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Erosion Control in Furrow Irrigation Using Polyacrylamide

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1. Introduction

Currently gravity irrigation remains the most widely used in agricultural areas and 90 percent of plantings, the water is applied to the plots by gravity. One of the main problems with these systems is erosion, which is a by product of the erosive forces of water over the row, which brings soil loss and therefore decreases in crop yield.

Erosion is the removal of surface soil material caused by water or wind (Kirkby, 1984). It is caused by several factors, such as steep slopes, climate, inadequate use of soil, vegetation cover and natural disasters; however, human activities can greatly accelerate erosion rates. This phenomenon is considered a severe problem because it is associated with inappropriate agricultural practices, overgrazing, poor utilization of forests, thickets, grasslands, forests, and changes in land use from forest land primarily for agricultural purposes.

According to Becerra (2005), the two main types of erosion are geological erosion and accelerated erosion. Geological erosion includes both training and erosive processes, which maintain the soil in a favorable balance, suitable for plant growth. Accelerated erosion and loss of soil degradation is a result of human activities.

Geological erosion when the soil is found in its natural environment under the cover of native vegetation. This type of erosion is responsible for the formation of soils and its distribution on the Earth's surface. The long-term effect of this type of erosion has led to larger landscape features such as canyons, meandering rivers, and valleys. In other words, this type of erosion is the result of the action of water, wind, gravity and glaciers.

Accelerated erosion, soil loss is usually associated with changes in vegetation and soil conditions and is caused mainly by water and wind. The forces involved in accelerated erosion are: (1) attack forces, which remove and transport the soil particles, (2) resistance forces, which limit the erosion.

Soil erosion is the main source responsible for the gradual decrease in fertility and therefore the productive capacity of soils. Erosion caused by hydric erosion, include the action of rain and runoff.

In general, water erosion is divided into erosion or splashing raindrops, sheet erosion, rill erosion, gully erosion and irrigation channels.

Soil splashing occurs when raindrops fall directly onto the soil particles or very thin areas of water, spraying huge amounts of soil due to the kinetic energy of impact. In plane soils, the dispersion of soil is more or less uniform in all directions, but on sloping soil will be a net transport downhill. If overland flow occurs, the removed particles are incorporated into the water flow and will be transported downstream before being deposited on the surface again.

Sheet erosion removes soil evenly in thin layers, due to the laminar surface flow in thin layers that runs along the soil. Raindrops cause the detachment of soil particles, increasing the sediment movement by filling the pores of the surface layer, reducing the rate of infiltration. The abrasive force and the drag of the laminar flow are a function of the depth and speed of runoff for soil particle or aggregate size, shape and density determined.

Rill erosion occurs when surface flow is concentrated, the water acts on the soil detaching and causing channels or small streams. These types of channels become stable and are easily seen. The detachment and transport are more severe because the speeds of moving water are higher runoff and hydraulic shear stress increases with the degree of slope and hydraulic radius of the section of the channel.

Gully erosion in open channels above the grooves, which collects water during or immediately after rainfall. Gully erosion, which causes a late stage that produces rill erosion, just as it is a post-sheet erosion.

The erosion in irrigation channels is due to soil detachment and transport of it are more severe, thus the flow velocity in the channel is greater than that caused by rain effects. Soil detachment increases with the degree of slope and hydraulic radius of the section of the channel.

One of the main mechanisms that cause water erosion is the formation of surface sealing when the soil is exposed to the action of the impact of raindrops and concentrated flows in the rills (Orts et al., 2000).

Seal formation is the result of two complementary mechanisms (Yu et al., 2003): a) physical disintegration of surface soil aggregates, and b) the physicochemical dispersion of clay, moving to deeper soil layers by infiltrating water. These block the pores below the surface and form a low permeability layer called "washing area".

Given these aforementioned problems, many forms are viable and economic alternatives, being the application of polyacrylamide (PAM) which is one of them. This has been as soil conditioning since 1950; however, the expansion of its use was not seen until the last decade (Green & Stott, 2001). When applied to soil it, increases the aggregate stability, reduce the release and transport of sediments, flocculate the suspended sediment, increases infiltration (Norton et al., 1993; Lentz et al., 2001; Leib et al. 2005) and is a non-toxic product whose by mechanical interaction degrades into CO2, water and nitrogen.

The PAM is a water soluble polymer with the ability to enhance soil stabilization. It is grouped in a class of compounds formed by polymerization of acrylamide (Lentz et al., 2001). Pure PAM is a homopolymer of identical units to that of acrylamide. The molecular weight gain increases the length of the polymer chain and consequently the viscosity of the PAM solution. It is currently used in the construction and agriculture, as a soil conditioner it on the anionic polymer of high molecular weight (10 - 20 mg mol^{-1}), whose structure is shown in Figure 1.

The mechanism responsible for reducing runoff and soil loss, and therefore the final increase in infiltration is related to the ionic strength of the PAM in the soil solution (Norton et al., 1993; Santos et al., 2000). Therefore, in the soil solution decreased clay dispersion and flocculation aid, according to the theory of diffuse double layer (Van Olphen, 1977).

