Controlling Erosion with Polymers

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Abstract: Soil structure may be improved by amending it with organic polymers. The use of Polyacrylamide (PAM) of high molecular weight (10 millions g/mol—15 millions g/mol) and moderate negative charge (15%—20% hydrolysis) for stabilizing the soil surface and decreasing runoff and erosion have been demonstrated in laboratory and field studies. Adding 5 mg/l—10 mg/l PAM to irrigation water in furrow irrigation prevents furrow erosion and increases infiltration rate and is applied on over 200, 000 ha in western USA. Treatment of the soil surface with 5 kg/ha—20 kg/ha of PAM increases the final infiltration rate of soils by an order of magnitude and reduces runoff and erosion several folds. In most of the field experiments, the polymer was dissolved in irrigation water prior to its application. This makes it impractical under rain fed conditions. Many studies are underway to find ways to spread uniformly on the soil surface dry PAM in very small amounts (5 kg/ha—20 kg/ha), while maintaining its effectiveness. Spreading mixtures of dry granular PAM with dry gypsum was found effective in laboratory studies and is being tested in field studies. The current understanding of the role of soil surface in determining runoff and erosion has led to the concept of treating only the soil surface with the polymers, rather than the cultivated layer, thus making their use cost effective.

Keywords: PAM, gypsum, infiltration, runoff, soil loss

1 Introduction

Erosion was recognized as a problem in early civilizations. Water erosion is the product of detachment of soil particles by raindrop impact or hydraulic shear stress and transport of the particles by shallow overland flow (interrill erosion) and concentrated confined flow (rill erosion). Traditional strategies for erosion control are based mainly on mechanical measures which 1) protect the soil surface from raindrop impact (mulching), 2) increase surface roughness to reduce runoff volume and flow velocity, and 3) alter slope-length gradient to minimize flow shear.

An alternative approach to soil conservation is the use of amendments, which increase aggregate stability, prevent clay dispersion and increase the cohesion forces between soil particles. Interest in organic polymers as soil conditioners was enhanced in the early 1950s when the Monsanto Company developed Krilium-a trade name for different organic polymers (Levy, 1995). Krilium was effective in stabilizing the soil structure; however the methodology of mixing the polymer with the tillage layer was too expensive for field agriculture.

The current understanding that seal formation, runoff and soil erosion are soil surface phenomena gave rise to the concept that it is necessary to treat and modify the properties of the soil surface only (Lentz *et al*., 1992; Levy, 1995; Shainberg *et al*., 1990; Sojka and Lentz, 2000). Consequently, small amounts of soil amendments are needed, which make their use for erosion control economically feasible.

2 Polyacrylamide (PAM) properties

Application of water soluble high molecular weight polymers, generally described as polyacrylamide (PAM), on soils have been shown to increase aggregate stability and decrease runoff and erosion. PAM is a chemical made up of many subunits (monomers) of acrylamide coupled together to form long chains (Fig. 1).
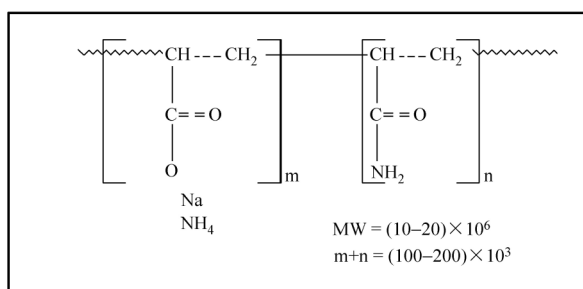
Fig. 1 Acrylamide and Na –acrylate in anionic PAM

