Soil Berms as an Alternative to Steel Plate Borders for Runoff Plots

Humberto Blanco-Canqui,* C. J. Gantzer, S. H. Anderson, and A. L. Thompson

ABSTRACT

Steel plates are often used to border runoff-erosion plots, but they are difficult to install and are expensive. This study assessed the effectiveness of using polyacrylamide (PAM; 2-propenamide, homopolymer) treated soil with and without geotextile fabric (GF) for soil berm plot borders in laboratory and field conditions. Hemispherically shaped soil berms of 250 mm wide by 150 mm high were constructed in erosion boxes. Erosion and runoff from untreated berms, berms treated with 9 kg ha^{-1} of PAM, and berms treated with 9 kg ha^{-1} of PAM and covered with GF (PAM-GF) were measured under simulated rainfall. A dry simulation run was conducted for 1 h followed by a wet simulation run after 24 h under field conditions. The PAM-GF reduced soil erosion from berms by 99% when compared with the untreated soil berm (control). Use of PAM alone reduced erosion from berms by ≈84%; however, erosion with PAM increased rapidly with time. Effectiveness of PAM alone decreased for reducing soil loss from 94% in the first 10 min of the 1-h dry run to 27% by the end of the 1-h wet run in field conditions. Although some runoff occurred from berms into the plots, this was insignificant for plot-to-berm ratios ≥10:1($P < 0.01$). Results show that soil berms treated with PAM and GF reduced erosion to nondetectable levels. The cost for soil berm construction is about 10% of that for steel plate plot borders. The PAM-GF treated soil berms can be an economical alternative to conventional steel plate plot borders especially for short-term runoff studies.

Field runoff-erosion studies are often conducted on plots in which runoff and soil erosion are measured. Plot boundaries are usually made of steel plates inserted vertically into the soil (Gilley et al., 2000). Use of such borders is a satisfactory means for bordering plots. The use of steel plates, however, has some disadvantages. Steel plates are relatively expensive to install and maintain. Moreover, installed plates prevent contour tillage operations. Experimental designs are often complicated, requiring many plots for studies of control of nonpoint source pollution. Such research may be more effectively performed with a less-permanent, lower-cost plot border.

Soil berms treated with anionic PAM and GF to prevent erosion from berms may be an alternative practice to use of steel plate borders. Laboratory (Peterson et al., 2002a; Yu et al., 2003) and field studies (Sojka et al., 1998; Lentz et al., 2001) have shown that PAM is effective for reducing erosion and runoff. Research shows that PAM reduces soil erosion by increasing aggregate stability (Aase et al., 1998; Bjorneberg et al., 2000), reducing soil surface sealing (Flanagan et al., 2002a), and thus maintaining soil porosity (Peterson et al., 2002b). Geotextile fabric materials, when used as soil cover, are highly effective for reducing soil erosion and runoff by absorbing the impact of rainfall, and reducing splash detachment and surface seal formation (Jennings and Jarrett, 1985; Martin, 1985; Krenitsky et al., 1998).

Use of soil berms as plot borders can benefit researchers. For example, seasonal erosion studies using runoff plots may require the annual or seasonal removal of metal borders for tillage, increasing the difficulty and labor costs for extraction, transport, storage, and reinstallation of metal plates. Recycling of steel plates may also represent an additional cost. The use of soil berms may also help overcome some management problems. The effectiveness of steel plate borders is readily damaged by rodent holes and other ground animals undercutting the metal borders, thus requiring additional maintenance compared with soil berms.

There are no data on the effectiveness of PAM when used in combination with GF for reducing soil erosion from soil berms for use as plot borders. Soil loss under the same level of PAM application has been shown to vary with the soil site-specific characteristics (Flanagan et al., 2002a, 2002b; Lu et al., 2002). There is a need to understand the amount of erosion from soil berms treated with PAM and GF for use as plot borders. It would be expected that some additional runoff from the berm would occur into the experimental plots in contrast to steel plate borders. This possible disadvantage must be quantified by determining the size of induced error to the runoff from measurements.

