

Evaluation of Powdered Polyacrylamide Application along with Source of Electrolytes in Controlling Sodic Soil Erosion

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Abstract

The anionic polyacrylamide (PAM) is recently used to rehabilitate saline and sodic soils. It is also applied to control soil erosion; however, few researches have tested the effectiveness of anionic PAM along with source of electrolytes application to control artificial sodic soil erosion. An experiment was conducted to study the effects of anionic PAM with and without gypsum on the erosion of sodic soils under saline rain water conditions. A clay loam soil was prepared to achieve three levels of exchangeable sodium percentage (*ESP*); 0.5, 9.9 and 25.5 with appropriate salts solutions. Soil samples were air-dried and packed in the trays. Powdered PAM, gypsum or a mixture of both were applied to the salt treated soils. Soils were subjected to simulated rain-storm of 40 mm h⁻¹ by a fixed rainfall simulator. Saline waters with different levels of electrical conductivity (*EC*); 0.13, 2, 5, and 8 dS m⁻¹ were used for simulated rains during the study.

It seems that the artificial soil showed fairly similar soil erosion characteristics as that reported on a natural sodic soil. It was found that the soil sodicity enhanced soil erosion under non-saline water. It seems that the effects of electrolyte source on soil erosion were affected by the soil initial electrical conductivity (*EC_e*) rather than by the *ESP* level of soil. PAM amendment substantially increased the surface runoff while at the same time controlled the soil losses. A reduction in surface runoff was found by applying gypsum or saline water on the soil treated with PAM. However, it seems that the mixed addition of PAM with gypsum or salts enhanced detachments of soil particles by raindrop impact.

Key words : Gypsum, saline water, polyacrylamide (PAM), artificial sodic soil, soil erosion

1. Introduction

Soil sodicity occurs naturally and can be enhanced by human activities such as irrigation. In arid and semi-arid areas, sodic soils exhibit poor soil-water and soil-air relation; these properties adversely affect root growth restricting plant production and making the soils difficult to work when wet or dry. The

total area, which has sodic soils, is estimated at about 135 million hectares; but as the distribution of sodic soils is very scattered worldwide the individual areas are often too small for inclusion in overview soil maps at a world scale (FAO-AGL, 2000).

Soil sodicity can affect many physicochemical reactions. Soil pH usually has a strong relationship with exchangeable sodium per-

centage (Tan, 1993). Problem of sodic soil is caused by the presence of sodium attached to clay in soil. A soil is considered sodic when the sodium reaches a concentration where it starts to affect soil structure. The sodium may extend diffuse double layer and thus weaken the bonds between soil particles when wetted resulting in the clay swelling and often dispersing. When this happens the clay particles spread out or disperse making the soil water turbid. The dispersed clay particles can then move through the soil and clog the pores. Both swelling and dispersion reduce infiltration and drainage. During irrigation and rainfall, such soils tend to have more runoff and thus be vulnerable to water erosion (Shainberg *et al.*, 1984). Agassi *et al.* (1981) reported a considerable runoff from dispersive non-calcareous sodic soil induced by rainfall. Soil loss becomes more severe under sprinkler systems with high spraying intensities and longer duration of surface irrigation. Runoff and eroded sediments not only lead to deterioration of land productivity, but also contribute substantially towards non-point source contamination of surface water bodies (Tang and Rengel, 2003).

The scarcity of good quality water forces farmers world wide to use poorer quality water or reuse drainage water for irrigation. In some arid areas, saline (electrical conductivity of 2 to 5.8 dS m⁻¹) and sodic (sodium adsorption ratio of 12 to 26) water have been used for irrigation (Levy *et al.*, 1995; Yamamoto *et al.*, 1980). Irrigation with such water introduces sodium to the exchange sites and leads to the buildup of high *ESP* levels of the soil (Mantell *et al.*, 1985). When exposed to the impact energy of water drops, aggregates with high *ESP* levels disintegrate more readily than those with low *ESP* levels (Shainberg *et al.*, 1992). Consequently, at high *ESP* levels the soil erosion is significantly higher than that at low *ESP* levels (Shainberg *et al.*, 1992).

Reduction of soil erosion can be obtained by improving soil structure and aggregate stability at the soil surface. Gypsum has been used to

improve soil physical properties such as soil aggregation and permeability as a result of providing electrolyte into the rainwater and also dissolved Ca ions into the soils as well (Shainberg *et al.*, 1989). On the other hand, Polyacrylamide (PAM) was found to improve soil structure by reducing clay dispersion (Saybold, 1994). An anionic PAM having large molecular weight has the ability to stabilize soil structure, reduce runoff and soil loss (Zhang and Miller, 1996), when soil solution cations can bridge negative charged clay particles with anionic PAM (Theng, 1984). For this process carboxyl groups of PAM are attaching with soil particles.

It was reported that the dissolution of PAM encouraged soil aggregation and structuring (Al-Abed *et al.*, 2003). This phenomenon could ensure reduction of soil loss by runoff. Beside, Yu *et al.* (2003) reported a decrease in infiltration rate after an anionic PAM application on the soil. This was caused by clogging pores by long chains of gel structured PAM. Also, small molecular weight PAMs may prevent coagulation of clay particles by cancelling the particle charges by adsorption (Heller and Keren, 2002; Shainberg and Levy, 1994; Shainberg *et al.*, 1989).

Treating sodic soil with anionic PAM or gypsum can improve soil structure (Shainberg *et al.*, 1989; Al-Abed *et al.*, 2003); however, few researches have tested the effectiveness of anionic PAM along with gypsum application on soil erosion (Tang *et al.*, 2006). The direct relationship between soil structure, PAM and gypsum application on soil erosion is not very clear. Moreover, the effect of anionic PAM on soil erosion was not fully studied.