The diffuse double layer is compressed to the surface of clay when the electrolyte concentration is increased and decreases the separation of clay particles. Due to compression of the double layer, the range of the repulsive forces is greatly reduced (Van Olphen, 1977), thereby promoting flocculation.

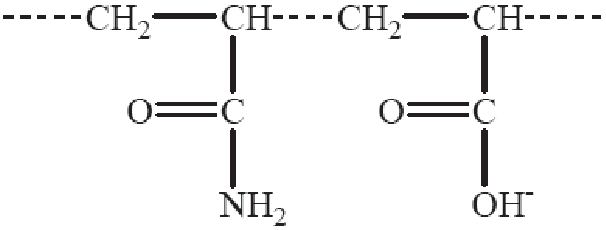


Fig. 1. Molecular structure of anionic polyacrylamide

Several studies have shown that PAM dissolved in irrigation water at a rate of 10 kg ha^{-1} improves water infiltration (Leib et al., 2005; Chávez et al., 2010) and may be increased from 7 to 8 times the final infiltration as compared with the control (Ajwa & Trout, 2006). However, at rate of 20 kg ha^{-1} applied in granular was this has proven to be effective in controlling erosion (Lentz & Sojka, 2000; Chávez et al., 2009), if applied in the first 5 mm of soil, it will reduce runoff by up to 30% as compared with the control plot (Yu et al., 2003), and may be increased by up to 54% of the aggregates stability (Lentz et al., 2001; Shrestha et al., 2006).

According to Leib et al. (2005) polyacrylamide application prior to irrigation control the erosion caused by concentrated flow in furrow irrigation systems, reducing soil detachment caused by hydraulic shear stresses. Wetting fronts are broader and infiltration is higher in the rows treated with polyacrylamide as compared with those that are untreated (Yu et al., 2003).

The use of PAM as alternative practice of soil conservation has been repeatedly proven to be an effective and viable (Bjorneberg et al., 2000; Santos et al., 2000; Lentz et al., 2001; Yu et al., 2003; Kornecki et al. 2005; Shrestha et al., 2006; Chávez, 2007; Chavez et al., 2009). However, this effectiveness depends on the type and charge density and molecular weight (Green et al., 2001). PAM with high molecular weight and low concentrations in the irrigation water has given better results for erosion control (Lentz & Sojka, 2000; Bjorneberg et al., 2003; Shrestha et al., 2006; Chávez, 2007; Chavez et al., 2009).

The application of PAM to soil is a viable way to control erosion, however, there are no current studies comparing the methods of implementation; therefore, the aim of this study was to evaluate three forms of application of PAM in a groove to find the one that is most effective in controlling soil erosion caused by concentrated flows, using a rate of 20 kg ha^{-1}.

2. Theory

Soil erosion process is associated with the action of two forces: hydraulics and resistance: the first break and remove the particles and carry them through the channels and the second, due to electrochemical nature, somehow prevents the detachment. The shear stress acting on the bottom of a river or channel, or on the soil surface, is one of the most significant variables of hydraulic power. Calculation of this is derived from the momentum equation for uniform flow in an open channel (Chow et al., 1988).

Rill erosion is a phenomenon that involves the detachment of soil particles and transports them due to the drag force of flowing water. The deposit of sediment is the result of the previous two phases, which are hauled through the grooves and led to the boundaries of the land, bringing with it problems of sedimentation in drainable networks, which are then translated into economic losses for users because the rehabilitation work needed for optimal functioning is expensive.

The basic equation in the process of erosion in rills and interrill is the sediment continuity equation for unsteady flow with little depth (Foster, 1982):

$$\frac{\partial q_s}{\partial x} + \rho_s \frac{\partial (cy)}{\partial t} = D_r + D_i \tag{1}$$

where q_s is the sediment load [$ML^{-1}T^{-1}$], x the downstream distance [L], ρ_s the particles density [ML^{-3}], c the sediment concentration [$ML^{-2}T^{-1}$], y the flow depth [L], t the time [T], D_r the rill erosion [$ML^{-2}T^{-1}$], and D_i the interrill erosion [$ML^{-2}T^{-1}$]. The erosion parameters q_s, D_r, and D_i are measured per unit width of the channel.

For shallow flows and gradually varied the term $\rho_s \partial (cy)/\partial t$ can be neglected, resulting in the continuity equation that is widely used for permanent flows:

$$\frac{dq_s}{dx} = D_r + D_i \tag{2}$$

The shear stress along the boundaries of the flow, leads to incision of the walls of a channel as long as such efforts exceed the tractive force or critical shear stress. The detachment of soil particles wetted perimeter can be well described by:

$$D = K(\tau_s - \tau_c)^{\alpha} \tag{3}$$

where D is the detachment of soil in a wet perimeter point [$ML^{-2}T^{-1}$], K the soil erodibility factor [$L^{-1}T$], τ_s the hydraulic shear stress acting on a surface wetting perimeter [$ML^{-1}T^{-2}$], τ_c the critical shear stress [$ML^{-1}T^{-2}$] and α has a value of 1.05.