The study hypothesis is that soil berms treated with PAM and covered with GF will reduce erosion to nondetectable levels for short-term rainfall simulation studies, and the runoff contribution from berms to the runoff from the experimental plots is nonsignificant for plot-to-berm area ratios ≥10:1. If these hypotheses are true, soil berms treated with PAM-GF can be used as a low-cost alternative for plot borders. The objective of this study was to evaluate the effectiveness of (i) PAM and GF alone and (ii) PAM combined with GF for reducing soil erosion and runoff from soil berms.

MATERIALS AND METHODS

Laboratory Study

Soil from an air-dried Ap horizon of a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) was used. Four soil berm treatments were tested for their effectiveness to resist soil erosion under simulated rainfall. Three replicates

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Abbreviations: GF, geotextile fabric; PAM, polyacrylamide; PAM+G, polyacrylamide and gypsum; PAM-GF, polyacrylamide and geotextile fabric.

were used in a completely randomized design. The four treatments were (i) soil berms with PAM, (ii) soil berms covered with GF (DuPont weed control fabric, Wilmington, DE), (iii) soil berms with PAM and GF, and (iv) soil berm without PAM or GF (control treatment). Air-dried soil with a water content of 0.025 $m^3 m^{-3}$ was lightly crushed and passed through an 8-mm sieve, then packed in a 300 mm wide by 450 mm long by 400 mm high Plexiglas box at a bulk density of 1.3 ± 0.05 Mg m^{-3}. The box was equipped with two 15-mm-diam. holes and two 15-mm drainage pipes with 2.5-mm-diam. holes spaced at 20-mm intervals to allow drainage. The drainage pipes were placed at the bottom of the box and covered with a layer of GF as a filter. A 70-mm-thick sand layer was placed between the GF and soil to allow drainage. A hemispherically shaped 250 mm wide by 150 mm high by 450 mm long soil berm was constructed in the box and set to a 5% slope. A new berm was constructed from air-dry soil for each test. A granular anionic PAM was dissolved in water to obtain a 100 mg L^{-1} solution. The PAM solution was uniformly hand-sprayed on the soil berms for the PAM and PAM-GF treatments at a rate of 9 kg ha^{-1}. The GF was laid on the berms following PAM application and secured with 20-mm long staples.

Simulated rainfall was applied to berms at an intensity of 93 ± 6 mm h^{-1}, 1 h after the PAM application using a laboratory simulator. This study was designed to simulate large rainfall events with a recurrence interval of a 100-yr return period for mid-Missouri. The rainfall simulator was positioned 1.5-m above the soil berm surface and provided a mean drop size of 1.3 mm diam. with a kinetic energy of 27.9 J mm^{-1} m^{-2}. Runoff was collected for 10 min after initiation of runoff. Weight and volume of the runoff sample were recorded. Sediment concentration was determined gravimetrically using the evaporation method (Brakensiek et al., 1979).

Field Study

This study was conducted on an eroded Mexico soil with a silty clay texture on a 4.5% slope. The site was rototilled to a depth of ≈80 mm before the study. Three soil berm treatments with three replicates were used in a completely randomized design. The treatments were (i) soil berms with PAM, (ii) soil berms covered with GF (DuPont weed control fabric), (iii) soil berms without PAM or GF (control treatment). A steel box was used to enclose the soil berms for testing. Boxes were 300 mm wide by 750 mm long by 450 mm high, with the major axis parallel to the slope. Two 50- by 50-mm openings were made at the lower end of the boxes for runoff collection. The boxes extended 150 mm below and 300 mm above the soil surface. Soil berms of 250 mm wide, 750 mm long, and 150 mm high were constructed inside the boxes along the direction of the natural slope. Berms were constructed using nearly equal amounts of disturbed soil from an area nearby. The soil berms were sprayed with 100 mg L^{-1} concentration of PAM at a rate of 9 kg ha^{-1}. The box extended 150 mm above the soil berms to reduce loss of soil splash. A rotating boom rainfall simulator was used to simulate rainfall at 69 ± 5 mm h^{-1} simultaneously for 1 h on all replicates of all the treatments (Swanson, 1965). Water supplied had an electrical conductivity of 1.2 dS cm^{-1}. All the experimental units were located along a radius 5 m from the center of the simulator to ensure a uniform rainfall application. Evaluation of rainfall distribution uniformity was performed by placing rain gauges adjacent to each treatment. Dry and wet simulation runs were conducted. The dry run simulation was conducted for 1 h followed by a wet run simulation after 24 h. Dry and wet runs were designed to simulate large natural rainfall events with a recurrence interval of a 10-yr return period for mid-Missouri. A V-shaped trough (50 by 50 by 350 mm) was affixed at the lower end of the steel frame to collect runoff. Runoff was collected every 10 min for 20 s to measure runoff and sediment. Runoff samples were collected during both the dry run and wet run. Samples were transported to the laboratory to gravimetrically measure sediment concentrations. Runoff amount from the field experiment was plotted against time of collection, and the resulting regression equations were integrated across time from 0 to 60 min to compute the runoff depth. Sediment mass and runoff data from both the laboratory and field studies were analyzed using General Linear Model Procedures (PROC GLM; SAS Institute, Inc., 1999). Single-df contrasts were used to test differences in runoff and soil loss among treatments. Confidence intervals of the means were computed and compared to determine whether differences were significant.