There is a limitation for basic research to be conducted on a natural soil due to inherent variability of the soil properties in the field. Controlling and measuring many physico-chemical parameters under field study with variable conditions of sodic soils could lead to a complexity and variation in measured values. As a result, it is hard to determine which factor

is more important and to predict where and when soil erosion events are going to take place in the field. These problems have generated the need for controllable simulation, such as simulated rainfall as well as simulated sodic soil. Rainfall simulation has been used for decades to study basic erosion processes that are difficult to study in detail on the field ; for example, surface sealing, soil aggregate stability, and raindrop detachment. Using artificial sodic soil may be a method for a basic study on sodic soils induced by blackish water irrigation. The current experiment was designed and carried out on the objective to analyze the effects of anionic PAM mixed with gypsum or under saline rain water on artificial sodic soil erosion. Therefore, conducting a basic study under laboratory condition will give precise understanding on the response of sodic soils to various amendments.

2. Materials and Methods

2.1 Soil preparation and analysis

The soil for the experiment was sampled from the paddy fields of Tottori prefecture, Japan. Smectite is the dominant clay mineral in this soil. Textural class of the soil was determined as clay loam by pipette method (Gee and Bauder, 1986). The pH of the soil was measured in 1 : 2.5 soil-water suspensions. Electrical conductivity (EC_e) was measured in saturation extract by electrical conductivity meter. Exchangeable cations are extracted by using sodium acetate solution and cation exchange capacity (CEC) was determined by quantifying the adsorbed sodium cation following replacement of the cation by 1N ammonium acetate solution. Quantification of cations was conducted by atomic absorption spectrophotometer. The selected properties of the soil are given in Table 1.

Soils were air-dried and passed through 2 mm mesh sieve. The soil samples were treated with $CaCl_2$, $MgSO_4$ and Na_2CO_3 to attain the following three levels of ESP : i) low ESP 0.5, ii) medium ESP 6.66, and iii) high ESP 25.5

Table 1 Some characteristics of the studied soil

Physicochemical properties	Values
Sand [>0.02 mm] (%)	39.6
Silt [$0.02-0.002$ mm] (%)	36.0
Clay [<0.002 mm] (%)	24.4
Bulk density ($g\ cm^{-3}$)	1.12
Hydraulic conductivity ($cm\ s^{-1}$)	6.92×10^{-5}
pH _{H20} [1 : 2.5]	5.61
EC_e ($dS\ m^{-1}$)	0.77
CEC ($cmol_c\ kg^{-1}$)	17.2
Clay minerals (%)	
Smectite	46~49
Chalcedony	37~38
Analcime	3.0~3.5
Plagioclase	2.7~5.5
Calcite	2.1~2.6
Dolomite	2.0~2.8
Pyrite	0.5~0.7
Quartz	0.5~0.7

(Table 2).

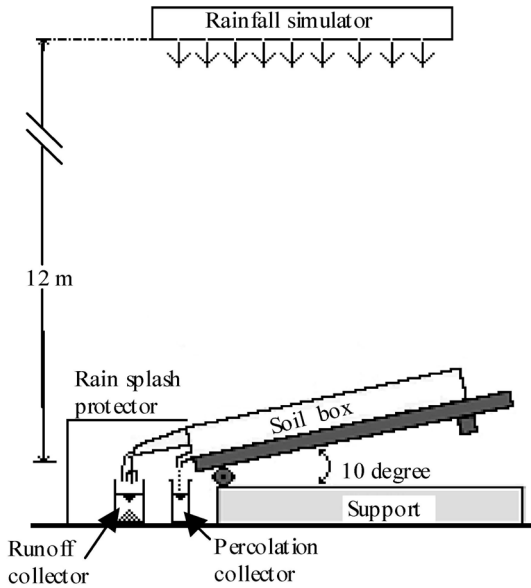
2.2 Soil erosion experiment

Steel boxes having a dimension of ($100 \times 50 \times 13$ cm) were used for this experiment. Boxes were filled with 7 cm of sand overlain to 3 cm thickness gravel layers. The treated soil was air dried and then uniformly packed with thickness of 3 cm to the top of the sand box.

The boxes were placed at 10° slope and $40\ mm\ h^{-1}$ simulated rainfall was applied for 2 hours. Rain water was prepared by mixing salts of $NaCl$ and $CaCl_2$ with tap water ($EC = 0.09\ dS\ m^{-1}$) to attain electrical conductivity (EC) levels of 0.13, 2, 5 and $8\ dS\ m^{-1}$. These saline rain waters were prepared in order to simulate the effect of saline water used in sprinkler irrigation. The sodium adsorption ratio (SAR) value of the rain water for every level of EC was maintained as 5. This SAR value was selected based on the average SAR of drainage water of irrigation reported in the previous research of Yamamoto *et al.* (1980) undertaken in Khuzestan areas of Iran. Moreover, this SAR value, which is classified to be higher

Table 2 Selected chemical properties of the salt treated soils

ESP level of soil	pH _{H2O} (1 : 2.5)	EC _e (dS m ⁻¹)	ESP	Exchangeable cations (cmol _c kg ⁻¹)		
				Na ⁺	Mg ²⁺	Ca ²⁺
Low	5.95~5.61	9.29	0.5	0.09	0.44	10.85
Medium	6.37~6.85	13.54	6.66	1.14	1.09	10.12
High	8.67~9.42	2.24	25.45	4.38	0.98	6.14

**Fig. 1** Soil erosion experiment

in the USDA Agricultural Handbook Guideline (US Salinity Lab. Staff, 1953), was also selected in order to analyze soil dispersion of the sodic soil.

A drip-type rainfall simulator with raindrop fall-height of 12 m was used for the study (Fig. 1). Average rain drop size was 2 mm. Runoff was collected by a flume connected at the lower end of the tray during every 5 minutes intervals. The sediments in the runoff were determined gravimetrically after oven-drying at 105°C for 48 hours.

The effect of gypsum, saline water and anionic PAM alone was determined by supplying of gypsum at the rate of 0, 1, and 5 Mg ha⁻¹, under saline rain water having *EC* values of 0.13, 2 and 8 dS m⁻¹, or dry PAM at the rate of 0,

20 and 80 kg ha⁻¹. The saline rain water of 0.13 dS m⁻¹, which is also referred as a non-saline rain water in the subsequent text, was used in the case of dry gypsum and anionic PAM. Prior to the simulated rainfall these chemical amendments were uniformly spread on soil surface.

