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ALLEY CROPPING AND TERRACING EFFECTS ON SURFACE RUNOFF, SOIL EROSION AND LOSS OF PLANT NUTRIENTS

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*Alley cropping was tested as an alternative to underground pipe-outlet parallel terraces for soil and water conservation in Cullman, AL on Hartsells sandy loam soil, 6.5% slope. Alley cropping treatments with hedgerows of mimosa (*Albizia julibrissin*), blackberry (*Rubus ursinus*) and switchgrass (*Panicum virgatum*), were compared to underground pipe-outlet parallel terraces and a no-barrier control in a sweet corn (*Zea mays*) - rye (*Secale cereale*) - cowpea (*Vigna unguiculata *(L) WALP) - rye - sweet corn rotation from August 2002 to July 2004. One replicate consisted of plots measuring 0.05ha, each of which was instrumented for measuring and sampling surface runoff and sediment with a 0.18-m HS flume and an ISCO automatic runoff sampler, respectively. Hedgerows and terraces were established in April-May 2002. Mimosa was pruned in July 2003, April and July 2004, and prunings left on the field. Water runoff was analyzed for sediment, N, P, and K concentrations and total losses. Blackberry, switchgrass and terrace treatments reduced water runoff losses by 45, 62, and 74%, respectively. Switchgrass and terraces reduced sediment yield by 76 and 84%, respectively. Total losses of NH_4-N and K were also significantly reduced in switchgrass and terrace treatments. The effectiveness of vegetative barriers in reducing surface runoff, sediment concentration and yield, plant nutrient concentrations and losses progressively improved over time. Switchgrass hedges were more effective than blackberry and mimosa hedgerows in reducing runoff, sediments and plant nutrients due to their rapid establishment and tillering to fill the row.*

INTRODUCTION

Soil erosion is a major concern in agricultural production. Almost 2 billion tons of soil are eroded from agricultural lands in the U.S. each year (NRCS, 2001), affecting soil productivity and water quality. Water runoff from cultivated fields can carry sediment and plant nutrients that are detrimental to the environment. In Alabama and elsewhere in the U.S., agricultural nonpoint source pollution is a leading cause of surface water contamination (Donner et al., 2004; Goolsby et al., 2000; USEPA, 2002). The effectiveness of terraces as soil conservation practice was reported in the U.S.A. (Alberts et al., 1978; Mills et al., 1992) and elsewhere (Chow et al., 1999; Huang et al., 2003). Terraces are rapidly built, but they require high capital investment for installation, especially for those with underground pipes. The use of hedgerows of closely-planted leguminous trees, such as leucaena (*Leucaena leucocephala*), or vegetative barriers of perennial grasses such as elephant grass (*Pennisetum purpureum*), switchgrass (*Panicum virgatum*) and vetiver (*Vetiveria zizanioides*) to form living terraces were tested and found efficient in reducing soil erosion (Dabney et al., 1995; Dabney et al., 1999; Lal, 1989). The grass strips provide many of the same benefits as terraces built with heavy construction equipment and are much cheaper to implement (Aase and Pikul, 1995).

Mimosa (*Albizia julibrissin*) was selected as a tree hedgerow in this experiment because of its resemblance to leucaena, widely promoted throughout the tropics for alley cropping and soil conservation. Mimosa was previously tested and found suitable for plant nutrient cycling in alley cropping in Georgia (Kang, 2004; Matta-Machado and Jordan, 1995).

In temperate alley cropping, trees for timber, fruit or nuts are widely spaced, slightly pruned and row crops are integrated mostly as a cash crop for maximization of field benefits in installation years while farmers wait for trees to mature (Garrett and Harper, 1998). Blackberry (*Rubus ursinus*) is a bramble grown in relatively wide row spacing with a cover of sod. Blackberry bears fruit from the third year after planting. It produces multiple stems forming a solid hedgerow and could be a suitable candidate crop for integration alley cropping systems in temperate zones. Previous studies have reported the effectiveness of blackberry in reducing soil erosion (Coleman et al., 1990; Dabney et al., 1999). In the U.S., there has been a revival of interest in grass hedges for soil conservation and switchgrass was successfully tested for erosion control (Dabney et al., 1995). Switchgrass grows fast and requires less input for its establishment.

Little information is available on the effect of alley cropping practice on surface water quality and no comparison has been made with terracing in the southeastern U.S. This research was carried out to study the effectiveness of alley cropping of mimosa, blackberry and switchgrass hedges in reducing surface runoff, sediment and plant nutrient losses compared to underground pipe-outlet parallel terraces and a no barrier control.

MATERIALS AND METHODS

The experiment was conducted at the North Alabama Horticulture Research Center, Cullman County, AL (34°18' N, 86°85' W) at an elevation of 244 m above mean sea level with annual precipitation averaging 1350 mm (Mesonet, 2004). The soil is a Hartsells sandy loam (fine-loamy, siliceous, thermic Typic Hapludult). The experiment started in August 2001 with field identification, land leveling and plot establishment.

The experimental design was a randomized complete block with four replicates. One replicate, dedicated to monitoring of soil erosion and runoff, consisted of five plots, one for each treatment, measuring 30.5 m along the slope and 15.2 m across a slope of 6.5 %. Alley cropping and grass hedge plots contained two barriers spaced 15.2 m apart (Figure 1), while the underground pipe-outlet parallel terrace plot had two terraces spaced at 15.2 m apart, one in the middle and another at the bottom of the plot. Each plot has the same type of barrier on top of the plot as shown in the Figure. Three more replicates had individual plots of 18 m x 9 m allowing precise, statistically verifiable, estimates of the effects of these conservation practices on crop yield.

The treatments consisted of three soil conservation barriers and a control which are: (a) a no barrier control, (b) underground pipe-outlet parallel terraces, (c) tree hedgerow alley cropping of mimosa, (d) fruit crop alley cropping of blackberry, and (e) grass barriers of switchgrass alley cropping. A no-barrier treatment was a control for determining the effectiveness of each practice at reducing erosion. The same cropping practices were used as in other treatments, except that the main crop covered the entire plot. Terraces were built with heavy machinery and spaced at 15.2 m intervals across the slope. Underground pipes connected to the inlet risers were placed in the plot to collect overflow runoff. Mimosa, blackberry and switchgrass hedges were planted in single rows spaced 15.2 m apart on contours. The location and spacing of the contours coincided with terrace locations.

Plots for runoff and sediment sampling were bordered with 30 cm high metal sheet to prevent surface runoff flow into or out of the plots. The metal borders were buried about 10 to 15 cm below the ground surface. At the lower side of the plots, V-shaped borders directed surface runoff to 0.18-m HS-flumes. Earthen ridges on lateral sides to facilitate field machine operations replaced metal sheets later.

