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EFFECTS OF POLYACRYLAMIDE ON RANGELAND SOILS AND PLANTS

by

Saud Leily R. Al-Rowaily

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1992

بسم الله الرحمن الرحيم

In the Name of ALLah, Most Gracious,
Most Merciful

TO MY PARENTS

ACKNOWLEDGMENTS

Praise and thanks is given first to God, who has provided the author with health, patience, and knowledge to complete this study.

I would like to express my sincere gratitude and appreciation to my major professor, Dr. Neil E. West, for his help, support, and parental concern during all phases of my study. I wish to express heartfelt thanks to my graduate committee, Dr. Chris Call and Dr. R. J. Hanks, for providing helpful suggestions and for their contributions to the manuscript.

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To my parents, for their love and forbearance, I dedicate this piece of work.

Saud Al-Rowaily

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ABSTRACT

Effects of Polyacrylamide on Rangeland Soils and Plants

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Utah State University, 1992

Major Professor: Dr. Neil E. West
Department of Range Science

The objectives of this study were to determine the effects of two forms of polyacrylamide (PAM) conditioners (Cross-linked and Non-cross-linked PAM) on evaporation, saturated hydraulic conductivity, water retention, crust and crack formation of soils, seed germination, and seedling and tubeling growth.

The two PAM conditioners, 0.2% concentration by weight, were mixed with seven soils of different textures (sandy loam, silt, silty clay loam, silt loam, fine sand, medium sand, and coarse sand) to investigate the effects on evaporation, saturated hydraulic conductivity, and water retention. Soil samples of different textures were brought to field capacity and placed in a growth chamber for two weeks to measure evaporation under a controlled environment.

A second experiment was carried out in the field to determine the effects of the two PAM conditioners on seedling emergence of crested wheatgrass, Agropyron desertorum, as well as on soil cracking, penetrometer resistance, and soil moisture. The two PAMs were mixed with a silt loam Xerollic Calciorthid at 0.2% concentration by weight. Seedling emergence was monitored directly for two weeks. Soil moisture was measured by TDR. Cracking was described by photographic means. Penetrometer resistance was measured by a hand-held penetrometer.

The third experiment was also carried out in the field, using the same soil texture as in experiment 2, to investigate the effects of the two PAMs on soil moisture at depths between 25 to 45 cm and on sagebrush (Artemisia tridentata) growth.

Evaporation was found to be significantly lower in the fine-textured controls than under the two PAM treatments. The sandy loam and sandy soils experienced significantly higher evaporation from the controls. The two PAM conditioners significantly reduced saturated hydraulic conductivity on all soil textures. Water retention increased in the PAM-treated textures at the matric potential range used (0.0, 0.05, 0.1, 1.5 MPa). The PAM application also did not improve grass seedling emergence or improve soil moisture, and did not have any significant affects on sagebrush growth. Larger cracks were found in the two plots treated with PAM than the controls. Lower penetrometer resistance occurred in the two PAM treatments compared to the untreated control.

From this study, it can be concluded that the application of PAM conditioners, at relatively high concentrations used, could be more viable on sandy textures. Other researchers are advised to try lower application rates than used here, particularly with finer textured soils.

(76 pages)

Introduction

Many arid or semiarid rangeland environments are characterized by limited soil water, poor water-holding capacity, high evaporation, and low soil organic matter (Stoddart et al., 1975). Crust formation, vesicular structure, physical degradation of the soil surface, high erodibility, and runoff are also some of the main problems limiting rangeland production (Wood, 1988; Singer, 1991) and seed germination and plant establishment (Woodhouse & Johnson, 1991).

Crust formation on soil surfaces is caused by a combination of three primary conditions (Paul & Clark, 1989; Agassi et al., 1981, 1985):

1. Loss of soil organic matter,
2. The effect of raindrop impact energy, which causes a disintegration of the soil aggregates and compaction, and
3. The dispersion of clay particles of soil surface.

Taylor (1962) reported that in semiarid or arid environments, rapid and highly rigid crust development is enhanced by high evaporation demand, and rapid drying of the soil surface. Crusts impair seedling emergence and plant establishment (Wood et al., 1982; Shainberg et al., 1990). Hanks & Thorpe (1957) reported that as soil crust hardness increases, seedling emergence decreases. Crusting also leads to increased runoff and erosion, followed by a reduction in infiltration (Agassi et al., 1985; Shainberg et al., 1990; Morin et al., 1981).

Water and wind erosion are also serious problems in rangeland environments (Singer, 1991). Unstable structure, low organic matter content, and the presence of salts (especially Na) lead to lack of surface soil moisture and sparse or nonexistent vegetation which, in turn, lead to some of the common problems in arid environments such as high wind and water erodibility (Singer, 1991). Dust storms caused by the action of the wind on a loose, dry, and sparsely vegetated ground surface (Middleton, 1986) are a common phenomenon in arid and semiarid regions. Al-Nakshabandi & El-Robee (1988) reported that sand storm frequency and dust fall in the Kuwait desert decrease with rainfall, soil moisture, and vegetational cover.

Vesicular structures are another problem in many rangeland soils (Wood, 1988). Vesicles are formed by trapped air after rainfall (Miller, 1971). Vesicular structures also impair seedling emergence and plant establishment (Taylor, 1962) and decrease infiltration, leading to soil erosion (Blackburn, 1975). Both crusts and vesicular structures make it difficult to reseed many rangelands.

One possible solution to overcome these rangeland limitations is the use of soil conditioners. Following some initial enthusiasm for soil conditioners in the early 1950s when the Monsanto Chemical Company marketed a patented chemical compound named "Krilium," interest declined because of the uncertainty of the outcome of cost-benefit analysis over a wide range of crops and climates. Symposia were held, one in Ghent, Belgium in 1975 (De Boodt, 1975), and one in Las Vegas, USA in 1973 (Gardner & Moldenhauer, 1975) to consider the use of conditioners. Also, an entire issue of Soil Science was recently devoted to the subject in 1986 (Soil Science, Vol. 141). These events occurred after improved formulations of more appropriate polymers invited reexamination of their utility.

Newer soil conditioners have been reported to improve plant seedling emergence, establishment, growth, and survival (Woodhouse & Johnson, 1991; Callaghan et al., 1988; Wallace & Wallace, 1986a, 1986b; Cook & Nelson, 1986; Helalia & Letey, 1989).

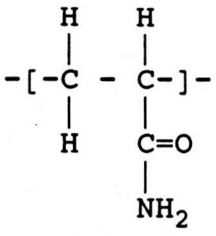
Synthetic conditioners have also been shown to reduce soil resistance (Rubio et al., 1990; Rubio et al., 1989; Terry & Nelson, 1986; Wallace & Wallace, 1986b; Steinberger & West, 1991; Cook & Nelson, 1986; Helalia & Letey, 1989; De Boodt, 1975) and evaporation, especially in soils with coarse textures (Woodhouse & Johnson, 1991; Rubio et al., 1990; De Boodt, 1975).

Synthetic conditioners also improve some important soil physical properties such as bulk density and aggregate stability (Terry & Nelson, 1986); improve infiltration (Smith et al., 1990; Terry & Nelson, 1986; Mitchell, 1986; Ben-Hur et al., 1989; Shainberg et al., 1990; Levy et al., 1992); and lead, in some cases, to reduced soil erosion (Smith et al., 1990; Wallace & Wallace, 1986; Gabriels & De Boodt, 1975; De Boodt, 1975).

Some of these soil conditioners are capable of absorbing large amounts of water (Woodhouse & Johnson, 1991; Johnson, 1984a). Callaghan et al. (1988) reported that a synthetic soil conditioner called polyvinylalcohol almost doubled the field capacity of sandy soil when added at a concentration of 0.5%.

Most of the work done with soil conditioners has concentrated on agronomic and horticultural soils (Ben-Hur et al., 1989; Wallace & Wallace, 1986a; Terry & Nelson, 1986; Cook & Nelson, 1986). There are very few studies on the use of soil conditioners in rangeland soils (Rubio et al., 1989; Rubio et al., 1990; Steinberger & West, 1991; Rubio et al., 1992). In all of these previous studies, there is a lack of information on how soil texture influences the efficacy of conditioners. Thus, we do not now know on which rangeland soils these conditioners might work best. Even if conditioners are expensive, there are good possibilities in using them in appropriate rangeland contexts such as mined land reclamation, campgrounds, sand and snow barriers, and roadside revegetation.

Polyacrylamide is a synthetic soil conditioner that is prepared by acrylamide polymerization (Azzam, 1980). The unit structure of PAM is:



$$\begin{array}{ccccc} & \mathrm{H} & & \mathrm{H} & \\ & | & & | & \\ -[- & \mathrm{C} & - & \mathrm{C} & -]- \\ & | & & | & \\ & \mathrm{H} & & \mathrm{C=O} & \\ & & & | & \\ & & & \mathrm{NH_2} & \end{array}$$

There are different kinds of PAM. Gel-forming cross-linked PAM has a long life span and can absorb up to 400 times its weight in deionized water. The intermediate-term PAMs dissolve very quickly and have a life span of about one to two years. Non-cross-linked polymers are very soluble and short-lived (Wallace & Wallace, 1990). Soil conditioners can be neutral, positively charged (polycations), or negatively charged (polyanions) (Theng, 1982).

Objectives

The general objectives of this research were to evaluate the efficacy of two types of PAM (cross-linked and non-cross-linked) to lessen crust formation, improve water retention, and enhance plant establishment and growth on rangeland soils. The specific objectives of this study were as follows.

1. To evaluate the effects of two kinds of PAM on evaporation, saturated hydraulic conductivity, and water retention of soils of differing textures.
2. To determine the effects of PAM on germination, growth, and survival of crested wheatgrass (Agropyron desertorum) seedlings.
3. To evaluate the influences of the PAM on cracking, crust formation, and soil moisture.
4. To determine the effects of PAM on growth and survival of big sagebrush (Artemisia tridentata) tubelings.

Hypotheses

Hypothesis 1

There will be no significant difference in evaporation, saturated hydraulic conductivity, and amount of water retained between untreated soils and those treated with PAM.

Hypothesis 2

There will be no significant difference in germination, growth or survival of crested wheatgrass (Agropyron desertorum) seedlings on untreated soils and those treated with PAM.

Hypothesis 3

There will be no significant difference in cracking and crust formation between untreated soils and those treated with PAM in the field.

Hypothesis 4

There will be no significant difference between growth and survival of big sagebrush (Artemisia tridentata) tubelings in untreated soils and those treated with PAM.

Hypothesis 5

There will no significant difference in soil moisture, infiltration, and retention in untreated soils and those treated with PAM.

Methods and materials

Experiment 1

The purpose of this study was to evaluate and compare the effects of two kinds of PAM (cross-linked and non-cross-linked) on evaporation, saturated hydraulic conductivity, and water retention in soils of various textures.

Non-cross-linked PAM with the trade name "Complete Green" is an anionic (relatively lower charge) PAM co-polymer combination with a molecular weight of 10-15 x 10^{-6} g/mol (Aly & Letey, 1988). This PAM was obtained from the Complete Green Company (Los Angeles, California).

Cross-linked PAM is a very persistent conditioner and has a high salt-buffering capacity. It can absorb water from between 40 and 500 times its own weight (Johnson, 1984b). This PAM is an anionic conditioner (Wodfford, D. J., 1992, personal communication). It was obtained from Western Polyacrylamide Inc. (Castle Rock, Colorado).

This study was carried out during the summer and fall of 1991. Soil textures used in this study are listed in Table 1. Texture was determined by the hydrometer method (Gee & Bauder, 1986). Organic matter percent was estimated indirectly through the organic carbon concentration (Nelson & Sommers, 1986). Electrical conductivity (EC) and pH were determined by using a 1:1 soil, water slurry.

In order to obtain a sandy loam soil, a buried horizon of

Table 1. Soil textures and means of other features of soils used in Experiment 1.