In case of mixing experiment either dry PAM mixed with gypsum or dry PAM subjected to saline water, prior to the simulated rainfall, dry gypsum was uniformly spread on the soil surface at the rate of 0, 1, 2, and 5 Mg ha⁻¹ whereas the dry PAM was uniformly spread at the rate of 0, 20 and 80 kg ha⁻¹. Application rate of the two chemical agents was arranged in a manner that the above two doses of the PAM were mixed with the three doses of gypsum to give a total of six different application conditions. The powdered anionic PAM (AP825) used in the experiment was manufactured by the Dia-Nitrix Co., Ltd, with a molecular weight of 1.1×10^7 g mol⁻¹ and 17 to 21% hydrolysis.

2.3 Soil intake rate study

Soils of highest *ESP* amended by anionic PAM, gypsum and mixtures of both were used in the intake rate study. Infiltration rate of the soil was measured using constructed soil column. The study was done following Bouwer (1963). Soil with thickness of 2.5 cm was packed uniformly in columns of 10 cm in height and 5 cm in diameter. The soil column was kept ponded with water depth of 5 cm. Water supply rate was monitored until the steady state condition. At the end, soil basic intake rate at steady state condition was calculated (Table 3). The infiltration experiment was performed with 2 to 3 replicates and with

Table 3 Soil basic intake rate (I_b in mm h^{-1}) of high *ESP* soils

Water quality used in this test	Non-saline water	Saline water 2 dS m^{-1}	Saline water 5 dS m^{-1}
Control	4.75	n/a [†]	n/a
PAM 20 kg ha^{-1} + Gypsum 2 Mg ha^{-1}	5.16	n/a	n/a
PAM 20 kg ha^{-1} + Gypsum 5 Mg ha^{-1}	5.50	n/a	n/a
PAM 80 kg ha^{-1} + Gypsum 2 Mg ha^{-1}	5.16	n/a	n/a
PAM 20 kg ha^{-1}	3.24	7.05	7.08
PAM 80 kg ha^{-1}	0.00	6.96	7.18

[†]n/a : not available

either non-saline or saline water.

2.4 Soil aggregate stability

The effect of PAM on soil aggregate stability of low and high *ESP* levels was tested under deionizer water to assimilate the effect of natural rain. A 30 g of the treated soil was spread on an aluminum plate (12 by 14.5 cm) to form a monolayer and then anionic PAM was applied by spraying the 5 ml of dilute PAM solution at a concentration of 350 mg L^{-1} . The treated soils were air-dried for 48 hours before analysis. Soil aggregate stability was done by a combination of wet-sieving using two aperture meshes of 2 and 0.075 mm and then measured by hydrometer method. Distilled water was used for wet-sieving.

3. Results and Discussion

3.1 Effect of gypsum or saline water on soil erosion

Gypsum is known as a dispersion-restricting agent for sodic soils due to electrolyte concentration and cation exchange effects (Shainberg *et al.*, 1989 ; Zhang and Miller, 1996). The performance of gypsum depends on the soil water electrolyte and Ca concentrations that result from gypsum dissolution, and on the efficiency of the Na-Ca soil exchange process (Keren and Shainberg, 1981). The effects of gypsum and exchangeable sodium percentage (*ESP*) of the soil on surface runoff and soil loss under non-saline rain water are shown in Fig. 2. It was found that the cumulative runoff of each treatment for 2 hours rainfall event did not clearly differ among the gypsum levels. The soil

which had highest *ESP* showed the highest values of surface runoff, followed by low *ESP*, and medium *ESP*. This result was in contrast with the initial EC_e of the soil as cited in the following order : high *ESP* soil < low *ESP* soil < medium *ESP* soil. Based on this ranking, it seems that the effectiveness of gypsum on improving soil infiltration was affected by the initial EC_e of the soil. It is important to mention that as EC_e was measured in saturation extract, this EC_e depends on the concentration of total soluble salts in the solution. And since soil *ESP* and EC_e are not linearly dependent, a possible decrease in EC_e with increasing soil *ESP* could be occurred such as seen in this study and also reported by Yamada *et al.*, (2002).

The soil loss was not clearly affected by gypsum application rate ; however, it seems that the effect of gypsum application varied accordingly to the level of *ESP* in the soil. Gypsum application reduces soil loss from high *ESP* soil. The soil having low *ESP* showed the lowest values of soil loss among treated soils. Gypsum helps clay particles to flocculate that may at least reduce seal formation on soil surface (Shainberg and Letey, 1984). During rainfall season, application of gypsum enhanced deposition of sediments and reduced the transport of finer particles by surface runoff (Warrington *et al.*, 1990 ; Yu *et al.*, 2003). The inconsistency of the results in this study as compared to those reported by previous researches were partly due to the initial condition of the low and medium *ESP* soils having high initial

