THE JOURNAL OF AGRICULTURE OF THE UNIVERSITY OF PUERTO RICO

Issued by the Agricultural Experiment Station of the University of Puerto Rico, Mayagüez Campus, for the publication of articles and research notes by staff members or others, dealing with scientific agriculture in Puerto Rico and elsewhere in the Caribbean Basin and Latin America.

VOL. 91 JULY AND OCTOBER 2007 No. 3-4

Use of polyacrylamide as an erosion control strategy in a highly eroded soil of Puerto Rico[1,2]

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J. Agric. Univ. P.R. 91(3-4):87-100 (2007)

ABSTRACT

High sediment loads from agriculture and construction sites are a major source of surface water contamination in Puerto Rico. The use of anionic polyacrylamide polymers (PAM) is quickly gaining recognition as a cost-effective short-term erosion control strategy. In this study we evaluated the effectiveness of different dosages and formulations of anionic PAM in a highly weathered soil (Corozal clay—Typic Hapludult) of the tropics under steep slope (20%) conditions. A series of indoor box experiments were conducted according to guidelines of the National Research Project for Simulated Rainfall. Three formulations of PAM, namely, SOILFLOC™ 300 E, SOILFIX™ LDP, and a synthetic formulation from Aldrich Chemical Company (PAM-Ald) were evaluated at the following rates: 0 (control), 20 kg/ha, 80 kg/ha, and 120 kg/ha of active ingredient. Simulated rainfall (7 cm/h) experiments were conducted at: one, two, eight, 30 and 60 days after polymer application. Additions of PAM at rates of 80 and 120 kg/ha significantly reduced sediment concentration in runoff relative to that of the control and of the 20 kg/ha

[1]Manuscript submitted to the Editorial Board on 5 April 2006.

[2]Funding for this study was obtained through a grant by the USDA McIntire Program (MS-012). We appreciate the collaboration of Vidal Santiago, Ramón Aponte and Francisco Castro.

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PAM rate. At their highest rates, all PAM products reduced sediment runoff by more than 75% relative to the control in all events. The effectiveness of the 20 kg/ha PAM rate was lost after two rainfall events. At the third runoff event the percentage sediment concentration reduction (relative to that of the control) was less than 50% for the 20 kg/ha PAM-Ald formulation and less than 20% in the case of SoilFloc. Time to runoff was largely influenced by soil moisture content. In the last two rainfall events (30 and 60 days after PAM application), time to runoff was also significantly influenced by PAM rate. Runoff occurred faster with the control and the low PAM rate relative to that of the high PAM rates. These results could be attributed to the effects of surface sealing and enhancement of rill formation at the surface of the control and the low (20 kg/ha) PAM treatments. Sixty days after PAM application, estimates of cumulative sediment production for the 30-minute runoff event were 2.3 Mg/ha in the control treatment vs. 0.18, 0.07, and 0.08 Mg/ha for the 120 kg/ha rate of SoilFloc, SoilFix, and PAM-Ald, respectively.

Key words: PAM, soil erosion, highly weathered soils, simulated runoff

RESUMEN

Uso de poliacrilamida como estrategia de control de erosión en un suelo altamente erodado de Puerto Rico

La alta sedimentación procedente de terrenos dedicados a la agricultura y la construcción es una de las principales fuentes de contaminación de los cuerpos de agua superficiales de Puerto Rico. El uso de polímeros aniónicos de poliacrilamida (PAM) ha ganado rápido reconocimiento como una alternativa costo-efectiva para el control de la erosión. En este estudio evaluamos la efectividad de varias formulaciones y dosis de PAM aniónico en un suelo altamente meteorizado del trópico (Corozal Arcilloso—Typic Hapludult) en condiciones de alta pendiente (20%). Se llevó a cabo una serie de experimentos con cajas de escorrentía siguiendo el protocolo del Proyecto Nacional de Simulación de Lluvia. Se evaluaron tres formulaciones de PAM: SOILFLOC™ 300 E, SOILFIX™ LDP, y una formulación sintética (PAM-Ald) de la compañía Aldrich Chemical. Cada formulación se evaluó en las siguientes dosis: 0 (control), 20 kg/ha, 80 kg/ha, y 120 kg/ha de ingrediente activo. Los experimentos de lluvia simulada se realizaron a uno, dos, ocho, 30, y 60 días luego de la aplicación del polímero. Las dosis de PAM de 80 y 120 kg/ha redujeron significativamente la concentración de sedimentos en el agua de escorrentía comparadas con el control y la dosis de 20 kg/ha. En sus dosis más altas todas las formulaciones de PAM redujeron la concentración de sedimentos en el agua de escorrentía en más de 75% comparado con la del control en todos los eventos de lluvia realizados. La efectividad de PAM a la dosis de 20 kg/ha se perdió luego del segundo evento de lluvia. Durante el tercer evento de lluvia la reducción en la concentración de sedimentos (comparado con la del control) fue menos de 50% en el caso de la formulación PAM-Ald y menos de 20% en el caso de SoilFloc para la dosis de 20 kg/ha. El tiempo requerido para la generación de escorrentía dependió grandemente del contenido de humedad del suelo. Durante los dos últimos eventos de lluvia (30 y 60 días luego de la aplicación de PAM), el tiempo requerido para la generación de escorrentía se afectó significativamente por las dosis de PAM. En el tratamiento control y en el de la dosis más baja de PAM la escorrentía ocurrió más rápido que en aquéllos con las dosis más altas de PAM. Estos resultados pudieran atribuirse a los efectos de sellado de superficie y aumentos en la formación de surcos o zanjillas en la superficie del control y en la de la dosis más baja (20 kg/ha) de PAM. Sesenta días luego de la aplicación del polímero, los estimados de producción de sedimentos cumulativos para un evento de 30 minutos de escorrentía