Soil Texture	pH (1:1)	EC (1:1) dS/m	Organic matter %	Sand %	Clay %	Silt %
Sandy loam	8.3	0.7	0.21	55	5	40
Silt	7.9	0.8	0.22	7	11	82
Silty clay loam	7.7	0.6	1.07	5	38	57
Silt loam	8.1	2.3	1.74	27	21	52
Fine sand	8.2	0.9	0.1	100	0.0	0.0
Medium sand	7.7	3.4	0.0	100	0.0	0.0
Coarse sand	7.4	2.1	0.0	100	0.0	0.0

a natural rangeland soil from east of Providence, Utah [belonging to the coarse-silty, mixed, mesic family of Calcicxerollic Xerochrepts, Hillfield Series (Soil Conservation Service and Forest Service, 1974)] was stirred in a garbage can with a mixture of tap water and sodium metaphosphate. The mixture was allowed to settle for twenty minutes, then the top of the mixture (with the silt and clay) was poured out. This process was repeated ten times to wash out the sodium [a possible confounding factor in PAM effectiveness (Johnson, 1984b; Johnson, 1985)]. The same technique (using water and sodium metaphosphate) was employed to separate clay from silt to obtain a soil with a high percentage of silt from the same soil.

The silty clay loam soil (Table 1) was obtained from Utah State University's South Farm, west of Providence [belonging to fine, mixed, mesic family of Aquic Arigiustolls, Nibley Series (Soil Conservation Service and Forest Service, 1974)]. In order to avoid soil with high organic matter, which is another confounding factor in PAM effectivenese (Wallace & Wallace, 1986c), this soil was obtained from a depth between 70 cm and 100 cm.

The silt loam soil (Table 1) was obtained from Curlew Valley, Utah [belonging to the fine, silty, mesic family of Xerollic Calciorthids, Thiokol Series (Bjerregaard et al., 1984)]. This soil is noted for its crusting and vesicular structure, which contribute to difficulties for seeding.

The sandy soils were obtained from a local sand and gravel company as pure silica sand with fine, medium, and coarse textures.

For the evaporation study, cylindrical PVC pipes were used (32 cm deep and 10 cm inside diameter). Each soil (air-dry) was mixed with PAM (0.2% by weight) using a cement mixer for 30 min. PAM content of 0.2% by weight was found to be a good rate of application through initial investigations by Steinberger & West (1991). Thirty PVC cylinders were filled with each soil texture; ten with each of the two PAM formulations and ten with the untreated soil (controls).

Each soil was brought to field capacity using deionized water. The cylinders were then randomly placed in a growth chamber for two consecutive weeks at 25°C and controlled relative humidity (Table 2). Total weight of each PVC cylinder was recorded at 24 hour intervals, and cylinders were spatially rerandomized to avoid microenvironmental effects. The evaporation in (gm / day) was converted to (cm / day) using the following equation:

$$1 \text{ gm of water} = 1 \text{ cm}^3 \text{ of water}$$

$$Evaporation(cm/day) = \frac{Evaporation(g/day)}{Area\ within\ tubes}$$

For the saturated hydraulic conductivity study (Klute & Dirksen, 1986), three samples of each soil texture were placed in deionized water upon a tray where the depth of the water was below the sample. Samples were left until they became

Table 2. Relative humidity (%) conditions under which the evaporation study was carried out

Day	% Relative H.
1	72
2	72
3	70
4	70
5	67
6	68
7	68
8	67
9	66
10	64
11	66
12	66
13	69
14	68

saturated. A constant head was maintained on the samples after transferring them to a rack. The volume of water (V) that passed in time (t) was measured. Also, the hydraulic head difference (H_2-H_1) was recorded. The sample length (L), the sample cross area (A), the wet weight (Ww), and the volume of the sample (Vs) were determined. Oven dry (Wd) weight was determined after placing the samples in an oven for 24 h at 110°C, so that bulk density could be calculated. The hydraulic conductivity (Ks) and the bulk density were calculated using the following equations:

$$Ks=\frac{VL}{At(H_2-H_1)}$$

$$Bulk\ Density(bd)=\frac{Wd}{Vs}$$

The volumetric water content (θ_v) of the samples was calculated as follows:

$$\theta v = \frac{(Ww-Wd)}{(dwVs)}$$

where dw is the water density.

Water retention was determined with a pressure plate apparatus (Klute, 1986). Soil samples were saturated by placing them in tap water. Two replicates of each texture were placed on the pressure plate. A filter paper was placed under each treated sample to prevent the conditioner from plugging the pores in the plate. A range of pressures (0.05, 0.1, 1.5 MPa) was applied to the samples. After equilibrium, the weight of each sample was taken. The samples were then oven-dried at 40°C for 24 h to find the water content. Soil water release curves for all the PAM-treated and the untreated soil textures were constructed. Matric potentials (Ψm) versus water content (θm) were calculated.

Experimental Design and Data Analysis

For the evaporation study, the experimental design was a split-split randomized block design where the soil textures were the whole plot, treatments were the subplot, and days were the sub-subplot because they were repeated measurements.

For the saturated hydraulic conductivity, the experimental design was a randomized block design with 7 replications (soil textures) and 3 subsamples.

For the water retention, the experimental design was a split-split randomized block design where the soil textures were the whole plot, treatments were the subplot, and matric potentials were the sub-subplot because they were repeated measurements. Analysis of variance was used to analyze the data.

Experiment 2

The purpose of this study was to evaluate the effects of PAM on seedling emergence, growth, and survival of crested wheatgrass (Agropyron desertorum). This study was started in May and carried out through October 1991 at the Green Canyon Ecology Center Compound in North Logan, Utah. Soil from the Curlew Valley site (described in Experiment 1) was removed up to the depth of 30 cm, transported to Green Canyon, mixed, and placed in a plot (8 m x 8 m, and 50 cm deep). The plot was divided into four blocks (Figure 1).

Polyacrylamide (0.2% by weight) was thoroughly mixed with some additional soil in a cement mixer for 40 min. The soil was then applied in a trench-like seedling furrow (10 cm wide x 11 cm deep x 270 cm long) (Figure 1). Some furrows received no PAM to serve as controls.

The same numbers (50 seed) of pure live seed of crested wheatgrass (Agropyron desertorum) were sown in each furrow on June 9, 1991. Some furrows were not sown in order to monitor

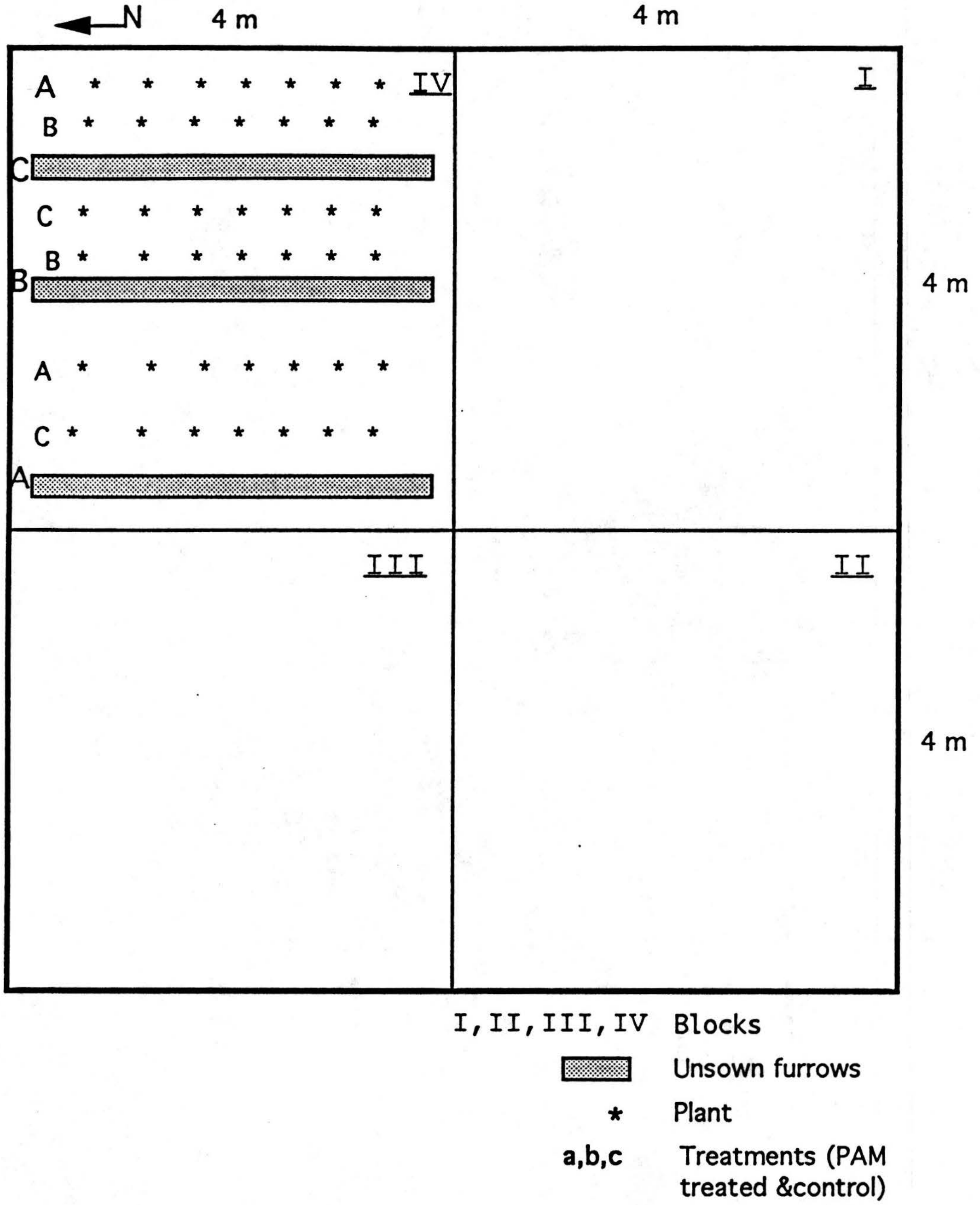


Figure 1. Schematic layout of experiment 2.

soil water without plants. The plot was then sprinkled with water to saturation on June 9th. Germination (percentage of pure live seed emerging), growth, and survival (percentage of plants surviving) were monitored daily for the first two weeks and weekly for the remainder of the growing season. Growth rate was monitored by counting new leaves and height progression of the plants. Weeds on these beds were eliminated weekly through hand cultivation.

Soil water content was monitored by using time-domain reflectometry (TDR) (Topp et al., 1984). Time-domain reflectometry is a relatively new technique for measuring soil water (Reeves & Smith, 1992). The time-domain reflectometry method is an accurate and simple technique. It is independent of soil type and is not affected by salt content (Reeves & Smith, 1992).

Twenty stainless steel rods (used to measure θ_v with TDR) were randomly placed throughout the plot. At each location, two rods (25 cm long and 5 cm apart) were horizontally placed under the furrows. Readings of soil water were taken with a time-domain reflectometry meter at times of initiation. The dates are listed in Table 3.

The volumetric water content (θ_v) was calculated following Topp et al. (1984) as:

$$\theta v = -0.053 + 0.0292 Ka - 5.5 \times 10-4 K_a^2 + 4.3 \times 10^{-6} K_a^3$$

where K_a is the apparent dielectric constant,

$$K_a = (ct/L)^2$$

Table 3. Dates at which the soil water readings were taken via TDR methods for both Experiments 2 and 3

Reading #	Date
1	June 10/1991
2	June 30/1991
3	July 5/1991
4	Aug. 22/1991
5	Aug. 28/1991
6	Sept. 4/1991
7	Sept. 12/1991
8	Sept. 25/1991

L is the length of the conductor (mm), c is the velocity of an electromagnetic signal in free space (300 $mm.nsec^{-1}$), and t is the travel time of the voltage pulse as measured by TDR (nsec).