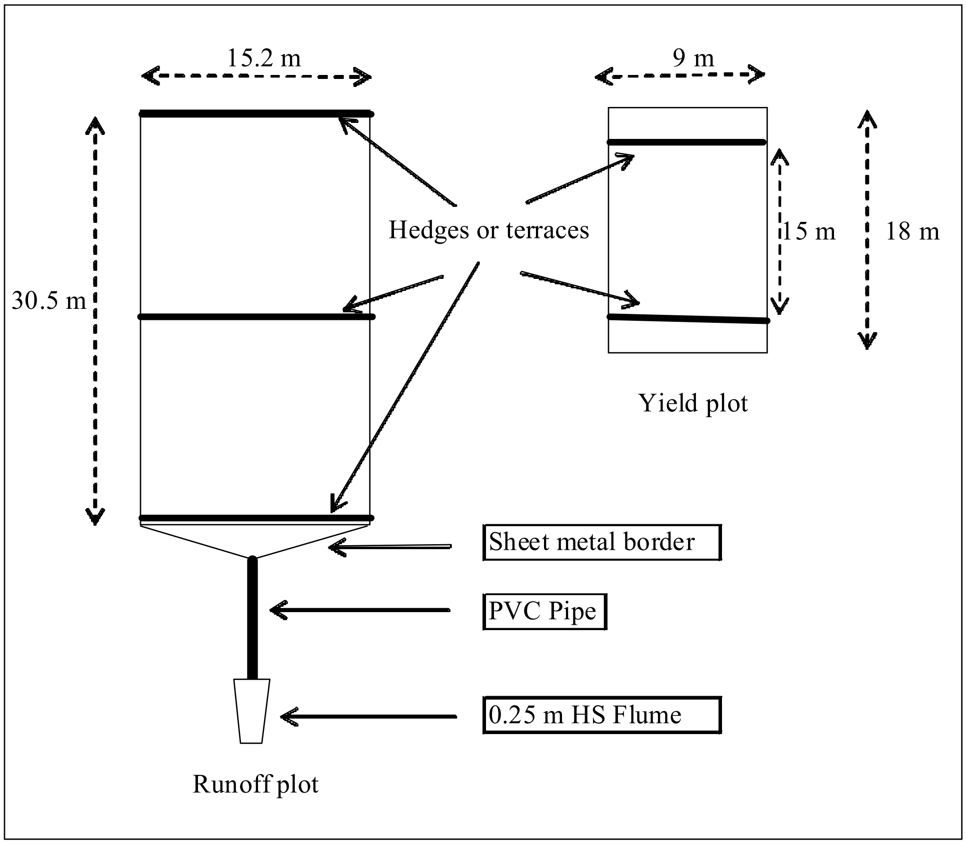

Figure 1. Layout of study plots.

The HS-flume was equipped with a stilling well housing a float-pulley-counterweight system to measure flow depth through the flume. The pulley was connected to a 100 kΩ potentiometer to detect rotational positions of the pulley according to the water depth changes in the flume. A CR10X datalogger (Campbell CSI, Logan, Utah) was connected to the potentiometer and recorded the water level in the flume by measuring the rotational positions of the potentiometer. Each complete turn of the potentiometer represented 0.3 m of water level in the flume. The flow depth was later used to calculate flow rate with a depth-flow rate calibration table. Once the runoff passed through the flume, it was channeled through a small trapezoidal shape basin where a tube connected to an ISCO 3700 (Isco, Inc., Lincoln, Nebraska) automatic runoff sampler sampled 20 mL every 2 minutes during runoff events. Two rain gages (1/100th in and 1/10th mm sensors) were installed and connected to the datalogger. The datalogger was programmed to record 15 minutes interval rainfall, 2 minutes runoff and hourly ambient temperatures during runoff generating rainfall events. Data were regularly downloaded using a Palm m105 series handheld PDA (Palm, Inc. Santa Clara, CA). Figure 2 shows field photos of the treatments and Figure 3 shows a 0.18-m HS flume and ISCO automatic runoff sampler installed at the field to measure surface runoff and to collect runoff samples.

Fig. 2-a. Mimosa (*Albizia julibrissin*) alley cropping

Fig. 2-b. Blackberry (*Rubus ursinus*) alley cropping.

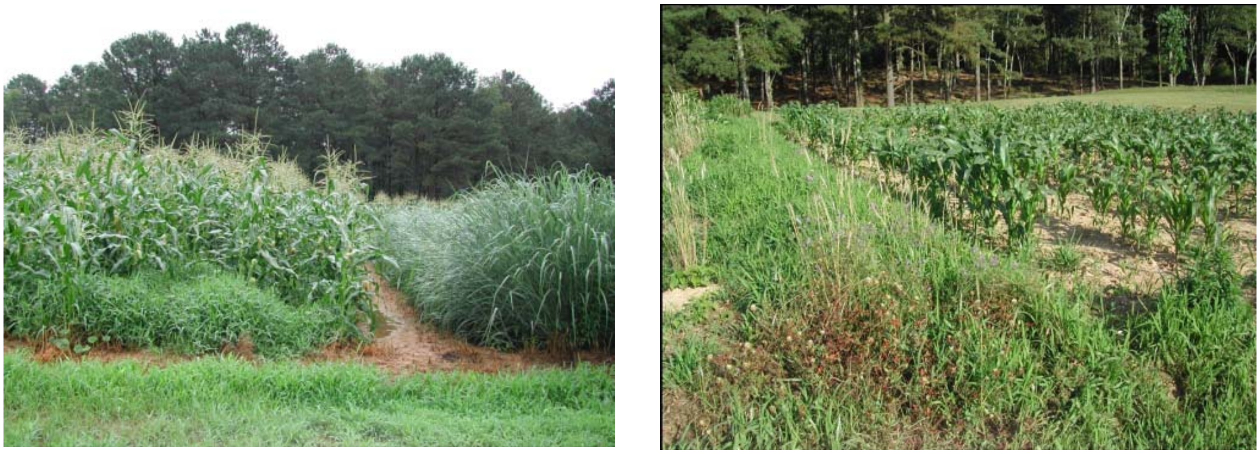

Fig. 2-c. Switchgrass (*Panicum virgatum*) alley cropping.

Fig. 2-d. Underground pipe-outlet parallel terraces.

Figure 2. Field photos of the experimental treatments: a) alley cropping with mimosa tree hedgerows, b) fruit crop alley cropping with blackberry hedgerows, c) alley cropping with grass barriers of switchgrass, d) underground pipe-outlet parallel terraces.