The molecular weight of PAM varies from a few thousands to approximately 20 million g/mol. The PAM used in agriculture has very high molecular weight (10 million g/mol—15 million g/mol), i.e., 100,000—200,000 repeating units, each with molecular weight of 71 g/mol (Barvenik, 1994). The approximate length of the PAM chains in solution may reach 0.1 mm—0.2 mm (Levy, 1995). PAM can be cationic, nonionic or anionic, with the latter form being the most commonly used. The charge density of the anionic PAM depends on the degree of hydrolysis, i.e., the number of amine groups substituted with OH^{-1} (Fig. 1, Barvenik, 1994). The PAM used in erosion control carry a negative charge on about one fifth of the monomers (20% hydrolysis). Anionic PAMs with molecular weight of 15 millions g/mol, form very viscous solutions at concentrations $\geqslant 0.1\%$ (Barvenik, 1994). Thus PAM solutions are impractical for commercial use (not suitable for pumping). Dry PAMs with diverse properties (various molecular weights, charge signs and charge densities) are commercially available and have the advantage of low shipping costs and long shelf life. Disadvantages of the dry PAM form are the need for dissolution equipment, dissolution time of at least 30 min—60 min, and dust release during handling if the particle size is too small. Control of erosion by PAM can be maintained by either adding the polymer to irrigation water or by applying the polymer directly to the soil surface. Both methods of PAM application are discussed next.

3　PAM addition to irrigation water

Controlling Furrow Erosion. Surface irrigation is the most widely used irrigation practice in the world. The magnitude of soil erosion associated with irrigation in general and with furrow irrigation in particular has been recognized (Carter, 1990). Typically, from 5 ton/(ha • year) to 50 ton/(ha • year) of soil can be lost from irrigated fields, and nearly three times that amount from near the furrow inlets (Berg and Carter, 1980). Furrow erosion can be prevented by adding PAM (10 mg/L) to the inflow water during the advancement time of the irrigation (Lentz *et al*., 1992; Lentz and Sojka, 2000). Summarizing many experiments it was concluded that this treatment reduced sediment loss by 93% compared with the control. Residual erosion abatement in a subsequent irrigation, without further addition of PAM, was approximately 50%. Use of PAM also increased net infiltration (15%—50%) and promoted greater lateral infiltration. Substantial runoff reductions have been documented for nutrients and pesticides. No adverse effects have been seen for soil microbial populations (Lentz and Sojka, 2000). The PAM-amended irrigation water can impact the system in two ways: (1) PAM is adsorbed onto soil surfaces, increasing soil cohesion and aggregate stability; and (2) PAM flocculates soil particles suspended in the furrow stream, producing larger aggregates that tend to settle out of the flow (Lentz and Sojka, 2000). Effective erosion control was achieved for a material cost below $3 per ha per irrigation. High effectiveness, low cost, and ease of application has resulted in rapid technology acceptance in the US (Lentz and Sojka, 2000).

Controlling Sprinkler Irrigation Erosion. Many semiarid and arid soils are prone to sprinkler irrigation induced erosion. As PAM greatly reduces erosion from furrow irrigation, the effect of dilute concentration of the polymer in sprinkler irrigation on runoff and erosion from soils was studied (Levy *et al*., 1992; Flanagan *et al*., 1997a&b). The effect of 5 mg/L, 10 mg/L and 20 mg/L PAM on soil permeability and erosion from loamy loess and a grumusol were studied during five consecutive irrigation of 60 mm each (Levy *et al*., 1992). The polymers were added to the irrigation water during the first 3

