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Lack of stability of soil aggregates for water movement is a major problem in arid soils due to low organic matter and higher sodium contents. Soil amendments for improving stability of structure and increasing infiltration of water are essential to solve water management problems in these areas.

Different rates of two amendments, gypsum and polyacrylamide, were applied to determine the optimum rate needed for maximum increase in infiltration of water into soil columns under laboratory conditions. The structural stability of soil samples taken from an experimental area at the Malheur Experiment Station, Ontario, Oregon was characterized by a wet sieving method.

It was found that gypsum salt applied at the rate of

25 tonnes/ha increased the infiltration. The wetting front of saturated and half saturated gypsum solutions moved faster into soil columns than that of water. The effect was due to replacing sodium from exchange sites by calcium ions. The saturated gypsum solution had equivalents of calcium that were more than double the total number of equivalents of exchangeable sodium in the entire soil column.

Polyacrylamide (PAM) solution applied at 7.5, 15, and 30 ppm concentration to soil columns did not increase the rate of infiltration over the check. This was apparently due to the adsorption of PAM on soil particles. However, the wetting front of water moved faster in PAM treated aggregates than in the check without PAM treatment. The PAM was mixed with soil at rates of 120 and 240 ppm by weight and aggregates were made by pressing the PAM treated soil through a 2 mm sieve. The columns were packed with these air-dried aggregates. Furthermore, it was found that stability of PAM treated aggregates was significantly higher than of the untreated aggregates.

The data analysis of the samples taken from a field trial at Malheur Experiment Station indicates that both gypsum and PAM increased the stability of soil structure over the check.

STABILITY OF SOIL STRUCTURE FOR WATER MOVEMENT IN AN ARIDISOL

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STABILITY OF SOIL STRUCTURE FOR WATER MOVEMENT IN AN ARIDISOL

1. INTRODUCTION

The Treasure Valley in Eastern Oregon has an agricultural resource-based economy. Economic development of this economy involves stimulating the production of high value crops and increasing the number of industries that process agricultural raw materials. Industry converts farm products into higher value forms, thus providing income and employment.

The potato has high productivity and can provide an adequate return per acre. The potato has been successfully industrialized in the Treasure Valley. The major industrialized product is frozen french fried potatoes. In the fall of 1985, the potato harvest presented processors with a problem of crisis proportions. Potato quality was insufficient to satisfy processors because of an internal defect called "sugar-end" or "dark end". A sugar-end potato from this region typically has more sugar in the stem end than in the rest of the potato. When the potato strips are fried at 375 F^{o} for a 2.5 minutes, the end with the greater sugars, the part of the potato strip near the stem end of the potato, develops a dark color which is unacceptable for the fast food industry.

There is reason to believe that "sugar-end" is associated with the development of water stress in the potato plant or potato tuber. It is further believed that this water stress may arise because of difficulties in managing water for good irrigation of the root zone in some potato fields.

The soils of the Treasure Valley are high in silt, low in clay, and low in organic matter; therefore, the infiltration of water into these soils is relatively slow. This slow water infiltration can have the consequence of causing great differences in the amount of water which infiltrates into the soil in various parts of the field. In some parts there may be large excesses of water, while in other parts there may be deficiencies. Under such conditions, it is difficult to continue to get good irrigations, putting the right amount of water at the right place at the right time for the full period of the potato crop season. These difficulties are further aggravated in some fields by relatively poor structure and soil tilth because of the very low organic matter content and susceptibility to soil compaction.

The objectives of the study were to characterize the stability of aggregates in an aridisol from eastern

Oregon, and to test the hypotheses that water infiltration can be improved by application of soil conditioners (gypsum and polyacrylamide), and that polyacrylamide can stabilize these soil aggregates.

2. REVIEW OF LITERATURE

2.1 On Infiltration

The soils of the Treasure Valley in Oregon are high in silt, low in clay and low in organic matter. Therefore, the infiltration of water into these soils is relatively slow.

During the early 1950's Marsh et al. (1956) found average infiltration rates of less than 0.25 cm per hour in corn fields in Oregon's Treasure Valley. Tileston (1953) demonstrated that the infiltration rates of these Treasure Valley soils often became reduced with repeated irrigation. In a later study, Buxton and Burr (1979) surveyed 22 potato fields in the same area and found that nearly one-half had infiltration rates of 0.25 cm per hour or less. The infiltration rates were similar for soils ranging in texture from 8 to 60% sand. Infiltration rates were higher for soils with high organic matter than for soils lower in organic matter. In addition there was a tendency for higher infiltration rates in furrows with low penetrometer resistance.

2.2 On Conditioners

Soil conditioning is the improvement of the soil physical condition. It has been shown that the addition of polymers can change the physical condition of the soil. Crust formation, compaction and physical degradation of structure of the surface soil are some of the main problems limiting agricultural production on soils in the World (Schamp et al., 1975). The properties of the soil that have to be improved depend on the soil, the climate and the crop. This means that each problem will have its own solution.

It is well established that appropriate polymeric soil conditioners properly used will increase pore space in soil, increase permeability and water infiltration and drainage, decrease runoff and result in soil drying faster after rain or irrigation. These results were established 30 years ago for synthetic soil conditioners (Hedrick and Mowry, 1952; Martin et al., 1952 and Quastel, 1954) and are still valid and continue to be obtained with new soil conditioners. It is generally considered that the increased availability of water is due to improved water infiltration, rather than to increased water holding capacity (Sherwood and Engibous, 1953). Treatment of the soil surface with polymer increased the infiltration by many centimeters per hour in individual cases (Sherwood and Engibous, 1953).

In a pot experiment on three different soils, Wallace and Wallace (1986) used three levels of polymers at the rate of 224, 448 and 673 Kg/ha. Then additional polymer in solution (56 Kg/ha) was added to saturate the soil, to stabilize the aggregates present and also to dissolve and fix the dry-applied polymers. They found that this method of combined dry and solution applications of polyacrylamide, a technique used to give a high level of soil conditioning, resulted in marked increases in earliness of seed emergence of lettuce and cotton and increased dry weight of seedlings. The lowest application rate was sufficient for maximum effect. In another study, Wallace and Wallace (1986b) applied new polymer soil conditioners to soil at rates in the range of 2.5 ppm and observed improvement in infiltration rates. Very low levels of polymers improved soil porosities, even though the rates were below the highest possible improvement. These results indicate that the degree of soil improvement may be matched with value of the crop to be grown for maximum economic benefit. Terry and Nelson (1986) conducted a study on a 12- * 12-m fallow site which was subdivided into 15 1 m^2 plots with at least 1 m between plots. Granulated PAM was applied to the dry surface of some of plots at the rate 200 Kg/ha. The PAM was tilled into the soil to a depth of 10 cm. An additional 200 Kg/ha PAM was applied to the PAM-treated plots, and the entire site was again tilled to a depth of 10 cm. The research site was then sprinkled with 5 cm of irrigation water. The soil was allowed to dry for 7 days and was then tilled for a third time. Flood-irrigated plots, including all the PAM-treated plots, were enclosed by raking surrounding soil into berms approximately 15 cm high. The PAM-treated plots were irrigated with 2.5 cm of a 1000 mg/Kg PAM solution. The total PAM application to the plots was 650 Kg/ha. The remainder of the plots were either flood- or sprinkle-irrigated with 2.5 cm of water. They found that irrigation method had no significant effect on aggregate stability, but the stability of aggregates from PAM amended soils was three to four times greater than the stability of untreated soils. This effect of PAM was immediate and also long-lasting.

Cook and Nelson (1986) in a study on the effect of polyacrylamide on seedling emergence in crust forming soils concluded that PAM solutions applied to the soil surface significantly improved crop emergence over surface granular PAM applications. However, neither liquid nor solid PAM improved existing physical properties. The results of a pot experiment on four different California soils showed that the ability of polymer to improve penetration was variable from soil to soil and not always correlated with the amount of polymer used (Wallace et al., 1986).