The strength of soil crust was measured in the field by a hand-held penetrometer (Bradford, 1986) at 19 random points on each furrow. Soil cracking was quantified following the techniques used by Steinberger & West (1991). Two random sections (10 m x 32 cm) in each furrow were photographed using a Polaroid Spectrum System® camera. Photographs were analyzed using a digitized image computer analysis program (Sigma-Scan®). Length and area of each crack were calculated, and the area was then divided by the length to get a comparison between treatments.

Experimental Design and Data Analysis

For cracking, penetrometer resistance and seed emergence, the experimental design was a complete randomized block design with four replications and three subsamples (furrows) (Figure 1). Two-way analysis of variance was used to analyze the data. For soil moisture, one-way analysis of variance was used to analyze the data.

Experiment 3

This study was carried out to evaluate the effects of PAM on shrub tubeling growth and survival. Two raised beds (2.4 × 1.8 m) were constructed at the Green Canyon Ecology Center compound using railroad ties. The beds were filled with the soil collected from Curlew Valley (described in Experiment 1) to 60 cm of depth. Polyacrylamide (0.2% by weight) was mixed with the same soil for 40 min. in a cement mixer and deposited in an augured hole (10 cm wide and between 10 cm to 50 cm deep) (Figure 2). The remainder of the hole and all the control holes were filled with untreated soil and then compacted to densities similar to those in the beds as a whole. Beds were sprinkled with water on May 7, 1991, before transplanting.

One-year-old shrub tubelings of big sagebrush (Artemisia tridentata) [hybrids between the Dove Creek and Hobble Creek accessions of yaseyana and tridentata subspecies (McArthur et al., 1988)], provided by Durrant McArthur of the U.S. Forest Service, were transplanted to equidistant points (45 cm a-part) on a grid in both beds on May 12, 1991. Tubelings were grouped into similar size and vigor classes and then one of

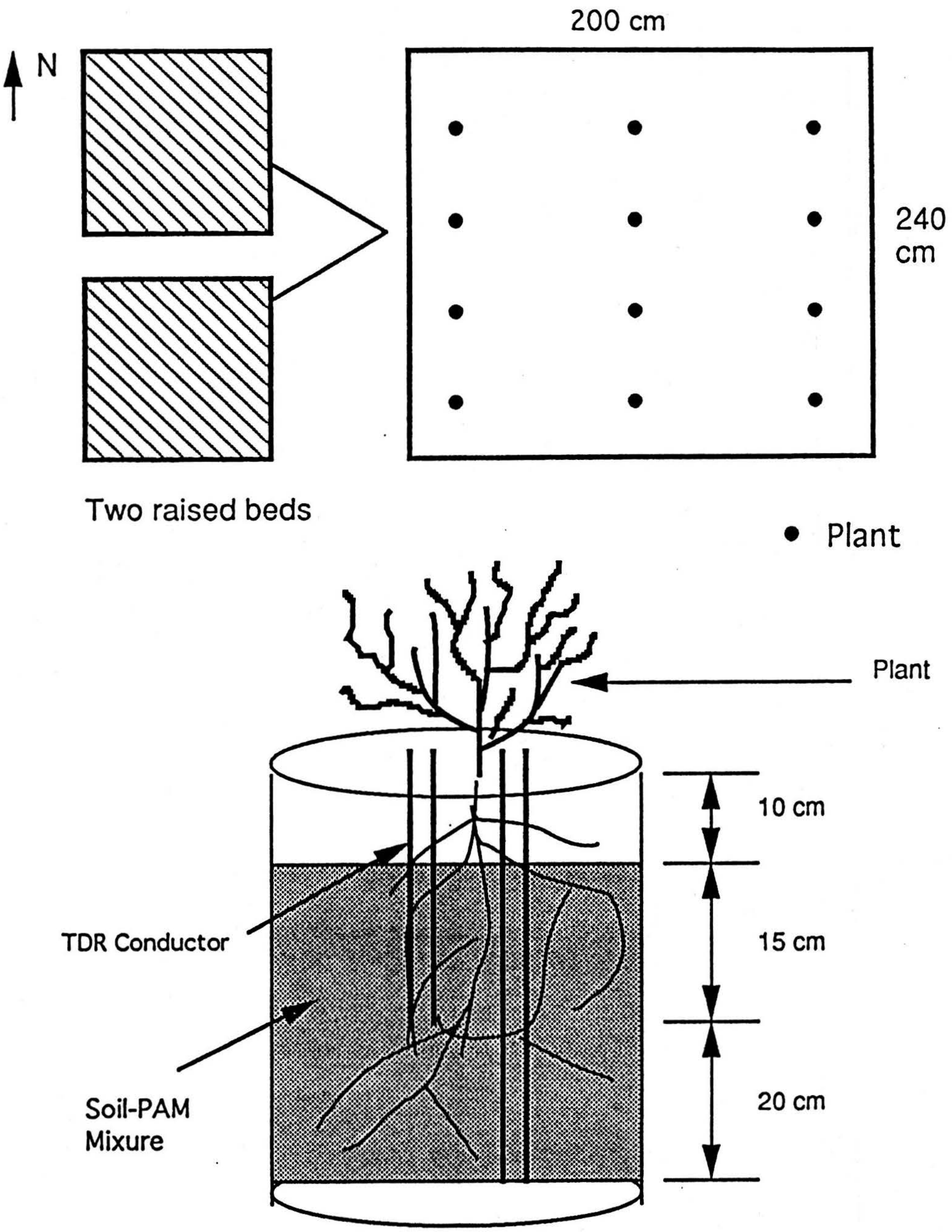


Figure 2. Schematic layout of experiment 3.

Each plant received 1000 ml of water at the time of planting by placing a PVC pipe around the plant and water was directly applied from above. Each tubeling was treated as an experimental unit. Weeds on these beds were eliminated weekly through cultivation. The survival and the growth rate of the shrubs were monitored weekly throughout the growing season. Growth rate was monitored by recording height and marked twig lengths to account for the initial biomass.

Soil water was monitored under each plant in each bed using the TDR technique. Four rods (two were 25 cm and two were 45 cm long and 5 cm apart) were placed vertically under each shrub (Figure 2). Moisture readings were taken periodically throughout the experiment (Table 3). At the end of the experiment, the plants were harvested to obtain their dry biomass. Cut portions of shrubs were placed in an oven for 25 hours at 48°C. The roots were also extracted by washing in a sieve (4 mm pore size) the soil and root mass between the depths of 25 cm and 45 cm. The extracted roots were oven-dried at 48°C for 24 hours.

Experimental Design and Data Analysis

The experimental design was a completly randomized design with eight replications (big sagebrush tubelings) (Figure 2). One-way analysis of variance was used to analyze the data. Two-way analysis of variance was used to analyze the sagebrush aboveground dry biomass.

Results and discussion

Experiment 1

Effect of two soil conditioners on evaporation

Detailed data on the average evaporation per day from each soil texture are given in Table 4. The highest observed cumulative water loss from evaporation over the two-week period was obtained from the silt soil. The second highest cumulative water loss in the same period was recorded from sandy loam. The other soils had similar cumulative evaporation (Figure 3).

Table 5 indicates that evaporation varied significantly (at 99% confidence level) because of soil texture differences, treatment differences, time differences, and the texture-treatment, texture-day, treatment-day, and texture-treatment-day interactions.

Cumulative water loss from all textures followed a decreasing trend as the water became less available (Figure 3). Evaporation was high in the first week for all soil textures. Evaporation remained similar throughout the second week, with the exception of silt textures.

Water evaporation from silty clay loam, silt, and silt loam was significantly increased by non-cross-linked PAM. In contrast, water loss from sandy textures was significantly higher in the control than the PAM-treated tubes.

After two weeks, maximum and minimum evaporation

Table 4. Evaporation rates (cm/day) from seven soil textures as influenced by two PAM conditioners over two weeks (numbers in parentheses are standard deviation from the mean)

Day	Silty Clay Loam			Sandy Loam		
	Control	Cross-linked PAM	Non-cross-linked PAM	Control	Cross-linked PAM	Non-cross-linked PAM
1	0.152 (0.04)	0.152 (0.03)	0.215 (0.08)	0.635 (0.19)	0.557 (0.06)	0.536 (0.14)
2	0.143 (0.04)	0.143 (0.04)	0.174 (0.03)	0.748 (0.19)	0.372 (0.10)	0.423 (0.13)
3	0.167 (0.04)	0.171 (0.05)	0.205 (0.05)	0.571 (0.08)	0.204 (0.06)	0.232 (0.04)
4	0.181 (0.05)	0.189 (0.05)	0.219 (0.06)	0.409 (0.08)	0.166 (0.07)	0.151 (0.02)
5	0.187 (0.05)	0.166 (0.04)	0.208 (0.05)	0.260 (0.04)	0.134 (0.02)	0.120 (0.01)
6	0.179 (0.05)	0.174 (0.05)	0.215 (0.04)	0.201 (0.02)	0.128 (0.02)	0.125 (0.01)
7	0.149 (0.03)	0.157 (0.04)	0.206 (0.06)	0.145 (0.01)	0.134 (0.02)	0.113 (0.02)
8	0.148 (0.03)	0.197 (0.05)	0.233 (0.04)	0.118 (0.01)	0.112 (0.02)	0.107 (0.01)
9	0.144 (0.04)	0.154 (0.05)	0.207 (0.05)	0.102 (0.01)	0.108 (0.01)	0.100 (0.01)
10	0.149 (0.04)	0.142 (0.03)	0.209 (0.05)	0.088 (0.01)	0.096 (0.02)	0.099 (0.01)
11	0.104 (0.03)	0.128 (0.04)	0.188 (0.05)	0.075 (0.01)	0.083 (0.01)	0.089 (0.01)
12	0.097 (0.03)	0.103 (0.02)	0.163 (0.05)	0.067 (0.004)	0.080 (0.01)	0.085 (0.01)
13	0.103 (0.02)	0.115 (0.04)	0.149 (0.02)	0.062 (0.01)	0.073 (0.01)	0.076 (0.01)
14	0.093 (0.02)	0.102 (0.03)	0.163 (0.04)	0.050 (0.003)	0.062 (0.003)	0.071 (0.01)

Table 4. (Continued)

Day	Silt Control	Silt Cross-linked PAM	Silt Non-cross-linked PAM	Silt loam Control	Silt loam Cross-linked PAM	Silt loam Non-cross-linked PAM
1	0.640 (0.16)	0.715 (0.25)	0.668 (0.24)	0.277 (0.07)	0.256 (0.08)	0.314 (0.10)
2	0.578 (0.17)	0.568 (0.19)	0.607 (0.17)	0.173 (0.04)	0.186 (0.10)	0.216 (0.05)
3	0.519 (0.10)	0.488 (0.15)	0.618 (0.22)	0.148 (0.04)	0.175 (0.04)	0.170 (0.03)
4	0.678 (0.22)	0.708 (0.27)	0.685 (0.16)	0.160 (0.02)	0.136 (0.03)	0.170 (0.05)
5	0.549 (0.10)	0.529 (0.18)	0.690 (0.20)	0.132 (0.03)	0.157 (0.04)	0.159 (0.03)
6	0.494 (0.16)	0.378 (0.13)	0.630 (0.16)	0.130 (0.03)	0.138 (0.03)	0.149 (0.03)
7	0.414 (0.15)	0.267 (0.06)	0.496 (0.21)	0.127 (0.03)	0.121 (0.02)	0.155 (0.04)
8	0.274 (0.12)	0.187 (0.02)	0.331 (0.09)	0.120 (0.02)	0.129 (0.03)	0.146 (0.04)
9	0.189 (0.04)	0.154 (0.02)	0.230 (0.02)	0.117 (0.03)	0.133 (0.03)	0.140 (0.04)
10	0.152 (0.03)	0.127 (0.02)	0.174 (0.02)	0.117 (0.03)	0.133 (0.04)	0.139 (0.03)
11	0.131 (0.03)	0.114 (0.02)	0.146 (0.01)	0.127 (0.03)	0.127 (0.04)	0.158 (0.04)
12	0.112 (0.02)	0.101 (0.01)	0.128 (0.01)	0.118 (0.03)	0.138 (0.03)	0.144 (0.03)
13	0.100 (0.02)	0.102 (0.03)	0.114 (0.01)	0.114 (0.03)	0.122 (0.04)	0.140 (0.03)
14	0.092 (0.01)	0.085 (0.01)	0.102 (0.01)	0.110 (0.03)	0.110 (0.03)	0.133 (0.02)