consecutive irrigation, and thereafter the soils were subjected to 2 additional irrigations of water only. During the first 3 irrigations, the final infiltration rate of the treated soils was significantly higher than those of the untreated samples (control). In the subsequent two irrigations with water only, the final infiltration rates values of the treated samples decreased to values similar to those of the control. Erosion of the thin treated layer and an insufficient amount of the polymer explained the low residual effect of the polymer. Soil losses in all the PAM treatments were significantly lower than those in the control (Fig. 2). PAM stabilized soil aggregates and increased the cohesion forces between the aggregates thus increasing their resistance to erosion. Soil losses decreased with successive irrigations (Fig. 2). The successive decrease in soil erosion in the first three irrigations with PAM was due to the accumulation of PAM and the stabilization of the aggregates at the soil surface. In the last two irrigations with tap water only (240 mm and 300mm), soil losses increased due to the erosion of the soil surface treated with PAM. The effect of PAM in irrigation water on soil losses from the silty loess was less pronounced (Fig. 2). Similar results were obtained by Flanagan *et al*. (1997) in a field study on small interrill plots (0.8 m wide$\times$0.6 m long) and larger rill plots (0.8 m wide$\times$10.7 m long).
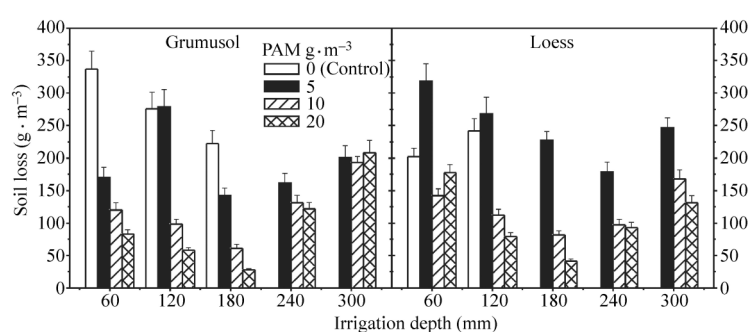

Fig. 2   Soil losses as a function of PAM concentration in 5 consecutive irrigations of 60 mm each. PAM was added to the irrigation water during first 3 consective irrigations(Levy *et al*., 1992)

It was concluded that PAM in irrigation water in concentration below 20 mg/L was very effective in preventing rill and furrow erosion. By comparison, dilute PAM solutions applied in sprinkler irrigation were somewhat less effective in preventing erosion (Flanagan *et al*., 1997a&b; Levy, 1995).

4   PAM addition to the soil surface

In Solution. In the case of natural rainstorms, PAM must be added to the soil surface prior to the rainy season. PAM may be added as a dry granular PAM or the dry PAM could be dissolved in water in concentration of up to 1,000 mg/L and the concentrated solution is then sprayed at the soil surface. Wallace and Wallace (1986) concluded that adding the polymer in a solution form was more effective in controlling seal formation and soil erosion and this method of polymer application is reviewed first.

Gabriels *et al*. (1973) was the first to demonstrate that surface application of a small amount (38 kg/ha) of an anionic PAM in solution was highly effective in maintaining high infiltration rate and preventing runoff and erosion. Similarly, Shainberg *et al*. (1990) also studied the effect of surface application of PAM on seal formation. They applied 10 kg/ha, 20 kg/ha and 40 kg/ha PAM dissolved in tap water to concentration of 0.5 g/L, and found that when, subsequently, distilled water rain was applied, the beneficial effect of rates above 20 kg/ha were insignificant in maintaining high infiltration rate (Fig. 3). They also found that the beneficial effect of the polymer was dramatically enhanced when the polymer was added in combination with gypsum (Fig. 3). For instance, the infiltration rate in the PAM treatment in distilled water (DW) was two to three times that of a untreated soil (control). But, when PAM application was supplemented with spreading of 5 Mg/ha of gypsum on the soil surface, the final infiltration rate was about 10 times higher than the control (Fig. 3). Gypsum spread at the soil surface dissolves and increases the electrolyte concentration in the soil solution above the flocculation value of

the soil clays (Oster *et al*., 1980). Flocculation of the soil clay is apparently a precondition for the cementing and stabilization of aggregates at the soil surface by anionic polymers.
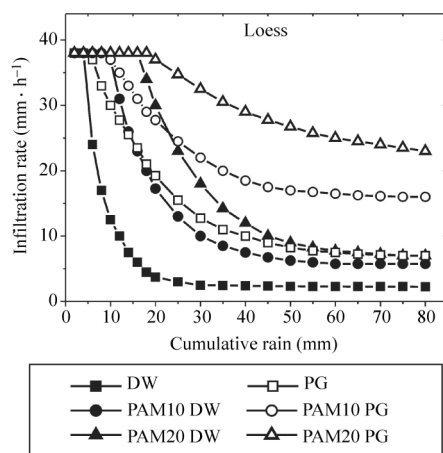