2.3 On Gypsum

Gypsum ($CaSO_4.2H_2O$) has been used for many years as an amendment for sodium affected soils, acting to displace Na held on soil colloids and increasing the ionic strength of the soil solution, thereby causing flocculation of the clays and improved structure, porosity and water infiltration (Keren and Shainberg, 1981; Loveday, 1984). Gypsum was suggested in the 1940's as a soil conditioner for improving the permeability of non-sodic Coastal Plain soils (Rinehart et al., 1953) and has since been shown to increase infiltration on non-sodic soils in Australia (Loveday, 1974), Israel (Agassi et al., 1982) and South Africa (de Plessis and Shainberg, 1985) and on sandy piedmont soils in the Southern United States (Miller, 1987). All these soils tend to be highly weathered, having very low levels of soluble salts naturally present to promote flocculation of the clay and maintain stable soil structure (Miller and Baharudin, 1986; Shainberg et al., 1981a). Infiltration of rainfall into a soil is a process upon which agriculture is dependent, both in supplying water to the root zone and in preventing excessive erosion due to high runoff volumes. Flocculation of the fine fraction of the soil is a prerequisite for the development of stable soil structure, which in turn results in stable macropores and high water intake rates (Quirk, 1978). Typically low infiltration and high erosion are most dramatically demonstrated on sodic soils, where infiltration may approach zero due to dispersion-induced surface sealing. Gypsum amendment is an effective reclamation method for these soils, replacing exchangeable Na with Ca to promote flocculation (Grierson, 1978). Although the accepted definition of sodic conditions specifies an exchangeable sodium percentage (ESP) of 15 (U.S. Salinity Lab. Staff, 1954), studies in Australia by Loveday (1974) and McIntyre (1979) have shown that substantial declines in hydraulic conductivity result from as little as 5% Na, and that gypsum may increase hydraulic conductivity on low-Na soils by increasing the ionic strength of the percolating solution, as well as by replacing exchangeable sodium. Rengasamy et al. (1984) have suggested a classification of soils based on their tendency to disperse spontaneously in water or to disperse only upon shaking. In their work, soil with sodium adsorption ratio (SAR) <3 did not spontaneously disperse in water but did upon shaking, with the degree of dispersion being highly correlated with the total cation concentration in a 5:1 soil/water extract. In Israel, low electrolyte levels have been related to clay dispersion and reduced hydraulic conductivities in low sodium (2<ESP<6) soils (Shainberg et al.,1981b).

Gypsum applied to the soil surface significantly increased infiltration under rainfall conditions (Agassi et al., 1982; Kazman et al., 1983). Similar results have been obtained on South African Alfisols (du Plessis and Shainberg, 1985). The effects of electrolyte concentration on electrical double layer thickness and repulsive forces between clay platelets is well understood (Van Olphen, 1977). Early research suggested that swelling minerals were largely responsible for reductions in hydraulic conductivity and that kaolinite was flocculated under nearly all conditions (McNeal and Coleman, 1966).

The studies by Rengasamy et al.(1984) and du Plessis and Shainberg (1985) demonstrate that kaolinite and micaceous soils with very low levels of Na can be easily dispersed and may have reduced infiltration rates where mechanical disturbance (i.e., raindrop impact) is able to catalyze the dispersion process and form a "washed in" layer of clay, blocking water transmission pores at the surface (Gal et al., 1984 ; Agassi et al.,1985). The results reported by Miller (1987a) for topsoil material from three typical Southeastern U.S. Ultisols(sandy texture, non-sodic and highly dispersible soils) indicate that phosphogypsum significantly increases the infiltration under rainfall conditions and reduces associated soil loss, particularly on finer textured soils. Chartres et al. (1985) observed that the application of gypsum at both 5 and 15 tonnes/ha rate decreased clay dispersion, increased microporosity and reduced crusting. However, it appeared to them that as gypsum is leached out of the surface layers, macroporosity decreased and crusting recurred. Therefore, it was suggested that to manage these soils to minimize aggregate breakdown due to dispersion, periodic applications of gypsum are required to maintain the clay colloids in a flocculated condition.

3. MATERIALS AND METHODS

3.1 Soil

Soil samples of silt loam (Coarse-silty, mixed, mesic, Xerollic Camberthids) were taken on March 31, 1987 from plots, B8d and C2C, of a soil amendment trial with potatoes on the Malheur Experiment Station. The station is located at 43°.58 N and 117°.02 W. Samples were air dried, ground, and sieved through a 2 mm sieve. The results of physio-chemical analysis of these samples are given in the table A1.

3.2 Column Preparation

A weight of soil sufficient to give a 17 cm long column was packed into a plastic cylinder with internal diameter of 2.3 cm. Some initial experiments were performed with bigger columns, 25 cm in length with internal diameter of 4 cm. A rubber cork with a small hole supported the soil at the bottom of the column and provided an outlet for air displaced during infiltration. Uniformity of packing was achieved by pouring small, weighed portions of soil into the column, while the base of the cylinder was gently and intermittently tapped on the bench.

3.3 Infiltration

The advance of the wetting front in vertical infiltration was measured with a plastic ruler attached to the column, as a function of time measured with a stop watch. To obtain a precise head, a Mariotte bottle with bubbling tube was positioned so that water was maintained at constant head on the soil surface. Some of the infiltration measurements were made on single samples, the rest were on duplicate samples.

3.3.1 Ground Gypsum

A commercial grade gypsum salt at the rate of 1, 2, 3, 5 and 10% by weight was mixed with the soil. A check with no gypsum was also used.

3.3.2 Gypsum Solution

The ground gypsum was added to distilled water to prepare a saturated solution of 2.8 Cmol Ca/liter concentration. A one-half saturated gypsum solution was made by dilution with distilled water. The two solutions were allowed to infiltrate through the packed columns under constant head of solution. A check treatment was also run. The infiltration measurements were made on duplicate samples.

3.3.3 Polyacrylamide (PAM) in Solution

The PAM salt was added to distilled water to a concentration of 7.5, 15, and 30 ppm. These solutions were used to infiltrate through the packed columns under constant head. Readings were taken on duplicate samples. A check with no PAM was also run.

3.3.4 Polyacrylamide Added to Soil

Forty ml of 600 and 1200 ppm PAM was added to 200 gram portions of air-dried soil to give a concentration of 120 and 240 ppm PAM by weight in soil, respectively. The wet soil samples were forced through a 2 mm sieve and air-dried. A check sample was prepared by adding 40 ml of water in 200 gram of soil sample and then forcing through a 2 mm sieve. The soil columns were packed with these air-dried aggregates, in duplicate. The water was allowed to infiltrate through columns under a constant head of water.

3.4 Water Stable Aggregates

Soil samples were taken by Dr. J. Vomocil on

October 7, 1987 from an Amendment Trial (B8d) on the Malheur Experiment Station. They were air-dried and sieved through a 2-mm sieve. Aggregate stability was determined by the Kemper and Rosenau (1986) method. This method is briefly described as follows:

1. A 4 g sample of 1-to 2-mm air-dried aggregates was weighed onto a sieve of 24 mesh/cm (0.26 mm hole size).
2. The aggregates were wetted slowly with water vapor (taking about 30 minutes) to a water content near field capacity in a humidifier (Hankscraft, Model # 3972A).
3. Sufficient distilled water was placed in weighed and numbered cans to cover the soil when the sieve was at the bottom of its stroke. The cans were placed in the recessed holders in the sieving apparatus
4. Numbered sieves were placed in the sieve holder and the assembly was lowered so that each sieve and the aggregates contained therein entered the corresponding can.
5. The motor was started and allowed to raise and lower the sieves 1.3 cm, 35 times/min, for 3 minutes +-5 seconds.
6. The sieves were then raised out of the water, and the numbered cans containing particles and small aggregates that had passed through the 24 mesh sieves

were placed on a tray.

