3 and 8.5 m riparian filters, respectively (Table 11). Concentrations of nitrate-N and ammonium-N were more variable and did not show a clear trend.

Table 11: Average Sediment and Chemical Concentrations for day 183, 1991.

Treatment	Sed	NO_3-N	NH_4-N
	(g/l)	(mg/l)	
field-1	17.85	8.64	3.24
field-2	13.04	8.00	3.47
grass4-2	1.01	10.96	2.68
grass8-1	0.29	1.32	1.32
grass8-2	0.69	7.00	1.58
riparian-1	1.18	5.0	1.57
riparian-2	3.08	14.32	3.74

Figures 44 - 49 summarize data from the storm at the Piedmont site on day 262. The grass and wooded filters reduced runoff volume and sediment load compared to the field edge plots (Figures 44 and 45). The runoff volumes for this storm followed the expected trend with the field edge plots the largest followed by the grass filters (Figure 44). For this storm, runoff from the riparian filters was less than 60% of the runoff from either field edge collector indicating that the flow remained disperse and did not concentrate during the storm.

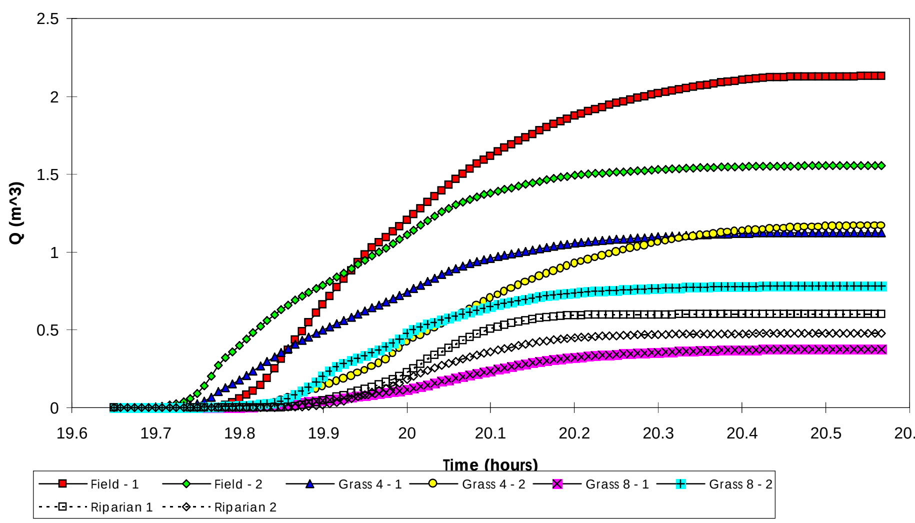


Figure 44. Runoff volumes for the Piedmont site, day 262 1991 (Rainfall=39 mm).

The first set of plots were used to compare sediment and chemistry results for this storm. For both the grass and riparian filters, sediment loads were less than 20% of the sediment measured from the field edge collector (Figure 45). Average sediment concentrations were reduced by similar amounts by the grass and riparian filters (Table 12).

Table 12: Average Sediment and Chemical Concentrations for Day 262, 1991.

Treatment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
field-1	1.50	1.36	0.0	1.79	1.46	1.08	4.51
grass4-1	0.48	4.63	0.0	2.67	3.56	3.21	11.49
grass8-1	0.90	0.0	4.8	0.0	2.13	2.93	2.67
riparian-1	0.71	4.17	0.0	2.17	2.17	2.0	9.17

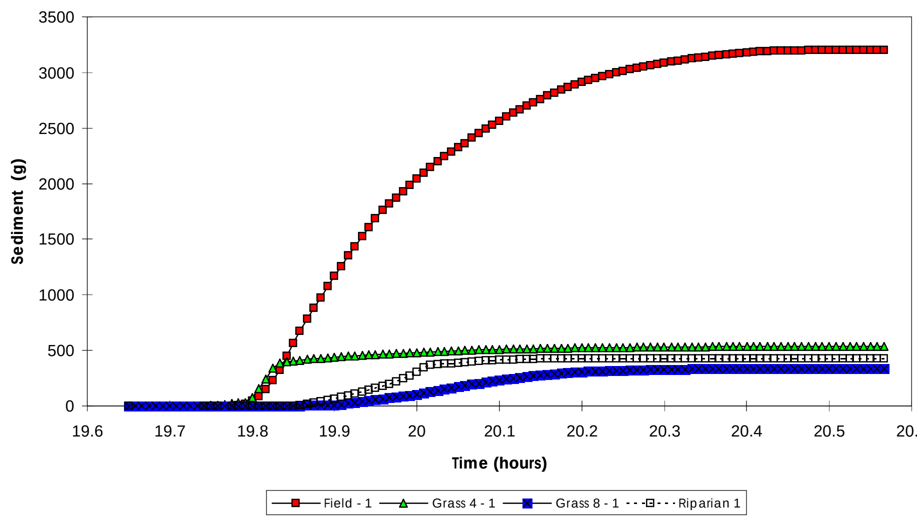


Figure 45. Sediment yield for the Piedmont site, day 262, 1991.

Figure 46 presents comparisons of Total Kjeldahl N loads for the set 1 plots. The largest load was from the field edge collector (Figure 46). The total Kjeldahl N load from the shorter grass filter was less than the load from the shorter riparian buffer. The longer grass filter yielded nearly 0 g of TKN.

The grass filters did produce larger chemical loads (nitrate-N, ammonium-N and total P) than the field edge collectors (Figures 47 - 49). The chemical concentrations were also larger and quite variable in the grass and riparian filters (Table 12). This could be due to a number of factors such as differences between the amount of field edge measured and that that actually entered the buffers and flushing of nutrients that arrived in the buffers during previous storms.

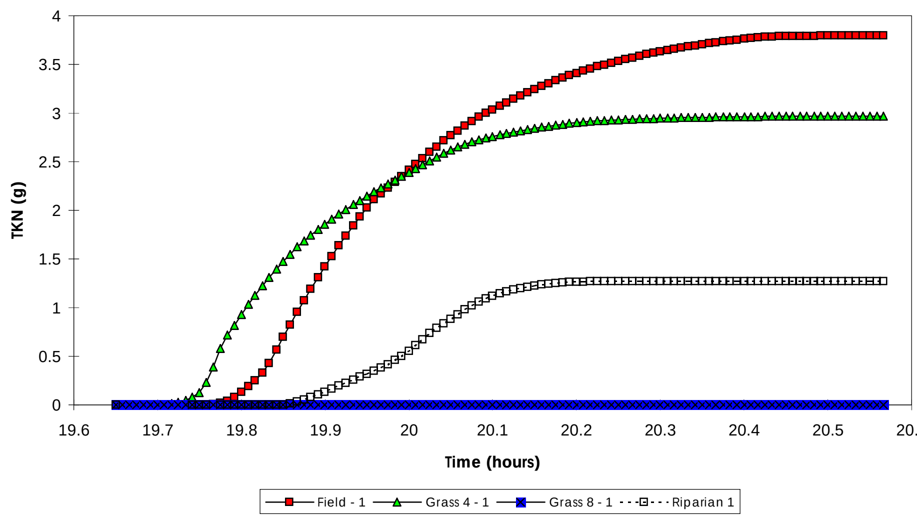


Figure 46. TKN load for the Piedmont site, day 262, 1991.