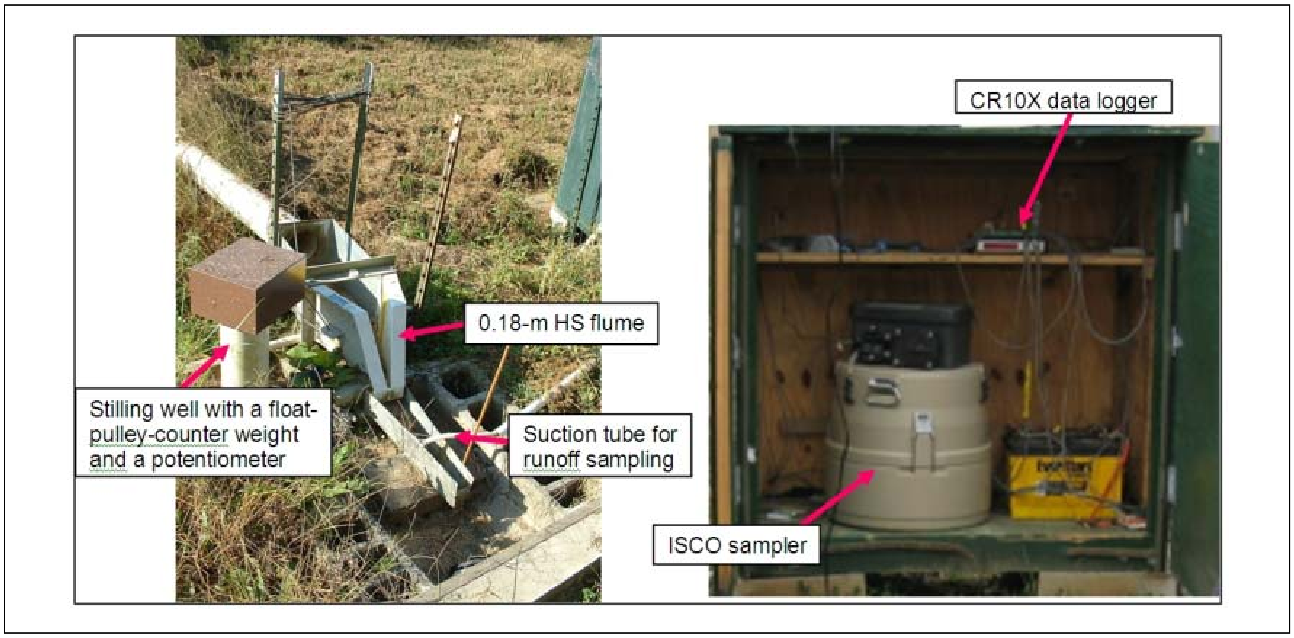

Figure 3. A 0.18-m HS flume, rain gages and ISCO automatic runoff sampler installed at the study site.

Mimosa, blackberry, and switchgrass hedgerows and terraces were established in April and May 2002, prior to corn planting. Switchgrass established easily and with about 100% emergence. For mimosa, although 95 % of seeds emerged, many plants suffered from weed competition, and died. We replanted the empty spots with plants raised in a greenhouse in November 2002 and March 2003. Mimosa was pruned three times at 50 cm height, on 10 July 2003, 16 April and 27 July 2004. Switchgrass was pruned once on 17 Mar. 2004. Prunings were left along hedgerows. The commercial blackberry (Chickasaw) cuttings were rooted upside down and less than 50% developed new shoots. They were replaced with variety Kiowa from tissue culture on 15 Nov. 2002. Blackberries were fertilized with 35 kg N and 45 kg Ca ha^{-1} as calcium nitrate in 2002; and 70 kg N and 90 kg Ca ha^{-1} during 2003 and 2004 cropping years. Blackberries were pruned (headed) at 1.50 m above ground after each harvest to allow them to better support the weight of the fruit and foliage. Glyphosate was applied to control weeds next to blackberry at 0.9 kg a.i. ha^{-1}.

Three and half Mg ha^{-1} of calcitic limestone were applied on October 2001 and 2.24 Mg ha^{-1} in subsequent years (2002 and 2003). In all seasons, conventionally tilled corn was followed by a winter cover crop of no-till cereal rye (*Secale cereale*). Soil preparation included chisel plowing with a chisel plow 7 shanks, and disking with a disk harrow attached to a John Deere 4240 tractor. Ninety kg N, 60 kg P_2O_5 and 60 kg K_2O (450 kg ha^{-1} NPK 13-13-13 and 100 kg ha^{-1} ammonium nitrate) were applied one day before planting. Three weeks after planting, 90 kg N (280 kg ha^{-1} ammonium nitrate) were broadcast as sidedress with a cyclone spreader. Sweet corn (Silver Queen) was planted spaced at 102 cm x 18 cm (54,447 plants ha^{-1}) on 4 June 2002, 23 Apr. 2003 and 20 Apr. 2004, respectively. Because of a planter failure in 2002 cropping season, an excess of seeds were planted and corn was thinned by hand two weeks after planting. In 2003, prior to conventional tillage, no-till corn was planted after mowing grass and application of halosulfuron-methyl and atrazine at 0.05 and 1.7 kg a.i. ha^{-1}. Corn failed to emerge properly and was replaced by cowpea var. Pichworth Pinkeye Purple Hull on 26 June 2003 following chisel plowing. Weed control consisted of applying S-metolachlor and imazethapyr at 2 and 0.02 kg a.i. ha^{-1} in 2002, S-metolachlor at 2 kg a.i. ha^{-1} during 2003 and Alachlor (Lasso) and atrazine at 2.25 and 3.8 kg a.i. ha^{-1}, respectively in 2004. In 2004, additional weed control was done by cultivation at N sidedress application. Esfenvalerate (Asana) and bifenthrin (Capture) were applied on 25 July and 16 Aug. 2003 at 0.05 kg and 0.2 kg a.i. ha^{-1}, respectively, to control cowpea curculio (*Chalcodermus aeneus*) on cowpea. Carbaryl was applied on 24 June 2004 to control Japanese beetle (*Popillia japonica* Newman) at 1 kg $a.i.ha^{-1}$.

Storm events producing measurable runoff in any plot were recorded for further investigations for runoff characteristics, sediment and plant nutrient concentrations and mass losses. Three annual periods were defined for runoff, sediment and plant nutrient monitoring, corresponding to 2002 as establishment year, from 25 July to 31 Dec. 2002, entire 2003 year and 2004, from 1 Jan. to 28 July. Runoff characteristics investigated were depth and runoff as percentage of rainfall. Runoff depth in mm is the amount of rainwater removed from the plot and recorded by the CR10X datalogger. Runoff percentage of rainfall is the ratio of runoff by rainfall amount multiplied by 100.

Water runoff samples were collected the next day after each rainfall event producing runoff, and frozen for transport to the laboratory at Auburn University. Fifty mL of runoff water samples were filtered through a 0.45 mm filter prior to chemical analyses. Nitrate-Nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) were determined in filtered runoff samples by standard colorimetric procedures on a microplate autoanalyzer (Sims, 1995). Dissolved P and K were determined in filtered runoff samples by ICAP. Sediment from 50 mL of runoff water was collected on a pre-weighed 0.45 mm filter. The filter and sediment were dried to a constant weight and then weighed to determine suspended solids. The filter and sediment were ashed in a muffle furnace at 450°C overnight followed by addition of 10 mL 1*N* HNO_3 and heating at 150°C until dryness, and addition of 1*N* HCl with further heating at 150°C prior to ICAP analyses for P and K (Hue and Evans, 1986). A sediment yield or mass loss of plant nutrients in kg ha^{-1} for a rainfall event is the product of concentration by runoff volume. A weighted concentration of sediment or plant nutrient is the ratio of total sediment or plant nutrient by runoff volume on a specific plot for a specific year. Annual total losses of plant nutrient are the sum of dissolved and sediment losses for a specific year for a particular plant nutrient. Average total losses were calculated for 2003 and 2004 years for a more equal comparison due to missing data in blackberry during 2002.

Regression equations of the form $\log(y) = a + bx$ were developed using SAS package (SAS, 2001) to describe the relationship between runoff depth, plant nutrient/sediment concentrations or losses and yield (y) vs. rainfall depth, rainfall intensity or runoff amount. The best fit was obtained using rainfall as the independent variable vs. runoff amount or rainfall intensity. The intercept, a, was set to zero and comparison was made between slopes, b. Due to sampling and recording failures in the blackberry plot in 2002, only 11 observations in 2003 and 4 observations in 2004 were subjected to regression analysis. Treatments were compared using the regression equation in the general linear model (Proc GLM) with rainfall depth as independent variable.