Table 4. (Continued)

		Fine Sand			Medium Sand	
Day	Control	Cross-linked PAM	Non-cross-linked PAM	Control	Cross-linked PAM	Non-cross-linked PAM
1	0.380 (0.10)	0.254 (0.11)	0.262 (0.09)	0.238 (0.09)	0.237 (0.08)	0.168 (0.03)
2	0.236 (0.08)	0.223 (0.05)	0.191 (0.07)	0.295 (0.12)	0.132 (0.05)	0.089 (0.02)
3	0.334 (0.13)	0.148 (0.05)	0.139 (0.04)	0.237 (0.08)	0.106 (0.05)	0.078 (0.01)
4	0.259 (0.11)	0.130 (0.06)	0.101 (0.02)	0.224 (0.08)	0.065 (0.03)	0.066 (0.01)
5	0.357 (0.14)	0.092 (0.02)	0.101 (0.02)	0.235 (0.08)	0.059 (0.03)	0.062 (0.01)
6	0.219 (0.09)	0.085 (0.02)	0.090 (0.01)	0.236 (0.11)	0.047 (0.01)	0.058 (0.004)
7	0.191 (0.13)	0.062 (0.01)	0.068 (0.01)	0.106 (0.06)	0.040 (0.01)	0.050 (0.01)
8	0.104 (0.08)	0.061 (0.01)	0.079 (0.07)	0.117 (0.09)	0.038 (0.01)	0.051 (0.01)
9	0.086 (0.10)	0.051 (0.004)	0.065 (0.01)	0.072 (0.07)	0.031 (0.01)	0.049 (0.004)
10	0.038 (0.03)	0.049 (0.01)	0.064 (0.01)	0.043 (0.04)	0.031 (0.01)	0.042 (0.01)
11	0.025 (0.01)	0.044 (0.004)	0.055 (0.01)	0.023 (0.01)	0.026 (0.004)	0.043 (0.005)
12	0.025 (0.01)	0.047 (0.01)	0.059 (0.01)	0.022 (0.01)	0.029 (0.003)	0.043 (0.005)
13	0.018 (0.003)	0.038 (0.003)	0.048 (0.01)	0.014 (0.01)	0.023 (0.01)	0.039 (0.004)
14	0.013 (0.002)	0.032 (0.01)	0.043 (0.01)	0.009 (0.002)	0.019 (0.01)	0.030 (0.01)

Table 4. (Continued)

		Coarse Sand	
Day	Control	Cross-linked PAM	Non-cross-linked PAM
1	0.284 (0.09)	0.161 (0.04)	0.125 (0.02)
2	0.229 (0.12)	0.077 (0.04)	0.069 (0.01)
3	0.272 (0.09)	0.044 (0.02)	0.056 (0.01)
4	0.185 (0.07)	0.035 (0.02)	0.045 (0.01)
5	0.172 (0.06)	0.033 (0.01)	0.051 (0.01)
6	0.158 (0.08)	0.026 (0.01)	0.046 (0.01)
7	0.260 (0.07)	0.023 (0.004)	0.037 (0.01)
8	0.101 (0.07)	0.027 (0.004)	0.039 (0.01)
9	0.063 (0.05)	0.021 (0.003)	0.032 (0.01)
10	0.058 (0.05)	0.020 (0.005)	0.033 (0.003)
11	0.030 (0.02)	0.020 (0.003)	0.029 (0.01)
12	0.028 (0.02)	0.023 (0.005)	0.033 (0.005)
13	0.017 (0.01)	0.017 (0.004)	0.026 (0.01)
14	0.011 (0.001)	0.013 (0.003)	0.021 (0.004)

LSD (0.05) = 0.0898 mean textures LSD (0.05) = 0.1034 mean treatments

LSD (0.05) = 0.1191 mean days LSD (0.05) = 0.1386 Text. * Treat. interaction

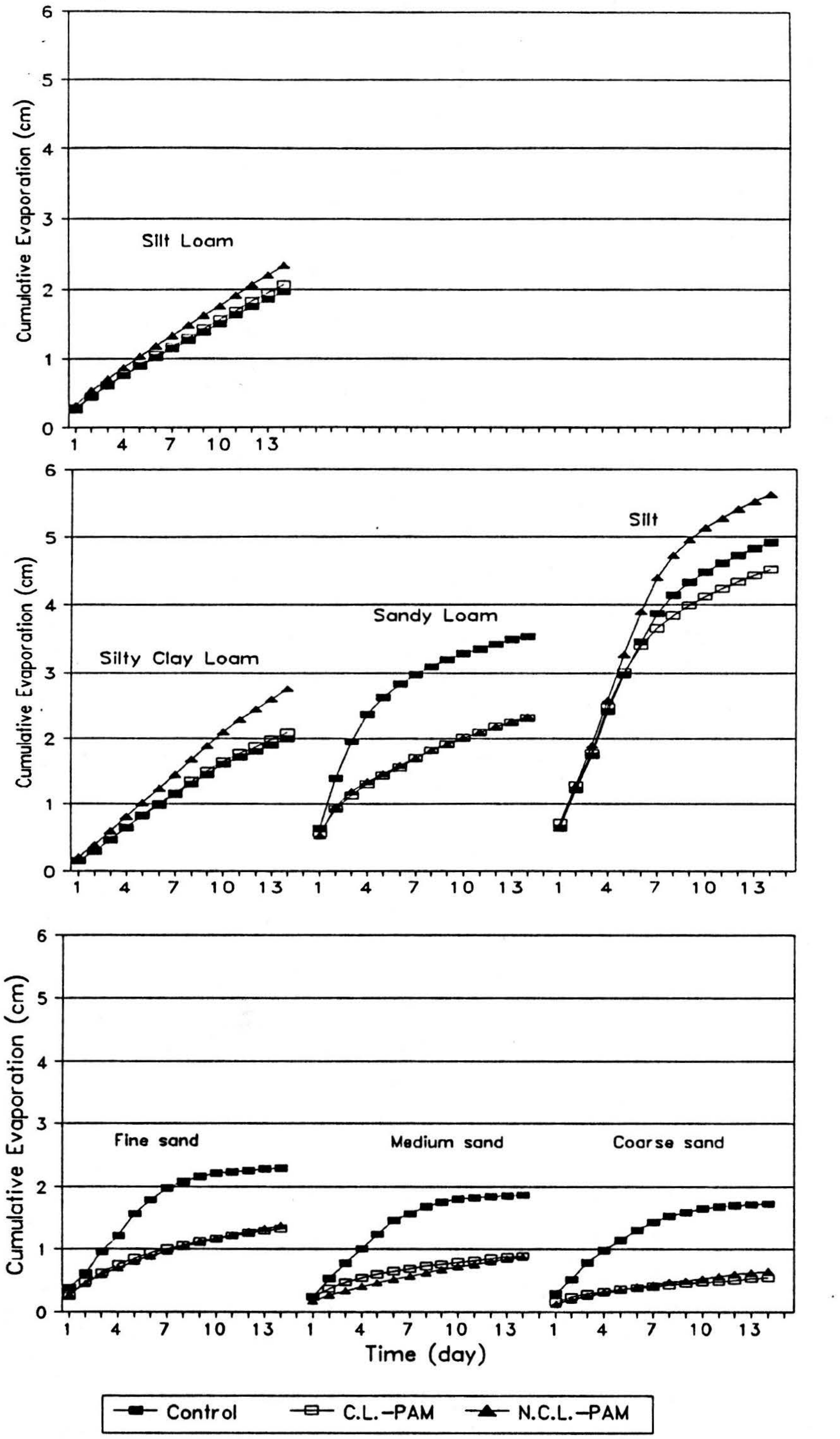


Figure 3. Cumulative evaporation rate as a function of time for seven soil textures as influenced by two PAM conditioners.

Table 5. Analysis of variance for evaporation rates in seven soil textures affected by two PAM conditioners over two weeks

SV	df	MS	F-Ratio	Signif.
Texture	6	168.29	594.34**	S
Treatments	2	16.38	57.84**	S
Text.*Treat.	12	4.77	16.85**	S
Error (a)	189	0.28		
Days	13	63.18	198.07**	S
Error (b)	117	0.32		
Text.*Days	78	2.78	34.79**	S
Treat.*Days	26	3.64	45.51**	S
Text.*Treat.*Days	156	0.52	6.5**	S
Error (c)	2340	0.08		
Total	2939			

** Significant at 99% confidence level.

resulting from the added non-cross-linked PAM was about 5.5, and <1 cm in silt and coarse sand, respectively. Changes in evaporation with the addition of non-cross-linked PAM over the controls ranged from -63% to +28% (Table 4). Of the seven non-cross-linked PAM treatments, four had measured evaporation that was lower than evaporation from the controls (Table 4 and Figure 3).

Evaporation was decreased by adding cross-linked PAM. Changes in evaporation, compared to the controls, ranged from -69% to +5%. Of the seven cross-linked PAM treatments, four had measured evaporation that was lower than evaporation from the control (Table 4 and Figure 3).

There were significant (99% confidence level) differences in mean evaporation between the first and the second week. Water loss from all textures decreased in an almost linear pattern. The potential of using PAM conditioners to lessen evaporation is more promising in sandy soils than other textures (Figure 3).

Non-cross-linked PAM appeared to prevent infiltration of water into the soil columns through making a jellylike substance that sealed soil surfaces. Water ponding was observed on non-cross-linked PAM-treated fine texture soils (silt loam, silt, and silty clay loam) during the first few days of this study. Unlike the field, this experiment was carried out in a laboratory using PVC cylinder where water was confind to a limited space. However, in the field experiments, water ponding was not observed mainly because water could have run off to the furrow sides.

Effect of two soil conditioners on saturated hydraulic conductivity

Detailed saturated hydraulic conductivity (Ks) data are presented in Table 6. Bulk density and volumetric water content at which Ks was measured are presented in the Appendix (Table 23). The highest observed Ks was obtained from coarse sand. The second highest Ks was obtained from medium sand, then fine sand, sandy loam, silt loam, silty clay loam, and silt, respectively. Table 7 illustrates the analysis of variance for Ks in the seven soil textures as affected by the treatments (Tables 24, 25, 26, 27, 28, 29, and 30 in the Appendix are one-way analysis of variance for individual soil textures).