7. Another set of numbered and weighed cans containing 100 cm^3 of dispersing solution (0.02% sodium metaphosphate) was placed in the apparatus.
8. If some aggregates remained stable after 5 minutes of sieving in the dispersing solution, the sieving was stopped and aggregates were rubbed across the screen with a rubber tipped rod until they were disintegrated.
9. Sieving was continued until materials smaller than the screen openings had gone through.
10. The sieves were raised and numbered cans placed on a separate tray.
11. Both sets of cans were placed in an oven at 105 C until the water had evaporated.
12. The material in the cans was weighed, subtracting the weight of the can and the 0.2 g of dispersing solute.
13. The fraction stable is equal to the weight of soil obtained in the dispersing solution dishes divided by the sum of the weights obtained in the two dishes.

4. RESULTS

4.1 Infiltration

Infiltration is the term applied to the process of water entry into the soil, generally by the downward flow through all or part of the soil surface. Infiltration rate is defined as the volume flux of water flowing into the profile per unit of soil surface (Hillel, 1980). However, the term infiltration is used here for rate of advance of the wetting front. A simple, approximate, useful approach, the Green and Ampt approach, to infiltration process was applied to estimate the infiltration rate. The advance of the wetting front in a uniformly packed column was measured as a function of time. The measured results of depth to wetting front were plotted as a function of square root of time to have a linear relation between the depth to wetting front and time in minutes.

4.1.1 Effect of Gypsum on Infiltration

4.1.1.1 Gypsum Salt, Experiment 1

This experiment was conducted in larger columns, 25 cm in length and 4 cm internal diameter. Initially, all the samples containing gypsum gave higher infiltration over the check, but after 3 minutes there were no differences in infiltration rate among all samples including the check (Fig. 1).

4.1.1.2 Gypsum Salt, Experiment 2

The experiment was repeated with smaller columns, 17 cm in length with an internal diameter of 2.3 cm. Readings of depth were taken at constant time intervals. The slopes of the lines in Fig. 2, indicate that the wetting front moved faster in soil columns mixed with gypsum when compared to the movement in the check column. This is seen more clearly in figure 3, where the 1 and 2% treatments have been omitted.

4.1.1.3 Gypsum Solution

The data (average of duplicate determinations in large columns) graphed in Figure 4 indicate that the wetting front of 1/2 saturated and saturated solution moved faster than the check (water). The regression analysis of the same data, tables 4 and 5, shows higher slopes (x-coefficients) for gypsum solution over water (check) infiltration. Due to limited data, statistical analysis was not possible.

The experiment was repeated in the smaller columns. The data plotted in Figure 5 showed the same trend, but the 1/2 saturated gave higher infiltration, as in the previous experiment. The readings of these columns were taken neither at constant time nor at constant depth to wetting front. This made it difficult to average the data. The regression analysis, table 6, shows that the gypsum solutions have higher slopes over water (check). The smaller column had a lower bulk density than the large column, therefore, the data from both experiments could not be treated together. The depth to wetting front vs $t^{1/2}$ lines did not always go through the origin. This is believed to be due to inaccuracies in determining zero time at the start of infiltration. Therefore, the data lines have not been extrapolated to zero.

The conclusion drawn for the rate of gypsum (1.5 tonnes/ha) needed to improve water infiltration in field conditions is based on the following calculations:

Determined concentration of gypsum saturated solution -- 2.8 Cmol Ca^{2+}/liter.

Molecular weight of $CaSO_4.2HO_2$ = 172 g.

Amount of gypsum required (172/40 * 1.12) =4.82 g

Assumed porosity = .40

Area of hectare-- 10^4 m^3

depth of soil -- 0.15 meter

Volume of pores = Volume of water= $10^4 * 0.15 * 0.40=$

$600\ m^3$ -- $600*10^3$ liters.

Gypsum salt needed to saturate one liter water = 4.82 g

Gypsum salt needed to saturate 600,000 liter(ha)=2889 Kg

For half saturated solution -- 1.45 tonnes/ha.

4.1.2 Effect of Polyacrylamide(PAM) on Infiltration

4.1.2.1 Polyacrylamide Solution

To test the effect of PAM solutions on infiltration, the solutions of 7.5, 15 and 30 ppm concentration were allowed to infiltrate into soil columns under a constant head of solution. All the treatments were duplicated.

A check without PAM was not run. The reason was that a full column set (6 columns at a time) was used to run three concentrations in duplicate. The data for the check was taken from other check data. This was determined by plotting all check runs of other experiments (average of duplicate determinations and some single runs) at the same scale (Fig. 8). The slower rate for the check from an experiment on the effect of gypsum solution on infiltration (table 4) could not be explained; therefore, less reliabilty is given to its results. The higher rate of depth to wetting front of the check run in an experiment on the effect of PAM mixed with the soil on infiltration (table 9) was expected, due to the larger aggregate size (moist soil was passed through 2 mm sieve and air-dried). The data on other check runs (table 2, 3 and 6) gave similar slopes (Fig. 8). This data was used as the check for this experiment.

The data(average of two) graphed in Figure 6 show that the effect of PAM was negative. After 3 minutes, the water (check) was moving 3.5 cm ahead of the PAM solution of all concentrations.

4.1.2.2 Polyacrylamide Mixed with soil

Soil aggregates were prepared by pressing the wet soil + PAM samples through a 2 mm sieve (detail in section 3.3.3). Figure 7 shows a large effect of PAM for these samples. At 4 minutes, the water in the column packed with aggregates containing 120 ppm PAM by weight, had penetrated twice as far as in the check treatment without PAM.

4.2 Soil Aggregate Stability

4.2.1 Effect of PAM on Soil Aggregate Stability (Samples prepared in the laboratory)

The soil was mixed with PAM solution to a concentration of 15, 30, and 60 ppm PAM on a weight basis. The wet mixture of PAM and soil was pressed through a 2 mm sieve and air dried. A check (without PAM but with water added to soil) was also pressed through a 2 mm sieve and then air dried. Stability measurements were made on triplicate samples by the Kemper and Rosenau (1986) method. The statistical analysis (table A11) shows that aggregates treated with 15, 30 and 60 ppm PAM by weight were significantly more stable than untreated aggregates (check). However, the differences in stability were not significant within the PAM treated aggregates.

4.2.2 Effect of Soil Amendments on Aggregate Stability, (Field Samples)

The samples were taken from a factorial experiment (1. check, gypsum and PAM; 2. traffic, non-traffic and 3. upper or lower part of furrow.) replicated 4 times. PAM was mixed with irrigation water at the rate of 4.5

Kg/ha. The data analysis indicates that both PAM and gypsum increased the stability of aggregates over the check (table A12). Consideration of the mean stability shows that the samples from traffic plots have lower stability than those from non-traffic plots. The data also shows that the aggregates from the lower part of furrow are more stable than those from the upper part of furrow.