fueron de 2.3 Mg/ha para el tratamiento control vs. 0.18, 0.07, y 0.08 Mg/ha para las dosis de 120 kg/ha de SoilFloc, SoilFix y PAM-Ald, respectivamente.

Palabras clave: PAM, erosión de suelo, suelos altamente meteorizados, escorrentía simulada

INTRODUCTION

The high sedimentation rates of water resources in Puerto Rico constitute a serious threat to sustainability. Recent analyses of the quality status of Puerto Rican waters indicate that close to 70% of the river kilometers monitored do not meet the water quality criteria for their designated uses (PREQB, 2003). In most cases, contamination has been attributed to excessive sediment and bacteria (Vachier, 1994). The high erosion losses occurring in our watersheds have significantly reduced the storage capacity of our reservoirs (Soller-López, 2001). Storage capacity losses range from 12 to 81% of their original capacity, with an average of 35% (Soller-López, 2001).

Soil erosion from land-clearing practices associated with agriculture and construction, often on very steep slopes, is the biggest contributor of sediments to surface waters. Smith and Abruña (1955) estimated that sediment losses could be as high as 284 Mg/ha/yr for a steep slope soil under fallow conditions. Contractors and farmers are generally reluctant to implement short-term erosion control practices such as mulch, sod and man-made blankets, because of high cost and labor requirements. These methods present the additional problem that they are ineffective for preventing rill erosion once rills develop beneath the mulches (Steven Green and Stott, 2001; Peterson et al., 2003). It is imperative to find cost-effective alternatives in order to prevent further deterioration of Puerto Rican waters.

In the last fifteen years the use of polyacrylamide (PAM)-based synthetic polymers has gained popularity as a suitable alternative for short-term erosion control of agricultural lands. PAM is a water-soluble polymer formed by the polymerization of acrylamide (Lu et al., 2002). The most commonly used PAM in natural environments is an anionic polymer with high molecular weight (12 to 20 Mg/mol) and 15 to 25% amide (NH_2) functional group replaced by OH to provide moderate negative charge (Lu and Wu, 2003). Sorption to soil is considered to come primarily from cation bridging (Lu et al., 2002).

Early applications of PAM to agricultural lands were restricted to furrow irrigation erosion control. However, recent studies indicate that PAM can be a cost effective erosion control alternative on a whole field scale. In gentle slope areas (<10%) applications of 20 kg/ha PAM generally result in more than 60% reduction in sediment production (Flanagan et al., 2003). On steeper slopes, application rates have to be increased. Flanagan et al. (2002a, b) observed greater than 50% reduction in sediment production from steep slopes (>30%) with applications of 80 kg/ha PAM. Among the benefits attributed to the use of PAM are reduction of soil erosion, increase in soil structure stability, increase in water infiltration, improvement of runoff quality, reduction of soil crust, and improvement of seedling germination (Lu and Wu, 2003). The encouraging results obtained with the use of PAM on a field scale have prompted scientists to evaluate the possibility of using PAM for short-term stabilization of steep slopes at construction sites, sanitary landfills and in the reclamation of highly eroded soils. These sites are usually denuded of vegetation and have very steep slopes thus highly vulnerable to soil erosion. In this study, a series of rainfall simulations were conducted to evaluate the effect of different dosages and formulations of PAM as an erosion control alternative on a highly weathered tropical soil (Ultisol) bare of vegetation.