Soil detachment in the rills due to incision is proportional to excess shear stress with respect to its critical value, ie α takes the value of 1.0, and K = K_r, called erodibility factor in the rill [$L^{-1}T$], this is (Foster, 1982):

$$D_r = K_r(\tau - \tau_c) \tag{4}$$

where D_r is the detachment of soil in the furrow [$ML^{-2}T^{-1}$], ie the mass of loosened soil in unit time per unit area, τ the hydraulic shear stress in the rill bed [$ML^{-1}T^{-2}$], τ_c the critical shear stress ensures that the soil particles are detached [$ML^{-1}T^{-2}$].

Soil resistance to shear forces of flowing water is called the critical shear stress (τ_c), or also tractive force, this value is the value of the regression line when it crosses the x-axis, ie when soil detachment begins by concentrated flow effect. For cohesionless soils, the Shields diagram is the method used to describe the tractive force of the individual particles.

According to Alberts et al. (1989) for cohesive sediment, the individual grains of sediment lie and remain in the background because of their own weight and resist horizontal movement due to friction with the adjacent grains. Therefore, the stabilizing force is associated with the submerged weight of individual grains. Whereas from a critical shear stress, the sediment may start to move, the Shields parameter is an expression that denotes the situation where the sediment is about movement, where the drag force equals the friction velocity. The sediment starts to move when the cutting speed of flow is greater than the critical shear rate.

For non cohesive materials, the critical shear stress has been associated with many soil properties, including the cutting force, salinity and moisture content (Alberts et al., 1989), and the percentage of clay, the average particle size, percentage of dispersion, organic matter content, cation exchange capacity, ratio of calcium - sodium and plasticity index (Prosser & Rustomji, 2000).

The typical range of critical efforts to cut agricultural soils is 1 to 3 Pa; however, Foster & Meyer (1975) recommended an average of 2.4 Pa. On the other hand, Alberts et al. (1989) developed a regression equation using an extension of the Water Erosion Prediction Project (WEPP model) with field data and found that the critical shear stress for agricultural soils can be estimated based on: the fine fraction of sand, fraction calcium carbonate, sodium adsorption ratio, specific surface area, clay fraction dispersed in water and clay fraction.

In agricultural soils with a clay fraction larger than 0.30 mm, Alberts et al. (1989) found that the tractive force of the soil can be predicted from the volumetric water content. Other relationships have been developed from data obtained from the WEPP model and the results are different from the original relationship.

Conceptually, the critical shear stress total of flow in a channel can be divided into two components: the roughness of the grain and form roughness (Graf, 1971). The effort hydraulic roughness of the grains is responsible for erosion and sediment transport. The total soil hydraulic effort is a combination of grain roughness and form, however, the form roughness is larger than the roughness of the grains; therefore, in the case of detachment in a channel it is necessary to know the stress distribution along the borders, ie the stress on the bed τ channel for uniform flow as given by:

$$\tau = \gamma_w R_h S_o \tag{5}$$

where γ_w a is the specific weight of water [ML^{-3}], R_h the hydraulic radius [L]; and S_o the slope of the furrow [LL^{-1}].

Because the shear stress distribution in the bed of the rill is not uniform, use of an average value thereof, which is considered as a potential detachment, but this can result in significant errors in the estimation of τ_c (Foster , 1982).

3. Application

The experimental work was developed in the hydrological module of the Faculty of Engineering of the Universidad Autonoma de Queretaro. PVC pipe class 14 of 30 cm in diameter was used and cut in half to form the simulated rill. The dimensions of the circular channel half-circle formed were: 0.30 m wide x 0.25 m deep at the center and 6 m in length, which was settled the soil at depth of 0.20 m at the center, with a bulk density similar to that observed in the field. Given the channel slope was 3%, the same as was achieved by three supports placed at the ends of the channel and in the center of it, see Figure 2 (Chávez, 2007).

The soil used, according to the FAO-UNESCO classification (1988), is a Pelic Vertisol representative of the study area.

The inflow water was provided to the system by a constant head tank of 60 liters, placed 2 m above the reference level, and water was supplied by a ¾ HP pump connected to a tank with capacity of 1000 liters. Inflow water in the furrow was regulated by a butterfly valve and measured by a flow meter, see Figure 3. The initial flow was 75 l h^{-1}, the second flow was 100 l h^{-1}, then further increases were 50 l h^{-1} until the maximum flow of 250 l h^{-1} was reached.