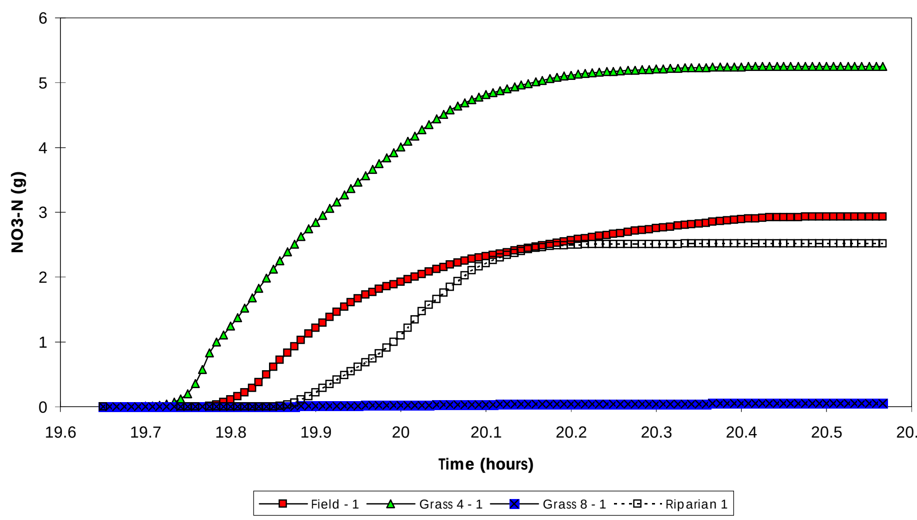


Figure 47. Nitrate-N load for the Piedmont site, day 262, 1991.

For the range of events we have monitored, the grass filter strips consistently reduced sediment loads. Reductions in sediment load with the grass filtration ranged from 10-20% to greater than 90% of the field edge measured sediment load. Discharge measurements did not always follow this trend. However, the runoff volumes from the grass filtered plots were often smaller than the corresponding field edge measurements by similar percentages. In general, the longer grass filters were more effective than the shorter grass filters in reducing runoff volumes, sediment transport and nutrient losses. For smaller storm events, there was often no runoff measured in the longer grass filters.

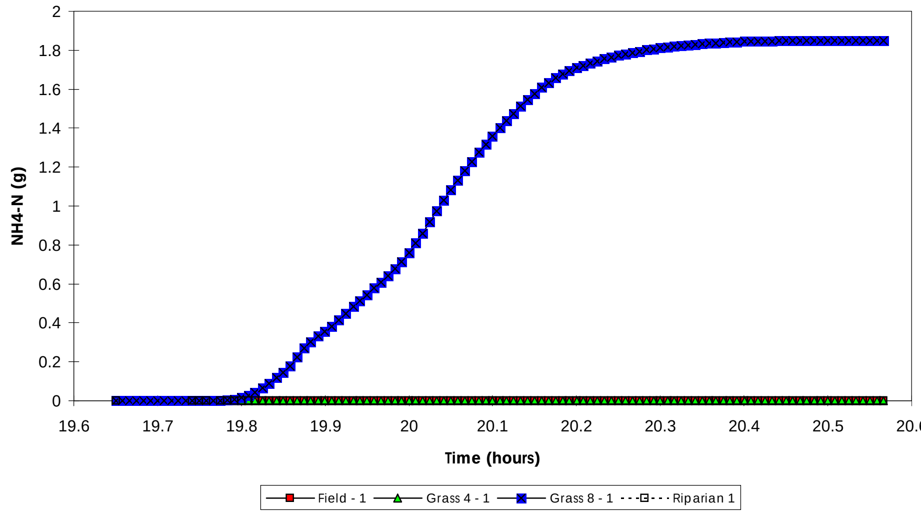


Figure 48. NH4 load for the Piedmont site, day 262, 1991.

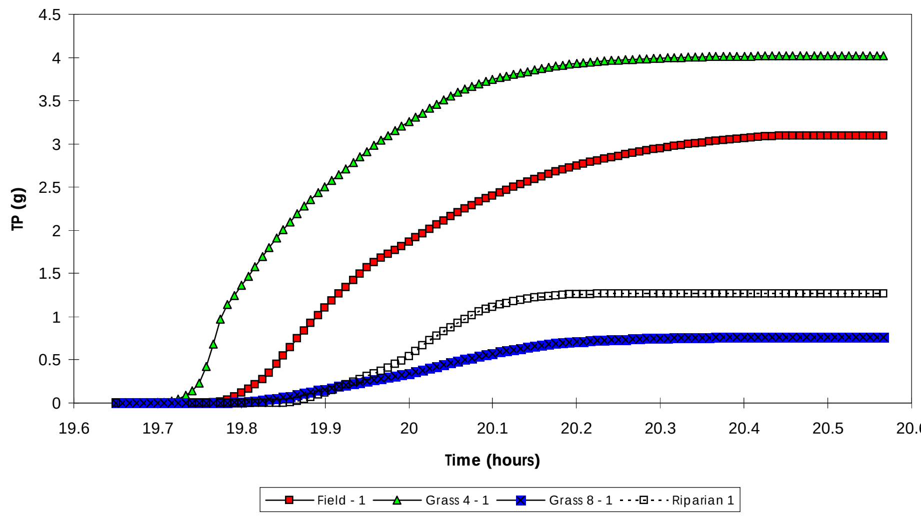


Figure 49. Total P load for the Piedmont site, day 262, 1991.

Average sediment concentrations generally showed large filtration by both the grass and riparian filters indicating that shorter buffers are quite effective treating sediment loads. Chemical concentrations tended to be more variable and larger with either grass or riparian filters. This is due in part to the function of the buffers. The buffers tend to trap sediment by decreasing the transport capacity of the runoff. Larger particle sizes of sediment are trapped first. The smaller particles tend to stay in suspension at lower transport capacities. These smaller particles carry adsorbed forms of the nutrients. Any chemicals that are deposited in the filters may be flushed by subsequent runoff events increasing loads and concentrations. Finally, the filters tend to reduce runoff volume which can also increase concentrations of sediment and chemicals.

FUTURE WORK

Work has continued on the project sites since the end of this report. Storm data has been collected from 1992-present. Parsons et al. (1994) reported on the status of the project through 1992 with findings similar to the preliminary conclusions contained here. Although the 4 m grass filters are effective for most storms, the 8 m filters are required as the filters age. This was found to be due to deposition of sediment near the front of the filters creating a berm that tends to concentrates runoff. The additional filter length is needed to allow the concentrated runoff to disperse into overland or sheet flow. The riparian buffers also required the additional length. As noted in this report, Parsons et al. (1994) found that the riparian buffers tended to be much more fragile and more easily channelized after the larger runoff events. The additional buffer length may also be important when considering treatment of subsurface flows. The extra length would provide more opportunity for infiltration and thus additional pathways for reducing chemical contaminants.