MATERIALS AND METHODS

The experiment followed the guidelines of the National Research Project for Simulated Rainfall (indoor runoff box protocol) (USDA-NRCS, 2001). Thirty runoff boxes (1 m long, 20 cm wide, and 7.5 cm deep, with back walls 2.5 cm higher than the soil surface) were constructed out of galvanized sheet metal. The boxes were filled with surface soil (0 to 7.5 cm) (Corozal clay series-Typic Hapludult) that had been previously air dried, thoroughly mixed and passed through a 3-mm sieve. The boxes were packed with enough soil to achieve a final bulk density of 1.1 g/cm.

A rainfall simulator was constructed according to the above guidelines. The simulator is based on the design of Miller (1987) using a TeeJet™ ½ HH-SS50WSQ nozzle placed in the center of the simulator at approximately 305 cm above the center of the runoff boxes. Rainfall was delivered at approximately 7 cm/h. Preliminary experiments confirmed that the rainfall uniformity coefficient was greater than 85% within the area of interest (data not shown).

Three anionic PAM formulations were evaluated: a) SOILFLOC™ 300 E (Hydrosorb, Inc. Orange, CA)[7]; b) a chemical grade formulation produced by Aldrich Chemical Company, Inc. (referred to henceforth as PAM-Ald); and c) SOILFIX™ LDP (Ciba Specialty Chemicals, Suffolk, VA). The latter formulation (SOILFIX™ LDP) arrived after the initial experiments (Trial A) had started. Thus, evaluation of SoilFix (Trial B)

[7]Trade names in this publication are used only to provide specific information. Mention of a trade name or manufacturer does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

was conducted using the same experimental set up at different dates. Three dosages of each formulation were evaluated: 20, 80, and 120 kg/ha of active ingredient. Application rates were achieved from stock solutions of varying concentrations made from a concentrated emulsion in the case of the commercial PAM formulations and from a dry powder in the case of PAM-Ald. A control (no polymer addition) was included for comparison purposes (except for Trial B, where lack of sufficient indoor boxes precluded the inclusion of a control treatment).

Treatments were applied 24 hours before the initial rainfall simulation on the boxes containing the air-dried soil. Boxes were kept inside a 6-m-high warehouse at all times to prevent exposure to outside weather. The trays were arranged in a completely randomized design with three replications. Rainfall events were treated as subplots and conducted at the following time intervals: one, two, eight, 30, and 60 days after treatment application. No rainfall was applied between runs. For each simulation run the boxes (up to five boxes at a time selected randomly) were placed on a metal frame inclined at a 20% slope to simulate field conditions. Rainfall was applied until 30 minutes of runoff had been collected from each box. Runoff was collected in an 11-L plastic container. In addition, discrete runoff samples (during 30 seconds) were collected at one, three, nine, 15, and 30 minutes after runoff initiation and treated as sub-subplots in the analysis. Parameters evaluated were antecedent soil moisture content [defined as water loss divided by moist (pre-dried) soil weight], time to runoff initiation, total runoff volume collected, total sediment production, and sediment concentration at different time intervals. Sediment content was determined by weight by filtering a known sample volume through a previously oven dried (105° C) and weighed glass fiber filter. The filter containing the sediment sample was submitted to another drying period (18 h at 105° C) prior to the final weight determination. Sediment concentrations were obtained from the discrete measurements taken at different time intervals. Estimates of cumulative sediment loss were obtained from samples that integrated the complete runoff event (obtained from the 11-L container). Sediment concentration results from these samples were multiplied by the total runoff volume collected in each case and expressed in Mg/ha by conversion of the indoor box volume into hectares. Statistical analyses were conducted using the ANOVA and correlation procedures of the SAS® (version 8.0) software package.

RESULTS AND DISCUSSION

Sediment Concentration

There were no significant differences in sediment concentrations obtained from the discrete samplings (1, 3, 9, 15, and 30 min after runoff initiation). Thus average values for each treatment per date combination were used for comparison purposes.

Trial A. Regardless of the formulation used, the addition of PAM resulted in a significant reduction of sediment concentration in runoff on all dates (Table 1). The effects were more dramatic and persistent at higher dosages (80 and 120 kg/ha). Although a significant reduction was observed initially at the lowest rate (20 kg/ha), its effectiveness was quickly lost in subsequent simulation events. By the third rainfall event, eight days after application (DAA), the sediment concentration at the 20 kg/ha rate had increased by more than 150% relative to its original value for each of the two PAM formulations. At that stage (8 DAA), the percentage sediment concentration reduction (relative to that of the control treatment) was less than 50% for the PAM-Ald formulation and less than 20% in the case of SoilFloc, which was no longer statistically different from the control treatment. In contrast, PAM additions at higher rates reduced the sediment concentration by more than 80% relative to that of the control in all (five) simulation events (Figure 1). These findings are in accord with results from other studies. Flanagan et al. (2003) indicated that although a greater than 60% sediment control can be achieved in gentle slope areas (<10%) with 20 kg/ha PAM, application rates have to be increased on steeper slopes to reach the same degree of