RESULTS

Rainfall and runoff

Rainfall was monitored from August 2002 to July 2004. Data were obtained from the experiment station's daily reading rainfall gauge located 500 m from the study site. January, March, April and June 2003 and 2004 were less rainy than the 7-year average recorded at Cullman Horticultural Research Center (Figure 4). Twenty-nine rainfall events generating runoff occurred during this time period among which 5 were recorded from August to December 2002, 17 during

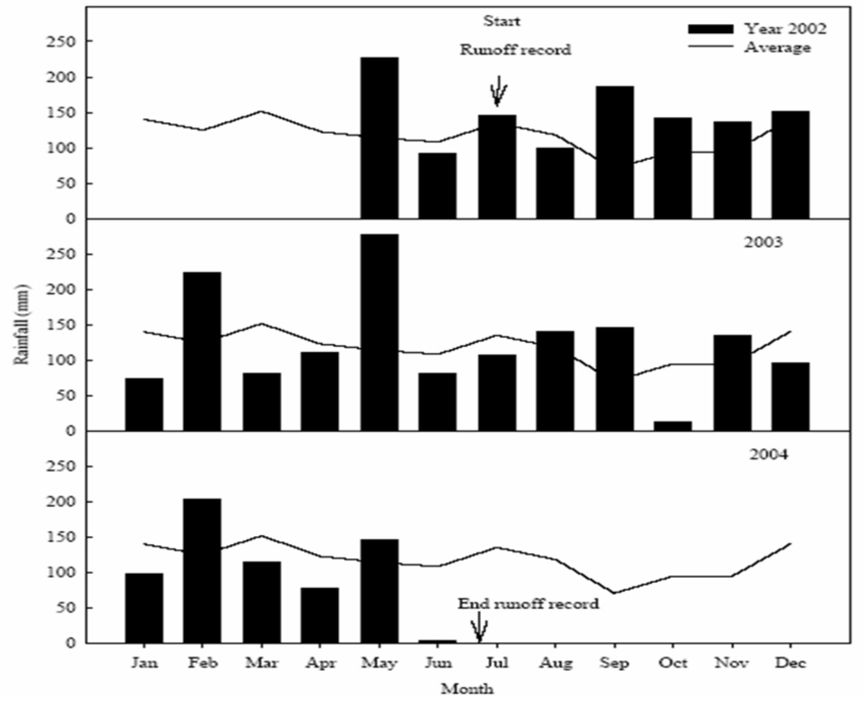

Figure 4. Long term annual average rainfall (7 years) at Cullman, Alabama, U.S.A. and observed rainfall data (2002 – 2004) at the study site.

2003 from January to August and 7 from January to July 2004 (Figure 5). Rainfall events generating runoff in 2002, 2003 and 2004 were 16, 63 and 21% of total for the study period.

Surface water runoff losses were significantly (p = 0.01) affected by treatment and were highest in the control (Table 1). Blackberry, switchgrass and terraces treatments reduced surface water runoff by 45, 62, and 74%, respectively. The terrace treatment had the lowest runoff losses. Blackberry and switchgrass treatments were not statistically different at the 0.05 probability level. Runoff data for the blackberry plot were not recorded in 2002 due to a recording system failure.

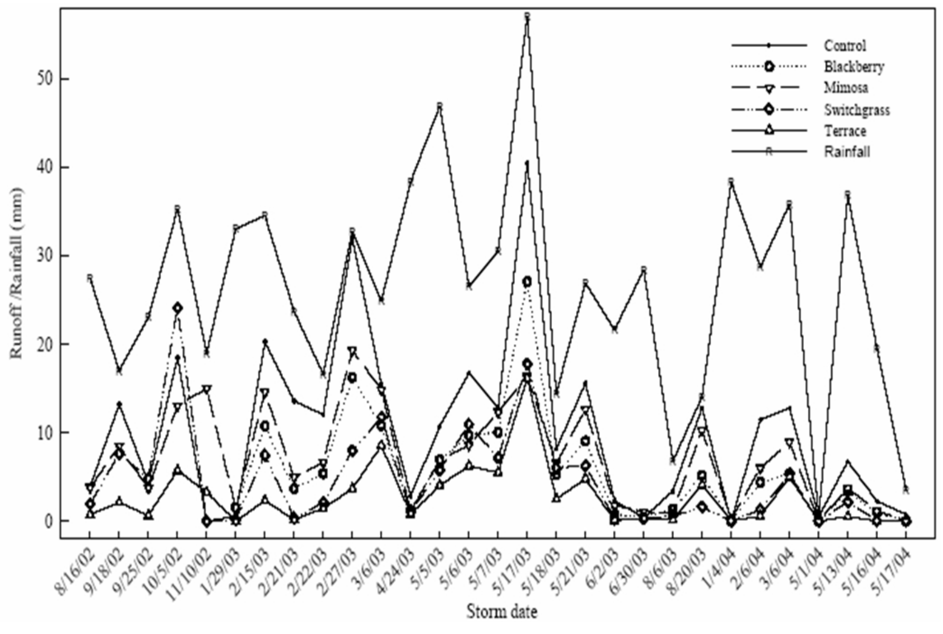

Figure 5. Rainfall events and associated runoff data from the treatments during the study period.

Runoff as percent of rainfall was highest in the control with 37% followed by mimosa, blackberry, switchgrass and terrace treatments (Table 1).

Sediment concentrations were significantly affected by the treatments (p = 0.001) and were highest in the control (Table 2). Switchgrass, terraces and blackberry treatments reduced sediment concentrations by 36, 52, and 26%, respectively. Annual weighted sediment concentrations were highest with mimosa hedgerows in 2002 followed by terraces, the control and switchgrass hedges (Table 2). In 2003 and 2004, sediment concentrations were highest in the control plot followed by plots with mimosa hedgerows, blackberry hedges, switchgrass and terraces. Sediment yield was highest in the control plot, and was significantly affected by treatments (Table 2). Terraces and switchgrass treatments reduced sediment yield by 84 and 56%.

Table 1. Rainfall generating runoff during the study period and runoff characteristics as affected by alley cropping and terracing.

		Treatment†					Treatment				
Period		C	B	M	S	T	C	B	M	S	T
	Rainfall	Runoff					Runoff as a percent of rainfall				
	mm	mm					%				
Aug. – Dec. 02	122	40	n/a	44	38	12	33	n/a	39	28	10
Jan. – Dec. 03	491	220	125	140	87	61	46	25	30	17	12
Jan. – July 04	163	34	14	20	9	6	28	6	9	4	3
Mean‡	327	127^{a}	70^{bc}	80^{b}	48^{cd}	33^{d}	37	15	20	10	7
S.E.		0.009	0.007	0.008	0.007	0.006					
P > t		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001					
Adj.R^2		80	80	77	75	71					

† C = control, B = blackberry, M = mimosa, S = switchgrass, T = terraces.

‡ Weighted mean calculated for 2003 and 2004 data only (15 observations). Means in same row followed by the same letter are not statistically different at the 0.05 probability level according to Tukey test.

Table 2. Weighted sediment concentration and annual sediment yield as affected by alley cropping and terracing.