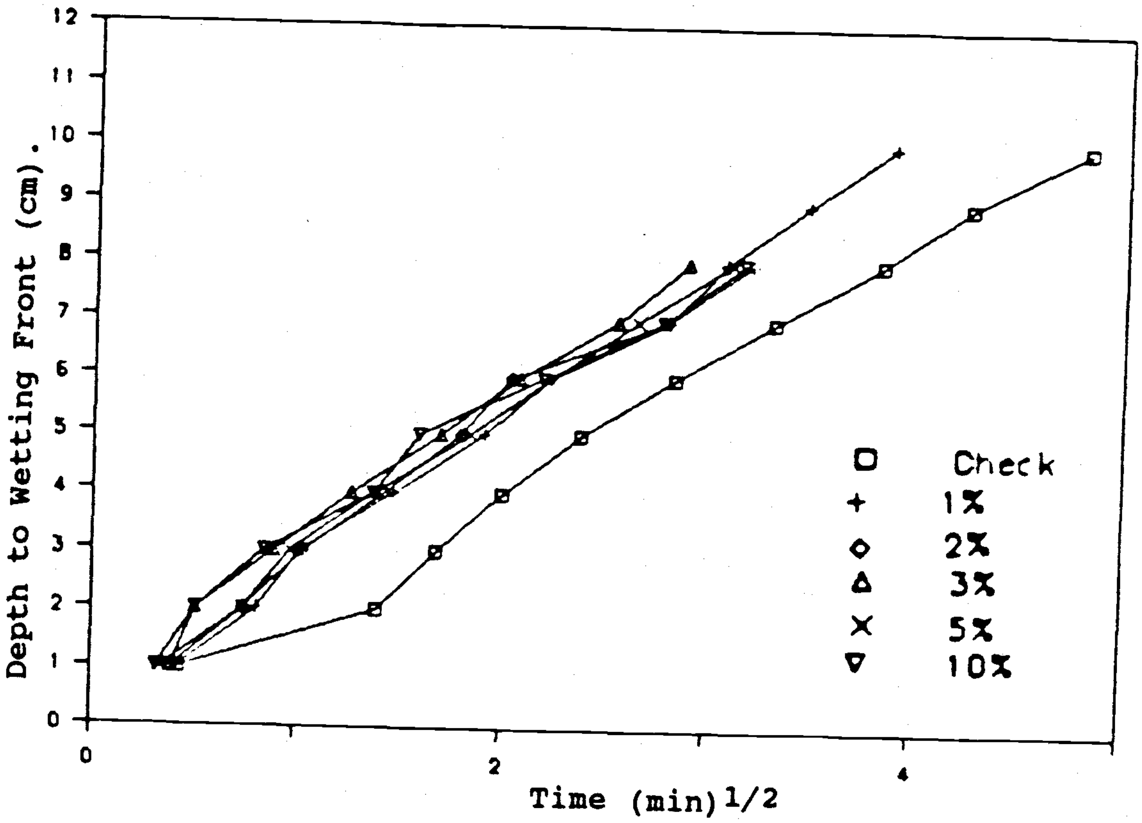

Figure 1 Effect of Solid Gypsum Mixed with Soil on Infiltration (large columns).

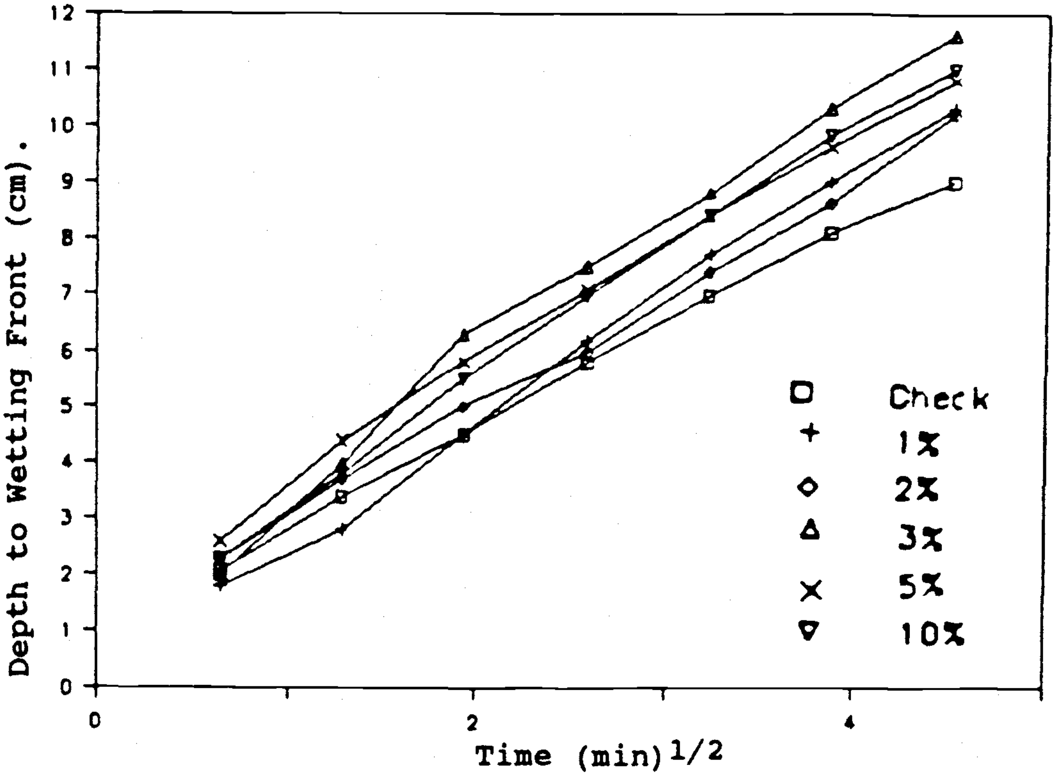

Figure 2 Effect of Gypsum Mixed with the Soil on Water Infiltration (small columns).

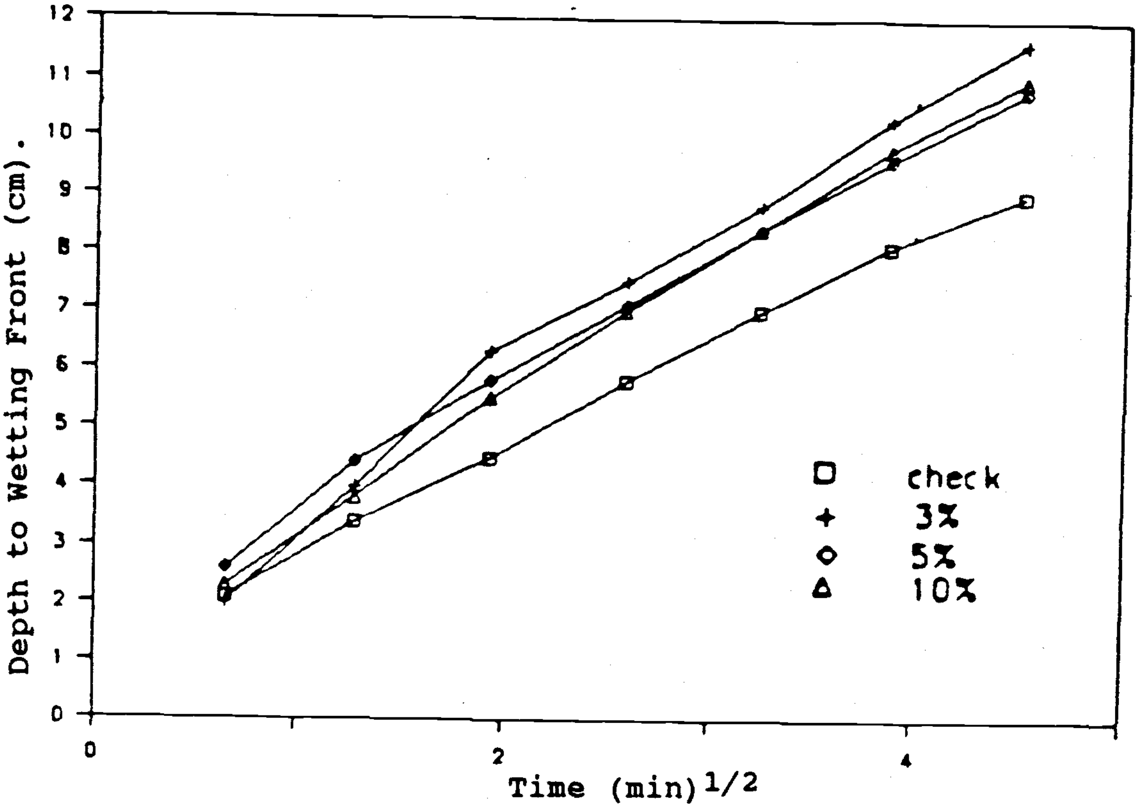

Figure 3 Effect of Gypsum Mixed with the Soil on Water Infiltration (Omitted 1 and 2% gypsum).