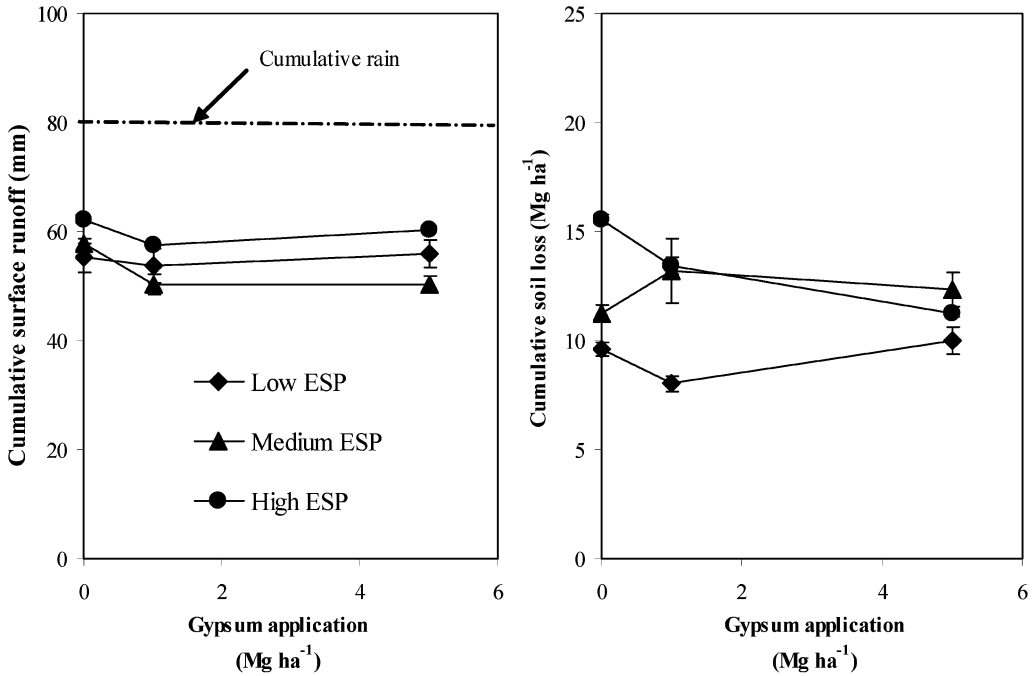


Fig. 2 Effect of gypsum on soil erosion at different *ESP* subjected to non-saline water

EC_e , 9.29 and 13.54 $dS m^{-1}$, respectively. The electrolyte concentration exceeded the cation exchange effect in soil.

Without gypsum application, the surface runoff from soils subjected to saline rain water decreased with increasing the electrolyte concentration of rain (Fig. 3). This result could be explained by the improvement of soil infiltration by restricting clay dispersion (Shainberg *et al.*, 1989; Zhang and Miller, 1996) of the whole soil layer. It was found that saline rain water with EC value 2 $dS m^{-1}$ enhanced soil loss of the medium and low *ESP* soils as compared to the non-saline rain water of 0.13 $dS m^{-1}$. However, the soil loss from the soil having high *ESP* decreased significantly with increasing the electrolyte concentration in rain (Fig. 3). For the low and medium *ESP* soils had high EC_e at the beginning of rainfall event. Combination of lower electrolyte concentration and rain drop impact of the saline water rainfall exceeded ion exchange effect following to apply saline water ($SAR=5$) rainfall. En-

hance in dispersion due to raindrop impact under dilute electrolyte concentration could happen at soil surface during saline water rainfall event. This caused more soil loss under 2 $dS m^{-1}$ rainfall without drop in infiltration rate. Then, soil loss decreased with higher EC saline rain water with the same SAR .

For both gypsum and saline water treatment, surface runoff and soil loss were varied and inconsistent since those might be highly affected by both *ESP*, SAR and the initial EC_e of the soil. Hereby, the interactive effect of EC_e , *ESP*, gypsum and saline water treatment was among the main reasons for differentiated ranking order of soil loss and surface runoff among all treatments as shown in Fig. 2 and Fig. 3.

3.2 Effect of PAM on temporal change of soil erosion under non-saline rain water

The temporal changes of runoff and soil loss during 2 hours simulated rainfall was affected by PAM application (Fig. 4). Runoff was great-

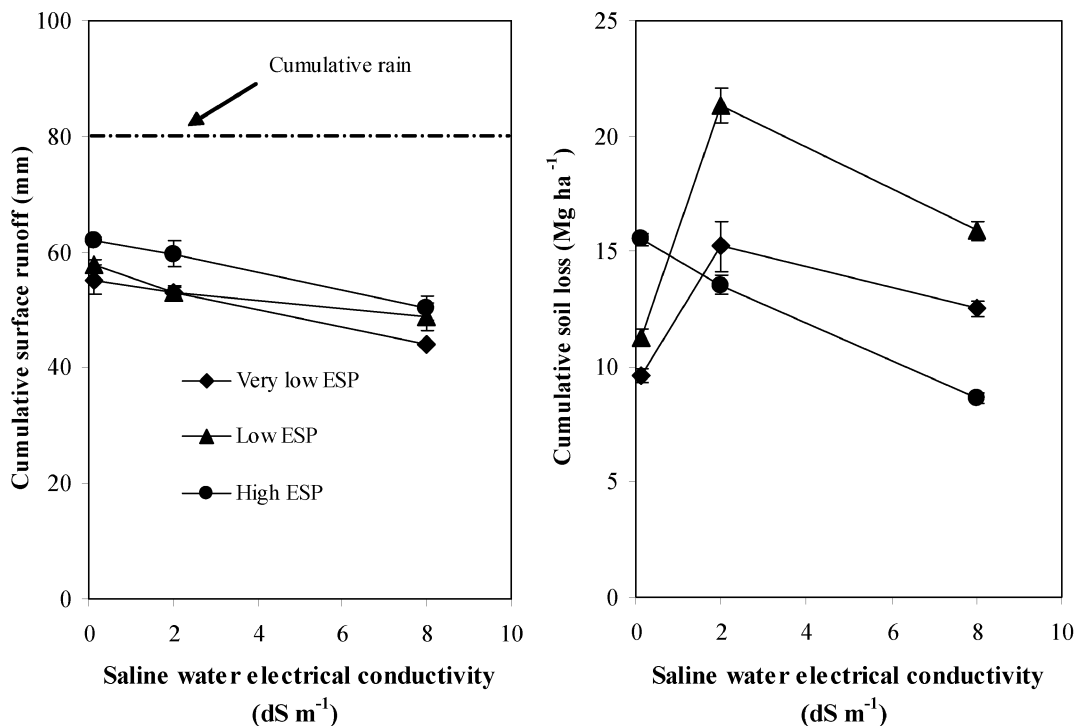


Fig. 3 Characteristics of soil erosion at different *ESP* without gypsum application subjected to saline water

er with higher dose of anionic PAM. This could happen due to the long chain of the PAM which clogged soil pores, prevented infiltration and enhanced surface runoff. This is supported to some extent by the soil basic intake rate test on the soil having high *ESP* (Table 3), showing that the water intake increased as follows : PAM 80 kg ha⁻¹ < PAM 20 kg ha⁻¹ < control. Soil loss decreased by higher amount of PAM incorporation in the following order : control > 20 kg ha⁻¹ > 80 kg ha⁻¹ PAM. Yu *et al.* (2003) and Al-abed *et al.* (2003) reported that anionic PAM effectively reduced soil loss and enhanced surface runoff water. The long chain of the ionic PAM polymer in the soil surface exposed to non-saline rain water could be a possible reason of reduction in soil loss. As Yu *et al.* (2003) explained that the chain length of the PAM polymer in diluted solutions might reach to a certain length and the polymer absorbed on external surfaces of aggregates and

bound soil particles together, thereby developing higher resistance to the impacts of raindrops.