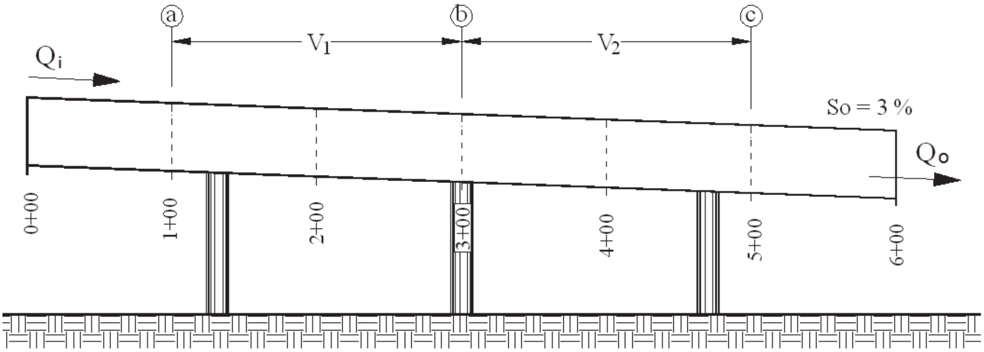


Fig. 2. Scheme of channel

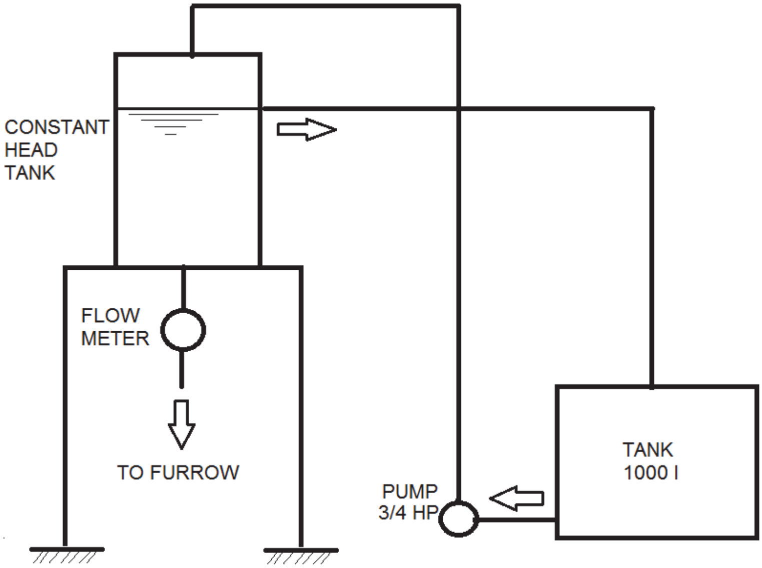


Fig. 3. System of water flow in the experiment

3.1 Treatments applied

Three treatments of PAM were applied on the soil at rate of 20 kg ha^{-1}: PAM applied as a granular, diluted PAM and injected into the inflow and diluted PAM and sprayed on the furrow bed, which were compared with measurements made in a furrow without a PAM application.

3.2 Measurement of variables

For the analysis of soil detachment D_r, critical shear stress τ_c and the shear stress τ were measured flow parameters such as speed and width of the water surface, which serves to identify areas of flow, wetted perimeter, hydraulic radius, and other parameters needed to determine the amount of detachment and forces acting on the rill. Plastic bottles was placed at the end of the rill in order to collect the runoff and sediment samples for laboratory evaluation. The velocity and width water surface parameters were measured three times directly into the rill at points a, b and c, see Figure 2, and for calculations the averages in each of flow quantified were used. The boundaries of these three sections correspond to specific sites where measurements of water velocity (v_1 and v_2) were made.

In this research it was assumed that the channel is rectangular shape, based on the progressive erosion of the flow before reaching a non-erodible soil layer takes this form (Lane & Foster, 1983). The calculation of flow depth was from the continuity equation: Q=Av, where Q is the flow and v the flow velocity in the channel. Considering that the area is given by A=bh, where b is the channel width and h the head, and it will have h=Q/bv. The speed is obtained as the average $v = \frac{1}{2}(v_1 + v_2)$. These data were used in the calculation of shear according to equation (5).

3.3 Calculation of the detachment rate Dr and critical shear stress τ_c

The calculation of the detachment rate D_r, was made with the amount of sediment collected in the containers for each of the measurements made in the different treatments, at a time and a rill area known as ($gm^{-2}s^{-1}$). The calculation of shear stress [Pa] was made using equation (5), where specific weight $\gamma_w = 9879$ Nm^{-2}, was taken assuming a constant temperature 20°C.

3.4 Measurement of erosion

The runoff and sediment samples were taken once the inflow was stable, using plastic bottles wide necked of a one liter capacity. The collected samples were weighed, flocculated with 10 ml of a saturated solution of aluminum sulfate, decanted and dried in an oven at 105 °C to constant weight.

4. Results

Table 1 shows the values of parameters obtained by fitting the experimental data of detachment and shear stress by the method of least squares of equation (4), ie: erodibility factor in the furrow K_r, the critical shear stress τ_c, the coefficient of determination r^2, and the value of the soil detachment rate in the furrow D_r with maximum flow of 250 $l\ h^{-1}$.

4.1 Detachment rate

The furrow detachment rate D_r obtained for the control was 6.9 $gm^{-2}s^{-1}$, but this value was significantly reduced in 67.6% with PAM applied in granular form to register a detachment of 2.3 $gm^{-2}s^{-1}$. This reduction was more pronounced when the polymer was applied diluted and injected into the inflow which is a common practice carried out in irrigation and sprayed on the soil; therefore, obtaining a reduction of 85.1% and 96.2% respectively, which is similar to results obtained by Lentz et al. (2001).