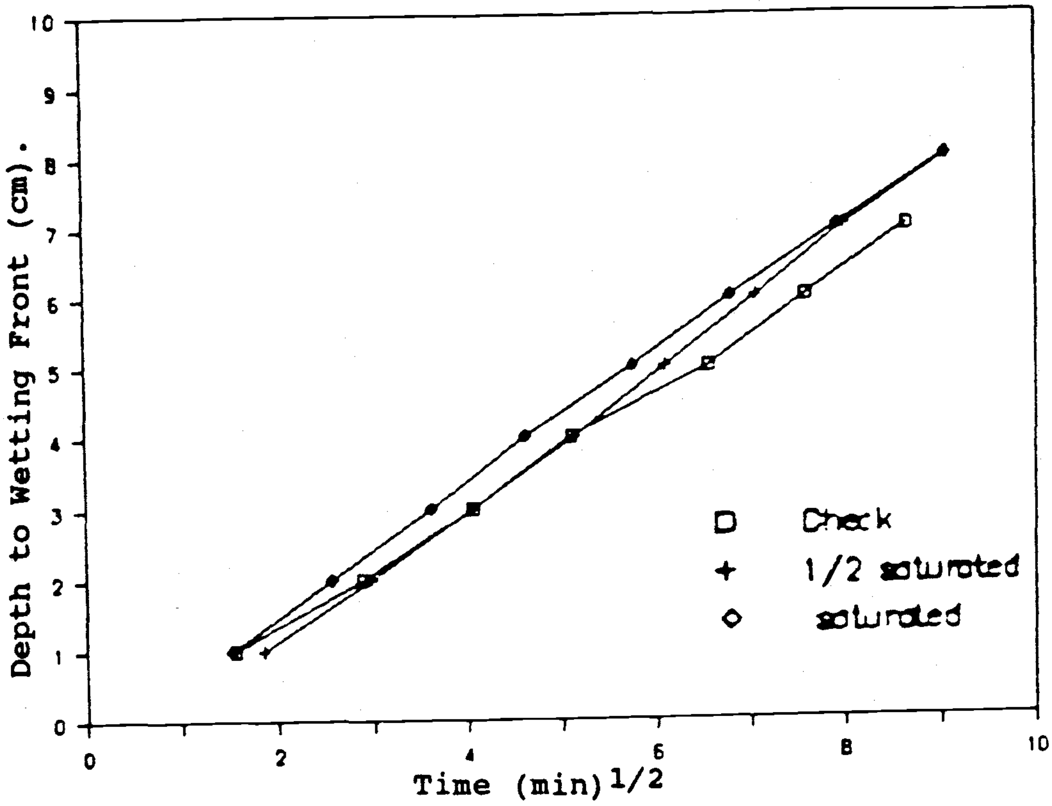

Figure 4 Effect of Gypsum Solution on Infiltration (large columns, saturation conc. not known).

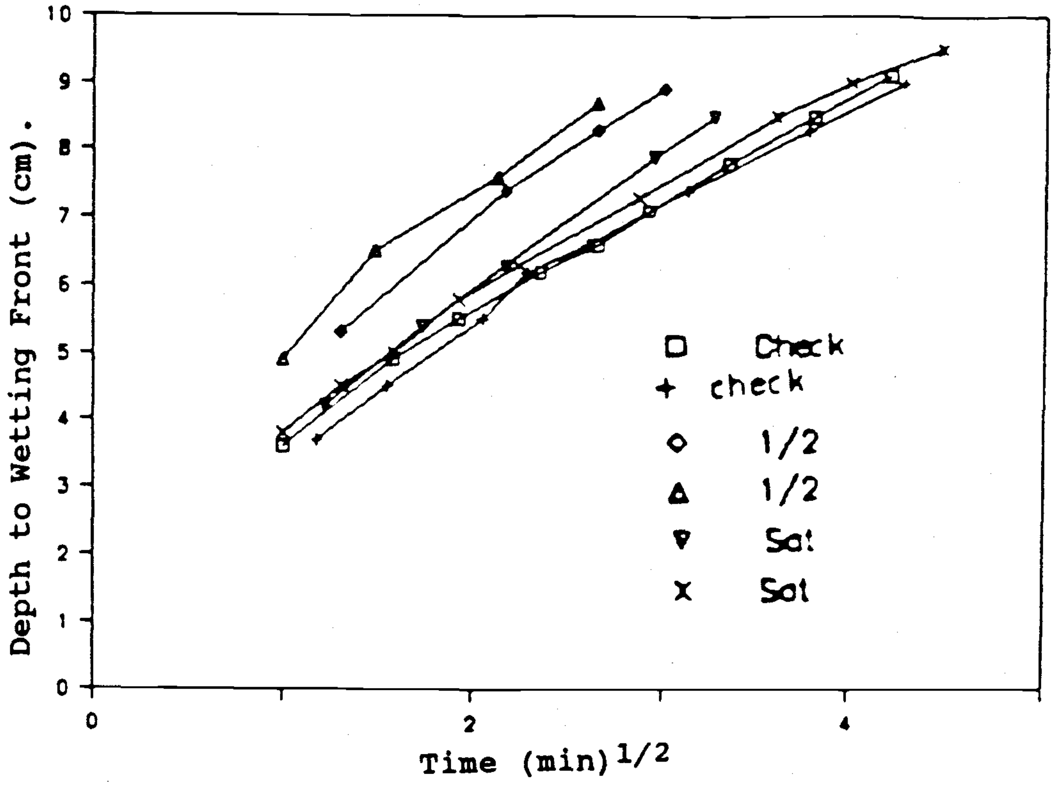

Figure 5 Effect of Gypsum Solution on Infiltration (small columns, saturation conc. measured).