Table 6. Effects of two PAM conditioners on saturated hydraulic conductivety, Ks, (mm/min) in three replictions of seven soil textures

		Treatment		
Texture	Rep	Control	Cross-linked PAM	Non-cross-linked PAM
Silt loam	1	0.024	0.002	0.0
	2	0.022	0.001	0.0
	3	0.022	0.003	0.0
	mean	0.023	0.003	0.0
Sandy loam	1	0.049	0.045	0.00015
	2	0.047	0.047	0.00010
	3	0.049	0.042	0.00003
	mean	0.048	0.045	0.00009
Silt	1	0.0009	0.0009	0.0
	2	0.0009	0.0010	0.0
	3	0.0009	0.0009	0.0
	mean	0.0009	0.0009	0.0
Silty clay loam	1	0.0046	0.0036	0.0
	2	0.0047	0.0041	0.0
	3	0.0057	0.0035	0.0
	mean	0.0050	0.0037	0.0
Fine sand	1	0.746	0.659	0.0
	2	0.457	0.658	0.0
	3	0.679	0.597	0.0
	mean	0.627	0.640	0.0
Medium sand	1	10.37	8.91	0.0
	2	7.16	8.14	0.0
	3	8.75	7.82	0.0
	mean	8.76	8.29	0.0
Coarse sand	1	19.63	17.03	0.0
	2	18.32	15.60	0.0
	3	18.17	12.67	0.0
	mean	18.71	15.10	0.0

Table 7. Analysis of variance for saturated hydraulic conductivity in seven soil textures as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Texture	6	174.181	431.14**	S
Treatments	2	99.283	245.75**	S
Text.*Treat.	12	44.901	111.14**	S
Error	42	0.404		
Total	62			

** Significant at 99% confidence level.

There were significant (99% confidence level) differences in mean Ks among soil textures, treatments, and the texture-treatment interaction. Coarse sand had significantly higher Ks than the other six soil textures. Medium sand also had significantly higher Ks than the other textures. There were no significant differences in Ks among the remaining textures (Figs. 4a and 4b). Ks was significantly decreased by non-cross-linked PAM in all the seven textures (Figs. 4a and 4b). On the other hand, there were no significant differences in Ks between the cross-linked PAM and the control. The cross-linked PAM did decrease Ks slightly.

The addition of non-cross-linked PAM conditioner severely depressed Ks in all soil textures. The effect on Ks by cross-linked PAM ranged from an increase of about +2% in silt to a decrease in the other soil textures, ranging from -85.7% to -5.3%, in silt loam and medium sand, respectively.

Contrary to expectations, application of PAM did not improve water infiltration in this laborarory study. These results might have been caused by the relatively high rate of application used. However, some other investigators have shown some similar results. When using PAM at different rates (0, 0.2, 2.0, 20.0, and 200.0 kg ha^{-1}), Rubio et al. (1989, 1990) reported that infiltration rates did not show clear consistent trends.

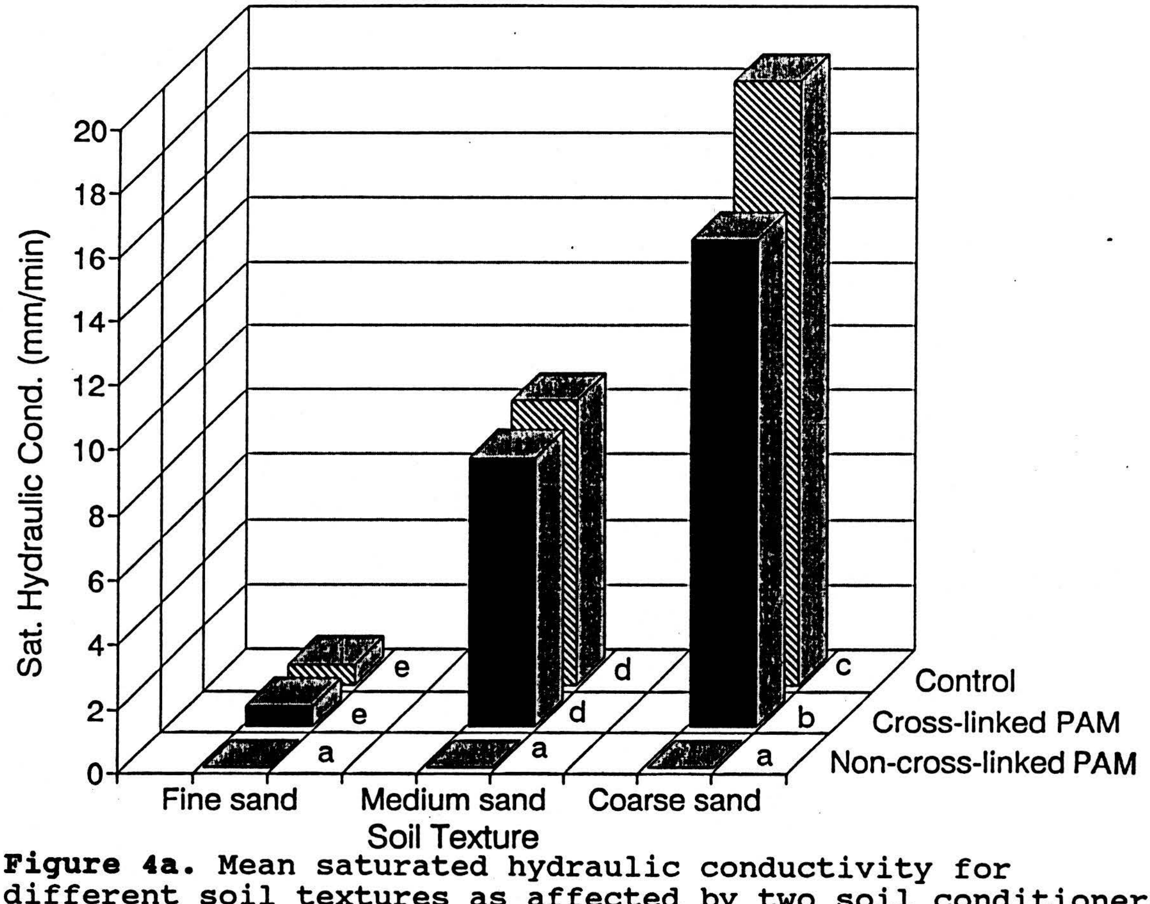


Figure 4a. Mean saturated hydraulic conductivity for different soil textures as affected by two soil conditioners (different letters are signficantly different at $p < 0.05$).

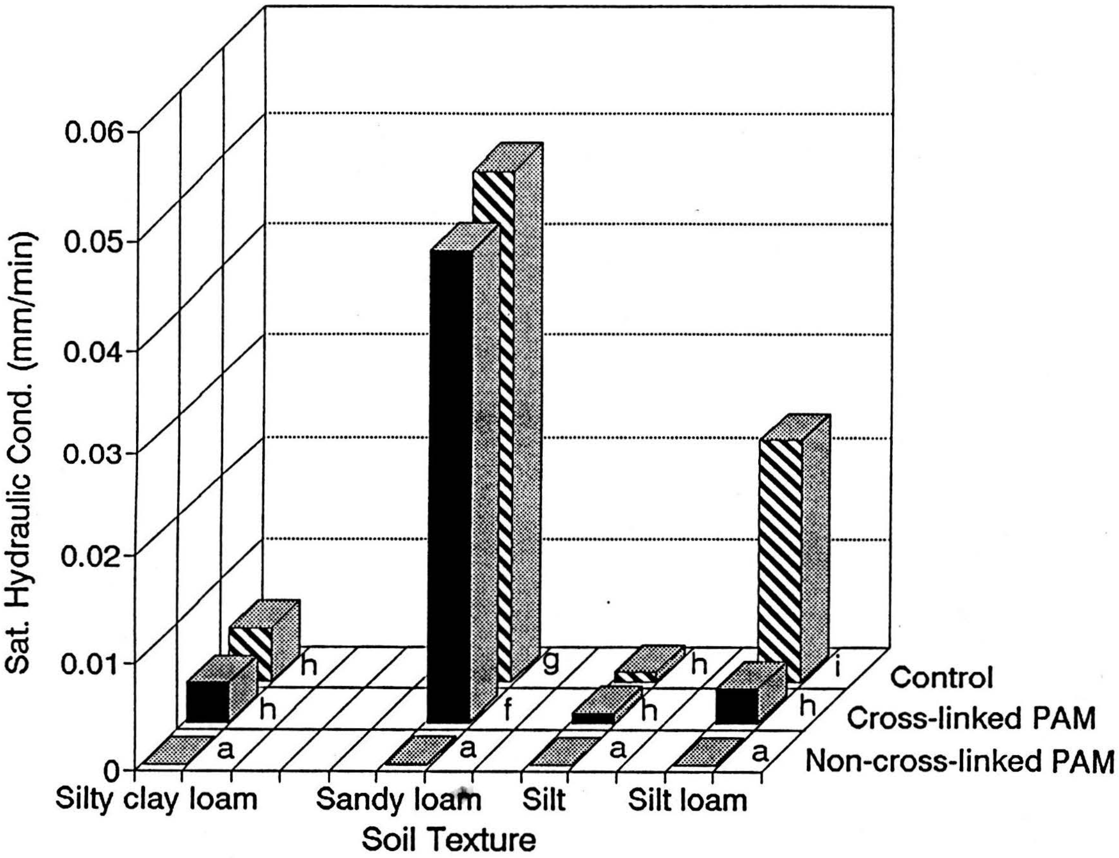


Figure 4b. Mean saturated hydraulic conductivity for different soil textures as affected by two soil conditioners (different letters are signficantly different at $p< 0.05$).

Effect of two soil conditioners on water retention

Detailed data on average water retention over a range of matric potentials are given in Table 8. The relation between soil matric potential and mass water content in the various textures is also shown in Figure 5. Table 9 shows the analysis of variance for soil moisture content as influenced by textures, treatments, and water matric potential. It is evident from analysis of variance that the soil water retention was significantly affected by the textures, treatment, and matric potential, and by their interactions.

The data generally show that for a given matric potential, the observed soil water content was higher for fine textures than the sandy textures. The water content in the soil at 1.5 MPa was decreased from 81% to 63% over that at 0.0 MPa.

At a given matric potential, water content increased with the addition of the two PAM conditioners. Al-Darby et al. (1992) recently also demonstrated a similar result in that the amount of water retained by the soil over a range of matric potentials significantly increased with the increase of gel-forming conditioner. Water content in treated soils at 0.0 MPa was higher than water content from lower values of matric potential. At a given matric potential, water content in the two PAM-treated soils was significantly (99% confidence level) higher than water content in the untreated soils. Comparing 0.0 and 1.5 MPa of matric potential, the moisture available

Table 8. Water content (Om, mass water/mass dry soil) for seven soil textures as related to matric potential (MPa) and influence by two PAM conditioners

Texture	MPa	Treatment Control		Cross-linked PAM		Non-cross-linked PAM	
		Rep 1	Rep 2	Rep 1	Rep 2	Rep 1	Rep 2
Silt loam	0.00	0.61	0.57	0.55	0.64	0.62	0.63
	0.05	0.26	0.27	0.31	0.26	0.48	0.54
	0.10	0.23	0.24	0.26	0.22	0.39	0.50
	1.50	0.18	0.17	0.18	0.20	0.19	0.23
Sandy loam	0.00	0.46	0.34	0.34	0.54	0.66	0.53
	0.05	0.22	0.14	0.40	0.43	0.59	0.51
	0.10	0.17	0.08	0.39	0.40	0.22	0.37
	1.50	0.06	0.04	0.07	0.11	0.12	0.13
Silt	0.00	0.39	0.45	0.56	0.58	0.71	0.53
	0.05	0.29	0.35	0.40	0.35	0.56	0.44
	0.10	0.17	0.30	0.27	0.21	0.45	0.37
	1.50	0.08	0.13	0.11	0.14	0.18	0.12
Silty clay loam	0.00	0.55	0.70	0.78	0.66	0.65	0.52
	0.05	0.30	0.35	0.39	0.38	0.41	0.38
	0.10	0.28	0.30	0.33	0.34	0.34	0.33
	1.50	0.2	0.23	0.27	0.22	0.25	0.21
Fine sand	0.00	0.36	0.37	0.75	0.58	0.66	0.50
	0.05	0.16	0.15	0.29	0.20	0.49	0.37
	0.10	0.14	0.13	0.27	0.16	0.42	0.31
	1.50	0.04	0.06	0.20	0.20	0.28	0.28
Medium sand	0.00	0.33	0.45	0.45	0.40	0.54	0.38
	0.05	0.18	0.12	0.24	0.20	0.47	0.29
	0.10	0.15	0.11	0.22	0.20	0.40	0.25
	1.50	0.04	0.20	0.20	0.18	0.23	0.19
Coarse sand	0.00	0.31	0.31	0.64	0.57	0.50	0.36
	0.05	0.18	0.12	0.57	0.25	0.28	0.28
	1.00	0.17	0.10	0.55	0.23	0.14	0.14
	1.50	0.04	0.23	0.23	0.26	0.23	0.16