		Sediment Concentration					Sediment Yield				
Parameter	Year‡	C†	B	M	S	T	C	B	M	S	T
		mg L^{-1}					kg ha^{-1}				
Soil Loss	2002	197	n/a	296	163	234	76.6	n/a	85.0	55.8	22.2
	2003	306	261	278	192	168	417.4	216.7	235.4	119.5	80.9
	2004	862	177	290	157	31	95.5	8.3	15.4	3.8	0.18
Mean§		348^{a}	257^{bc}	278^{ac}	191^{bc}	166^{bc}	513^{a}	225^{a}	251^{a}	123^{b}	81^{b}
Slope		0.012	0.009	0.010	0.007	0.006	0.085	0.068	0.072	0.055	0.048
S.E.		0.004	0.001	0.003	0.001	0.001	0.013	0.011	0.012	0.010	0.009
P > t		0.008	<0.0001	0.007	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Adj.R^2		37	80	37	80	74	74	70	70	66	64

† Treatment: C = control, B = blackberry, M = mimosa, S = switchgrass, T = terrace.

‡ Year: 2002: From 25 July to 31 Dec., corn harvested on 15 Aug., stubbles left in the field until 28 Oct. at rye planting. 2003: 1 Jan. 2003 to 31 Dec. Corn planted on 20 Apr. and 20 May, replaced on 26 Jun. by cowpea. 2004: 1 Jan. to 6 July. Corn planted on 20 Apr. and harvested on 6 July.

§ Weighted mean calculated for 2003 and 2004 data only (15 observations). Means in same row followed by the same letter are not statistically different at 5% according to Tukey test.

Nitrogen

Treatments did not significantly affect NH_4-N concentrations in water runoff at the 0.05 probability level (Table 3). Concentrations of NO_3-N in water runoff were significantly affected by treatments and were highest in the control (Table 3). Switchgrass treatment reduced NO_3-N concentration by 68 %. Mimosa treatment ranked highest for NO_3-N concentrations in 2002, whereas the control ranked highest in 2003 and 2004.

Switchgrass and terrace treatments significantly reduced NH_4-N losses by 64 and 50%, respectively (Table 3). Losses of NO_3-N were highest in the control and were significantly affected by treatments at the 0.001 probability level (Table 3). Blackberry, switchgrass and terrace treatments significantly reduced NO_3-N losses by 77, 86 and 84%, respectively.

Phosphorus

Dissolved P concentrations were significantly affected by treatments at the 0.001 probability level (Table 4). Mimosa and switchgrass treatments decreased dissolved P concentration by 28%, while the decrease in terrace treatment was 9%. Highest annual dissolved P concentrations in 2002 and 2004 were observed in mimosa treatment, whereas blackberry treatment had the highest concentration in 2003. Sediment P concentrations were not significantly affected by treatments (Table 5). Highest concentrations of P in sediment were found in mimosa treatment in 2002, in the control and terrace treatments in 2003 and in blackberry treatment in 2004. Dissolved P losses

Table 3. Weighted concentrations and total losses of NH_4 and NO_3 as affected by alley cropping and terracing.

		Concentrations						Losses				
Parameter	Year†	Control	Blackberry	Mimosa	Switchgrass	Terrace		Control	Blackberry	Mimosa	Switchgrass	Terrace
		mg L^{-1}						kg ha^{-1}				
NH_4-N	2002	0.10	n/a	0.35	1.06	0.22		0.1	n/a	0.10	0.36	0.02
	2003	0.79	2.85	1.22	0.65	1.15		1.07	2.37	1.03	0.40	0.55
	2004	0.32	0.23	1.37	0.00	0.06		0.04	0.01	0.07	0.00	0.00
Mean§		0.75^{a}	2.71^{a}	1.23^{a}	0.62^{a}	1.14^{a}		1.11^{a}	2.38^{a}	1.11^{a}	0.40^{bc}	0.55^{bc}
Slope		0.019	0.030	0.027	0.014	0.025		0.006	0.008	0.005	0.004	0.004
S.E.		0.004	0.004	0.005	0.003	0.007		0.001	0.002	0.001	0.001	0.000
P > t		0.002	<0.0001	<0.0001	0.000	0.002		<0.0001	0.00	<0.0001	<0.0001	<0.0001
Adj.R^2		61	75	66	64	47		78.0	62.0	76.0	78.0	85.0
NO_3-N	2002	0.48	n/a	1.14	0.71	0.91		0.19	n/a	0.33	0.24	0.09
	2003	2.46	0.99	2.43	0.84	1.19		3.35	0.82	2.06	0.52	0.57
	2004	3.42	1.11	2.54	0.07	2.17		0.38	0.05	0.13	0.00	0.01
Mean§		2.53^{a}	1.00^{ab}	2.44^{a}	0.81^{b}	1.20^{ab}		3.72^{a}	0.87^{bc}	2.20^{ac}	0.53^{bc}	0.59^{bc}
Slope		0.036	0.025	0.035	0.018	0.029		0.011	0.005	0.007	0.004	0.004
S.E.		0.008	0.006	0.008	0.004	0.006		0.002	0.001	0.002	0.001	0.001
P > t		0.0001	0.001	0.001	0.001	0.0001		<0.0001	<0.0001	0.002	<0.0001	<0.0001
Adj.R^2		58	51	52	52	58		81	85	60	82	86

† Treatment: C = control, B = blackberry, M = mimosa, S = switchgrass, T = terrace.

‡ Year: 2002: From 25 July to 31 Dec., corn harvested on 15 Aug., stubbles left in the field until 28 Oct. at rye planting. 2003: 1 Jan. 2003 to 31 Dec. Corn planted on 20 Apr. and 20 May, replaced on 26 Jun. by cowpea. 2004: 1 Jan. to 6 July. Corn planted on 20 Apr. and harvested on 6 July.

§ Weighted means and total losses (based on 15 observations in 2003 and 2004). Means in same row followed by the same letter are not statistically different at the 0.05 probability level according to Tukey test.

Table 4. Weighted concentrations of dissolved and sediment P and annual P losses in runoff as affected by alley cropping and terracing.

		Concentrations					Losses				
Parameter	Year†	Control	Blackberry	Mimosa	Switchgrass	Terrace	Control	Blackberry	Mimosa	Switchgrass	Terrace
		mg L^{-1}					kg ha^{-1}				
Dissolved P	2002	0.56	n/a	1.18	0.49	0.92	0.22	n/a	0.34	0.17	0.09
	2003	1.35	2.77	0.93	0.97	1.18	1.84	2.30	0.79	0.60	0.57
	2004	0.52	0.39	0.93	0.32	0.88	0.06	0.02	0.05	0.01	0.01
Mean‡		1.29^{a}	2.64^{b}	0.93^{b}	0.94^{b}	1.18^{b}	1.90^{a}	2.31^{a}	0.84^{a}	0.61^{a}	0.57^{a}
Slope		0.036	0.034	0.028	0.022	0.022	0.007	0.008	0.005	0.004	0.004
S.E.		0.012	0.003	0.006	0.003	0.004	0.001	0.002	0.001	0.001	0.0001
P > t		0.008	<0.0001	0.000	<0.0001	<0.0001	<0.0001	0.00	<0.0001	<0.0001	<0.0001
Adj.R^{2}		37	90	62	76	71	83	65	86	83	90
Sediment P	2002	0.64	n/a	0.86	0.63	0.72	0.25	n/a	0.25	0.21	0.07
	2003	0.83	0.63	0.49	0.57	0.66	1.13	0.52	0.41	0.36	0.32
	2004	0.39	0.73	0.2	0.01	0.01	0.04	0.03	0.01	0.00	0.00
Mean‡		0.80^{a}	0.64^{a}	0.47^{a}	0.55^{a}	0.65^{a}	1.18^{ac}	0.56^{ac}	0.42^{ac}	0.36^{ac}	0.32^{bc}
Slope		0.022	0.017	0.017	0.016	0.020	0.006	0.004	0.004	0.004	0.004
S.E.		0.007	0.004	0.005	0.004	0.005	0.0009	0.0004	0.0004	0.0005	0.0004
P > t		0.005	0.001	0.003	0.0004	0.001	0.0003	<0.0001	<0.0001	0.0002	<0.0001
Adj.R^{2}		40	53	44	58	53	80	90	90	86	91

† Year: 2002: From 25 July to 31 Dec., corn harvested on 15 Aug., stubbles left in the field until 28 Oct. at rye planting. 2003: 1 Jan. 2003 to 31 Dec. Corn planted on 20 Apr. and 20 May, replaced on 26 Jun. by cowpea. 2004: 1 Jan. to 6 July. Corn planted on 20 Apr. and harvested on 6 July.