This result in Fig. 4 seems consistent with the effects of PAM on the stability of soil aggregate of the low and high *ESP* levels as given in Fig. 5. The stability of the aggregate having 2 to 0.075 mm was enhanced by anionic PAM application. This is probably due to the anionic PAM incorporation with soil particles and reduction of sediment formation. PAM is an adhesive agent which is combining small particles into from large ones that can resist soil erosion. The large fraction (>0.075 mm) was reported as an appropriate range to assess the ability of soils to withstand rain impacts (Rasiah and Kay, 1995). Furthermore, as fraction of the largest aggregate increased, the formation of small particles decreased (Berthès and Roose, 2002). The results in general indicate that PAM stabilized the larger size frac-

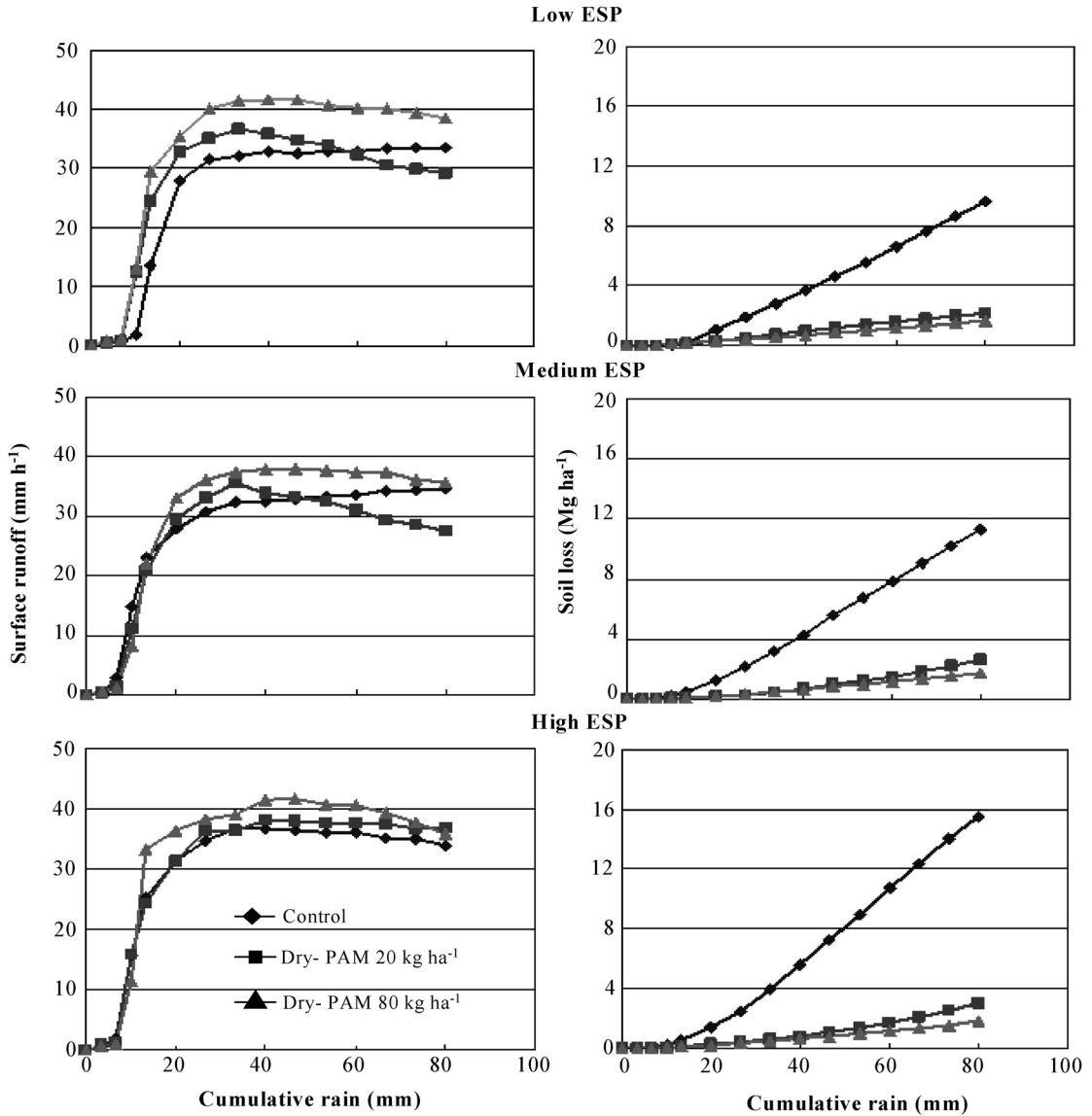


Fig. 4 Effect of PAM on surface runoff and soil loss at different *ESP* subjected to non-saline water

tions, suggesting that soil erosion from soil treated with PAM would be less than that from control and this result is consistent with reports by other workers (Berthès and Roose, 2002).