TABLE 1.—*Runoff sediment concentration for the rainfall simulation events. Results constitute an average of samples obtained at 1, 3, 9, 15, and 30 min after runoff initiation.*

	Sediment concentration (mg/L)/ Days after treatment application (DAA)					
Treatment	1 DAA	2 DAA	8 DAA	30 DAA	60 DAA	Overall
TRIAL A						
Control	327.68 a[1]	471.05 a	535.65 a	716.83 a	682.73 a	546.79 a
SoilFloc 20 kg/ha	135.18 b	239.70 b	387.52 b	641.16 a	650.13 a	410.74 b
SoilFloc 80 kg/ha	46.76 c	75.74 c	110.09 d	139.02 c	131.65 c	100.65 d
SoilFloc 120 kg/ha	42.82 c	75.80 c	98.85 d	83.04 c	77.93 c	75.69 de
PAM-Ald 20 kg/ha	62.32 c	190.91 b	275.10 c	363.19 b	358.08 b	249.92 c
PAM-Ald 80 kg/ha	39.33 c	41.05 c	89.66 d	124.30 c	114.72 c	81.81 de
PAM-Ald 120 kg/ha	47.42 c	26.79 c	42.07 d	53.76 c	58.96 c	45.80 e
TRIAL B						
SoilFix 20 kg/ha	43.57 a[1]	98.24 a	124.27 a	116.13 a	154.16 a	107.28 a
SoilFix 80 kg/ha	29.28 b	22.67 b	28.74 b	41.09 b	45.88 b	33.53 b
SoilFix 120 kg/ha	25.55 b	20.96 b	21.93 b	32.00 b	32.54 b	28.44 b

[1]Within a column, means followed by the same letter are not different at the $\alpha = 0.05$ level of probability according to Tukey's test.

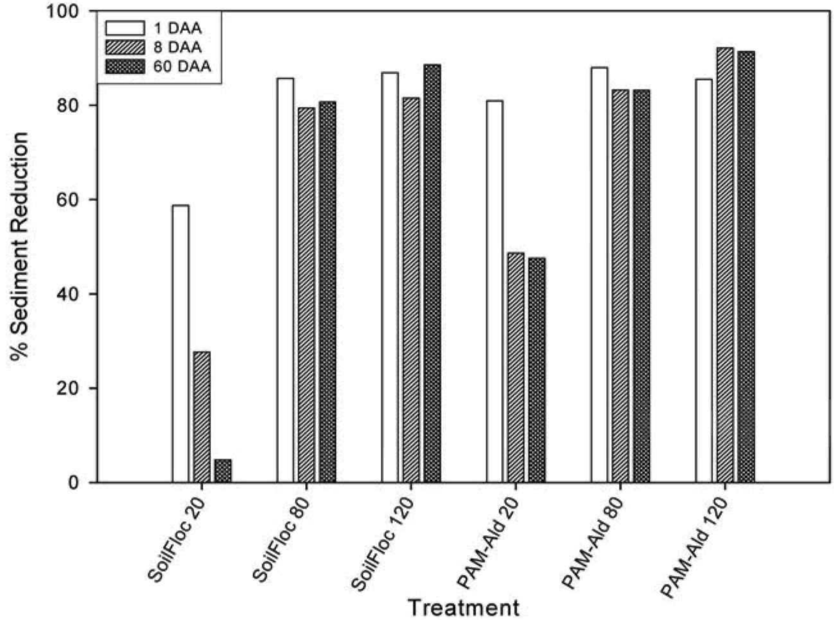

FIGURE 1. Percentage sediment concentration reduction of the PAM treatments relative to the control (trial A). DAA refers to days after treatment application.

success. Flanagan et al. (2002b, 2003) reported a 99% sediment yield reduction from the first rainfall event on steep slopes (>30%) treated with 80 kg/ha PAM. In concordance with our case, PAM effectiveness continued to be greater than 80% relative to the control in subsequent events.

The concentration of sediment in runoff followed an exponential decay expression as a function of the PAM dosage used (Figure 2). Changes in sediment concentration with time were more significant for the control and the lowest polymer rate (20 kg/ha) treatments.