Treatments	**D_r***	**K_r**	τ_c	**r^2**
	[$gm^{-2}s^{-1}$]	**[$m^{-1}s$]**	**[Pa]**	
Control	6.9436	4.218	0.6498	0.9328
Granular PAM	2.2521	2.116	1.0770	0.9108
Injected PAM	1.0371	1.261	1.1084	0.9027
Sprayed PAM	0.2662	0.757	1.3923	0.9178

Table 1. Summary of results obtained from the application of PAM. Linear Equation. (*Maximum flow 250 l h^{-1}).

The reduction in soil detachment is due to the length of the chain anionic PAM presented, which when in contact with the negative charges of clays binds to it forming stronger bonds, providing greater resistance to soil evolution (Lentz, 2003). Consequently, when irrigation water comes in contact with the soil, and the PAM has been diluted and previously applied it has already reacted to the soil by providing greater cohesion, otherwise, the polymer applied granular form, which interacts with soil particles until it is dissolved with water.

Erosion data obtained from the furrow are represented in Figure 4 with a linear fit, where the reference furrow recorded an erosion rate of 0.30 g l^{-1} with initial flow and increasing the flow rate 100 l h^{-1} increased the release to 18.30 g l^{-1}, whereas with 150 l h^{-1} the increase was only 5.7 g l^{-1}, an increase of 150 l h^{-1} at 200 l h^{-1} had a low impact on the rate of sediment (6.3 g l^{-1}), and with a flow of 250 l h^{-1} there was an increase of 16.3 g l^{-1} as compared to the previous test.

Soil detachment began treatment with the granular PAM with a flow of 150 l h^{-1} and an erosion rate of 0.4 gl^{-1}. With the same flow, this initiates the release with the injected PAM in the inflow, but reported only 0.1 g l^{-1}, while with the sprayed PAM on the soil there was no detachment. An important difference was observed in the behavior of D_r. The values were approximately 1 which are very similar in the furrow control applying a flow of 100 l h^{-1} and the furrow treated with injected PAM in the inflow applying a flow of 250 l h^{-1}, while values of D_r for treatments with the sprayed PAM on the soil are still below these values.

The critical shear stress, defined as the point from which particles star to detach and transport the soil, present significant differences using a significance level α of 0.05 in student t-test between the control and treatments ($p < 0.0001$). Therefore, to control the critical shear stress by 0.65 Pa was obtained, whereas treatment with granular PAM is 1.12 Pa, which means that the application of PAM increases the soil resistance to erosion in furrows to increase the value of τ_c. This increase was less pronounced in treatment with injected PAM in the inflow, with 1.11 Pa the critical shear stress; however, the furrow treated with sprayed PAM on the soil had a greater effect recorded value of 1.39 Pa. This increase is approximately double that of the strength of soil resistance to detachment caused by concentrated flows into the furrows with respect to the control treatment. The detachment rate with the inflow of 250 l h^{-1} can be seen in Figure 5.