Other work that has been completed includes the development and testing of an event oriented model to describe surface flow through the grass buffers. This work was completed in the summer of 1993 (Muñoz-Carpena 1993). The work developed stable numerical procedures to model overland flow and describe the fate of sediment through the buffers (Muñoz-Carpena et al. 1991, 1992, 1993a, 1993b). The model was tested with the databases described in this report.

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GLOSSARY

A. Units of Measurement

mg/l	Milligrams per liter
mg/mg	Milligrams per milligrams
mg/g	Milligrams per gram
g/l	Grams per liter
ml	Milliliter (=cubic centimeter)
mm	Millimeter
m	Meter
ft	Foot
v	Volts
min	Minute
m^3	Cubic meters
Kg	Kilograms
ha	Hectare
m^2	Square meters

B. Parameters

CL	Chloride (units both as mg/l for concentration and g for loads)
DC	Direct current (units v)
N	Nitrogen
NO_3-N	Nitrate-nitrogen (units both as mg/l for concentration and g for loads)
NH_4-N	Ammonium-nitrogen (units both as mg/l for concentration and g for loads)
OP	Orthophosphate form (soluble) (units both as mg/l for concentration and g for loads)
P	Phosphorus
Q	volume of runoff (units m^3)
TKN	Total Kjeldahl Nitrogen (units both as mg/l for concentration and g for loads)
TP	Total Phosphorus (particulate) (units both as mg/l for concentration and g for loads)

C. Terms

runoff — In this study we refer to surface water in excess of infiltration

vegetative filter strip
: A planted or natural area located down slope from a source area for surface runoff.

grass buffer — A planted grass area located down slope from a source area for surface run-off.

riparian buffer
: A natural vegetative area located down slope from a source area for surface runoff on or near a flood plain.

HS flume — A type of flume used to measure surface runoff by concentrating flow into a channel through a constriction. Flow rate is functionally related to the water height at the constriction.

filter strip — Used the same as buffer in this study

hydrograph — Relationship of runoff versus time during a storm.

datalogger — A computer-based piece of instrumentation to monitor voltages and other instrumentation and store the data for later retrieval.

potentiometer
: An electrical device presenting a variable resistance in an electrical circuit.

bridge circuit
: An electrical circuit consisting of a known resistance and an unknown resistance such that the voltage drop across the unknown resistance can be measured to determine the unknown resistance.

APPENDIX 1. Description of Soils at the Research Sites

Table 1: Piedmont Site, Pit No 2, State Soil Series, Location: South side, center of cultivated plots[a]

Depth (cm)	Horizon	Description
0-20	AP	Brown to dark brown (10YR4/3) fine sandy loam (light); weak fine granular structure; friable; abrupt to Bt1
20-36	Bt1	Dark Brown (10YR4/4) sandy clay loam; friable to slightly firm; weak to moderate subangular blocky structure; clear wavy boundary to Bt2
36-60	Bt2	Yellowish brown (10YR5/4-5/6) fine sandy clay loam to clay loam; weak fine subangular blocky structure; common gravel; friable to slightly firm; lower Bt2 has yellowish red (5YR5/6) mottles in other parts of trench; clear wavy boundary to Bt3
60-105	Bt3	Variegated Yellowish Red (5YR4/8), Strong brown (7.5YR5/6) and light reddish brown (2.5YR6/4) clay loam; strong fine to medium subangular blocky structure; gray and brown bodies are friable to firm; red bodies are firm in upper part to friable lower part; 2.5YR colors increase in abundance with depth; lower Bt is compact and dry

a. Note: Entire soil is in older alluvium that is 5 to 7+ meters above the present stream alluvium.

Table 2: Piedmont Site, Pit 4, State Soil Series. Location: Northwest corner at edge of filter area near field edge. This site represents the soils in the grass filters.

Depth (cm)	Horizon	Description
0-23	Ap	Brown (10YR4/3) gravely fine sandy clay loam;bmoderate medium granular structure; abrupt wavy lower boundary; soil material is old alluvium.
23-38	Bt1	Strong brown (7.5YR4/6) clay loam to clay; moderate fine subangular blocky structure; slightly firm; clear lower boundary
38-70	Bt2	Strong brown (7.5YR5/6) sandy clay loam to clay loam; common fine gravel with few redder and grayer mottles in lower part; moderate fine subangular blocky structure; few fine mica plates; abrupt wavy lower boundary
70-93	BC1	Yellowish red (5YR5/6) and yellowish brown (10YR5/6) gravely sandy clay loam; gravel content estimated at 60 to 70 percent; gravel from 4 mm to 200 mm; clear wavy lower boundary
93+	BC2	Variegated strong brown (7.5YR5/6) and brown (10YR5/6) fine sandy clay loam; common fine grayer mottles ; weak fine subangular blocky structure

Table 3: Piedmont Site, Pit 5, Cecil Soil Series, Location: Between timbered slope run-off plots, represents soils on forested slope for Wake County Filter Plots 7 & 8

Depth (cm)	Horizon	Description
0-20	A1 and E	A1 and E Dark brown (10YR4/2) loamy sand in upper 5cm; grades to brown (10YR5/2) gravely fine sandy loam; very weak fine granular structure; abrupt wavy boundary
20-55	Bt1	Red (2.5YR4/6) gravely clay loam with pockets of reddish brown (5YR5/4) gravely sandy clay loam; abrupt wavy lower boundary from 48 to 67 cm; base of hillslope sediment
55-102	IIBt2[a]	Red (2.5YR5/6) clay; abundant fine mica; grades downward to a sandy clay loam at base; medium to strong fine subangular blocky-structure; firm; clear smooth lower boundary
102-125	IIBC1	Red (2.5YR4/6 to 5/6) fine sandy clay loam with common fine to medium brownish yellow to light yellowish brown (10YR6/6 to 6/4) mottles; abundant fine mica; very weak medium to coarse subangular blocky structure; friable; clear smooth lower boundary
125-145	IIBC2	Variegated red (2.5YR5/6) reddish yellow (7.5YR5/8 and 7/6) greasy fine sandy clay loam to loam; abundant very fine mica; friable; massive

a. The Roman numeral II indicates a change in materials within the soil profile. The above profile has 55 cm of hillslope sediment. Below 55 cm this profile is developing in a mica gneiss saprolite.