LSD (0.05) = 0.0725 mean texture

LSD (0.05) = 0.0835 mean treatment

LSD (0.05) = 0.03114 mean matric potential

LSD (0.05) = 0.044 mean treat. * matric potenial

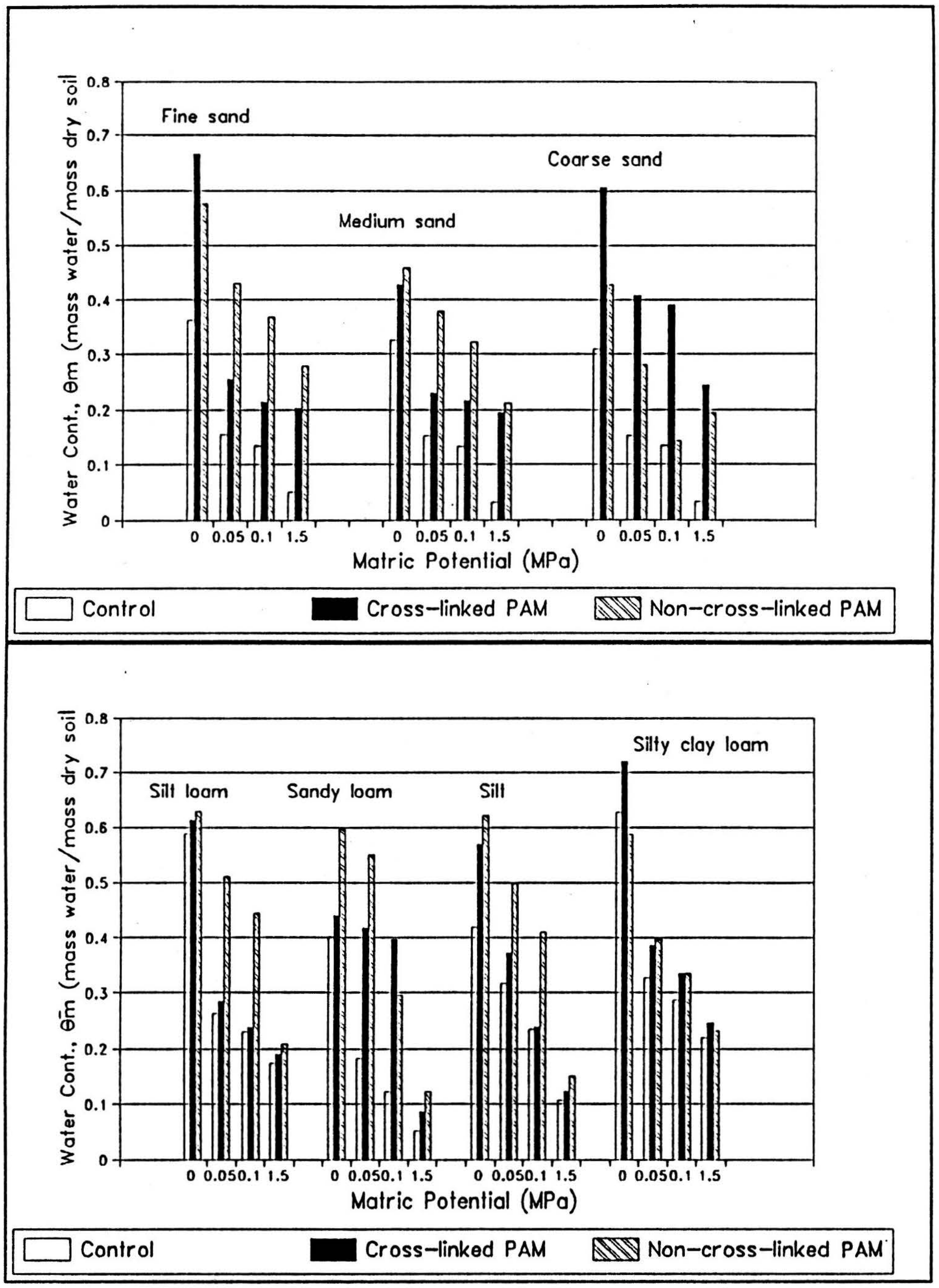


Figure 5. Water content (θm) for seven soil textures as a function of matric potential and affected by two PAM conditioners.

Table 9. Analysis of variance for water content (θm) in seven soil textures as related to materic potential and as affected by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Texture	6	0.0548	5.20^{**}	S
Treatments	2	0.3339	31.71^{**}	S
Text.*Treat.	12	0.0272	2.59^{**}	S
Error (a)	21	0.0105		
Matric potential	3	0.9723	194.62^{**}	S
Error (b)	3	0.005		
Text.* MP	18	0.0108	4.72^{**}	S
Treat.* MP	6	0.0126	5.50^{**}	S
Text.*Treat.*MP	36	0.0055	2.42^{**}	S
Error (c)	60	0.0223		
Total	167			

** Significant at 99% confidence level.

soil was decreased from 78% to 64%, as influenced by the PAM treatments.

The increase in water content for a given value of matric potential under the two PAM treatments does not automatically mean that there is more water available for plants, because these soil conditioners may alter field capacity and the wilting point for a given texture. Callaghan et al. (1988) reported that polyvinylalcohol almost doubled the field capacity of sandy soil when added at 0.5%. The importance here is the relative differences noted. Application of PAM also altered bulk densities (Table 23).

Experiment 2

Effect of two PAM conditioners on cracking and penetrometer resistance

Detailed data on the area/length cracking ratio and penetrometer resistance on the soil surface are shown in Table 10. These data indicate that adding PAM amendments led to significant (99% confidence level) increases in the area/length cracking ratio. The area/length cracking ratio on the soil surface in cross-linked PAM treatments was significantly (99% confidence level) greater than that of the control and non-cross-linked PAM treatments. The cross-linked amendment involves crystals of PAM that absorb water and swell. As evaporation takes place, soil surface shrinks back, leading to a greater chance of cracking. In contrast, there was no significant difference between non-cross-linked PAM and control treatments (Table 11).

The mean penetrometer resistance data show that the surface of the soil crust in the control had the greatest resistance (Table 10). Both cross-linked and non-cross-linked treatments yielded similar results. Data in Table 12 indicate that PAM amendments had significantly (99% confidence level) decreased soil crusting. Penetrometer resistance on the surface of the soil crust in control treatments was significantly (99% confidence level) greater than that of the cross-linked and non-cross-linked PAM treatments. There was no significant difference between cross-linked and non-cross-

Table 10. The influence of two PAM conditioners on penetrometer resistance (kg/cm^2) and cracking (numbers within parentheses are standard deviations from the mean)

	Treatments	Replications				
		1	2	3	4	Mean
Penetrometer Resistance (Kg/cm^2)	Control	2.969 (0.877)	2.201 (0.713)	1.856 (1.117)	2.125 (0.753)	2.288
	Cross-linked PAM	0.739 (0.360)	1.062 (0.547)	1.291 (0.607)	1.154 (0.575)	1.062
	Non-cross-liked PAM	1.335 (0.238)	1.724 (0.537)	1.796 (0.531)	1.604 (0.513)	1.615
Cracking Area/length ratio	Control	0.345 (0.115)	0.245 (0.314)	0.538 (0.312)	0.432 (0.302)	0.390
	Cross-linked PAM	0.447 (0.321)	0.808 (0.464)	0.896 (0.307)	0.758 (0.369)	0.735
	Non-cross-liked PAM	0.434 (0.171)	0.658 (0.229)	0.436 (0.311)	0.467 (0.153)	0.499

LSD (0.01)= 0.159 mean treatment for penetrometer resistance.
LSD (0.01)= 0.211
mean treatment for cracking.
LSD (0.05)= 0.158

Table 11. Analysis of variance for soil cracking as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Block	3	0.18		
Treatments	2	0.99	6.697	S
Block * Treat	6	0.15		
Error	84	0.01		
Total	95			

Table 12. Analysis of variance for penetrometer resistance as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Block	3	0.09		
Treatments	2	198.32	9.34	S
Block * Traet.	6	9.20		
Error	672	0.43		
Total	682			

linked PAM treatments in regard to penetrometer resistance. In a greenhouse study, using the same application rate (0.2%) of PAM in a coarse-silty, carbonitic, mesic Typic Haploxeroll, Steinberger & West (1991) found that there was significantly greater cracking in control soils than in soils treated with PAM and significatly greater soil resistance in PAM-treated soils than the controls. However, Rubio et al. (1990), using 10, 20, 40 kg ha^{-1} of PAM, found that as PAM concentration increased, soil resistance decreased.

Effects of two soil conditioners on seedling emergence and soil moisture

Seedling emergence of crested wheatgrass was recorded over a two-week period (Table 13). Crested wheatgrass seedlings emerged well, both with and without PAM applications. No significant differences were found among treatments. Comparing seedling emergence by day also showed that there was no significant difference in seedling emergence in the first week of the experimental period. However, seedling emergence was greater (at 99% confidence level) in the last two days compared to the first four days of the trial (Figure 6 and Table 14). There were no significant effects on the emergence by the treatment-day interaction. In view of the pronounced soil crusting in the control soil, it was surprising that there was no significant difference in crested wheatgrass seed emergence among treatments. Contrary to expectations, mean seedling emergence was apparently higher on controls (but not significantly) than PAM-treated portions of the plots. Steinberger & West (1991), using 0.2% of polyacrylamide (PAM) in a coarse-silty, carbonatic, mesic

Table 13. Cumulative seedling emergence of crested wheatgrass as affected by two PAM conditioners (numbers within parentheses are standard deviation from the mean)

Treatments	% Seed Emergence						
	Days						
	1	3	5	7	9	11	13
Control	3.4 (4.2)	9.3 (6.8)	11.0 (7.9)	14.6 (10.5)	15.1 (10.5)	21.4 (12.9)	21.8 (12.3)
Cross-linked PAM	8.0 (5.5)	11.3 (6.0)	13.1 (5.0)	15.3 (6.0)	15.3 (7.7)	15.4 (8.0)	15.1 (7.5)
Non-cross-linked PAM	3.9 (2.7)	5.9 (2.1)	7.9 (3.8)	9.8 (5.4)	10.5 (6.0)	10.3 (5.7)	10.5 (5.8)