RESULTS AND DISCUSSION

Soil Loss

Mean soil loss from treatments for laboratory and field studies is presented in Fig. 1. Reduction in soil loss was compared with the control treatment. Soil berms treated with PAM-GF produced the least erosion in both laboratory and field settings ($P < 0.01$). The PAM-GF treatment reduced erosion to 99%. The soil loss from the treatments ordered: PAM-GF > GF ≈ PAM > control (Fig. 1A). The PAM treatment was as effective as using the GF treatment alone for controlling soil loss ($P > 0.10$). On the basis of the laboratory results, the GF treatment was not as effective as PAM-GF for reducing soil loss ($P < 0.01$). Results show that PAM in combination with GF reduced soil losses to a nondetectable level. The GF enhanced the PAM performance and maintained PAM activity longer, most likely by intercepting raindrop energy and reducing development of surface seals. Krenitsky et al. (1998) found that erosion reduction was about 80% from construction sites when GF was used to cover the disturbed soil surface areas. This may be explained by the fact that GF protects the soil berm from the direct raindrop impact and allows PAM to remain in interaction with soil particles longer, increasing PAM effectiveness.

The PAM treatment was significantly less effective than PAM-GF for reducing soil loss under both laboratory and field conditions ($P < 0.01$). Soil loss from the PAM treatment was reduced by 86% in the laboratory ($P < 0.01$; Fig. 1A) and by 82% during the field dry run, but PAM effectiveness decreased greatly during the wet run, reducing only 27% of soil loss compared with the control ($P < 0.01$; Fig. 1B). We observed that PAM decreasingly lost its effectiveness during the wet run. Reduction in soil loss using PAM alone was greater than that found by Yu et al. (2003) who reported that 10 kg ha^{-1} of dry PAM reduced sediment losses by only 31% when compared with the control treatment from laboratory erosion pans under 36 mm h^{-1} simulated rainfall. Their lower effectiveness may be explained by the application of dry PAM. The dry PAM is commonly less effective than PAM in solution for stopping soil erosion as it dissolves very slowly (Peterson et al., 2002b). The initial PAM effectiveness is attributed to