Table 4: Coastal Plain Site (Kinston, NC), Pit 1, Location: one-third distance downslope from the SW corner of the runoff plots; far corner from the entry point. Slope 1%

Depth (cm)	Horizon	Description
0-25	Ap	Grayish brown (10YR5/2) fine sandy loam to loamy sand; massive; friable abrupt smooth lower boundary
25-48	E	White (10YR8/2) loamy sand to fine sandy loam; single grain; slightly brittle at base; abrupt wavy intertounged boundary; abrupt to
48-78	Bt1	Light yellowish brown (10YR6/4) medium sandy clay loam with few fine browner mottles; few fine grayer mottles; friable; weak fine subangular blocky structure; texture ranges from clay loam to sandy clay loam around the pit; clear wavy boundary to Bt2
78-98	Bt2	Variegated dark yellowish brown (10YR5/6) light brownish gray (2.5Y6/2) and strong brown (7.5YR5/8) sandy loam to sandy clay loam; massive; friable; clear wavy boundary to
98-113	Bt3	Variegated as Bt2 above; sandy clay loam; common medium yellowish red and red (5YR5/8 and 2.5YR5/8) mottles; friable to slightly firm; massive

Table 5: Coastal Plain Site (Kinston, NC), Pit 5, Location: Southwest middle of filter area below plot 1 (field edge).

Depth (cm)	Horizon	Description
0-25	Ap	Grayish brown (10YR5/2) fine sandy loam to loamy sand; weak medium granular; friable; clear indistinct boundary to IIApb
25-44	IIApb[a]	Dark grayish brown (10YR4/2) fine sandy loam to loamy sand; slightly brittle; massive; clear irregular lower boundary to
44-63	IIBt1b	Light gray (10YR7/2) sandy loam to sandy clay loam; massive; friable; abrupt irregular boundary to
63-94	IIBt1b	Brownish yellow (10YR6/6) heavy sandy clay loam; common fine strong brown (7.5YR5/6) and light brownish gray (10YR6/2) mottles in lower part;gradual smooth boundary to
94-128	IIBt2b	Variegated light yellowish brown (10YR6/4) light brownish gray (10YR6/2) strong brown (7.5YR5/6) and yellowish red (5YR5/6) sandy clay loam; medium sand size

a. The Roman numeral II indicates a change in materials within the soil profile. The above profile has 55 cm of hillslope sediment. Below 55 cm this profile is developing in a mica gneiss saprolite.

Table 6: Coastal Plain Site (Kinston, NC), Pit 6, Location: Between 4 and 8 meter riparian filters.

Depth (cm)	Horizon	Description
0-12	A1	Very dark grayish brown (10YR3/2) fine sandy loam to loam; fine moderate medium granular structure; clear to E
12-25	E	Brown (10YR5/3) fine sandy loam to loamy sand with streaks of darker material; friable; clear smooth boundary to
25-36	BA	Yellowish brown (10YR5/6) heavy sandy loam to light sandy clay loam; texture grades from coarse at top to fine at bottom; friable; medium moderate subangular blocky structure; clear to
36-58	Bt1	Yellowish brown (10YR5/4) sandy clay loam to clay loam; common very pale brown (10YR7/3) mottles; firm; moderate medium subangular blocky structure; clear smooth to
58-65	Bt2	Variegated yellowish brown (10YR5/4) light brownish gray (2.5Y6/2) strong brown (7.5YR5/6 and yellowish red (5YR5/6) fine sandy clay loam; smooth and may be clay loam; massive; slightly firm; clear smooth boundary to
65-88	BC	Light brownish gray (2.5Y6/2) fine sandy clay loam; common medium to coarse yellowish red (5YR5/6) and strong brown (7.5YT5/6) mottles; redder mottles are horizontally oriented

APPENDIX 2. Summary of Daily Rainfall Data for the Coastal Plain and Piedmont Sites.

Coastal Plain

Table 1: 1990 Daily rainfall for storms monitored at the Coastal Plain site.

Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)
219	53.082	229	0.254	236	0.254
220	42.164	231	4.572	241	27.682
221	7.874	232	0.762	242	0.254
226	0.508	233	0.254	297	42.930
227	2.032	234	23.368	313	1.524
228	32.004	235	10.668	314	45.212

Table 2: 1991 Daily rainfall for storms monitored at the Coastal Plain site.

Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)
61	15.240	173	14.986	225	0.254
62	35.306	174	0.254	228	(40.894)
63	0.254	207	0.254	253	45.212
88	72.386	208	49.022	261	7.874
89	10.922	209	23.876	262	3.048
103	0.254	210	4.572	263	20.320
104	10.414	211	32.766	267	17.526
167	19.812	214	0.254	268	54.356
168	1.016	215	7.366	269	1.778
169	32.006	219	17.780	275	5.080
170	33.274	221	14.224	276	25.146
171	38.100	222	0.254	278	3.048
172	9.652	224	11.938		

Piedmont

Table 3: 1990 Daily rainfall for storms monitored at the Piedmont site.

Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)
166	3.556	209	0.254	298	28.702
167	0.508	218	7.874	299	4.318
168	3.048	219	0.508	332	4.318
170	25.908	220	5.842	333	25.396
173	7.112	221	20.320	334	0.254
174	3.302	222	4.826	337	5.334
191	8.128	223	0.254	338	0.508
192	5.334	226	41.654	341	3.556
193	1.270	228	71.634	342	2.032
194	29.718	234	0.254	349	1.270
195	2.032	235	0.508	353	5.334
198	34.544	236	0.254	354	12.192
202	2.286	237	3.048	355	20.320
203	0.254	295	7.366	356	0.254
208	1.524	296	27.178	358	0.508

Table 4: 1991 Daily rainfall for storms monitored at the Piedmont site.

Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)	Day of Year	Rainfall (mm)
2	7.366	184	5.842	239	0.508 (43.2)
3	4.318	191	1.524	262	(39.37)
4	0.254	192	11.430	267, 268	(14.732)
7	0.254	206	4.064	288	8.382
10	0.254	207	32.766	313	11.176
11	7.366	208	10.160	314	11.430
12	0.254	211	5.842	360	0.762
61	20.320	214	4.572 (8.13)	361	18.288
88	0.762	224	(19.05)	362	31.496
168	(9.65)	226	2.540 (41.91)	363	6.604
170, 171	(72.39)	232	7.366 (20.32)	364	0.254
183	27.432				

Table 5: 1992 Daily rainfall for storms monitored at the Piedmont site.

Day of Year	Rainfall (mm)
3	68.326
4	39.116
23	9.906

APPENDIX 3. Summaries of Storm Data for the Coastal Plain and Piedmont sites.

Coastal Plain

Table 1: Summary of 1990 Coastal Plain Storms

Treatment	DAY	Volume (m^3)	Sediment (g)	Average Concentration (g/L)
field-1	253	3.030	3585.1	0.91
field-2		3.638	-[a]	
grass4-1		3.037	1326.8	0.35
grass4-2		3.534	-	
grass8-1		3.283	9726.9	2.54
grass8-2		3.673	-	

a. Data missing or not measured.

Table 2: Summary of 1990 Coastal Plain Storms: Contaminant Loads.

Treatment	DAY	Vol.	Sed.	NO_3-N	NH_4-N	TKN
		(m^3)	(g)			
field-1	296	1.624	1286.9	0.3	117.7	43.7
field-2		3.677	-[a]	-	-	-
grass4-1		1.662	1718.8	1.1	101.9	63.7
grass4-2		1.590	-	-	-	-
grass8-1		5.409	1879.5	1.5	77.5	463.2
grass8-2		5.134	-	-	-	-

a. Data missing or not measured.