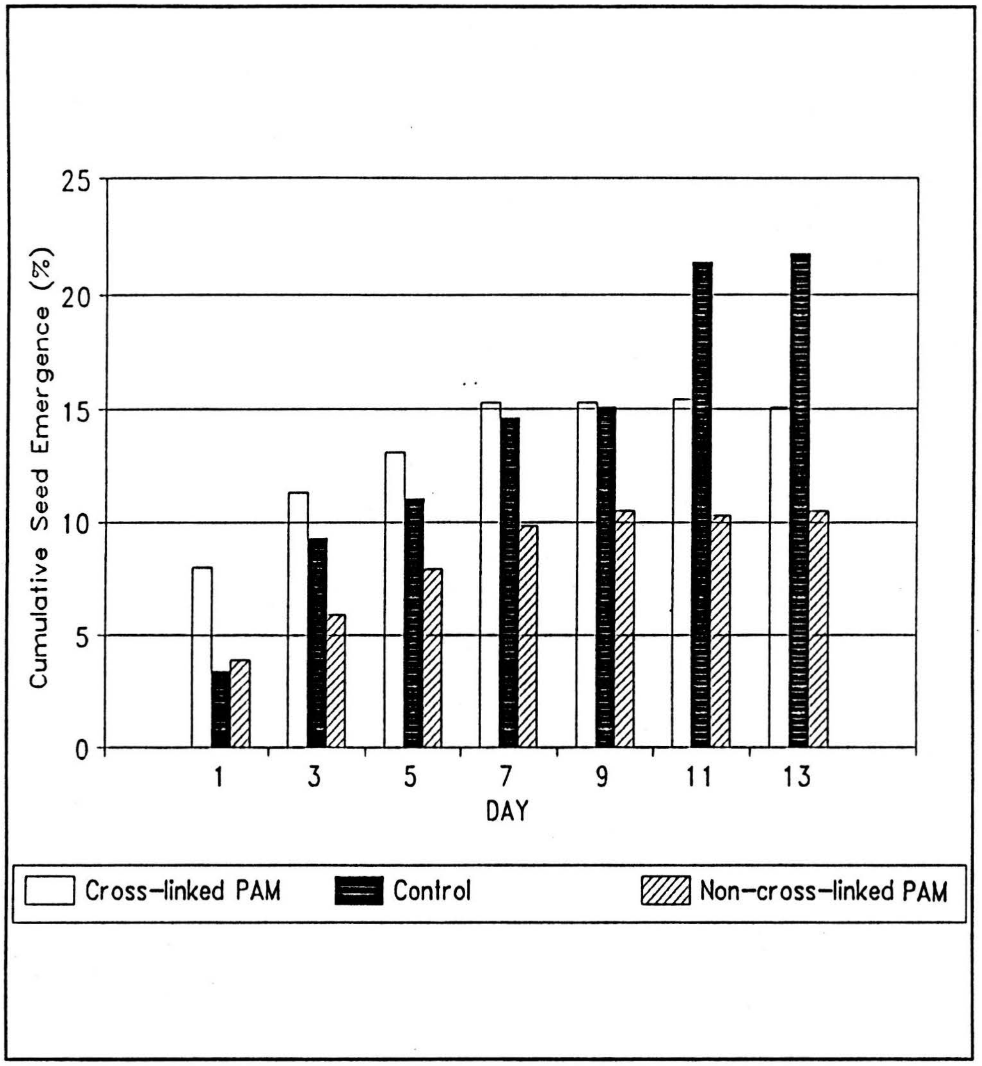


Figure 6. Cumulative seedling emergence of crested wheatgrass as influenced by two PAM conditioners.

Table 14. Analysis of variance for percent seed emergence of crested wheatgrass as influenced by two PAM conditioners

SV	df	MS	F-Ratio	P-value	Signif
Block	3	5.5			
Treatments	2	3.33	0.695	>0.25	NS
Error (a)	6	4.79			
Days	6	3.96	16.78	0.000	S
Error (b)	18	0.24			
Treat. * Days	12	0.3	1.09	>0.25	NS
Error (c)	36	0.27			
Subsamples	78	0.22			
Total	167				

Typic Haploxeroll seeded with *Bromus tectorum*, reported a similar result. In a recent paper, Rubio et al. (1992) examined the effect of polyacrylamide (PAM) on seedling emergence of rangeland grasses: blue panicgrass (*Panicum antidotale* Retz.), King Ranch bluestem (*Bothriochloa ischaemum* [K.]King), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), plains bristlgrass (*Setaria macrostachya* H.B.K.), and 'Salado' alkali sacaton (*Sporobolus airoides* [Torr.] Torr.). They reported that emergence of blue panicgrass and sideoats grama seedlings increased with PAM application during the summers of 1987 and 1988. Emergence of 'Salado' alkali sacaton and King Ranch bluestem was not affected by the application of polyacrylamide. In contrast, Hamilton & Lowe (1982) reported decreased germination of tobacco with high levels of polymer application, apparently because of crusting.

Soil water content data are presented in Table 15 and Figure 7. Mean soil water content over three months was higher in the controls (but not significantly) than the soils with

Table 15. The effect of two PAM conditioners on soil moisture content (numbers within parentheses are standard deviations from the mean)

Treatments	Soil moisture (Ov)								Mean
	Time								
	J.10	J.30	Jy.5	Ag.22	Ag.28	Spt.4	Spt.12	Spt.25	
Control	0.258 (0.02)	0.217 (0.03)	0.198 (0.04)	0.147 (0.05)	0.292 (0.09)	0.183 (0.05)	0.285 (0.035)	0.203 (0.034)	0.299
Cross-linked PAM	0.263 (0.04)	0.196 (0.03)	0.176 (0.04)	0.156 (0.04)	0.284 (0.04)	0.171 (0.03)	0.361 (0.038)	0.197 (0.03)	0.226
Non-cross-linked PAM	0.289 (0.02)	0.184 (0.03)	0.159 (0.02)	0.134 (0.02)	0.266 (0.05)	0.163 (0.027)	0.346 (0.035)	0.191 (0.027)	0.216

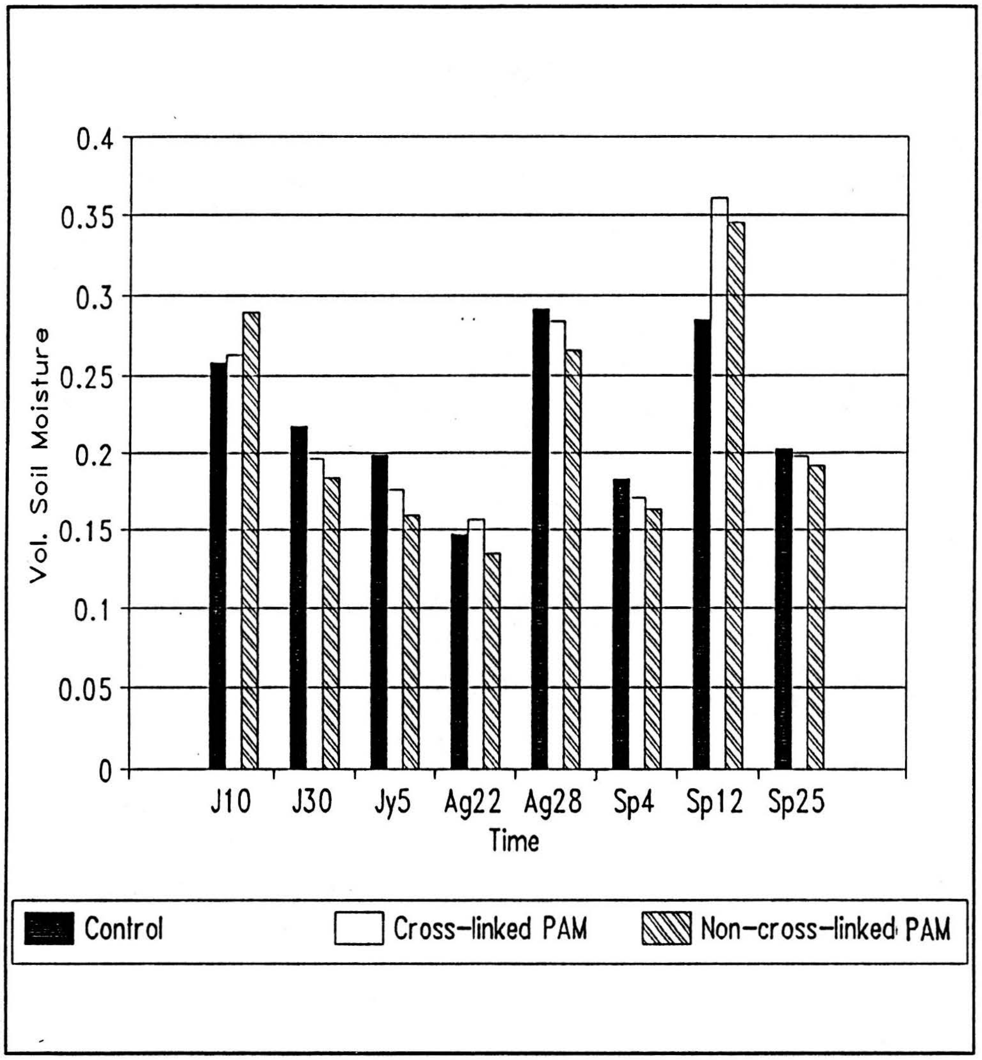


Figure 7. Effect of two PAM amendments on soil water content (J= June; Jy= July; Ag= August; Sp= September).

PAM added. The overall mean soil water level of the three months was highest in cross-linked PAM-treated plots. Soil water was higher by 1.2% and 4.0% than the overall average moisture level from the control and non-cross-linked sites, respectively. Results of statistical analysis in Table 16 indicate that there were no overall significant differences among treatments. There were, however, fluctuations of water level in soils during the three months because there were rainfall events on certain days, particularly August 28 and September 12. For this reason, significant differences in soil moisture level were observed on those days.

Table 16. Analysis of variance for soil water as affected by two PAM conditioners

SV	df	MS	F-Ratio	P-value	Signif.
Treatments	2	0.0012	0.75	0.477	NS
Days	7	0.0823	50.06	0.000	S
Treat. * Days	14	0.0026	1.57	0.096	NS
Error	136	0.0016			
Total	159				

In view of the pronounced soil cracking on cross-linked PAM plots, it was surprising that there were no significant differences in soil water among treatments. In contrast, water availability was similar in all treatments.

On August 2, 1991, crested wheatgrass plants were defoliated by grasshoppers; thus growth rate of this grass could not be followed further.

Experiment 3

Effect of two PAM conditioners on soil moisture and big sagebrush biomass

Soil moisture content data are listed in Table 17. The soil moisture content over three months decreased from the first day of measurement to the last day of measurement (Figure 8). Soil moisture content was greater on June 10, June 30, and July 5 in cross-linked PAM-treated soil. However, the moisture was greater in non-cross-linked PAM-treated soil on August 22, August 28, September 4, September 12, and September 25. The overall mean soil moisture levels during the three months were similar in all treatment sites (0.27, 0.28, and 0.28 of moisture levels for control, cross-linked PAM, and non-cross-linked PAM treatments, respectively).

Table 18 shows there were no significant differences in mean soil moisture among treatments. Comparing days' effects on soil moisture, there were significant differences (95% confidence level) observed among days.

The soil moisture on June 10, June 30, and July 5 was significantly (99% confidence level) higher than the soil moisture reading on August 22, August 28, September 4, September 12, and September 25. The soil moisture measurements on June 10, June 30, and July 5 were 47.6%, 41.7%, and 40.2%, respectively, greater than the soil moisture determined on September 25. The measurements of soil moisture

Table 17. The effect of two PAM conditioners on soil moisture content at the 25 to 45 cm depth (numbers within parentheses are standard deviations from the mean)

Treatments	Soil moisture (Θv)								Mean
	Time								
	June 10	June30	July 5	Augt. 22	Augt. 28	Sept.4	Sept.12	Sept. 25	
Control	0.37	0.31	0.35	0.27	0.21	0.25	0.20	0.20	0.27
	(0.15)	(0.1)	(0.05)	(0.07)	(0.07)	(0.07)	(0.09)	(0.07)	
Cross-linked PAM	0.40	0.40	0.37	0.23	0.26	0.25	0.18	0.19	0.28
	(0.14)	(0.16)	(0.12)	(0.12)	(0.14)	(0.13)	(0.9)	(0.09)	
Non-cross-linked PAM	0.37	0.31	0.28	0.32	0.27	0.28	0.21	0.25	0.28
	(0.14)	(0.17)	(0.16)	(0.09)	(0.07)	(0.07)	(0.07)	(0.07)	