Trial B. SoilFix exhibited behavior similar to that of the other PAM treatments, being highly efficient in the control of sediment concentration in runoff. At its highest rates SoilFix remained effective through multiple rain events, exhibiting at all times sediment concentration values of less than 50 mg/L (Table 1; Figure 2). However, as with the other PAM formulations, the 20 kg/ha rate lost its effectiveness after two rainfall events.

Time to Runoff

Trial A. There were no effects of PAM formulation or application rate in the time required for the initiation of runoff during the first three sim-

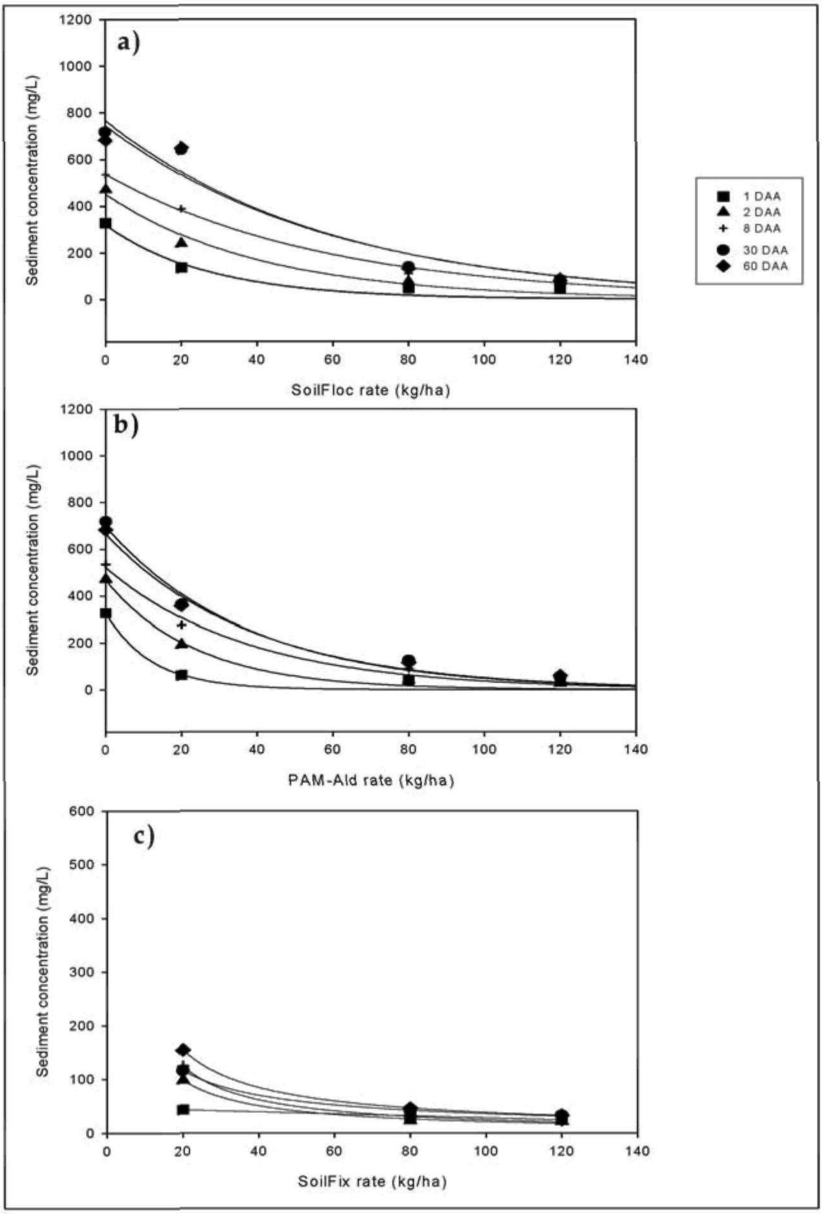

FIGURE 2. Sediment concentration in runoff for the different PAM formulations; a) SoilFloc; b) PAM-Ald; and c) SoilFix (trial B).

ulation events (Table 2). However, time to runoff in the last two simulation runs (30 and 60 DAA) was significantly influenced by the PAM rate used. During these events time to runoff increased with PAM rates according to a Langmuirian function (Figure 3). This result could be a reflection of the effects of surface sealing and enhancement of rill formation at the surface of the control and the low (20 kg/ha) PAM treatments. Raindrop impact induces aggregate breakdown and clay dispersion, which in turn promotes seal formation in denuded soils (Shainberg et al., 1994). Seal formation in turn reduces water infiltration and promotes runoff. The effects are aggravated with time as rill formation occurs. Research has shown that in structured soils high molecular weight anionic PAM inhibits soil dispersion and surface seal formation by promoting aggregate stability (Sojka et al., 1998; Lu et al., 2002; Lentz and Bjorneberg, 2003). This stability in turn promotes greater water infiltration and reduces particle detachment and transport in PAM-treated soils.