‡ Weighted mean calculated from 15 observations in 2003 and 2004 data. Means in same row followed by the same letter are not statistically different at the 0.05 probability level according to Tukey test.

were not significantly affected by treatments at the 0.05 probability level (Table 4). Losses of P in sediment were highest in the control and were affected by treatment at the 0.001 probability level (Table 4). Terrace plots had 73% less P losses compared to the control. Mimosa treatment and the control had highest sediment P losses in 2002, whereas the control ranked highest in 2003 and 2004.

Potassium

Dissolved and sediment K concentrations were not significantly affected by treatments at the 0.05 probability level (Table 5). Annual concentrations of dissolved K were highest in terraced plot in 2002 and 2004, and in plot with blackberry hedgerows in 2003. Highest concentrations of dissolved K were recorded in 2002 and decreased over time. Sediment K concentrations presented the same pattern as for dissolved K over time. They were highest in plot with switchgrass hedges during 2002, in the control plot during 2003 and in plot with mimosa treatment during 2004. Switchgrass and terrace treatments significantly reduced dissolved and sediment K losses compared to the control (Table 5).

Total losses of plant nutrients

Total losses of plant nutrients is the sum of dissolved and sediment losses. Treatment effect was not significant for total P losses at the 0.05 probability level (Table 6). Total K losses were highest in blackberry treatment and the control and were significantly affected by treatments at the 0.01 probability level (Table 6). Terrace and switchgrass treatments reduced total K losses by more than 60%.

Table 5. Weighted concentrations of dissolved and sediment K and annual losses as affected by alley cropping and terracing.

		Concentrations					Losses				
Parameter	Year†	Control	Blackberry	Mimosa	Switchgrass	Terrace	Control	Blackberry	Mimosa	Switchgrass	Terrace
		mg L^{-1}					kg ha^{-1}				
Dissolved K	2002	13.2	n/a	25.94	8.09	26.05	5.1	n/a	7.46	2.77	2.47
	2003	14.03	26.84	10.11	13.49	10.28	19.11	22.28	8.58	8.39	4.95
	2004	6.02	1.14	4.28	2.01	8.76	0.67	0.05	0.23	0.05	0.05
Mean‡		13.43^{a}	25.47^{a}	9.77^{a}	13.06^{a}	10.26^{a}	19.78^{a}	22.33^{a}	8.80^{ac}	8.44^{bc}	5.00^{bc}
Slope		0.068	0.075	0.064	0.070	0.064	0.028	0.025	0.018	0.017	0.013
S.E.		0.010	0.009	0.009	0.011	0.010	0.004	0.005	0.003	0.003	0.002
P > t		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001
Adj.R^2		76	83	75	74	74	76	72	73	73	78
Sediment K	2002	19.1	n/a	59.5	69.3	54.6	7.43	n/a	17.1	23.7	5.2
	2003	0.84	0.40	0.34	0.169	0.34	1.15	0.34	0.29	0.16	0.16
	2004	3.01	2.57	5.33	0.81	0.89	0.33	0.12	0.28	0.02	0.01
Mean‡		1.01^{a}	0.52^{a}	0.63^{a}	0.19^{a}	0.34^{a}	1.48^{a}	0.46^{bc}	0.57^{ac}	0.12^{bc}	0.17^{bc}
Slope		0.015	0.010	0.010	0.006	0.010	0.007	0.005	0.004	0.003	0.003
S.E.		0.003	0.003	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0.0004
P > t		0.001	0.002	0.001	0.000	0.000	0.003	0.0004	0.0004	0.001	0.0001
Adj.R^2		55	46	52	57	61	65	88	83	80	88

† Year: 2002: From 25 July to 31 Dec., corn harvested on 15 Aug., stubbles left in the field until 28 Oct. at rye planting. 2003: 1 Jan. 2003 to 31 Dec. Corn planted on 20 Apr. and 20 May, replaced on 26 Jun. by cowpea. 2004: 1 Jan. to 6 July. Corn planted on 20 Apr. and harvested on 6 July.

‡ Weighted mean calculated from 15 observations in 2003 and 2004 data. Means in same row followed by the same letter are not statistically different at the 0.05 probability level according to Tukey test.

Table 6. Annual total losses of P and K as affected by alley cropping and terracing.

		Treatment						Treatment				
Parameter	Year†	Control	Blackberry	Mimosa	Switchgrass	Terrace	Parameter	Control	Blackberry	Mimosa	Switchgrass	Terrace
		kg ha^{-1}						kg ha^{-1}				
Total P	2002	0.47	n/a	0.59	0.383	0.16	Total K	12.57	n/a	24.56	26.47	7.66
	2003	2.97	2.82	1.21	0.958	0.89		20.26	22.61	8.86	8.50	5.11
	2004	0.10	0.05	0.06	0.008	0.01		1.00	0.17	0.51	0.068	0.08
Mean‡		3.07^{a}	2.87^{a}	1.27^{a}	0.97^{a}	0.89^{a}	Mean‡	21.26^{a}	22.79^{a}	9.37^{ac}	8.57^{bc}	5.17^{bc}
Slope		0.009	0.009	0.006	0.005	0.005	Slope	0.028	0.025	0.018	0.017	0.013
S.E.		0.001	0.002	0.001	0.001	0.001	S.E.	0.004	0.005	0.003	0.003	0.002
P > t		<0.0001	0	<0.0001	<0.0001	<0.0001	P > t	<0.0001	0.0003	<0.0001	<0.0001	<0.0001
Adj. R^2		79	67	86	80	88	Adj. R^2	76	66	73	73	78

† Year: 2002: From 25 July to 31 Dec., corn harvested on 15 Aug., stubbles left in the field until 28 Oct. at rye planting. 2003: 1 Jan. 2003 to 31 Dec. Corn planted on 20 Apr. and 20 May, replaced on 26 Jun. by cowpea. 2004: 1 Jan. to 6 July. Corn planted on 20 Apr. and harvested on 6 July.

‡ Weighted mean calculated from 15 observations in 2003 and 2004 data. Means in same row followed by the same letter are not statistically different at the 0.05 probability level according to Tukey test.