3.3 Effect of PAM mixed with gypsum on soil erosion under non-saline rain water

As shown in previous sections, the cumulative runoff and cumulative soil loss were not

clearly affected by gypsum application rate or by *ESP* level (Fig. 2). While, PAM application alone was found enhancing surface runoff and decreasing soil loss (Fig. 4). As shown in Fig. 6, mixing PAM with gypsum decreased surface runoff compared to the soil treated with PAM alone. Higher dose of gypsum application caused generally a slight decrease in surface runoff. It seems that the low rate of PAM application mixed with gypsum is more effective

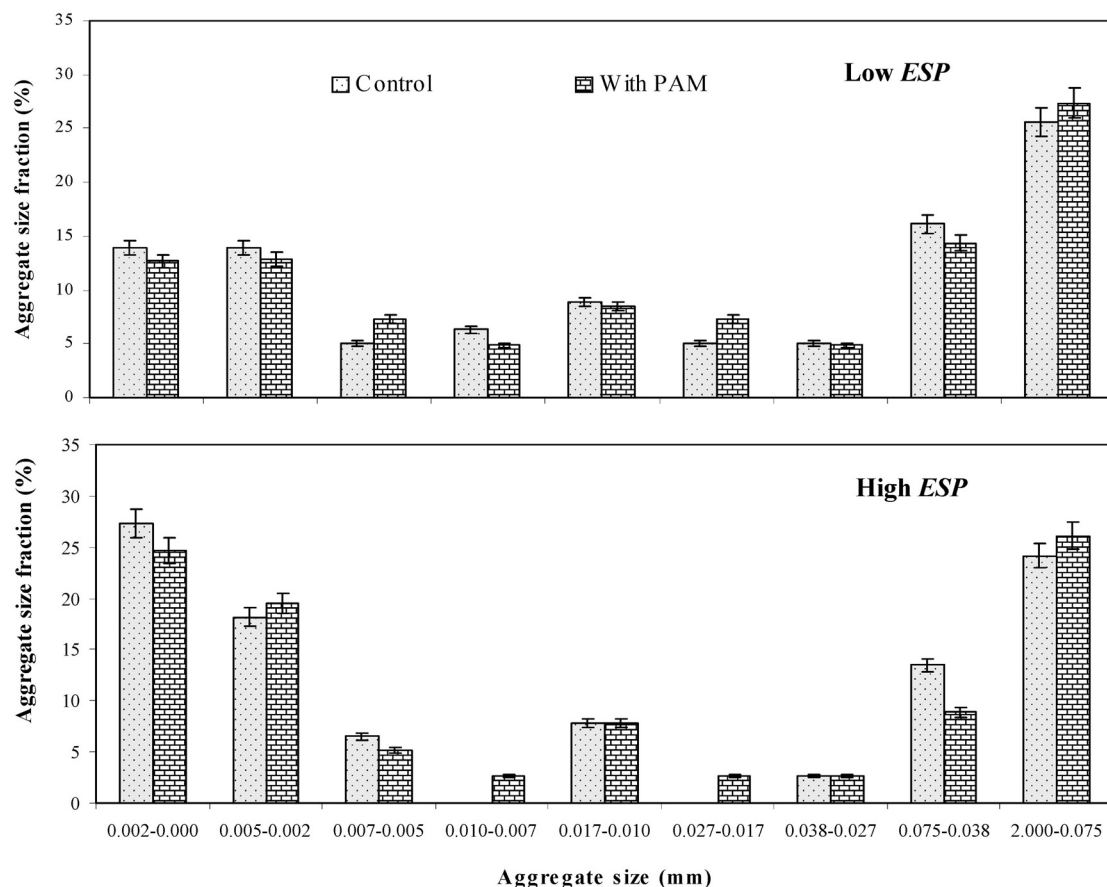


Fig. 5 Effect of PAM on soil aggregate stability at two different soil ESP levels

tive for certain soils than gypsum application alone. On the other hand, the application of PAM with gypsum greatly reduced the soil loss compared to gypsum alone (Fig. 2 and Fig. 6). The maximum load of soil loss from soil treated with PAM mixed with gypsum was 7 Mg ha^{-1} whereas the minimum load of soil loss from that treated with gypsum alone was 8 Mg ha^{-1} . In detail, an increase in trend of cumulative soil loss with increasing gypsum application was found particularly on the soil treated with PAM at the rate of 20 kg ha^{-1} . This was similar to the results of Yu *et al.* (2003). He reported that PAM along with gypsum treatments was found less effective than the application of PAM alone for reducing soil loss of silty loam. Shrink of the PAM structure ac-

companied by a decrease in viscosity in the presence of electrolyte, especially gypsum, could be a reason of less effectiveness of PAM with gypsum treatment. Although, surface application of dissolved PAM mixed with a source of electrolytes such as phosphogypsum has been reported to be more effective in decreasing seal formation, surface runoff, and soil erosion (Shainberg and levy, 1994). The use of dry PAM mixed with gypsum also could result in lower runoff and wash erosion levels than gypsum alone in loamy sand and clay soils (Tang *et al.*, 2006), which is in agreement with our result for intake rate observed on high ESP soils (Table 3).

Basic intake rate of high ESP soil under non-saline water differed among treatments as