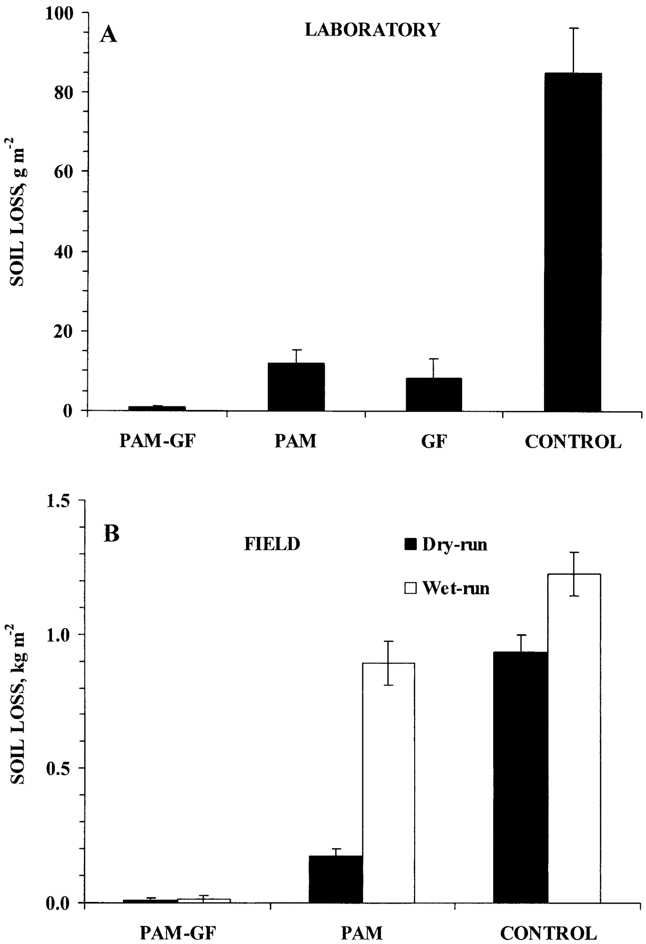

Fig. 1. Mean soil loss on an event basis from soil berms treated with polyacrylamide (PAM), geotextile fabric (GF), and PAM plus GF (PAM-GF), and a control berm without PAM or GF; (A) laboratory and (B) field for the dry and wet run rainfall simulations. Error bars represent standard deviation of the mean (n = 3).

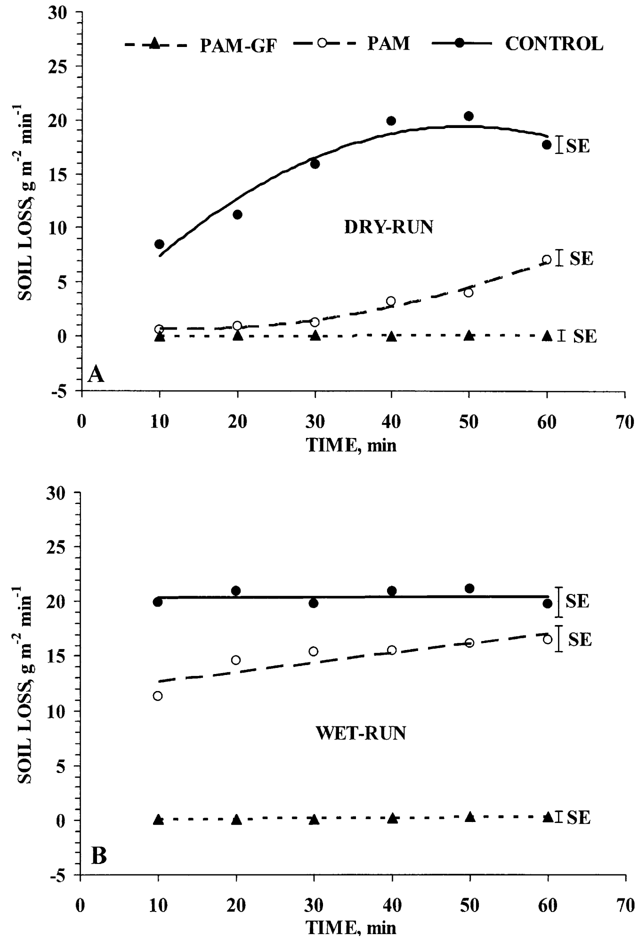

Fig. 2. Mean soil loss within the event from soil berms treated with polyacrylamide (PAM) and PAM plus geotextile fabric (PAM-GF), and a control berm without PAM or GF under field conditions for the (A) dry and (B) wet run rainfall simulations. Error bars represent the pooled standard error of the treatment means (n = 3).

stabilization of aggregates and reduction of surface seals, resulting in reduced particle detachment and increased infiltration (Flanagan et al., 2002a).