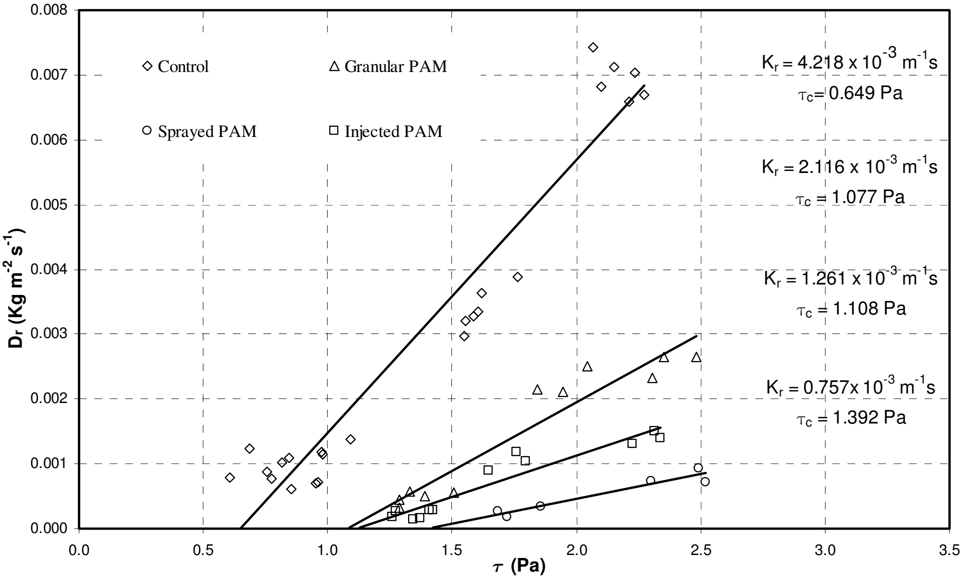


Fig. 4. Linear relation of the soil detachment with the treatments

4.2 Rill erodibility factor Kr

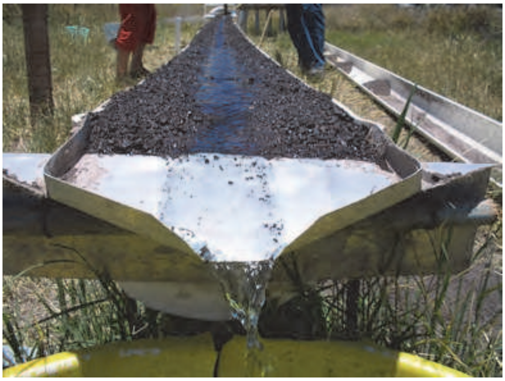
The erodibility factor K_r decreases by 50% as compared to the control as a result of the addition of PAM to soil in granular form. This change is associated with the PAM changes the physical and chemical properties of soil, with greater cohesive strength of particles and improving the stability of the aggregates. However, the soil response to the application of PAM is different in each treatment. Considering only the three forms of implementation of PAM shows that the average value of K_r for granular application is 2.11 m s^{-1}, this decreases to 1.26 m s^{-1} and 0.75 m s^{-1} with sprayed PAM on the soil and injected in the inflow, respectively, see Figure 6. Therefore, the regression slope indicates that the application of polymer sprayed on the soil, is the most efficient way to control erosion.

The data (τ, D_r) were fitted to a straight line, but it is possible that the erodibility factor itself depends on the shear stress at the furrow bed. Consequently, the data also were fitted with equation (3). Equations (3) and (4) are equivalent, if the erodibility factor is the next unit:

$$K_r = K\left(\tau - \tau_c\right)^{\alpha - 1} \tag{6}$$

Estimates of coefficient values K $[M^{1-\alpha}L^{-2+\alpha}T^{-1+2\alpha}]$ and from the exponent α of equation (3) were obtained with the method of least squares, using equation (3) in the form $\tau = \tau_c + \left(1/K\right)^{1/\alpha} D_r^{1/\alpha}$. Values are reported in Table 2 and shown graphically in Figure 7.

Control



Granular PAM

Injected PAM Sprayed PAM

Fig. 5. Detachment in the furrows treatments with PAM and the control

Making a comparison between the linear and the potential model shows that the critical shear stress for untreated furrow decreases from 0.649 to 0.0035 Pa, which indicates that the erosion starts when the irrigation water comes in contact with the surface soil. The critical shear stress in the soil application of granular PAM increased 0.267 Pa, while injected PAM into the inflow increased 0.221 Pa. In addition, with the relationship potential, sprayed PAM on the soil decreased by 0.237 Pa soil strength in relation to the linear model.