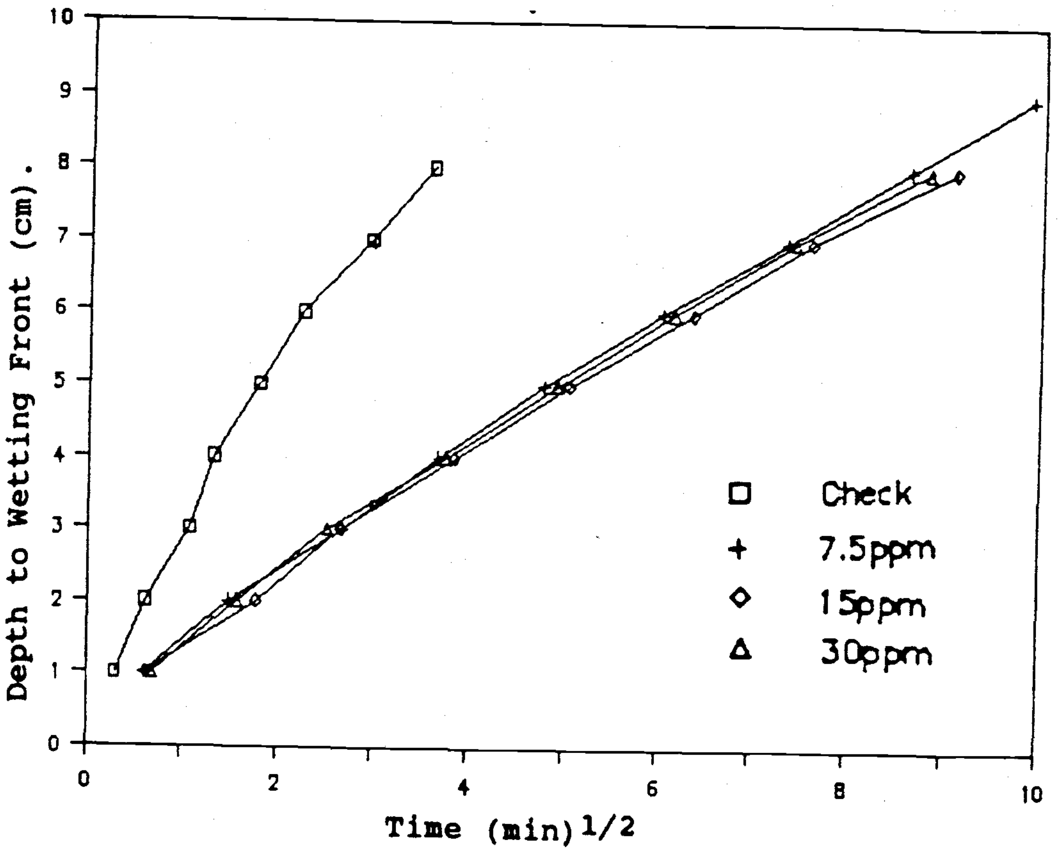

Figure 6 Effect of PAM Solution on Infiltration (Average of duplicate determinations).

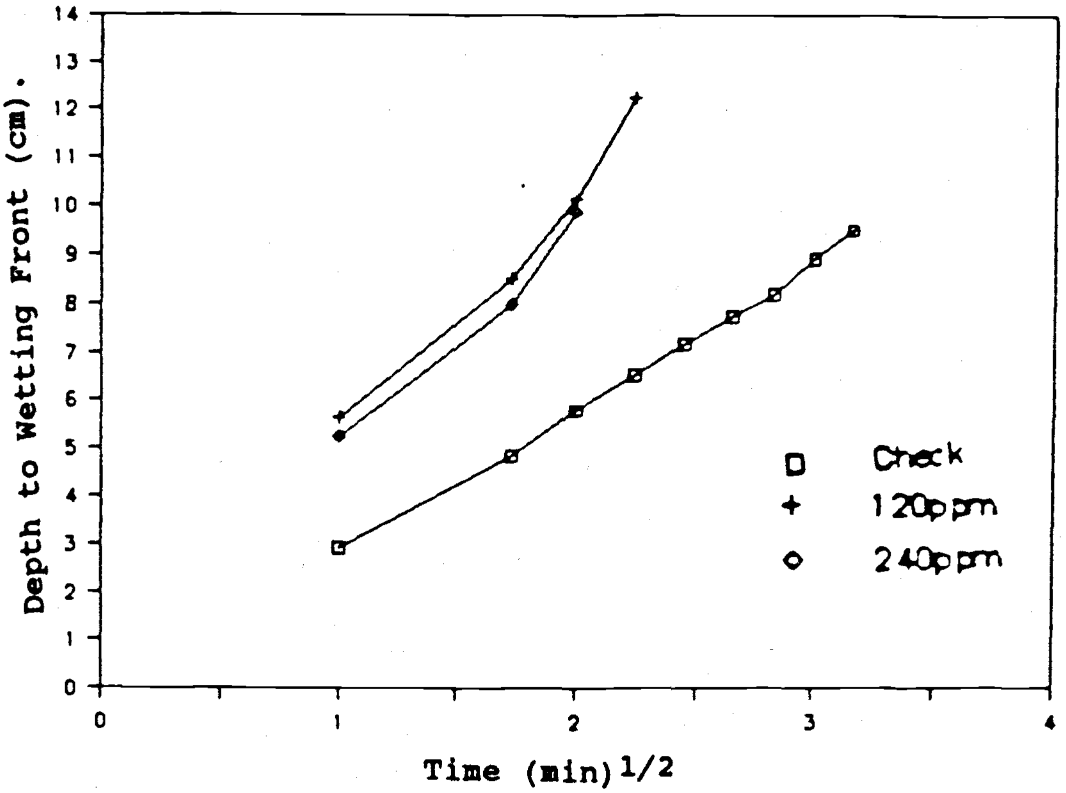

Figure 7 Effect of PAM Mixed with the Soil on Infiltration (Average of duplicate determinations).

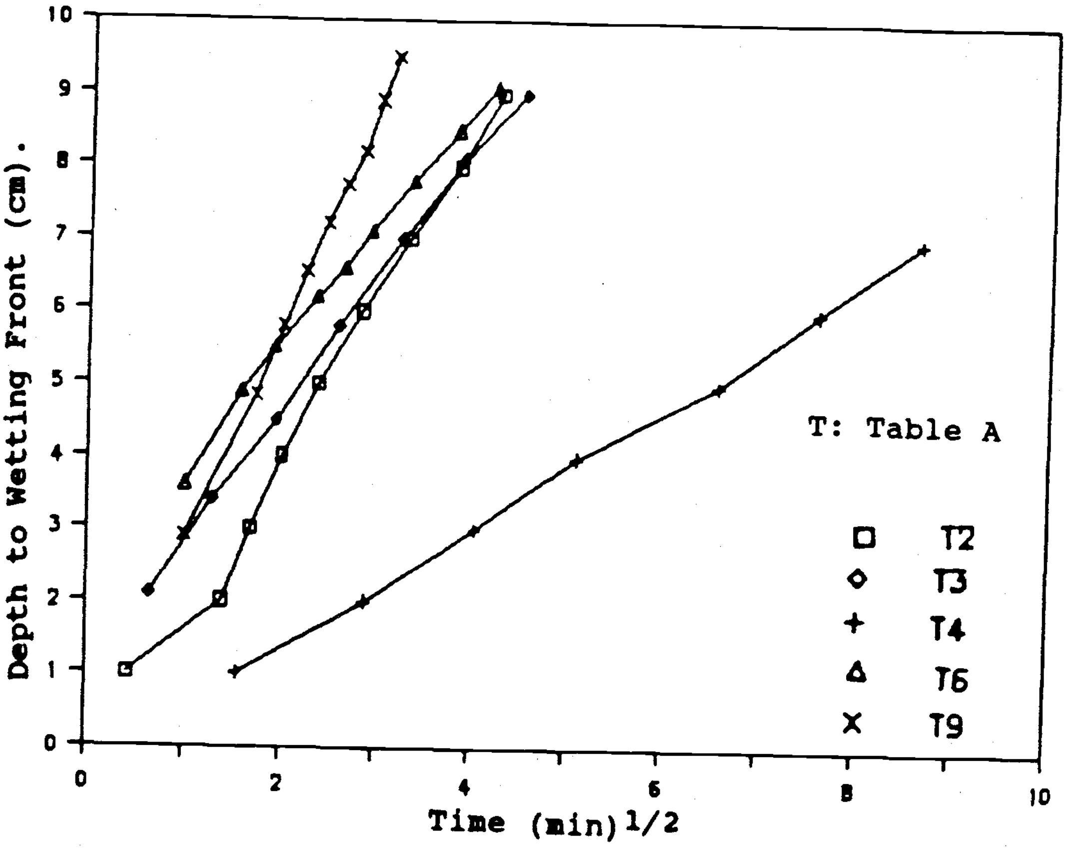

Figure 8 Infiltration Comparison of Check Samples.

5. DISCUSSION

5.1 On Infiltration

5.1.1 Effect of Gypsum

The depth to the wetting front with time was measured to determine the effectiveness of gypsum (salt and solution) in promoting water intake of soil samples taken from the Malheur Experiment Station.
The data were plotted in terms of wetting depth vs square root of time (Fig. 1, 2, 4 and 5). The regression x-coefficients (slopes) for these samples are given in tables A2 to A6.