Analysis of soil loss within runs was conducted to study the duration of PAM effectiveness (Fig. 2A and 2B). Dry run results in Fig. 2A indicate that differences between PAM and PAM-GF were insignificant during the first 30 min of runoff ($P > 0.10$; Fig. 2B). However, PAM effectiveness decreased after 30 min. These results indicate that 9 kg ha^{-1} of PAM is insufficient to control erosion to low levels for rainfall events longer than 30 min. Rainfall decreases PAM effectiveness, leaving berms increasingly unprotected from the raindrop impact. Because PAM penetration into the soil is limited, it quickly lost its effectiveness as the soil was eroded. Indeed, Lu and Wu (2003) reported that PAM has very low penetration into the soil profile. The effectiveness of PAM for reducing erosion decreased from 94 to 82% between the first 30 min and the end of the 1-h dry run. In contrast, soil loss from berms treated with PAM-GF remained negligible. Decrease in PAM effectiveness after 30 min of runoff is in contrast with the findings by Peterson et al. (2002b), who reported that soil loss from recently tilled soils treated with 60 kg ha^{-1} PAM did not increase within 1 h of rainfall simulation at 75 mm h^{-1}. The higher PAM effectiveness in their study is probably because of the greater amount of PAM used, which was 6.7 times greater than in this study.

During the wet run, the PAM-GF treatment mirrored the dry run behavior having the least soil loss of the three treatments, reducing 99% of soil loss ($P < 0.01$; Fig. 2B). However, soil loss from the PAM treatment continued to increase with time. PAM effectiveness for reducing soil loss decreased from 94% in the first 10 min of 1-h dry run to 27% by the end of the 1-h wet run, and the soil loss differences between control and PAM treatments were only significant at the 0.05 level. During the first hour of simulation (dry run), large visible aggregates remained in the surface of PAM-treated berms, and the soil erodibility was lower than in control treatments, but the PAM effect diminished with time. Results show that the duration of PAM effectiveness is short for intense rains. Soil loss from berms with PAM would eventually equal the losses from the control treatment after 2 h of rainfall. Flanagan et al. (2002b) reported that application of 80 kg ha^{-1} PAM on disturbed 32% sloping soils was effective on reducing soil loss by 54% after nine rainfall events, and 40% from 19 events over a 6-mo period. The decrease of PAM effectiveness in their study was not as rapid as in this study, which may partly be explained by the greater PAM application. Because durability of erosion control by PAM is short, we speculate split application of PAM after major rainfall events may be a successful treatment.

Runoff

Comparisons of runoff among treatments were conducted to address the question of runoff contribution from the berm onto the runoff plots. Mean event runoff for both the laboratory and field data are presented in Fig. 3. Treatments were compared with the control treatment, which had the highest runoff ($P < 0.01$). The PAM-GF treatment produced the lowest runoff in the laboratory, and for the 1-h dry run in the field ($P < 0.01$). The PAM-GF treatment reduced runoff by 21% in the laboratory (Fig. 3A) and 29% for the dry run field conditions (Fig. 3B). The laboratory data indicates that the GF treatment was as effective as the PAM treatment in reducing runoff ($P > 0.10$; Fig. 3A). The PAM treatment had 13% less runoff for both laboratory and field settings ($P < 0.01$). Analysis of runoff within runs showed that runoff from the control and PAM treatments increased quadratically, while runoff from the PAM-GF treatment increased linearly during the 1-h dry run (Fig. 4A). Confidence intervals of the mean values in Fig. 4A showed that runoff among treatments was significantly different in this order: PAM-GF > PAM > control ($P < 0.01$). However, runoff differences among the control, PAM, and PAM-GF treatments during the 1-h wet run reduced rapidly with time, and differences after 30 min were insignificant ($P > 0.10$; Fig. 4B).

Results show that PAM is effective for reducing runoff from soil berms only during the early stages of rainfall. The PAM effectiveness diminishes rapidly with time. This may be mainly due to soil saturation, surface sealing, and soil consolidation. Our results support the findings of other studies. Peterson et al. (2002a) reported that 40 kg ha^{-1} of PAM with 5000 kg of gypsum (PAM+G) applied on silty clay loam packed in erosion boxes was highly significant in reducing runoff, but that runoff amount increased progressively beyond 30 min of rainfall. They suggested that runoff from the PAM+G