DISCUSSION

Overall, surface water runoff, sediment and plant nutrient concentrations and losses were higher in 2003 than in other years due to highest rainfall amount recorded during this period. In 2002, highest water runoff losses of 44 mm were recorded in mimosa plot followed by the control, switchgrass and terrace plots. For this period, plots with vegetative barriers were almost identical to the no barrier control because hedgerows were not well established. This evidence was reported elsewhere with switchgrass or other vegetative barriers (Angima et al., 2000; Joslin and Schoenholtz, 1997). Terraces were effective since the beginning of the experiment when they were built. Blackberry and switchgrass treatments were not significantly different for runoff losses, similar to the findings by Dabney et al. (1999), who did not find any difference between switchgrass and blackberry hedges for erosion control. Switchgrass and blackberry hedgerows were more effective than mimosa in reducing runoff and sediment due to their ability to form a thick and more efficient barrier to water movement than mimosa hedgerow.

The effectiveness of terraces for reducing runoff and sediment yield is consistent with Alberts et al. (1978) who reported substantial runoff and soil loss reduction in the Missouri Valley for terraced fields compared to unterraced fields. Mills et al. (1992) computed probability distributions of soil loss and rainfall retention rates from rainfall, runoff, and soil loss data for three watersheds in the Southern Piedmont of the U.S. Considerable soil loss risk reduction was observed for watersheds with less land slope and with terrace and grassed waterways. Furthermore, terraces were more effective than vegetative barriers, consistent with Navas et al. (1994) who found, on a 30% field slope in Metapàn (El Salvador), 70 and 54% of soil loss reduction over a 5-year period with terraces compared to unterraced plots and living barriers, respectively. The effectiveness of the vegetative barriers were shown with an increased reduction rate of soil erosion over time and this trend would continue to improve as the hedgerows will further develop. Reduction in water runoff and soil loss was reported elsewhere with terraces (Chow et al., 1999; Huang et al., 2003).

Reduction of runoff and sediment losses from the tree alley cropping is similar to the results of Narain et al. (1997), who reported 41% reduction of runoff in corn plot alley cropped with leucaena on a 4% slope in India., On a 24% field slope in Jamaica, alley cropping with *Calliandra calothyrsus* reduced water runoff and soil loss by 45 and 35%, respectively (McDonald et al., 2002). Alley cropping with *Inga edulis* spaced 4 m apart reduced water runoff and soil loss on a 15-20% field slope by 83% and 93%, respectively, compared to sole cropped rice and cowpea in annual rotation over 6 years study in Peru (Alegre and Rao, 1996). Paningbatan et al. (1995) observed a soil erosion rate of 5 Mg ha $^{-1}$ year $^{-1}$ in the Philippines with 5 m spaced hedgerows of desmanthus (*Desmanthus virgatus*) established along the contour compared to 100 to 200 Mg ha^{-1} year $^{-1}$ with farmer's practices. A corn – cowpea sequence alley cropped with cassia (*Cassia siamea*) annually yielded 13 and 2 % less runoff and soil loss, respectively, compared to the treeless control on a 14% slope in Kenya (Kiepe, 1996). These results were attributed to increased infiltration rates resulting from terrace formation and high infiltration rates in soil adjacent to hedgerows. An 80% decrease in sediment concentration in water runoff was reported with alley cropping involving leucaena hedgerows in Nigeria (Lal, 1997). Vegetative barriers and terraces reduce sediment concentration by reducing slope length and thus reduce the detaching energy of water runoff (Schwab et al., 1993).

Our results with switchgrass in erosion control are consistent with Gilley et al (2000). On slopes ranging from 8 to 16%, grass hedges reduced runoff by 22 to 52% and soil loss by 53 to 57% with or without tillage, respectively. Switchgrass effect in reducing NH_4-N losses is consistent with Eghball et al. (2000), who reported 60% loss reduction with switchgrass hedges on a 12% field slope in Iowa. Findings by those authors for different forms of phosphorus are inconsistent with ours. Indeed, they reported 35% reduction in different forms of P with a single narrow switchgrass hedge in their experiment. There were no treatment effects on total P losses in this experiment. This contrasts with reports from alley cropping with desmanthus in India and leucaena in the Philippines (Comia et al., 1994; Narain et al., 1997), where alley cropping reduced P losses. In these experiments, hedgerows were spaced 5 and 10 m, respectively, allowing for a more efficient slope reduction than in our experiment.

Treatments did not significantly affect NH_4-N concentrations at the 0.05 probability level (Table 3). These results are inconsistent with Lal (1997), who reported reduced concentrations with respect to the control for leucaena alley cropped with corn/cowpea in Nigeria. Applied N fertilizer quantities were far less than those applied in our experiment, implying that less N was available for surface losses. However, closer hedgerow spacing (4 m) in his research would have increased N added with higher amount of N-rich biomass applied to the soil (Lal, 1997). Total losses of NH_4-N were highest in blackberry and mimosa treatments due to supplemental N added on blackberry hedgerows as calcium nitrate annually, and symbiotic N fixation in mimosa, together with soil application of biomass from mimosa hedgerows. Reduced NH_4-N losses in switchgrass and terraces were due to reduced water runoff losses in these plots.

High dissolved K losses can be explained by the high level of this element in the soil. In sandy soil, K can be easily washed away if a barrier is not in place to reduce runoff losses (Foth and Ellis, 1997). Switchgrass and mimosa treatments had substantial sediment K loss in 2002, mostly because they were not well established. Terraces contributed to a better retention of K in plots than did vegetative barriers.

Sediment and plant nutrients in soil are regularly washed away from plots in water runoff as a result of soil erosion. They are loaded in streams and constitute a threat to human health and aquatic life. Highest sediment concentrations of 2770 mg L^{-1} and 2340 mg L^{-1} were measured in the control plot on 16 May 2004 and in mimosa plot on 17 May 2004. These concentrations were the result of erosive storms occurring the day after field cultivation for weed control. Sediment concentrations in water runoff exceeding 0.5 g L^{-1} can impair drinking water quality supplies (USEPA 2002). One can argue that this is a one-time occurrence and cannot have an environmental or economic effect on the community as a whole. However, due to multiplicative effects of these occurrences in several cultivated fields, water quality can be impaired. According to the United States Environmental Protection Agency (USEPA 2002), agricultural nonpoint source pollution is a leading cause of surface water contamination in Alabama. High concentrations of sediment in drinking water supplies increase treatment costs (Lal, 2001).

Different forms of N can affect human or aquatic life when concentrations exceed a fixed tolerance level. Ammonium-N concentrations regularly exceeding 0.05 mg L^{-1} are harmful to fish and other aquatic species (Boyd, 2000; Rouse et al., 1999). Concentrations of NH_4-N in our experiment frequently exceeded this limit. Concentrations of NO_3-N exceeded the USEPA recommended limit of 10 mg L^{-1} for drinking water supplies, twice in the mimosa treatment and once in the terrace plot in 2002. These results are consistent with Donner et al. (2004), who pointed out the increasing concentration of nitrate in the Mississippi river due to heavily fertilized lands in the corn belt, including Iowa, Illinois and Indiana.

Phosphorus is not generally listed as a threat in water quality standards for human consumption. However, concentrations of P play an important role in eutrophication of aquatic media. Observed P concentrations during this study regularly exceeded the upper limit favorable to algal growth. Practices that tend to reduce water runoff will reduce the amount of P delivered to streams and other aquatic systems and thus protect water quality. Potassium is not an immediate threat to human health. Concentrations of K recorded in this study were well above trace quantities considered adequate for the protection of freshwaters ecosystems (Boyd, 2000).