Table 3: Summary of 1990 Coastal Plain Storms: Contaminant Concentrations.

Treatment	DAY	Sed.	NO_3-N	NH_4-N	TKN
		(g/l)	(mg/l)		
field-1	296	0.79	0.2	50.9	33.9
field-2		-[a]	-	-	-
grass4-1		1.02	0.5	61.5	25.8
grass4-2		-	-	-	-
grass8-1		0.29	0.2	13.6	80.2
grass8-2		-	-	-	-

a. Data missing or not measured.

Table 4: Summary of 1990 Coastal Plain Storms: Runoff Measurements Only.

Treatment	DAY	Vol. (m^3)	DAY	Vol. (m^3)
field-1	219-221	3.535	241	1.715
field-2		4.141		1.965
grass4-1		2.181		1.529
grass4-2		3.663		1.802
grass8-1		3.644		1.551
grass8-2		4.267		0.199
field-1	226-234	2.903	314	0.118
field-2		3.523		0.155
grass4-1		2.985		0.206
grass4-2		3.054		0.081
grass8-1		2.791		0.097
grass8-2		3.625		0.111

Table 5: Summary of 1991 Coastal Plain Storms: Sediment Loads

Treatment	DAY	Vol. (m^3)	Sed (g)	DAY	Vol. (m^3)	Sed (g)
field-1	61,62	0.002	0.3	173	1.329	-[a]
field-2		0.003	-		1.691	-
grass4-1		0.002	0.7		0.949	-
grass4-2		0.002	-		0.897	4576.9
grass8-1		0.001	0.1		0.994	3180.9
grass8-2		0.004			0.992	1812.8
riparian-1			-		1.706	-
riparian-2					1.893	-
field-1	171	0.378	-	208,211	6.629	-
field-2		0.573	5241.0		8.948	-
grass4-1		0.186	2444.6		4.131	4900.7
grass4-2		0.129	294.1		3.331	6063.7
grass8-1		0.207	359.8		3.855	2814.9
grass8-2		0.223	524.0		4.330	4609.6
riparian-1		1.291			8.528	
riparian-2		0.106			16.607	
field-1	172	0.179	-	289	0.167	528.2
field-2		0.327	215.6		0.066	150.3
grass4-1		0.003	3.4		0.000	0.0
grass4-2		0.006	27.1		0.000	0.0
grass8-1		0.000			0.000	0.0
grass8-2		0.001			0.000	0.0
riparian-1		0.086			0.159	27.6
riparian-2		0.002			0.000	0.0

a. Data missing or not measured.

Table 6: Summary of 1991 Coastal Plain Storms: Sediment Concentrations

Treatment	DAY	Sed (g/l)	DAY	Sed (g/l)
field-1	61,62	0.09	173	-[a]
field-2				-
grass4-1		0.54		-
grass4-2				2.52
grass8-1		0.14		1.74
grass8-2				1.17
riparian-1				-
riparian-2				-
field-1	171	-	208,211	-
field-2		8.19		-
grass4-1		1.13		2.37
grass4-2		2.2		4.88
grass8-1		0.66		2.00
grass8-2		1.8		1.72
riparian-1				
riparian-2				
field-1	172	-	289	1.46
field-2		0.54		1.57
grass4-1		1.17		0.0
grass4-2		3.9		0.0
grass8-1				0.0
grass8-2				0.0
riparian-1				0.16
riparian-2				0.0

a. Data missing or not measured.

Table 7: Summary of 1991 Coastal Plain Storms: Contaminant Loads.

Treatment	Vol.	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(m^3)	(g)						
	Days 88,89							
field-1	1.437	318	0.7	0.7	1.8	0.7	0.6	1.0
field-2	2.287	-[a]	-	-	-	-	-	-
grass4-1	1.185	118	0.2	0.9	0.0	0.0	0.7	1.3
grass4-2	1.642	-	-	-	-	-	-	-
grass8-1	2.765	-	-	-	-	-	-	-
grass8-2	2.263	-	-	-	-	-	-	-
	Days 167-170							
field-1	3.965	-	-	-	-	-	-	-
field-2	3.918	48760	16.3	0.0	35.6	12.7	1.3	5.7
grass4-1	2.251	-	-	-	-	-	-	-
grass4-2	2.326	15163	12.4	0.1	23.8	11.3	1.9	14.4
grass8-1	2.454	-	-	-	-	-	-	-
grass8-2	2.673	344	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	6.404	9281	0.0	0.0	0.0	0.0	0.0	0.0
riparian-2	5.053	938	0.0	0.0	0.0	0.0	0.0	0.0
	Days 214-221							
field-1	2.578	-	-	-	-	-	-	-
field-2	2.381	13477	1.7	0.0	5.5	2.2	0.3	0.1
grass4-1	0.732	798	-	-	-	-	-	-
grass4-2	1.151	716	0.9	0.0	1.1	0.7	0.4	1.2
grass8-1	0.569	177	-	-	-	-	-	-
grass8-2	0.840	1912	2.7	0.2	3.2	1.6	1.3	5.8
riparian-1	2.652	-	-	-	-	-	-	-
riparian-2	2.527	-	-	-	-	-	-	-
	Day 263							
field-1	0.531	2496	0.8	0.0	3.4	1.3	0.2	0.1
field-2	0.395	2315	0.7	0.0	3.3	1.0	0.2	0.1

Table 7: Summary of 1991 Coastal Plain Storms: Contaminant Loads.

grass4-1	0.006	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass4-2	0.018	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass8-1	0.087	354	0.1	0.0	0.1	0.1	0.0	0.0
grass8-2	0.020	0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	0.382	1054	0.7	0.0	1.5	0.7	0.2	0.1
riparian-2	0.103	25	0.1	0.0	0.3	0.1	0.1	0.1
	Days 267-276							
field-1	1.981	2413	0.9	0.0	2.5	0.9	0.2	0.0
field-2	3.057	165	2.7	0.0	0.0	0.0	1.1	0.0
grass4-1	4.446	91038	25.0	0.0	122.8	57.2	10.0	0.0
grass4-2	5.320	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass8-1	2.883	1987	0.9	0.0	4.4	2.2	0.9	0.3
grass8-2	7.970	0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	6.921	2327	0.5	0.0	2.4	1.1	0.1	0.0
riparian-2	9.348	4447	2.3	0.0	5.1	2.2	0.8	0.0

a. Data missing or not measured.

Table 8: Summary of 1991 Coastal Plain Storms: Contaminant Concentrations.