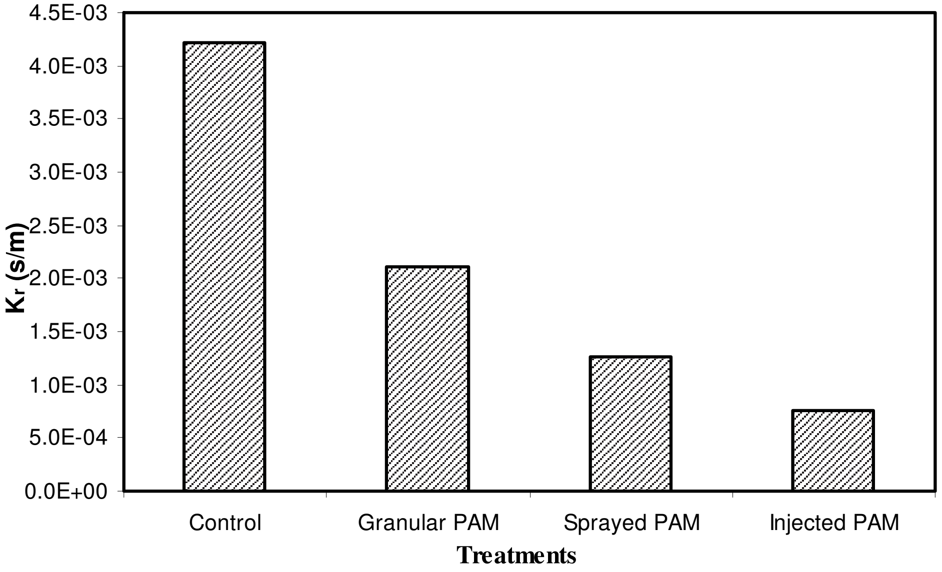


Fig. 6. Erodibility factor in the furrows treatments with PAM and the control

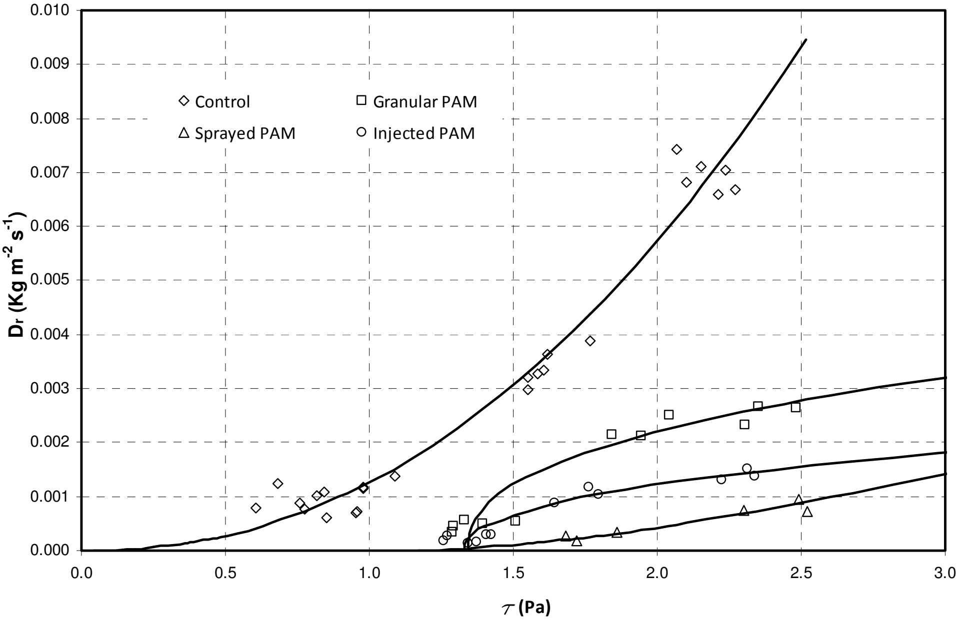


Fig. 7. Potential relation of the soil detachment with the treatments

If the linear model is taken as the valid model, the erodibility factor K_r in the furrow remains constant; however, as shown in the potential model, this value is dynamic, ie varies in function of the applied flow.

Treatments	D_r^*	K	τ_c	α	R²
	$gm^{-2}s^{-1}$	$g^{1-\alpha}m^{-2+\alpha}s^{-1+2\alpha}$	Pa		
Control	6.9436	1.2727	0.0035	2.1763	0.9560
Granular PAM	2.2521	2.6121	1.3443	0.4024	0.9324
Injected PAM	1.0371	1.4598	1.3290	0.4319	0.9489
Sprayed PAM	0.2662	0.5539	1.1546	1.5408	0.9225

Table 2. Summary of results obtained from the application of PAM. Potential Equation. (*Maximum flow 250 l h^{-1}).

4.2 Sediment loss

Sediment loss as shown in Figures 8 and 9 , where the difference between the control furrow with respect to the furrows treated with PAM is significant. For a flow of 100 l h^{-1}, the control furrow lost about 20 g per liter of water passing through the furrow, while the PAM-treated furrows have no losses.