Fig. 3   Infiltration rate of loess, treated with PAM (10 kg • ha^{-1} and 20 kg • ha^{-1}) and gypsum (5 Mg • ha^{-1}), as a function of rain depth (Shainberg *et al*., 1990)

Soil loss from sandy loam samples treated with 20 kg/ha of PAM in combination with a source of electrolytes (either using tap water rain or distilled water rain together with gypsum addition to the soil surface), and exposed to simulated rainfall was studied by Smith *et al*. (1990). PAM plus electrolytes treatments resulted in soil losses of <10% of the soil losses obtained in the untreated samples (Fig. 4). However, electrolytes or PAM alone (without electrolytes) reduced soil losses by only 50%. It was suggested that the beneficial effect of the combined treatment of PAM and electrolytes was not only because of reduced runoff but also because soil particles at the soil surface were larger than those in the untreated soil and, hence, these particles were more difficult to detach and entrain in the runoff.
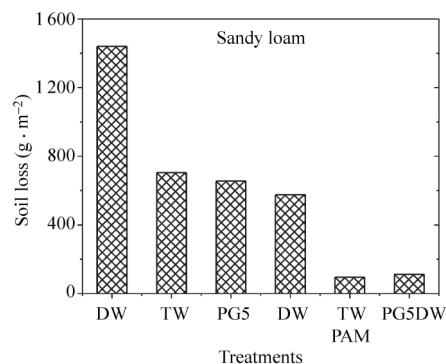

Fig. 4   Soil loss from sandy loam treated with 20 kg • ha^{-1} PAM in combination with a source of electrolyties TW-tap water, DW-distilled water, G-gypsum(Smith *et al*., 1990)

The beneficial effect of dissolved PAM applied to the soil surface in decreasing soil erosion was also demonstrated in field studies at steep slopes (Agassi and Ben-Hur, 1992; Flanagan *et al*., 1997b). Agassi and Ben-Hur (1992) studied the effect of 20 kg/ha of PAM (supplemented by 10 Mg/ha gypsum) on soil losses from slopes of 33%—60% and 15 m—25 m long, under natural rain conditions. Soil losses from the PAM treatments decreased 6 fold to 10 fold in comparison with the control. Flanagen *et al*. (1997b) arrived at a similar conclusion that soil surface application of the PAM was effective in controlling erosion, even at very high water inflow levels.

Spreading Dry Granules. In most PAM applications (and all those described up to now) PAM dissolved in water was applied to the soil surface. This practice is not possible in rain-fed agriculture because water for dry PAM dissolution is not available. In order to apply 10 kg/ha—20 kg/ha of PAM in solution containing 1g/L, the volume of the solution to be sprayed is 10 m^3/ha—20 m^3/ha. Also, it is difficult to dissolve dry PAM in water and the resultant solution is very viscous. Thus, labor and water needed for PAM dissolution and spraying makes PAM in solution application in dry land farming uneconomical. In addition, uniform spreading of a small amount of dry PAM (10 kg/ha—20 kg/ha) in the field is very difficult. Thus, the dry PAM granules must be mixed with a cheap material that is available close to the fields. Cheap materials that were tested were either dry gypsum or dry local soil.