Effect of Soil Moisture on Time to Runoff

Time to runoff was strongly affected by soil moisture (Table 3). The relationship followed an exponential decay function for the control and lower PAM rates but tended to become more linear at higher PAM rates (Figure 4). This finding could also be explained by the effects of surface sealing at the control and lower PAM rates. The addition of PAM apparently promoted aggregate formation, which increased water infiltra-

TABLE 2.—*Time to runoff initiation for the rainfall simulation events.*

	Time to runoff (minutes after rainfall initiation)/ days after treatment application (DAA)				
Treatment	1 DAA	2 DAA	8 DAA	30 DAA	60 DAA
TRIAL A					
Control	28.24 a[1]	1.61 a	2.82 a	3.72 d	8.60 c
SoilFloc 20 kg/ha	33.64 a	1.61 a	3.00 a	5.18 cd	10.48 bc
SoilFloc 80 kg/ha	31.00 a	1.39 a	3.78 a	8.45 abc	14.58 ab
SoilFloc 120 kg/ha	29.59 a	2.21 a	3.63 a	9.33 ab	16.51 a
PAM-Ald 20 kg/ha	31.90 a	1.65 a	2.92 a	5.92 bcd	12.57 abc
PAM-Ald 80 kg/ha	31.59 a	2.27 a	3.97 a	9.69 ab	13.60 abc
PAM-Ald 120 kg/ha	27.80 a	1.55 a	3.60 a	10.02 a	13.92 ab
TRIAL B					
SoilFix 20 kg/ha	19.89 a[1]	1.33 a	4.34 a	16.97 a	21.44 b
SoilFix 80 kg/ha	21.75 a	1.00 a	4.65 a	16.11 a	22.23 b
SoilFix 120 kg/ha	21.04 a	1.43 a	5.28 a	14.56 a	24.29 a

[1]Within a column, means followed by the same letter are not different at the $\alpha = 0.05$ level of probability according to Tukey's test.

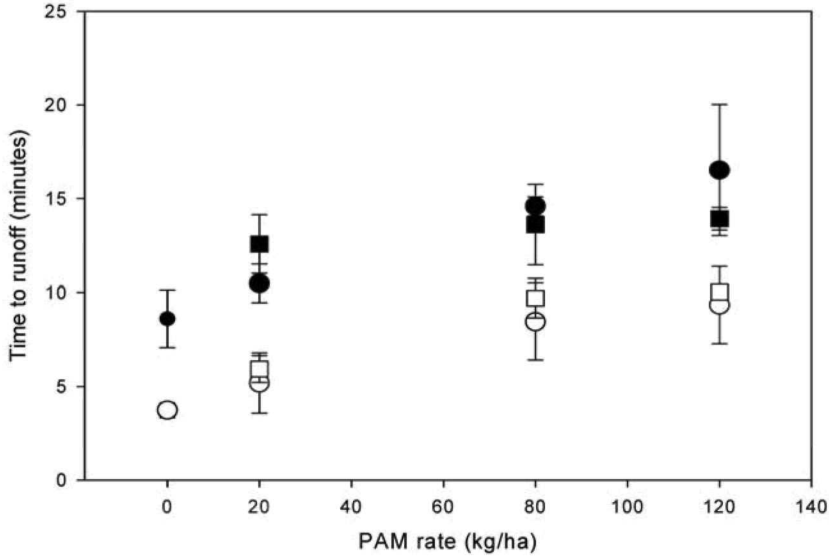

FIGURE 3. Relationship between PAM rate and time to runoff for the 30 and 60 day rainfall simulation events. DAA refers to days after treatment application. Circles refer to SoilFloc (open -30 DAA; filled -60 DAA), and squares refer to PAM-Ald (open -30 DAA; filled -60 DAA).

tion and retarded time-to-runoff initiation. In the case of SoilFix (Trial B) time to runoff was also largely controlled by soil moisture. In this case, the effect of SoilFix rate was significant only at the last rainfall event, with the highest rate (120 kg/ha) exhibiting the longer time to runoff value as expected (Table 2).