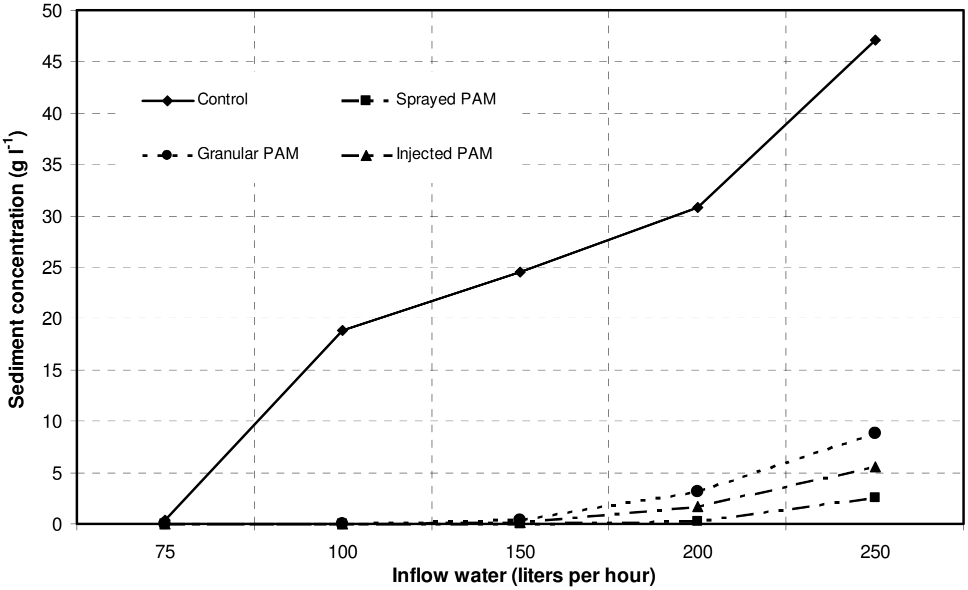


Fig. 8. Soil loss associated with different flow rates in all treatment

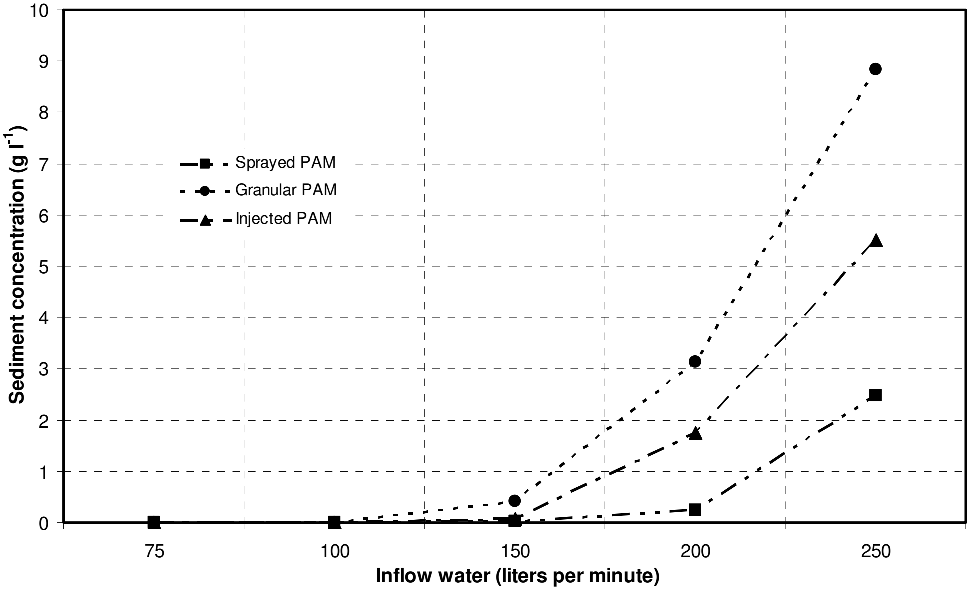


Fig. 9. Soil loss associated with different flow rates in the furrow with PAM

The same figures show that with an inflow of 200 l h^{-1} the furrow treated with sprayed PAM has a sediment concentration of only approximately 0.20 g l^{-1}, injected PAM 1.80 g l^{-1} while the injected PAM and sprayed PAM lost 3.10 g l^{-1}, as compared with the reference furrow loses on average 30.8 g l^{-1}, for an efficiency of 90-99% in the control of erosion. Orts et al., (2000) obtained a 97% reduction in soil erosion by applying PAM; however, the flow rate used was 23 l h^{-1}.

On the other hand, with flow of 250 l h^{-1} the control furrow lost about 45 g l^{-1} while the furrows treated with granular PAM saw loses 9 g l^{-1}, and sprayed PAM on the soil saw loses of less than 5 g l^{-1}. Therefore, reducing sediment loss is 80-94%. The efficiency of PAM decreased, but due to the lack of measurement with higher flow rates to 250 l h^{-1}, one can not infer that this decrease is progressive. It would be necessary to carry out investigations to see if the trend is the same.

5. Conclusion

The application of polyacrylamide to the soil in any of the forms of application helps to reduce the detachment of soil particles caused by the hydraulic efforts and the critical shear stress. However, liquid application is more effective in controlling erosion.

With the PAM implementation the sediment loss in the control furrow (45 g l^{-1}) was reduced to 10, 5 and 0.2 g l^{-1} with applications of granular PAM, diluted and injected in the inflow, and diluted and sprayed on the soil, respectively. This is because the PAM provided the cohesion between soil particles, increasing by more than one order of magnitude resistance to detachment.

The values of critical shear stress and rill erodibility factor are different between the linear model and potential model; however, the linear model over estimates the value of critical shear stress of control treatment, and for treatments with PAM, this value is sub estimate except with the PAM sprayed treatment. The furrow erodability factor obtained with the model potential is not constant; however, there is a need to experiment with higher flow rates than those applied in this experiment to see if the trend continues or there is a change.

Finally, the properties of the soil type and amount of clay, type of ions in solution and the ionic strength of soil solution, and the pH affect the efficiency of polyacrylamide to control soil erosion. Therefore, if in addition to applying the polymer, combined with other soil conservation practices, the results obtained will be better.

6. References

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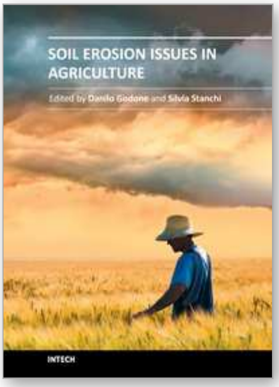

Soil Erosion Issues in Agriculture

Edited by Dr. Danilo Godone

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The book deals with several aspects of soil erosion, focusing on its connection with the agricultural world. Chaptersâ€™ topics are various, ranging from irrigation practices to soil nutrient, land use changes or tillage methodologies. The book is subdivided into fourteen chapters, sorted in four sections, grouping different facets of the topic: introductive case studies, erosion management in vineyards, soil erosion issue in dry environments, and erosion control practices. Certainly, due to the extent of the subject, the book is not a comprehensive collection of soil erosion studies, but it aims to supply a sound set of scientific works, concerning the topic. It analyzes different facets of the issue, with various methodologies, and offers a wide series of case studies, solutions, practices, or suggestions to properly face soil erosion and, moreover, may provide new ideas and starting points for future researches.

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