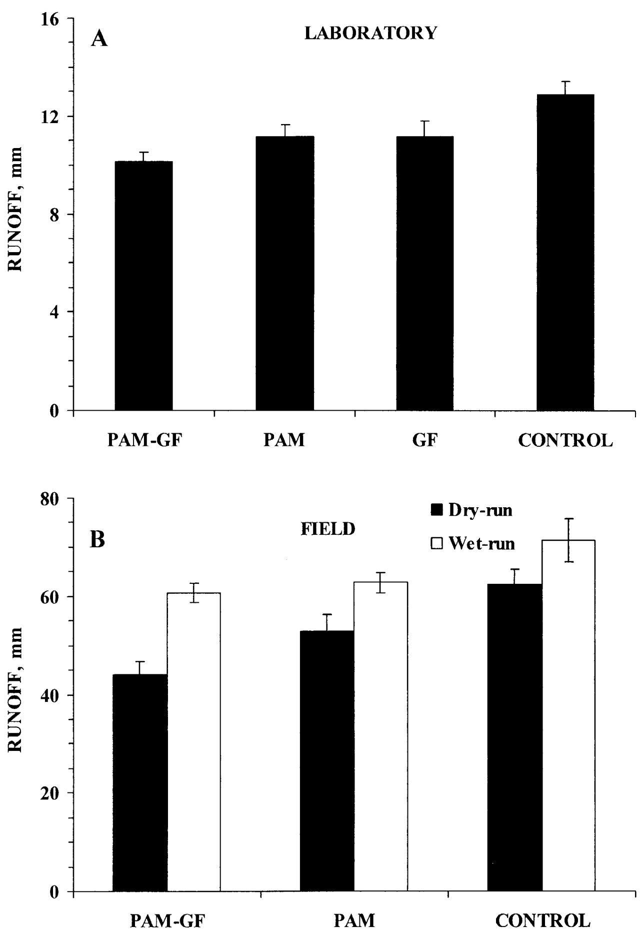

Fig. 3. Mean runoff on an event basis from soil berms treated with polyacrylamide (PAM), geotextile fabric (GF), and PAM plus GF (PAM-GF), and a control berm without PAM or GF using simulated rainfall; (A) laboratory and (B) field. Error bars represent standard deviation of the mean ($n = 3$).

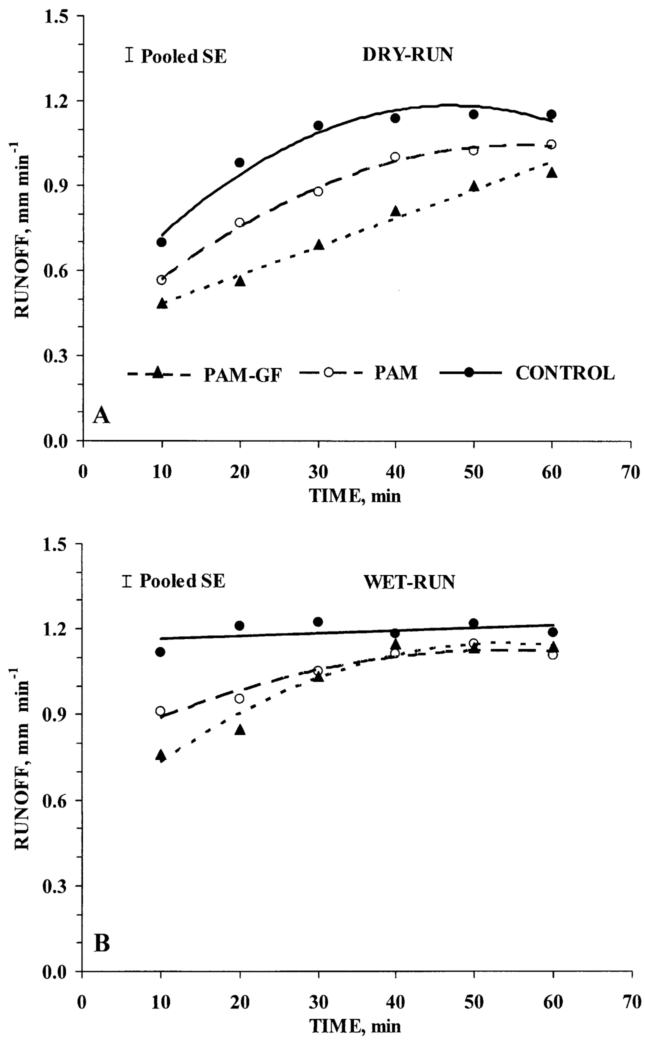

Fig. 4. Mean runoff within the event from soil berms treated with polyacrylamide (PAM), PAM plus geotextile fabric (PAM-GF), and a control berm without PAM or GF under field conditions for the (A) dry- and (B) wet-run rainfall simulations. Error bars represent the pooled standard error of the treatment means ($n = 3$).