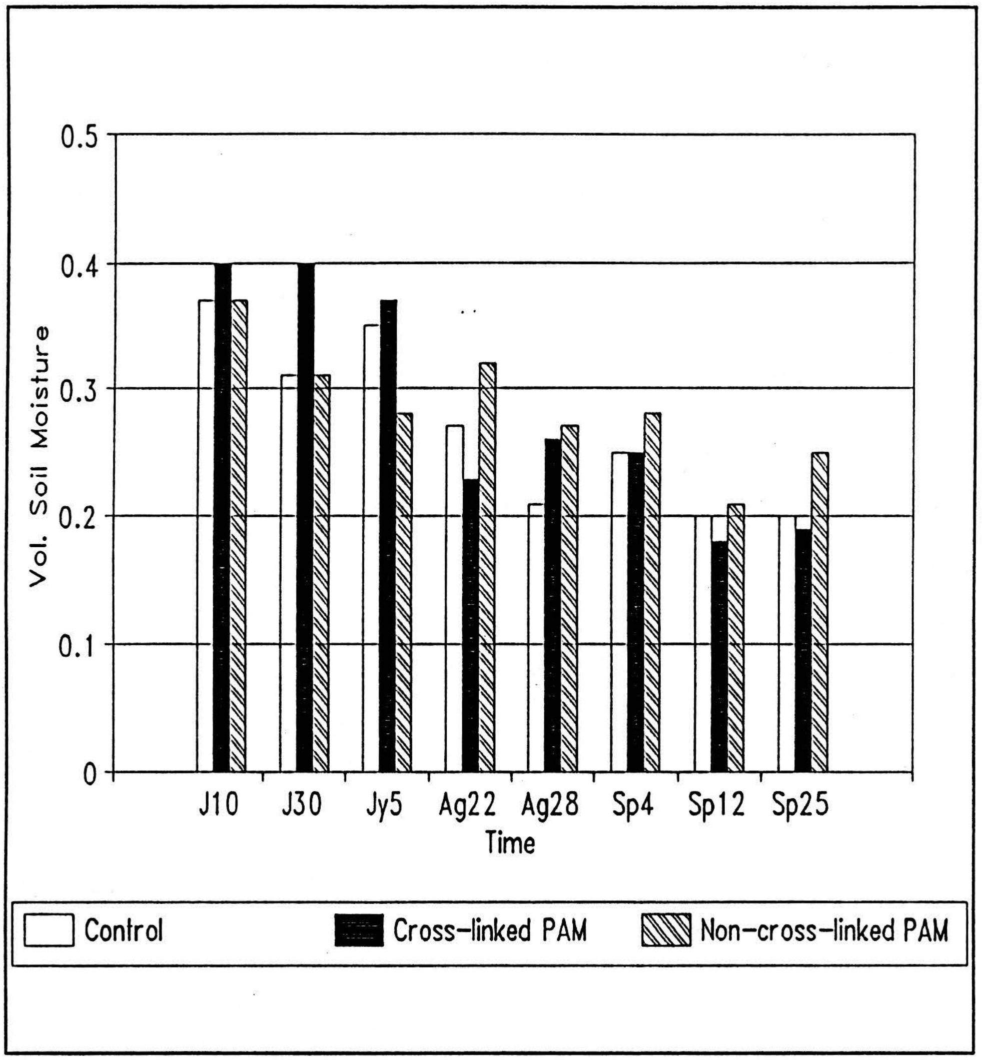


Figure 8. Effect of two PAM conditioners on soil water content at 25 to 45 cm of depth (J= June; Jy= July; Ag= August; Sp= September).

Table 18. Analysis of variance for soil water between the 25 to 45 cm depth as influenced by two PAM conditioners

SV	df	MS	F-Ratio	P-value	Signif.
Treatments	2	0.004751	0.067	>0.25	NS
Error (a)	21	0.07072			
Days	7	0.097367	20.694	0.000	S
Error (b)	49	0.004705			
Treat. * Days	14	0.010221	73.928	0.000	S
Error (c)	84	0.007233			
Total	192				

taken on August 22, August 28, and September 4 were higher (99% confidence level) than the moisture content observed on September 25; the former two were also higher than the measurement of moisture on September 12, at the same level of confidence. The soil moisture measurements on August 22, August 28, and September 4 were 27.2%, 23.5%, and 20.2%, respectively, greater than the soil moisture determined on September 25.

Soil moisture was affected significantly (95% confidence level) by treatment-day interactions. Figure 8 illustrates that soil moisture content recorded earlier in the experiment (June 10, June 30, and July 5) was higher in soil treated with cross-linked PAM conditioner, but the soil treated with the same PAM conditioner had lower moisture levels than the control and non-cross-linked treatment sites later, except August 28 when it was higher than the control. Non-cross-linked PAM conditioner type-day interaction resulted in higher soil moisture levels in that soil on August 22, August 28, September 4, September 12, and September 25 than the control and cross-linked PAM treatments. In many studies, PAM conditioners were usually reported to retain more soil water than the control. In this case, soil moisture levels from the PAM conditioner sites did not differ significantly from the moisture level in the controls.

Dry big sagebrush aboveground biomass data (Table 19) and root biomass data (Table 20) showed no significant differences in growth among treatments (Table 21 and 22). Sample size was small and variance was high, however, enhancing the chance for a Type II error.

Table 19. The effect of two PAM conditioners on big sagebrush aboveground dry biomass (gm)

Treatments	Replications							
	1	2	3	4	5	6	7	Mean
Control	27.7	43.6	5.8	25.8	15.6	28.4	40.8	26.8
Cross-linked PAM	6.4	47.8	0.6	42.5	9.5	9.1	57.3	24.7
Non-cross-linked PAM	32.6	42.0	14.6	4.4	12.6	56.7	50.7	30.5

Table 20. The effect of two PAM conditioners on big sagebrush dry root biomass (gm)

Treatments	Replications								
	1	2	3	4	5	6	7	8	Mean
Control	1.4	0.8	1.1	1.9	0.3	0.3	0.97	*	0.97
Cross-linked PAM	0.1	0.3	0.6	1.1	2.8	0.7	2.8	2.9	1.41
Non-cross-linked PAM	2.8	3.1	0.4	0.1	0.6	2.9	2.8	1.8	1.81

* Missing Data; Plant defoliated by harvested ants on June 24,1991

Table 21. Analysis of variance for sagebrush aboveground dry biomass as affected by two PAM conditioners

SV	df	MS	F-Ratio	P-value	Signif
Treatments	2	102.37	0.457	>0.25	NS
block	6	547.16	2.441		
Error	12	224.17			
Total	20				

Table 22. Analysis of variance for sagebrush dry root biomass as affected by two PAM conditioners

SV	df	MS	F-Ratio	P-value	Signif
Treatments	2	1.15	0.87	0.44	NS
Error	18	1.31			
Total	20				

Summary and conclusion

Effects of two polyacrylamide amendments (cross-linked PAM and non-cross-linked PAM), at one level of concentration (0.2%), on rangeland soils and two plants species of different growth form were investigated. Evaporation, hydraulic conductivity, and water retention were evaluated for seven soil textures. Germination of _Agropyron desertorum_, soil cracking, penetrometer resistance, and soil moisture were investigated in the field with one translocated soil. In addition, aboveground biomass and root density of _Artemisia tridentata_ and soil moisture at depths of 25 to 45 cm were investigated in the field with the same soil presenting revegetation difficulties.

The following conclusions are made:

(1) The two polyacrylamide conditioners did not significantly reduce evaporation from fine soil textures (silt, silt loam and silty clay loam), but did reduce evaporation from coarse sandy textured soils.

(2) The two polyacrylamide conditioners did not increase saturated hydraulic conductivity, but rather decreased it especially the non-cross-linked PAM. Thus, the effect of PAM conditioners as amendments to improve infiltration is not feasible, at least at the one concentration level used. These results indicate limited value of PAM in enhancing storage and reducing evaporation of water from soils.

(3) Both PAM conditioners did increase water retention at a given matric potential. However, this does not mean there will be more water available to plants because these conditioners alter field capacity.

(4) Contrary to expectations from literature, the two PAM treatments did not improve total seedling emergence of <u>Agropyron desertorum</u>.

(5) Greater cracking was significantly present in non-cross-linked PAM-treated plots than both the controls and the cross-linked PAM-treated plots.

(6) The two PAM treatments had significantly lower penetrometer readings than the control, showing the effect of these conditioners in ameliorating penetrability.

(7) Both field experiments showed, however, that the two PAM conditioners did not improve soil moisture.

(8) PAM conditioners did not have any significant effect on sagebrush (<u>Artemisia tridentata</u>) tubeling growth and root density. Sample size was small and variance was high, so the likelihood of a Type II error is high.

Because there were significant differences in effects of treatments on evaporation, saturated hydraulic conductivity, and amount of water retained, the first hypothesis was rejected. In addition, there were significant differences in effects of treatments on cracking and crust formation, so the third hypothesis was also rejected. However, there were no significant differences in effects of treatments in germination of crested wheatgrass, growth and survival of big sagebrush, and soil moisture; therefore, the second, the fourth, and the fifth hypotheses were accepted.

Results of this study suggest PAM conditioners may become important in improving soil water on sandy textures through evaporation reduction. It is also reasonable to conclude that the application of PAM may reduce soil resistance.

Any future studies or usage of PAM conditioners should take into consideration different application rates of these synthetic conditioners. The rates used in this study were relatively high compared to most practical applications. The addition of just one other application rate would have doubled the size and thus the cost of these experiments, however.

Further chemical properties of soil should also be tested and correlated with responses to PAM. The potential in using these synthetic conditioners is most promising in sandy textured soils. Most seeding difficulty from crusting is, however, encountered in fine-textured soils, casting doubt on the applicability of PAM to lessen this major problem.

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Appendix

Table 23. Bulk density and volumetric water content for the seven soil textures used in experiment 1

Soil Texture	Treatment	Bulk Density	Volumetric Water Content
Sandy loam	Control	1.36	0.92
	Cross-linked PAM	1.11	0.93
	Non-cross-linked PAM	1.03	0.94
Silt	Control	1.27	0.92
	Cross-linked PAM	1.11	0.97
	Non-cross-linked PAM	1.10	1.00
Silty clay loam	Control	1.08	0.91
	Cross-linked PAM	1.15	1.00
	Non-cross-linked PAM	1.07	1.00
Silt loam	Control	1.11	0.90
	Cross-linked PAM	1.09	0.91
	Non-cross-linked PAM	1.16	0.90
Fine sand	Control	5.40	1.00
	Cross-linked PAM	3.35	1.00
	Non-cross-linked PAM	4.73	1.00
Medium sand	Control	5.90	1.00
	Cross-linked PAM	3.42	1.00
	Non-cross-linked PAM	4.62	1.00
Coarse sand	Control	5.69	1.00
	Cross-linked PAM	349	1.00
	Non-cross-linked PAM	4.16	1.00

Table 24. Analysis of variance for saturated hydraulic conductivity for silt loam as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	0.00047244	605.692	S
Error	6	0.00000078		
Total	8			

LSD (0.05) = 0.001764

Table 25. Analysis of variance for saturated hydraulic conductivity for sandy loam as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	0.00211637	846.25	S
Error	6	0.0000026		
Total	8			

LSD (0.05) = 0.003222

Table 26. Analysis of variance for saturated hydraulic conductivity for silt as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	0.0000008411	756.9757	S
Error	6	0.0000000011		
Total	8			

LSD (0.05) = 0.0000666

Table 27. Analysis of variance for saturated hydraulic conductivity for silty clay loam as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	0.000020271	128.2975	S
Error	6	0.0000001578		
Total	8			

LSD (0.05) = 0.0007936

Table 28. Analysis of variance for saturated hydraulic conductivity for fine sand as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	0.40035	49.75	S
Error	6	0.00805		
Total	8			

LSD (0.05) = 0.0655

Table 29. Analysis of variance for saturated hydraulic conductivity for medium sand as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	72.841	75.61	S
Error	6	0.963		
Total	8			

LSD (0.05) = 1.9606

Table 30. Analysis of variance for saturated hydraulic conductivity for coarse sand as influenced by two PAM conditioners

SV	df	MS	F-Ratio	Signif.
Treatment	2	295.48	158.72	S
Error	6	1.86		
Total	8			

LSD (0.05) = 2.725