Treat-ment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
	Days 88-89						
field-1	0.10	0.34	0.34	1.25	0.34	0.42	0.70
field-2	-[a]	-	-	-	-	-	-
grass4-1	0.11	0.44	0.76	0.0	0.0	0.59	1.10
grass4-2	-	-	-	-	-	-	-
grass8-1	-	-	-	-	-	-	-
grass8-2	-	-	-	-	-	-	-
	Days 167-170						
field-1	-	-	-	-	-	-	-
field-2	17.85	8.39	0.0	9.09	3.24	0.33	1.45
grass4-1	-	-	-	-	-	-	-
grass4-2	6.97	8.48	0.04	10.23	4.86	0.82	6.19
grass8-1	-	-	-	-	-	-	-
grass8-2	1.91	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	4.94	0.0	0.0	0.0	0.0	0.0	0.0
riparian-2	0.72	0.0	0.0	0.0	0.0	0.0	0.0
	Days 214-221						
field-1	-	-	-	-	-	-	-
field-2	4.38	0.71	0.0	2.31	0.92	0.13	0.04
grass4-1	1.08	-	-	-	-	-	-
grass4-2	2.94	0.6	0.0	0.96	0.61	0.35	1.04
grass8-1	1.35	-	-	-	-	-	-
grass8-2	2.28	3.21	0.24	3.81	1.90	1.55	6.9
riparian-1	-	-	-	-	-	-	-
riparian-2	-	-	-	-	-	-	-
	Day 263						
field-1	5.42	1.51	0.0	6.4	5.65	0.38	0.19
field-2	5.52	1.77	0.0	8.35	2.53	0.51	0.25

Table 8: Summary of 1991 Coastal Plain Storms: Contaminant Concentrations.

grass4-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass4-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass8-1	3.04	1.15	0.0	1.15	1.15	0.0	0.0
grass8-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	2.76	1.83	0.0	3.93	1.83	0.52	0.26
riparian-2	0.90	0.97	0.0	2.91	0.97	0.97	0.97
	Days 267-276						
field-1	1.21	0.45	0.0	1.26	0.45	0.10	0.0
field-2	0.06	0.88	0.0	0.0	0.0	0.33	0.0
grass4-1	20.48?	5.62	0.0	27.62	12.87	2.25	0.0
grass4-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
grass8-1	0.69	0.31	0.0	1.53	0.76	0.31	0.10
grass8-2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1	0.34	0.07	0.0	0.35	0.16	0.0	0.0
riparian-2	0.48	0.25	0.0	0.55	0.24	0.09	0.0

a. Data Missing or not measured.

Piedmont

Table 9: Summary of 1990 Piedmont Storms: Sediment Loads

Treatment	Vol. (m^3)	Sed (g)	Vol. (m^3)	Sed (g)
	Days 191-194		Day 226	
field-1	1.453	-[a]	2.618	94310.7
field-2	2.087	-	6.171	-
grass4-1	1.327	23408.9	2.825	19546.9
grass4-2	2.067	-	2.684	-
grass8-1	1.301	-	2.922	14889.0
grass8-2	2.133	-	2.990	-
riparian-1	2.465	-	3.471	-
riparian-2	1.974	-	2.962	-
	Days 198-199		Day 296	
field-1	3.329	-	0.046	0.0
field-2	4.075	-	0.268	-
grass4-1	4.310	13316.9	0.093	0.0
grass4-2	5.410	-	0.645	-
grass8-1	3.752	7735.1	0.149	0.0
grass8-2	5.050	-	0.286	-
riparian-1	6.104	-	0.169	-
riparian-2	4.926	-	0.147	-
	Days 221		Day 354-355	
field-1	0.412	390.2	0.372	-
field-2	1.206	-	0.170	-
grass4-1	0.768	1676.3	0.236	51.6
grass4-2	0.550	-	0.331	-
grass8-1	0.282	76.1	0.367	0.4
grass8-2	0.557	-	0.274	-
riparian-1	0.128	-	0.232	-
riparian-2	1.133	-	0.027	-

a. Data missing or not measured.

Table 10: Summary of 1990 Piedmont Storms: Sediment Concentrations

Treatment	Sediment (g/l)	
Day	191-194	226
field-1	-[a]	36.0
field-2	-	-
grass4-1	17.64	6.92
grass4-2	-	-
grass8-1	-	5.10
grass8-2	-	-
riparian-1	-	-
riparian-2	-	-
Day	198-199	296
field-1	-	0.0
field-2	-	-
grass4-1	3.09	0.0
grass4-2	-	-
grass8-1	2.06	0.0
grass8-2	-	-
riparian-1	-	-
riparian-2	-	-
Day	221	354-355
field-1	0.95	-
field-2	-	-
grass4-1	2.18	0.22
grass4-2	-	-
grass8-1	0.27	0
grass8-2	-	-
riparian-1	-	-
riparian-2	-	-

a. Data missing or not measured.

Table 11: Summary of 1990 Piedmont Storms: Contaminant Loads

Treatment	Vol.	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(m^3)	(g)						
	Days 228-229							
field-1	5.488	45491. 5	20.3	1.2	72.2	27.4	3.7	24.8
field-2	9.365	-[a]	-	-	-	-	-	-
grass4-1	5.822	25489. 8	11.6	0.4	43.6	24.0	2.8	9.5
grass4-2	6.535	-	-	-	-	-	-	-
grass8-1	6.558	18905. 2	10.4	0.1	34.7	20.6	2.7	12.9
grass8-2	6.179	-	-	-	-	-	-	-
riparian-1	6.862	-	-	-	-	-	-	-
riparian-2	3.859	-	-	-	-	-	-	-
	Day 333							
field-1	2.543	8057.4	1.2	1.9	11.3	3.5	1.2	6.2
field-2	2.784	-	-	-	-	-	-	-
grass4-1	3.008	2907.6	1.6	1.9	12.2	4.1	1.8	7.5
grass4-2	3.824	-	-	-	-	-	-	-
grass8-1	2.860	4616.0	1.3	1.8	10.1	3.3	2.1	9.2
grass8-2	2.744	-	-	-	-	-	-	-
riparian-1	1.187	-	-	-	-	-	-	-
riparian-2	0.889	-	-	-	-	-	-	-

a. Data missing or not measured.

Table 12: Summary of 1990 Piedmont Storms: Contaminant Concentrations

Treatment	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
	(g/l)	(mg/l)					
	Days 228-229						
field-1	8.29	3.70	0.22	13.16	4.99	0.67	4.52
field-2	-[a]	-	-	-	-	-	-
grass4-1	4.38	1.99	0.07	7.49	4.12	0.48	1.63
grass4-2	-	-	-	-	-	-	-
grass8-1	2.88	1.59	0.02	5.29	3.14	0.41	1.97
grass8-2	-	-	-	-	-	-	-
riparian-1	-	-	-	-	-	-	-
riparian-2	-	-	-	-	-	-	-
	Days 228-229						
field-1	3.17	0.47	0.75	4.44	1.38	0.47	2.44
field-2	-	-	-	-	-	-	-
grass4-1	0.97	0.53	0.63	4.06	1.36	0.6	2.49
grass4-2	-	-	-	-	-	-	-
grass8-1	1.61	0.45	0.63	3.53	1.15	0.73	3.22
grass8-2	-	-	-	-	-	-	-
riparian-1	-	-	-	-	-	-	-
riparian-2	-	-	-	-	-	-	-

a. Data missing or not measured.