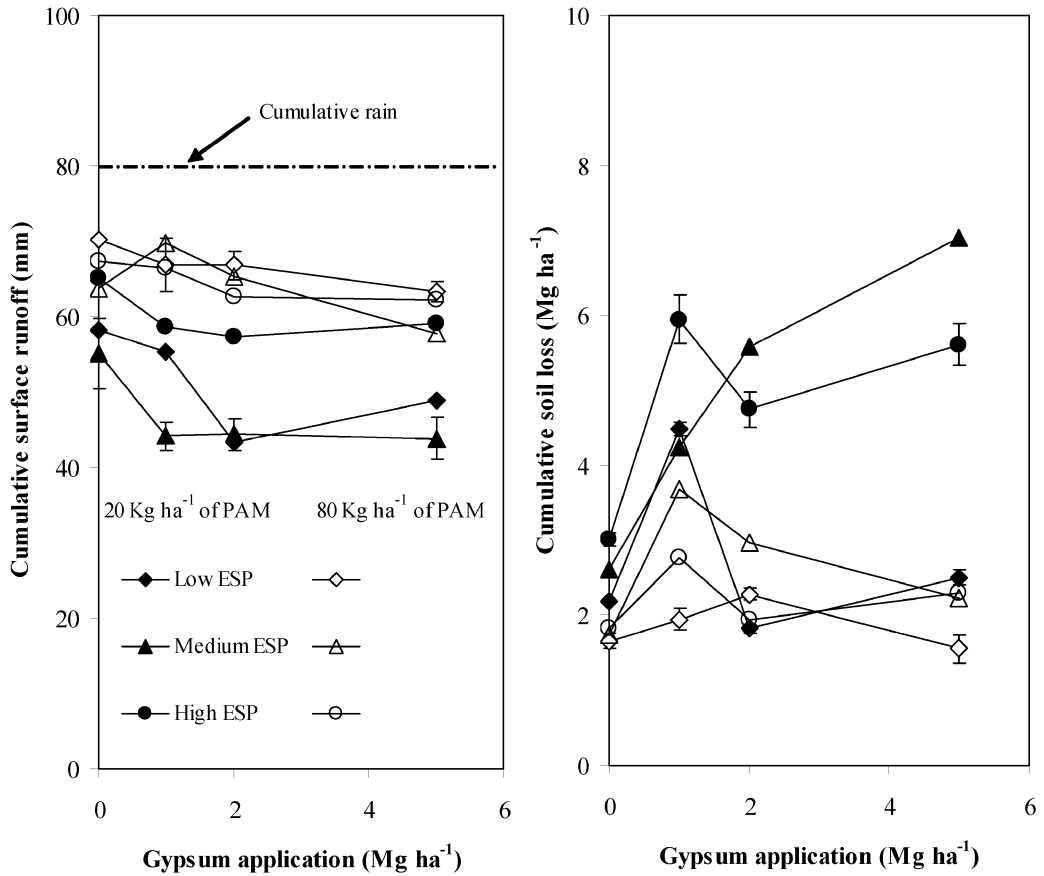


Fig. 6 Characteristics of soil erosion at different *ESP* and treated with PAM mixed with gypsum subjected to non-saline water

follows : PAM 80 kg ha⁻¹ < PAM 20 kg ha⁻¹ < PAM 20 + gypsum 2 Mg ha⁻¹ ≈ PAM 80 + gypsum 2 Mg ha⁻¹ < PAM 20 + gypsum 5 Mg ha⁻¹ (Table 3). It seems that improving the soil infiltration is the benefit from the application of PAM with a source of electrolytes such as gypsum on sodic soil conservation, since the PAM efficacy for preventing seal formation was enhanced by the presence of electrolytes (Shainberg *et al.*, 1990).

3.4 Effect of PAM on soil loss under various saline rain waters

PAM treated soil showed greater soil loss under saline water rainfall than non-saline water rainfall (Fig. 4 and Fig. 7). The increase in soil loss could be associated to the shrinking of PAM chain structure as reported by Yu *et al.*

(2003). Soil loss decreased with increasing PAM application rate except with the soil having medium *ESP* and also with the low *ESP* one when this soil was subjected to 8 dS m⁻¹ saline rain water (Fig. 7). A significant decrease in soil loss with increasing PAM application rate was found on the soil having the highest *ESP*, 25.45, in which whose *EC_e* was the lowest among treatments. In the low and high *ESP* soils treated with PAM, it seems that increasing *EC* of the saline rain water enhanced cumulative soil loss but decreased surface runoff (Fig. 7). Decrease in surface runoff with increasing *EC* in saline rain water shows that the soil infiltration was substantially improved. It seems that the effects of saline water on the soil treated with PAM were fairly similar to

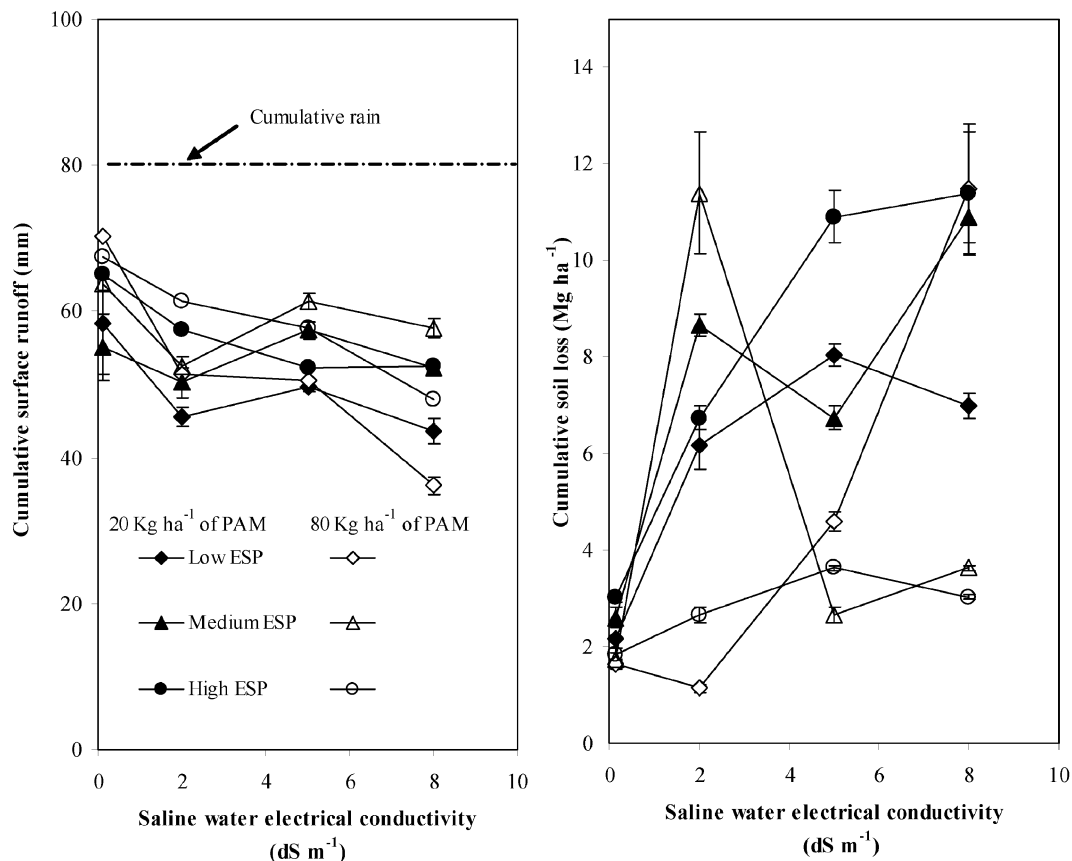


Fig. 7 Effect of PAM on soil erosion at different ESP subjected to saline rain water