Yu *et al*. (2002) studied in the laboratory the effect mixing dry granular PAM (10 kg • ha^{-1} and 20 kg/ha), with the upper 5 mm of the soil, or with gypsum (2 Mg/ha and 4 Mg/ha) added to the soil surface, on runoff and erosion from two soils, a loess and a grumusol, exposed to simulated distilled water rain of 36 mm/hr. They found that mixing dry PAM with the upper soil layer reduced infiltration rate, increased slightly runoff and reduced very significantly soil erosion from the two soils, compared with the control (Fig. 5). Spreading PAM mixed with gypsum was effective in increasing infiltration rate and reducing erosion (Fig. 6). The effect of spreading dry PAM mixed with gypsum on infiltration rate, runoff and erosion was similar to the effect of spraying dissolved PAM and gypsum on infiltration rate runoff and erosion (Fig. 3 and Fig. 5).
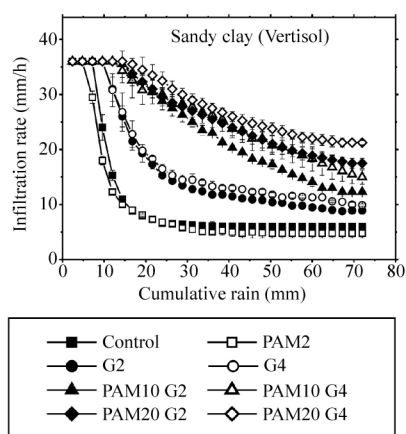

Fig. 5 Infiltration rate of grumusol treated with dry PAM(10 kg • ha^{-1} and 20 kg • ha^{-1}) and gypsum(2 Mg • ha^{-1} and 4 Mg • ha^{-1}) and exposed to simulated DW rain
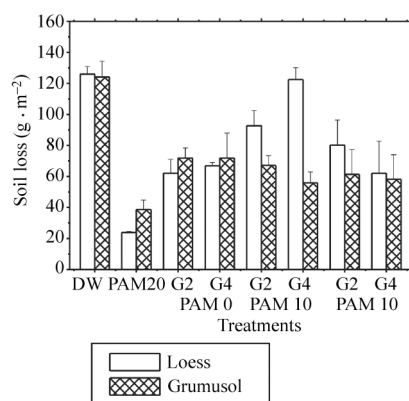

Fig. 6 Total soil loss from Loess and grumusol exposed to 72 mm DW rain. The soils were treated with gypsum (2 Mg • ha^{-1} and 4 Mg ha^{-1}) and dry PAM(0 kg • ha^{-1}, 10 kg • ha^{-1} and 20 kg • ha^{-1})

The effect of PAM mixed with the soil on runoff and erosion during distilled water rain was unexpected and was used to explain the mechanism by which PAM interact with the soil particles. During the rain, the dry PAM dissolved in the soil solution. Anionic polymers are good flocculent and only few segments of the polymer chain (which consists of 100,000 to 200,000 monomers) are adsorbed on the soil particles, while the long tails are in solution (Ben-Hur and Keren, 1997). Thus, the anionic PAM has a relatively long grappling distance that facilitates the formation of interparticle bridges and flocculates. The long chains cement soil particles together and reduce soil erosion. However, at the same time the tails of the long chains block the conducting pores of the soil and reduce the hydraulic conductivity of the soil surface. Thus, PAM mixed with the soil surface, reduces rain infiltration rate and increases runoff. With increase in electrolyte concentration in the soil solution (by spreading gypsum at the soil surface), the repulsion forces between the negative sites on the anionic polymer diminishes and the polymers exists as coiled and short chains which are not as effective in reducing the hydraulic conductivity of the soil surface and in preventing soil erosion.

5 Summary

Adding soil polymers to the soil surface can serve as an option to prevent soil erosion. Small amounts of negative polymers (< 20 kg/ha) with very high molecular weight (10 million g/mol—20 million g/mol), added to the soil surface, either in solution or dry, are effective in preventing particles detachment and hydraulic shear stress. The use of polymers to prevent furrow erosion is already practiced on > 1 million ha. Applying dissolved PAM to the soil surface was effective in preventing runoff and erosion. However, this practice is difficult to apply under rain-fed conditions. The efficiency of spreading dry PAM, mixed with gypsum or soil material, in preventing erosion under rain-fed conditions is in its early stages of research. Further research is needed to fully understand and establish whether their use for agricultural and environmental purposes is economically feasible.

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