treatment would quickly approach that of the control treatment under intense rains. Similarly, Aase et al. (1998) found that 2 kg ha^{-1} of PAM reduced runoff by 70%; however, runoff from PAM-treated and untreated soil after 30 min of irrigation at 80 mm h^{-1} was the same.

Our results suggest that there will be the least runoff contribution into the runoff plots from the berms treated with PAM plus GF up to 90 min of rainfall simulation. Runoff contribution from the treatments will be the same as the berms become saturated. The error introduced to the total amount of runoff from additional runoff from the berms was compared with the variability in measured runoff data from the Universal Soil Loss Equation continuous cultivated fallow plots at the Midwest Research Claypan Farm (Ghidey and Alberts, 1998). Confidence intervals of runoff showed that the error induced from berms would be insignificant ($P < 0.01$) for plots having a plot-to-berm area ratio of 10:1. The smallest plot area that would eliminate this error would be ≈15 m^2 bordered with 0.25-m-wide berms with a total area of 1.5 m^2. Since added surface runoff from berms is insignificant for plots having a plot-to-berm area ratio of 10:1, formation of concentrated flow along the berms is not expected to occur in large runoff plots (Blanco-Canqui et al., 2004). In conclusion, results indicate that there would be some additional runoff from berms but its contribution to runoff is small.

Soil Berms as an Alternative to Steel Plate Plot Borders

Results from our studies indicate that the use of 9 kg ha^{-1} of PAM in combination with GF is an effective treatment for reducing soil loss (<1%) from soil berms. Soil loss was reduced to 0.007 ± 0.003 Mg ha^{-1}. Thus, soil berms treated with both PAM and GF can be an alternative to steel plate borders. The berms can be constructed, deconstructed with tillage, and then reconstructed. Unlike the construction of soil berms, installation of steel plate borders requires special tools for driving the metal plates into the soil and frames to keep the metal plates straight while driving them (M. Olson, 2003, personal communication). Costs for purchasing and installing the steel plate borders are expensive. Steel plate borders are commonly driven ≈150 mm into the soil. However, in Alfisols, which have argillic horizons, they are often driven deeper (≈200 mm) to prevent runoff underneath the steel plate, increasing the cost because a taller plate is required (Ghidey and Alberts, 1998). Soil berms eliminate concerns about any runoff undercutting steel plates as well as reducing the costly installation. Importantly, the cost of material for constructing soil berms is relatively low. For example, the cost of PAM per 1-m length of soil berm, based on the cost of 1 kg of anionic PAM of ≈$20, is about $0.01 when applied at a rate of 9 kg ha^{-1}. Therefore, the total cost per 1-m length of soil berm including PAM ($0.01), GF ($0.20) and labor ($0.32) is about $0.53 m^{-1}. In contrast, the cost per 1-m length of steel plate border including 16 gauge steel plates ($3.00), labor ($2.00), and tools ($0.50) may be as much as $5.50 m^{-1}. Thus, the material and construction costs for soil berms would be ≈10% of the cost of steel plate borders. As an example, for an experiment having 18 plots with a length of 20 m each, the cost of steel plate borders would be about $3980.00 for both lateral borders, whereas the cost of berms would be about $360.00.

In conclusion, soil berms treated with PAM and overlaid with GF can be a simple and economical alternative to steel plate plot borders particularly for temporary and relatively large plots for studies under simulated rainfall conditions. We speculate that berms treated with PAM-GF treatment can perform reasonably well for at least one season. Should the berms be used for long-term studies, they may need to be repaired and PAM reapplied for a continued erosion reduction. Again, soil berms are envisioned to have a potential application as plot borders for short-term runoff studies. Further research should focus on evaluation of soil berms under variable rainfall intensities and multiple PAM applications. Furthermore, because sorption attributes of PAM may vary by soil, additional research is needed with other soils.

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