Cumulative Sediment Production

Extrapolation of the results obtained with the indoor box (g/m^3) to the field scale (Mg/ha) offers a broader perspective on the role of PAM in erosion control. These estimates are presented for illustrative purposes only since our experimental approach is not sensitive to effects that are relevant at the landscape scale. After successive events (30 and 60 DAA) the sediment loss rate for the control treatment was roughly one-third of the maximum annual soil loss tolerance factor recommended by the Natural Resource Conservation Service for a sustainable system (Table 4). Considering that such losses are the result of one rainfall event lasting only enough time to produce 30 minutes of runoff, one can visualize the enormous potential for soil losses on a yearly basis. In contrast, the highest PAM rates (80 and 120

TABLE 3.—*Antecedent soil moisture for trial A (calculated on a moist soil weight basis).*

	Antecedent Soil Moisture (%, w/w)/ Days after treatment application (DAA)				
Treatment	1 DAA	2 DAA	8 DAA	30 DAA	60 DAA
Control	12.73 ab[1]	30.29 b	28.29 b	19.78 a	13.70 b
SoilFloc 20 kg/ha	11.95 b	31.26 ab	28.69 ab	21.07 a	13.94 b
SoilFloc 80 kg/ha	13.87 ab	31.82 ab	29.33 ab	21.81 a	17.04 ab
SoilFloc 120 kg/ha	14.60 a	30.57 ab	29.31 ab	20.68 a	16.32 ab
PAM-Ald 20 kg/ha	12.56 ab	33.13 a	31.14 a	20.78 a	16.20 ab
PAM-Ald 80 kg/ha	12.27 ab	31.19 ab	30.50 ab	22.47 a	17.76 ab
PAM-Ald 120 kg/ha	12.27 ab	30.79 ab	29.64 ab	21.56 a	19.07 a

[1]Within a column, means followed by the same letter are not different at the $\alpha = 0.05$ level of probability according to Tukey's test.

kg/ha) exhibited a significant reduction in sediment production. PAM-Ald achieved a greater than 80% sediment reduction relative to that of the control at those levels. In the case of SoilFloc such a reduction percentage was achieved only at the 120 kg/ha rate since at the 80 kg/ha rate the efficiency dropped close to 70% after the second rain event. Still the effect of both polymers on sediment production control was highly significant.

Our results indicate that PAM could represent a practical short-term option for erosion control at agricultural and construction sites. From an economic perspective, PAM appears to be viable. At an approximate cost of $5 per kilogram of material (Steven Green and Stott, 2001), an application rate of 80 kg/ha, would amount to $400.00/ha plus labor. The material can be applied by spraying with commercially available equipment.

From an environmental perspective anionic PAMs exhibit a low toxicity to mammals (LD_{50} values >5 g/kg) and no toxicity to fish (LCD_{50} values >100 mg/L) (Barvenik, 1994). Concerns focus on the effects of residual concentrations of acrylamide, its basic monomer, in the PAM formulation. Research has shown that the degradation of PAM does not result in the release of acrylamide (Barvenik, 1994). Acrylamide has proven to be a carcinogenic compound as well as a potential neurotoxin. To prevent damage, state regulations limit the concentration of residual levels of acrylamide in anionic PAMs used in soil systems to less than 0.05%. Nevertheless, prior to allowing the use of PAM as an erosion control alternative in Puerto Rico, research must be conducted to ensure that PAM levels in runoff generated from PAM-applied plots remain negligible and that appropriate management guidelines are developed to fit our conditions.