The saturated gypsum solution (2.8 cmol/Kg) had more than double the equivalents of calcium than the total number of equivalents of exchangeable sodium in the entire soil column (table A1). Therefore, the increase in infiltration could be attributed to the flocculation of soil particles by calcium ions, to the removal of sodium from exchange sites or to increasing electrolyte concentration of the percolating solution.

The results follow the general pattern described by Prather et al. (1978) where the rates of wetting increased significantly with gypsum application (table A14). They attributed this to the effect of increasing electrolyte concentration of the initial infiltrating soil solution on soil permeability. The soils they used had higher electrical conductivity (29.2 mmhos/cm) and pH (8.5) than the soil samples used in this study (table A1). The very high rate of gypsum salt (100 Mg/ha) applied in their columns is comparable to the rates (22, 44, 67 and 134 Mg/ha) used in this study. They found that a comparison of Ca added to exchangeable Na removed did not indicate "per equivalent" efficiency of gypsum because all the gypsum applied was not necessarily brought into solution.

The results are also in agreement with those reported by Agassi et al. (1982). In a laboratory study on semi arid soils, they found that phosphogypsum contributed Ca-electrolytes to the soil solution and prevented chemical dispersion of the clay. Furthermore, it was noticed that phosphogypsum, when spread over the soil, was more beneficial in increasing the infiltration than when mixed with soil. It may be pointed out that our findings were from limited laboratory experiments on ground and sieved soil samples. Therefore, actual rates of gypsum would differ for improving infiltration in the field.

5.1.2 Effect of Polyacrylamide (PAM)

When PAM solution at lower concentration (17, 34, and 67 Kg PAM/ha) was allowed to infiltrate through a soil column, the infiltration decreased compared with the check without PAM (Fig.6). This is in contrast to the results obtained by Wallace and Wallace (1986). They reported that the PAM solution at 5.5, 11, and 22 Kg/ha rates increased infiltration over the check.

When PAM salt was mixed with moist soil (at the rate of 269 and 538 Kg/ha), the aggregates formed by forcing the mixture through a sieve were stable. The infiltration was very much higher than for the check. It is concluded that infiltration of water in the field would be promoted by PAM salt when mixed with soil, but that application of PAM as solution would not enhance the infiltration.

Terry and Nelson (1986) found that a soil to which PAM was applied at 650 Kg/ha and tilled three times had an infiltration rate under sprinkler irrigation approximately twice as great as that of the flood-irrigated control. Except for application rate and technique, the results reported here are similar to those reported by Wallace et al (1986). They reported that PAM solutions applied to soils had to be left one day for "curing", a process in which polymers are fixed to the clay, and which requires partial drying and time. Their data showed that the ability of the polymers to improve water penetration varied from soil to soil and was not always correlated with the amount of PAM used. It was also observed that sandy soils responded less than loamy and clayey soils.

5.2 On Stability of Aggregates

An aggregate is a group of primary particles that cohere to each other more strongly than to other surrounding soil particles. Stability of aggregates is a function of whether the cohesive forces between particles withstand the applied disruptive force (Kemper and Rosenau, 1986).

Processing the soil samples with PAM in the laboratory at rates of 34, 68 and 140 kg/ha significantly increased the stability of aggregates over the check without PAM. It should be pointed out here that these rates are very high; if applied in the field, the economic advantage is questionable. However, similar results have been shown in the trials by Helalia and Letey (1988). They reported that the polymers even at low rates can be quite effective in promoting soil flocculation. The effectiveness of polymers in promoting flocculation was checked by determining the rate at which soil settled after being shaken in polymer solutions.

The aggregate stability analysis of samples taken from a field trial at the Malheur Experiment Station, determined by Kemper and Rosenau (1986) method, showed that PAM and gypsum increased the stability of aggregates. The aggregates of the samples taken from the lower part of the furrow were significantly more stable than those from the upper part of the furrow. The reason seems to be the furrow irrigation with PAM solution. As one would expect, the aggregates of the samples from traffic treated plots were significantly less stable than from non-traffic treated plots.

6. SUMMARY AND CONCLUSIONS

6.1 SUMMARY

This study is an attempt to complement and enhance field experiments for improving stability of structure and increasing infiltration of water by using soil amendments in arid soils that face water shortage.

Stability of soil aggregates for enhanced water movement is one of the major problems in arid soils, due to their low organic matter and higher sodium contents. Soil amendments for improving stability of soil structure and thus increasing infiltration of water are essential to solve water management problems in these soils. A laboratory study was conducted on soil samples taken on the Malheur Experiment Station to measure the effect of soil amendments, gypsum and polyacrylamide (PAM) on aggregate stability and water movement. The influence of gypsum salt and solution on infiltration of water was measured. The effect of different rates of PAM on improving stability of soil structure and on increasing infiltration of water was also measured. The stability of soil structure of samples from field Amendment Trial was also characterized.

From the laboratory experiments, it was found that gypsum, both salt and saturated solution, increased the infiltration of water. The results on PAM, thoroughly mixed with soil, show that stability is improved and infiltration increases in columns packed with PAM-treated aggregates. However, PAM solution, when allowed to infiltrate through columns, decreased infiltration. PAM was adsorbed on soil particles due to its cation charge.

The statistical analysis of the data showed that PAM applied at the rate of 4.5 Kg/ha in a field trial at the Malheur Experiment Station, increased the stability of soil structure over the check without PAM.

6.2 CONCLUSIONS

The results show that gypsum at the rate of 1.45 tonnes/ha, is needed to improve the infiltration of water. The rates are based on 1/2 saturated gypsum solution used in the laboratory. Gypsum as solution is recommended instead of salt, due to its low solubility (0.2%/liter).

The data show that PAM in solution decreased the infiltration but when PAM was thoroughly mixed with soil and dried, aggregate stability was improved and infiltration increased. However, 120 ppm PAM by weight is a very high rate; therefore, field trials are needed to find optimum PAM rates for improving infiltration of water.

The analysis of data on aggregate stability of field samples shows that both PAM and gypsum increased the aggregate stability.

7. REFERENCES

Agassi, M., J. Morin, and I. Shainberg. 1982. Laboratory studies on infiltration and runoff control in semi-arid soils in Israel. Geoderma. 28:345-356.

Agassi, M., J. Morin, and I. Shainberg. 1985. Effect of raindrop impact energy and water salinity on infiltration rates of sodic soils. Soil Sci. Soc. Am. J. 49:186-190.

Buxton, D.R and J. Burr. 1979. Reducing compaction associated with potato production in Oregon. Proc. 12th Annual Conf. Oregon Potato Growers Annual Meeting and Trade Fair. P 126-147.

Chartres, C.J., R.S. Greene, G.W. Ford, and P. Rengasamy. 1985. Effect of gypsum on macro-porosity and crusting of two red duplex soils. Aust. J. Soil Res. 23:467-479.

Cook, D.F., and S.D. Nelson. 1986. Effect of polyacrylamide on seedling emergence in crust forming soils. Soil Sci. 141:328-333.

du Plessis, H.M., and I. Shainberg. 1985. Effect of exchangeable sodium and phosphogypsum on the hydraulic properties of several South African soils. S. Afr. J. Plant Soil 2:179-185.

Gal, M., L. Arcan, I. Shainberg, and R. Keren. 1984.

Effect of exchangeable sodium and phosphogypsum on crust structure-Scanning electron microscope observations. Soil Sci. Soc. Am. J. 48:872-878.

Gierson, I.T. 1978. Gypsum and red-brown earths. p. 315-324. In W.W. Emerson et al. (ed.) Modification of Soil Structure. Wiley & Sons, New York.

Hedrick, R., and D.T. Mowry. 1952. Effect of synthetic polyelectrolytes on aggregation, aeration and water relationships of soil. Soil Sci. 73:427-441.

Kazman, Z., I. Shainberg, and M. Gal. 1983. Effect of low levels exchangeable sodium and applied phosphogypsum on the infiltration rate of various soils. Soil Sci. 135:184-192.