Table 13: Summary of 1991 Piedmont Storms: Sediment Loads.

Treatment	Vol. (m^3)	Sed (g)	Vol. (m^3)	Sed (g)	Vol. (m^3)	Sed (g)
	Day 2		Day 73		Day 214	
field-1	0.043	5.3	0.003	0.0	0.091	340.4
field-2	0.196	-[a]	0.000	0.0	0.328	0.0
grass4-1	0.156	32.4	0.002	0.0	0.236	315.9
grass4-2	0.028	-	0.000	0.0	0.047	5.7
grass8-1	0.079	21.4	0.003	2.1	0.000	0.0
grass8-2	0.050	-	0.011	0.0	0.000	0.0
riparian-1			0.000	0.0	0.002	2.2
riparian-2			0.000	0.0	0.101	0.0
	Day 7		Day 77		Day 232	
field-1	0.539	1143	0.427	0.0	0.734	2395
field-2	1.282	-	0.779	-	0.752	3521
grass4-1	0.511	107.4	0.480	801.7	0.614	658.0
grass4-2	0.598	-	0.287	-	1.019	684.8
grass8-1	0.746	96.4	0.305	0.0	0.212	23.4
grass8-2	0.553	-	0.313	-	0.038	149.2
riparian-1	0.308	-	0.003	-	0.866	1045
riparian-2	0.082	-	0.000	-	0.705	1060
	Days 11,12		Day 169		Day 239	
field-1	0.154	14.0	0.001	4.0	1.964	1155
field-2	0.160	-	0.384	-	2.679	0.0
grass4-1	0.310	19.1	0.164	0.0	2.071	978.2
grass4-2	0.173	-	0.000	-	2.074	789.9
grass8-1	0.137	0.0	0.000	0.0	0.919	0.0
grass8-2	0.111	-	0.000	-	0.099	0.3
riparian-1	0.121	0.0	0.000	0.0	2.101	713.8
riparian-2	0.013	0.0	0.000	0.0	2.978	6980
	Day 20		Day 192		Day 288	

Table 13: Summary of 1991 Piedmont Storms: Sediment Loads.

field-1	0.141	0.0	0.216	-	0.118	201.8
field-2	0.058	-	0.533	-	0.260	0.0
grass4-1	0.185	108.4	0.406	-	0.286	0.0
grass4-2	0.112	-	0.073	-	0.014	0.0
grass8-1	0.136	10.3	0.001	-	0.011	0.0
grass8-2	0.144	-	0.010	-	0.013	0.0
riparian-1			0.048	-	0.002	0.0
riparian-2			0.001	-	0.009	0.0
	Days 61-63		Days 207,208		Day 314	
field-1	2.672	5918	2.508	11576	0.006	0.6
field-2	3.785	-	3.058	22259	0.274	0.0
grass4-1	2.994	849.8	2.355	2840	0.162	0.0
grass4-2	3.169	-	1.307	2540	0.000	0.0
grass8-1	4.296	918.1	0.483	921.6	0.000	0.0
grass8-2	3.908	-	0.352	8	0.000	0.0
riparian-1	0.147	-	5.307	4738	0.000	0.0
riparian-2	0.118	-	1.806	2314	0.000	0.0
	Day 66		Day 211		Days 361,362	
field-1	0.011	34.2	0.028	145.3	0.024	0.0
field-2	0.783	-	0.098	0.0	0.431	0.0
grass4-1	0.075	228.6	0.079	0.0	0.005	1.5
grass4-2	0.002	-	0.023	0.0	0.004	0.2
grass8-1	0.000	0.0	0.000	0.0	0.001	0.0
grass8-2	0.000	-	0.001	0.0	0.000	0.0
riparian-1	0.001	-	0.000	0.0	0.006	0.1
riparian-2	0.015	-	0.000	0.0	0.003	0.2

a. Data missing or not measured.

Table 14: Summary of 1991 Piedmont Storms: Sediment Concentrations.

Treatment	DAY	Sed (g/l)	DAY	Sed (g/l)	DAY	Sed (g/l)
field-1	2	0.12	73	0.0	214	3.74
field-2		-[a]		0.0		0.0
grass4-1		0.21		0.0		1.34
grass4-2		-		0.0		5.7
grass8-1		0.27		0.7		0.0
grass8-2		-		0.0		0.0
riparian-1				0.0		1.1
riparian-2				0.0		0.0
field-1	7	2.12	77	0.0	232	3.26
field-2		-		-		4.68
grass4-1		0.21		1.67		1.07
grass4-2		-		-		0.67
grass8-1		0.13		0.0		0.11
grass8-2		-		-		3.92
riparian-1		-		-		1.21
riparian-2		-		-		1.50
field-1	11, 12	0.09	169	4	239	0.59
field-2		-		-		0.0
grass4-1		0.06		0.0		0.47
grass4-2		-		-		0.38
grass8-1		0.0		0.0		0.0
grass8-2		-		-		0.0
riparian-1		0.0		0.0		0.34
riparian-2		0.0		0.0		2.34
field-1	20	0.0	192	-	288	1.71
field-2		-		-		0.0
grass4-1		0.58		-		0.0
grass4-2		-		-		0.0

Table 14: Summary of 1991 Piedmont Storms: Sediment Concentrations.

grass8-1		0.08		-		0.0
grass8-2		-		-		0.0
riparian-1				-		0.0
riparian-2				-		0.0
field-1	61, 63	2.21	207, 208	4.62	314	0.1
field-2		-		7.28		0.0
grass4-1		0.28		1.21		0.0
grass4-2		-		1.94		0.0
grass8-1		0.21		1.91		0.0
grass8-2		-		0.02		0.0
riparian-1		-		0.89		0.0
riparian-2		-		1.28		0.0
field-1	66	3.11	211	5.19	361- 362	0.0
field-2		-		0.0		0.0
grass4-1		3.04		0.0		0.30
grass4-2		-		0.0		0.05
grass8-1		0.0		0.0		0.0
grass8-2		-		0.0		0.0
riparian-1		-		0.0		0.02
riparian-2		-		0.0		0.67

a. Data missing or not measured.