CONCLUSIONS

This research was carried out to study the effectiveness of alley cropping of mimosa, blackberry and switchgrass hedges in reducing surface runoff, sediment and plant nutrient losses compared to underground pipe-outlet parallel terraces and no barrier control. Blackberry, switchgrass and terrace treatments significantly reduced surface water runoff by 45, 62 and 74% compared to the control, respectively. Switchgrass and terraces effectively reduced sediment yield by 76 and 84%, respectively. Total losses of NH_4-N were also significantly reduced in switchgrass and terrace treatments. Losses in plots with blackberry hedges were higher than in the control due to supplemental addition of N fertilizer to blackberry hedgerows. The terrace treatment significantly reduced sediment P losses by 73%, whereas differences between treatments for total P losses were not significant at the 0.05 probability level. Switchgrass and terrace treatments significantly reduced dissolved, sediment and total K losses.

Effectiveness of vegetative barriers in reducing surface runoff, sediment concentration and yield, plant nutrient concentrations and losses progressively improved over time since initial stands in 2002 and 2003 were poor. Their effectiveness is expected to improve in the next few years as switchgrass and blackberry tillers fill the row and as pruned mimosa branches reinforce the barrier. Switchgrass hedges were more effective than blackberry and mimosa hedgerows in reducing runoff, sediments and plant nutrients due to its rapid establishment and tillering to fill the row. Most losses occurred during year 2003, which was the rainiest during this study, and generated the highest runoff losses. Switchgrass hedges were a good alternative to costly terraces for erosion control and water quality protection.

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REFERENCES

Aase, J.K., and J.L. Pikul. 1995. Terrace formation in cropping strips protected by Tall Wheatgrass Barriers. Journal of Soil and Water Conservation 50:110-112.

Alberts, E.E., G.E. Schuman, and R.E. Burwell. 1978. Seasonal runoff losses of nitrogen and phosphorus from Missouri Valley loess watersheds. J Environ Qual 7:203-208.

Angima, S.D., M.K. O'Neill, A.K. Onwega, and D.E. Stott. 2000. Use of tree/grass hedges for soil erosion control in the Central Kenyan highlands. Journal of Soil and Water Conservation 55:478-482.

Boyd, C.E. 2000. Water quality. An introduction. Kluwer Academic Publishers, Norwell, Massachusetts.

Chow, T.L., H.W. Rees, and J.L. Daigle. 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: A field evaluation. Journal of Soil and Water Conservation 54:577-583.

Coleman, T.L., A.U. Eke, U.R. Bishnoi, and C. Sabota. 1990. Nutrient Losses in Eroded Sediment from a Limited-Resource Farm. Field Crops Research 24:105-117.

Comia, R.A., E.P. Paningbatan, and I. Hakansson. 1994. Erosion and Crop Yield Response to Soil-Conditions under Alley Cropping Systems in the Philippines. Soil & Tillage Research 31:249-261.

Dabney, S.M., L.D. Meyer, W.C. Harmon, C.V. Alonso, and G.R. Foster. 1995. Depositional patterns of sediment trapped by grass hedges. Transactions of the ASAE 38:1719-1729.

Dabney, S.M., Z. Liu, M. Lane, J. Douglas, J. Zhu, and D.C. Flanagan. 1999. Landscape benching from tillage erosion between grass hedges. Soil & Tillage Research 51:219-231.

Donner, S.D., C.J. Kucharik, and J.A. Foley. 2004. Impact of changing land use practices on nitrate export by the Mississippi River. Global Biogeochemical Cycles 18.

Foth, H.D., and B.G. Ellis. 1997. Soil fertility. Second edition ed. Lewis Publishers, New York.

Garrett, H.E., and L.S. Harper. 1998. The Science and Practice of Black Walnut Agroforestry in Missouri, U.S.A.: A Temperate Zone Assessment, pp. 97-110, *In* L. E. Buck, et al., eds. Agroforestry in Sustainable Agricultural Systems. Lewis Publishers, Inc.

Goolsby, D.A., W.A. Battaglin, B.T. Aulenbach, and R.P. Hooper. 2000. Nitrogen flux and sources in the Mississippi River Basin. Science of the Total Environment 248:75-86.

Huang, M.B., J. Gallichand, and P.C. Zhang. 2003. Runoff and sediment responses to conservation practices: Loess plateau of china. Journal of the American Water Resources Association 39:1197-1207.

Hue, N.V., and C.E. Evans. 1986. Procedures used for soil and plant analysis by the Auburn University Soil Testing Laboratory.

Joslin, J.D., and S.H. Schoenholtz. 1997. Measuring the environmental effects of converting cropland to short-rotation woody crops: A research approach. Biomass & Bioenergy 13:301-311.

Kang, H. 2004. Hedgerow pruning effects on alley cropped maize: light interception, water relations and yields. M.S. Thesis., Auburn University, Auburn, Alabama.

Kiepe, P. 1996. Cover and barrier effect of *Cassis siamea* hedgerows on soil conservation in semi-arid Kenya. Soil Technology 9: 161-171.

Lal, R. 1989. Agroforestry Systems and Soil Surface Management of a Tropical Alfisol .2. Water Runoff, Soil-Erosion, and Nutrient Loss. Agroforestry Systems 8:97-111.

Lal, R. 1997. Soil degradative effects of slope length and tillage methods on alfisols in western Nigeria .1. Runoff, erosion and crop response. Land Degradation & Development 8:201-219.

Lal, R. 2001. Soil degradation by erosion. Land Degradation & Development 12:519-539

Matta-Machado, R.P., and C.F. Jordan. 1995. Nutrient Dynamics During the First 3 Years of an Alleycropping Agroecosystem in Southern USA. Agroforestry Systems 30:351-362.

Mesonet. 2004. Information for current Auburn University Mesonet automated weather stations. [Online]. Available by Mesonet, Auburn University. http://www.awis.com/mesonet/station_list (posted March 1, 2004; verified March 1, 2004).

Mills, W.C., A.W. Thomas, and G.W. Langdale. 1992. Seasonal and crop effects on soil loss and rainfall retention probabilities: An example from the U.S. Southern Piedmont*1. Soil Technology 5:67-79.

Narain, P., R.K. Singh, N.S. Sindhwal, and P. Joshie. 1997. Agroforestry for soil and water conservation in the western Himalayan Valley Region of India 1. Runoff, soil and nutrient losses. Agroforestry Systems 39:175-189.

NRCS. 2001. 1997 National resources inventory: highlights. United States Department of Agriculture - National Resources Conservation Service., Washington, D.C.

Rouse, J.D., C.A. Bishop, and J. Struger. 1999. Nitrogen pollution: An assessment of its threat to amphibian survival. Environmental Health Perspectives 107:799-803.

SAS Institute Inc. 2001. Sas software. Release 8.2. Release 8.2. SAS Institute Inc, Cary, NC, USA.

Schwab, G.O., D.D. Fangmeier, W.J. Elliot, and K.R. Frevert. 1993. Soil and Water Conservation Engineering Fourth ed.:508.

Sims, G.K., T.R. Ellsworth, and R.L. Mulvaney. 1995. Microscale determination of inorganic nitrogen in water and soil extracts. Communications in Soil Science and Plant Analysis:303-316.

USEPA.2002. National Water Quality Inventory. EPA 841-R-02-001. U.S. Environmental Protection Agency, Washington D.C.

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