those soils treated with gypsum mixed with PAM (Fig. 6). Based on the results in Fig. 6 and Fig. 7, it shows a distinct reduction of soil loss from soil treated either PAM with gypsum or PAM with saline water compared to that from the soil treated with either gypsum or saline water alone (Fig. 2 and Fig. 3). The aim of gypsum application was to increase the electrolyte concentration on soil surface prior to rainfall to restrict the dispersion of clay particles. In this experiment, higher initial electrolyte concentration of the soil could shrink the PAM structure and decrease its efficiency in binding soil particles. This could be the reason that PAM together with saline water induced higher detachments of soil particles and less surface runoff, which could be verified by analyzing the changing pattern of both surface runoff

and soil loss on the medium ESP soil in Fig. 7. Laboratory and field studies with anionic PAM (e.g., Gardiner and Sun, 2002; Bjerneberg *et al.*, 2003; Vacher *et al.*, 2003) have demonstrated that addition of small amounts of PAM (10–20 kg ha⁻¹) on the soil surface were effective to maintain high permeability and decrease runoff and soil loss from soils exposed to impact of rain drops, especially when the PAM was applied together with a source of electrolytes (Tang *et al.*, 2006). In our study, where the effect of PAM on soil erosion of sodic soils was tested with solutions of different electrolyte concentrations; the results obtained were inconsistent and could not relate to the salt concentration of rain water used particularly on the medium ESP soil (Fig. 7). Ben-Hur *et al.* (1992b) and Levy *et al.* (1995) have noted that

even at $ESP=9$, the impact of PAM tested with solutions of different electrolyte concentrations was found ineffective or less effective on soil erosion from sodic soil as compared to non-sodic conditions. Conversely, these same authors found that PAM mixed with source of electrolytes was very effective in reducing soil erosion even at $ESP>25$ (Levy *et al.*, 1995). In our study, it seems that the impact of PAM tested with solutions of different electrolyte concentrations was found effective in reducing surface runoff only on the soil having high ESP and low ECe , precisely under the soil treated with 80 kg ha^{-1} PAM (Fig. 7).

The increased PAM application exhibited lower infiltration rate in the high ESP soil of intake rate experiment (Table 3). The final rate of water intake differed among the treatments as follows: PAM 80 kg ha^{-1} with non-saline water < PAM 20 kg ha^{-1} with non-saline water < PAM 80 with saline water of 2 dS m^{-1} < PAM 20 with saline water of 2 dS m^{-1} ≤ PAM 20 with saline water of 5 dS m^{-1} < PAM 80 with saline water of 2 dS m^{-1} . When PAM was mixed with saline water, the accumulated electrolytes on soil surface improved hydraulic conductivity even under high sodic conditions. However, adding PAM with high concentration (80 kg ha^{-1}) might induce soil surface sealing and consequently inhibit infiltration rate. In the study conducted by Tang *et al.* (2006), he found increasing ESP from 5 to 20 in the loamy sand decreased final infiltration rate from 14 to 2 mm h^{-1} and increased runoff and wash erosion in the control; similar trends but of different magnitude were noted in the other soil types. He concluded that spreading PAM mixed with gypsum or gypsum alone was effective in maintaining final infiltration rate, low runoff, and low wash erosion levels as compared with control.

4. Conclusion

The effects of anionic PAM mixed with gypsum and subjected to saline rain water on artificial sodic soil erosion under simulated

rainfall condition were studied. The effects of gypsum and saline water treatments on surface runoff and soil loss on different soil sodicity level were affected initial soil ESP , ECe , and SAR and EC of rain water. Soil loss seems to be controlled by soil surface conditions such as ECe , and ESP of the soil and EC and rain drop impact of simulated saline water rainfall while infiltration and runoff may be affected whole soil chemical conditions.

The anionic PAM was very effective than applying electrolyte source alone in controlling soil loss. Beside, PAM could not reduce runoff or in some case reduced water intake of soil since PAM clogged pores of the surface soil. This side effect was improved by supplying electrolytes by either applying gypsum or saline water rainfall. Those electrolytes may shrink PAM structure and prevent clogging pores by PAM. PAM application is effective to reduce soil loss, however sensitivity of PAM structure and physical properties on electrolyte concentration must be considered. This is important especially planning PAM application onto saline and sodic soil that inherently contains some sort of electrolytes.

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ソーダ質土壌の侵食防止における電解質処理を併用した 粉末状高分子凝集剤利用の効果

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要 旨

近年、高分子凝集剤 (PAM) は、塩類土壌及びソーダ質土壌における土壌流亡を抑制させる改良材として用いられている。しかしながら PAM と電解質の併用による人工ソーダ質土壌を用い、土壌流亡の抑制効果について検討した研究は、今まであまり行われていない。ここでは、人工ソーダ質土壌において、PAM による改良と石膏添加の有無が、塩水降雨によって生じる土壌流亡に及ぼす抑制効果を検討した。最初に、埴壤土に数種の塩溶液を加えて処理し、3種類の交換性 Na 率 (*ESP*) を有する供試土壌 (*ESP* が 0.5, 9.9, 25.5%) を作製した。供試土は風乾して土壌槽に充填した。粉状 PAM と石膏及びこれらの混合物の3種はそれぞれ、塩処理を施した土壌に添加した。この土壌槽に降雨シミュレータ装置を用い、強度 40 mm h^{-1} の降雨を与えた。降雨には数種類の電気伝導度 (*EC* が 0.13, 1, 2, 5, 8 dS m^{-1}) を有する塩水を用いた。実験の結果、人工ソーダ質土壌は PAM 添加によって、自然のソーダ質土壌と同様の流亡傾向を示した。清水を用いた降雨条件下では、土壌中におけるナトリウム割合の増加に従って、土壌流亡量が増加した。塩類溶液の土壌流亡に対する効果は、土壌の *ESP* レベルよりも初期における土壌の電気伝導度によって影響を受ける傾向がみられた。PAM 添加は表面流出水量をいくらか増加させたが、土壌の損失量が抑制された。また PAM で改良した土壌では、石膏の添加または塩水を用いた降雨条件下において表面流出水量が減少した。しかしながら、PAM と石膏または塩を混合した場合、降雨の衝撃によって土壌剥離が増加する傾向が見られた。

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