Table 15: Summary of 1991 Piedmont Storms: Contaminant Loads

Treat ment	DAY	Vol.	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
		(m^3)	(g)						
field-1	88	1.450	5603.6	0.4	1.9	5.0	2.1	0.6	3.4
field-2		2.050	-[a]	-	-	-	-	-	-
grass4-1		2.009	1065.9	2.2	4.3	12.7	4.2	2.6	13.6
grass4-2		1.561	-	-	-	-	-	-	-
grass8-1		1.328	2550.1	0.6	2.0	2.7	1.4	1.4	7.4
grass8-2		1.236	-	-	-	-	-	-	-
riparian-1		0.802	-	-	-	-	-	-	-
riparian-2		0.264	-	-	-	-	-	-	-
field-1	170	1.847	6527.3	7.6	0.0	12.5	5.8	0.6	7.7
field-2		2.210	25209. 7	2.3	0.0	27.1	12.9	0.2	1.6
grass4-1		1.177	2300.4	4.4	0.0	5.8	3.9	1.7	5.6
grass4-2		0.930	1137.0	3.0	0.0	4.1	2.9	1.0	3.1
grass8-1		0.140	17.0	0.3	0.0	0.2	0.2	0.3	0.2
grass8-2		1.673	1306.5	3.1	0.0	2.7	2.8	2.2	3.5
riparian-1		1.456	297.6	3.0	0.0	1.9	1.5	0.8	3.5
riparian-2		0.488	0.0	0.0	0.0	0.0	0.0	0.0	0.0
field-1	183	0.833	14868	7.2	2.7	-	-	-	-
field-2		1.325	17273	10.6	4.6	-	-	-	-
grass4-1		1.121	-	-	-	-	-	-	-
grass4-2		0.447	450.4	4.9	1.2	-	-	-	-
grass8-1		0.152	44.7	0.2	0.2	-	-	-	-
grass8-2		0.443	305.0	3.1	0.7	-	-	-	-
riparian-1		0.700	826.3	3.5	1.1	-	-	-	-
riparian-2		0.454	1397.7	6.5	1.7	-	-	-	-
field-1	226- 227	2.326	661.9	0.5	0.0	0.5	0.3	0.3	0.0

Table 15: Summary of 1991 Piedmont Storms: Contaminant Loads

field-2		2.858	3834.9	2.5	0.0	4.4	2.3	0.6	3.6
grass4-1		2.193	369.6	1.9	0.1	2.3	1.5	1.3	3.0
grass4-2		1.392	169.8	1.4	0.0	1.6	1.2	0.9	1.7
grass8-1		0.386	17.6	0.5	0.0	0.6	0.7	0.6	0.6
grass8-2		0.236	0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1		1.517	813.4	1.6	0.0	2.3	1.7	1.0	0.7
riparian-2		1.768	944.7	1.5	0.1	5.0	1.9	0.7	1.8
field-1	262	2.128	3199.2	2.9	0.0	3.8	3.1	2.3	9.6
field-2		1.553	-	-	-	-	-	-	-
grass4-1		1.123	535.6	5.2	0.0	3.0	4.0	3.6	12.9
grass4-2		1.167	-	-	-	-	-	-	-
grass8-1		0.375	335.7	0.0	1.8	0.0	0.8	1.1	1.0
grass8-2		0.782	-	-	-	-	-	-	-
riparian-1		0.600	428.8	2.5	0.0	1.3	1.3	1.2	5.5
riparian-2		0.476	-	-	-	-	-	-	-

a. Data missing or not measured.

Table 16: Summary of 1991 Piedmont Storms: Contaminant Concentrations.

Treatment	DAY	Sed	NO_3-N	NH_4-N	TKN	TP	OP	CL
		(g/l)	(mg/l)					
field-1	88	3.86	0.28	1.31	3.45	1.45	0.41	2.34
field-2		-[a]	-	-	-	-	-	-
grass4-1		0.53	1.10	2.14	6.32	2.09	1.29	6.77
grass4-2		-	-	-	-	-	-	-
grass8-1		1.92	0.45	1.51	2.03	1.05	1.05	5.57
grass8-2		-	-	-	-	-	-	-
riparian-1		-	-	-	-	-	-	-
riparian-2		-	-	-	-	-	-	-
field-1	170	3.53	4.11	0.0	6.77	3.14	0.32	4.17
field-2		11.41	1.04	0.0	12.26	5.84	0.1	0.72
grass4-1		1.95	3.74	0.0	4.93	3.31	1.44	4.76
grass4-2		1.22	3.23	0.0	4.41	3.12	1.08	3.33
grass8-1		0.12	2.14	0.0	1.43	1.43	2.14	1.43
grass8-2		0.78	1.85	0.0	1.61	1.67	1.32	2.09
riparian-1		0.2	2.06	0.0	1.3	1.03	0.55	2.4
riparian-2		0.0	0.0	0.0	0.0	0.0	0.0	0.0
field-1	183	17.85	8.64	3.24	-	-	-	-
field-2		13.04	8.00	3.47	-	-	-	-
grass4-1		-	-	-	-	-	-	-
grass4-2		1.01	10.96	2.68	-	-	-	-
grass8-1		0.29	1.32	1.32	-	-	-	-
grass8-2		0.69	7.00	1.58	-	-	-	-
riparian-1		1.18	5.0	1.57	-	-	-	-
riparian-2		3.08	14.32	3.74	-	-	-	-

Table 16: Summary of 1991 Piedmont Storms: Contaminant Concentrations.

field-1	226- 227	0.28	0.21	0.0	0.21	0.13	0.13	0.0
field-2		1.34	0.87	0.0	1.54	0.8	0.21	1.26
grass4-1		0.17	0.87	0.05	1.05	0.68	0.59	1.37
grass4-2		0.12	1.01	0.0	1.15	0.86	0.65	1.22
grass8-1		0.05	1.3	0.0	1.55	1.81	1.55	1.55
grass8-2		0.0	0.0	0.0	0.0	0.0	0.0	0.0
riparian-1		0.54	1.05	0.0	1.52	1.12	0.67	1.46
riparian-2		0.53	0.85	0.06	2.83	1.07	0.40	1.02
field-1	262	1.50	1.36	0.0	1.79	1.46	1.08	4.51
field-2		-	-	-	-	-	-	-
grass4-1		0.48	4.63	0.0	2.67	3.56	3.21	11.49
grass4-2		-	-	-	-	-	-	-
grass8-1		0.90	0.0	4.8	0.0	2.13	2.93	2.67
grass8-2		-	-	-	-	-	-	-
riparian-1		0.71	4.17	0.0	2.17	2.17	2.0	9.17
riparian-2		-	-	-	-	-	-	-

a. Data missing or not measured.

Table 17: Summary of 1992 Piedmont Storms: Sediment Loads.

Treatment	DAY	Vol. (m^3)	Sed (g)
field-1	3,4	0.543	1338.7
field-2		0.998	0.0
grass4-1		0.049	317.4
grass4-2		0.150	32.0
grass8-1		0.029	1.4
grass8-2		0.093	0.0
riparian-1		0.535	3689.6
riparian-2		0.106	45.5
field-1	23	0.057	39.6
field-2		0.031	0.0
grass4-1		0.102	12.8
grass4-2		0.023	0.0
grass8-1		0.009	0.0
grass8-2		0.065	0.0
riparian-1		0.071	37.5
riparian-2		0.003	0.0

Table 18: Summary of 1992 Piedmont Storms: Sediment Concentrations.

Treatment	DAY	Sed (g/l)
field-1	3,4	2.47
field-2		0.0
grass4-1		6.48
grass4-2		0.21
grass8-1		0.05
grass8-2		0.0
riparian-1		6.90
riparian-2		0.43
field-1	23	0.69
field-2		0.0
grass4-1		0.13
grass4-2		0.0
grass8-1		0.0
grass8-2		0.0
riparian-1		0.53
riparian-2		0.0