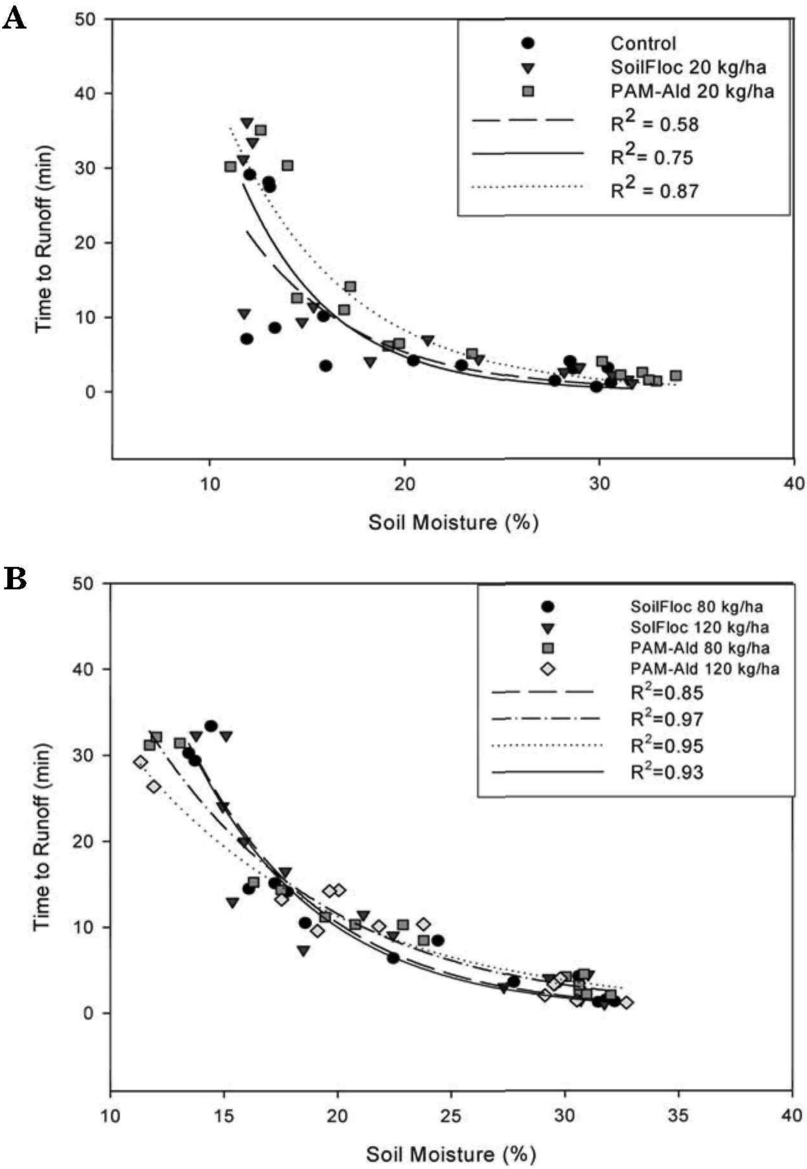

FIGURE 4. Relationship between soil moisture and time to runoff for treatments in trial A. R^2 are the coefficients of determination of the fit of the data to a nonlinear regression model of the type: y = a * exp (-b * X). A) Solid line corresponds to PAM-Ald, dotted line to SoilFloc, and dash line to control. B) Solid line corresponds to SoilFloc 80 kg/ha, dash line to SoilFloc 120 kg/ha, dash-dot line to PAM-Ald 80 kg/ha, and dotted line to PAM-Ald 120 kg/ha.

TABLE 4.—*Composite sediment production for the rainfall simulation events (Trial A).*

	Sediment Production (Mg/ha)/Days after treatment application (DAA)				
Treatment	1 DAA	2 DAA	8 DAA	30 DAA	60 DAA
Control	0.62 a[1]	1.28 a	1.25 ab	3.04 a	2.27 a
SoilFloc 20 kg/ha	0.18 b	0.59 b	1.33 a	1.72 ab	1.92 a
SoilFloc 80 kg/ha	0.03 b	0.20 bc	0.34 abc	0.95 b	0.59 bc
SoilFloc 120 kg/ha	0.02 b	0.17 bc	0.19 bc	0.57 b	0.18 bc
PAM-Ald 20 kg/ha	0.07 b	0.56 b	1.05 abc	1.39 ab	1.32 ab
PAM-Ald 80 kg/ha	0.02 b	0.10 bc	0.15 bc	0.55 b	0.28 bc
PAM-Ald 120 kg/ha	0.01 b	0.04 c	0.02 c	0.20 b	0.08 c

[1]Within a column, means followed by the same letter are not different at the $\alpha = 0.05$ level of probability according to Tukey's test.

CONCLUSIONS

The use of anionic polyacrylamide constitutes an effective alternative for temporary erosion control. Under the conditions evaluated in this study (steep slope soils denuded from vegetation), application rates of PAM must be higher than 20 kg/ha, the dosage recommended for gentle slope areas in the United States. After five simulated rainfall events, PAM application rates of 80 and 120 kg/ha still exhibited a greater than 75% sediment concentration reduction relative to that of the control. The effects can be dramatic when results are extrapolated to the field level. Estimates of sediment production during a 30-minute runoff event were 2.3 Mg/ha for the control treatment and 0.18, 0.07, and 0.08 Mg/ha for the 120 kg/ha rate of SoilFloc, SoilFix, and PAM-Ald, respectively.

Time to runoff was largely controlled by soil moisture. However, after successive rainfall events, increases in PAM rate also increased the time required for the generation of runoff. Other scientists have attributed this finding to the reduction of surface sealing and the increase in water infiltration by PAM.

The effectiveness of PAM will be affected by soil mineralogy, organic matter content, accompanying anions, as well as the effects of abiotic and biotic degradation factors. In addition, there is a need to quantify PAM losses via runoff under conditions pertinent to Puerto Rico. Research is needed to elucidate these factors and to establish management guidelines geared to ensuring maximum PAM effectiveness and avoiding potentially deleterious impact on the environment.

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