Kemper, W.D. and E.J. Koch. 1966. Aggregate stability of soils from the western portions of United States and Canada. U.S. Dept. Agric. Tech. Bull. 1355.

Kemper,W.D., and R.C. Rosenau. 1986. Aggregate Stability and Size Distribution. In Methods of Soil Analysis, pt. 1, 2nd ed. A. Klute (ed.). Agronomy 9. p.425-441

Keren, R., and I. Shainberg. 1981. Effect of dissolution rate on the efficiency of industrial and mined gypsum in improving infiltration of a sodic soil. Soil Sci. Soc. Am. J. 45:102-107.

Loveday, J. 1974. Recognition of gypsum-responsive soils. Aust. J. Soil Res. 25:87-96.

Loveday, J. 1984. Amendments for reclaiming sodic soils. In Soil Salinity under Irrigation. L. Shainberg and J. Shalhevet (ed.) Springer-Verlag, New York, pp. 220-237.

Marsh, A.W., F.M. Tileston, and J.W. Wolfe. 1956. Improving irrigation in Eastern Oregon. Oregon State Univ. Agric. Expt. Station. Bull. 558.

Martin,W.P., G.S. Taylor, J.C. Engibous, and E. Burnett. 1952. Crop responses from field applications of soil conditioners. Soil Sci. 73:425-471.

McIntyre, D.S. 1979. Exchangeable sodium, subplasticity, and hydraulic conductivity of some Australian soils. Aust. J. Soil Res. 17:115-120.

McNeal, B.L., and N.T. Coleman. 1966. Effect of solution composition on the hydraulic conductivity. Soil Sci. Soc. Am. Proc. 30:308-312.

Miller, W.P. 1987. Infiltration and soil loss of three gypsum-amended Ultisols under simulated rainfall. Soil Sci. Soc. Am. J. 51:1314-1320.

Miller, W.P., and M.K. Baharuddin. 1986. Effect of dispersible clay on infiltration and soil loss of southeastern soils. Soil Sci. 142:235-240.

Prather, R. J., J. O. Goertzen, J. D. Rhoades, and H. Frenkel. 1978. Efficient amendment use in sodic soil reclamation. Soil Sci. Soc. Am. J. 42:782-786.

Quastel, J.H. 1954. Soil Conditioners. Ann. Rev. Plant Physiol. 5:75-92.

Quirk, J.P. 1978. Some physio-chemical aspects of soil structural stability-a review. p. 3-16. In W.W. Emerson et al. (ed.) Modification of Soil Structure. Wiley & Sons, New York.

Rengasamy, J.C., G.R. Blake, J.C.F. Tedrow, and F.E. Bear. 1953. Gypsum for improving drainage of wet soils. N.J. Agric. Exp. Stn. Bull. 772.

Rengasamy, P., R.S.B. Greene, G.W. Ford, and A.H. Mehanni. 1984. Identification of dispersive behavior in the management of red-brown earths. Aust. J. Soil Res. 22:413-422.

Rinhart,J.C., G.R. Blake, J.C.F. Tedrow and F.E. Bear. 1953. Gypsum for improving drainage of wet soils. N. J. Agri. Exp. Stn. Bull. 772.

Schamp, N., J. Huylebroeck, and M. Sadones. 1975. Adhesion and adsorption phenomena in soil conditioning. In Soil Conditioners. Soil Sci. Soc. Am. Special publ. No 7. p 13-23.

Shainberg, I., J.D. Rhoades, and R.J. Prather. 1981a. Effect of low electrolyte concentration on clay dispersion and hydraulic conductivity of a sodic soil. Soil Sci. Soc. Am. J. 45:273-277.

Shainberg, I., J.D. Rhoades, D.L. Suarez, and R.J. Prather. 1981b. Effect of mineral weathering on clay dispersion and hydraulic conductivity of sodic soils. Soil Sci. Soc. Am. J. 45:287-291.

Sherwood, L.V., and J.C. Engibous. 1953. Status report on soil conditioning chemicals II, Soil Sci. Soc. Am. Proc. 17:9-16.

Taylor, G.S., and W.P. Martin. 1953. Effect of soil aggregating chemicals on soils. J. Agric. Engr. 34: 550

Terry, R.E., and S.D. Nelson. 1986. Effects of polyacrylamide and irrigation on soil physical properties. Soil Sci. 141:317-320.

Tileston, F.M. 1954. Irrigation, infiltration, and salinity studies on the Owyhee project Malheur County, Oregon. 1953. Annual project report, Oregon Agric. Exp. Stn. and U.S. Bureau of Reclamation Region 1, Soil Conservation Service.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and

Improvement of Saline and Alkali Soils. USDA Agric. Handb. 60. U.S. Government Printing Office, Washington, DC.

van Olphen, H. 1977. An Introduction to Clay Colloid Chemistry. John Wiley & Sons, Ins., New York.

Wallace, A., and G.A. Wallace. 1986a. Effect of soil conditioners on emergence and growth of tomato, cotton and lettuce seedlings. Soil Sci. 141:313-316.

Wallace, A., and G.A. Wallace. 1986b. Effect of very low rates of synthetic soil conditioners on soils. Soil Sci. 141: 324-327.

Wallace, A., G.A. Wallace, and A.M. Abouzamzam. 1986. Effect of soil conditioners on water relationships in soils. Soil Sci. 141: 346-352.

APPENDIX

Table A1 Physico-chemical Analysis of the Soil Samples.

Sample	pH	K	Ca	Mg	Na	OM	Clay	Silt	Sand	Texture Class
		-----(Cmole/Kg)-------				%	%	%	%	
B8d	7.6	1.78	15.2	5.3	.62	1.27	22	12	66	Silt Loam
C2c	7.4	1.02	17.4	5.5	.48	1.75	23	13	64	Silt Loam

Table A2 Effect of Gypsum Salt mixed with Soil on Infiltration (large columns).

Wetting Front Depth(cm)	Check	1%	2%	3%	5%	10%
	Treatments(gypsum) Time(min)1/2					
1.00	0.43	0.41	0.39	0.39	0.34	0.32
2.00	1.39	0.80	0.74	0.50	0.74	0.50
3.00	1.68	1.02	1.03	0.89	0.97	0.84
4.00	2.00	1.47	1.42	1.27	1.37	1.37
5.00	2.38	1.91	1.79	1.70	1.85	1.60
6.00	2.83	2.22	2.04	2.08	2.22	2.19
7.00	3.32	2.80	2.79	2.56	2.65	2.78
8.00	3.83	3.07	3.20	2.89	3.10	3.16
9.00	4.26	3.47				
10.00	4.82	3.89				

```
Check     Regression Output:                1%     Regression Output:
Constant                        -0.38350 Constant                    0.129882
Std Err of Y Est                0.325449 Std Err of Y Est            0.183737
R Squared                       0.989729 R Squared                   0.996726
No. of Observations                   10 No. of Observations               10
Degrees of Freedom                     8 Degrees of Freedom                 8

X Coefficient(s)  2.184728               X Coefficient(s)  2.548820
Std Err of Coef.  0.078685               Std Err of Coef.  0.051644


  2%      Regression Output:                3%     Regression Output:
Constant                        0.351955 Constant                    0.484886
Std Err of Y Est                0.340437 Std Err of Y Est            0.259788
R Squared                       0.983443 R Squared                   0.990358
No. of Observations                    8 No. of Observations                8
Degrees of Freedom                     6 Degrees of Freedom                 6

X Coefficient(s)  2.476347               X Coefficient(s)  2.616272
Std Err of Coef.  0.131174               Std Err of Coef.  0.105385


    5%    Regression Output:                10%    Regression Output:
Constant                        0.328913 Constant                    0.790000
Std Err of Y Est                0.178596 Std Err of Y Est            0.339382
R Squared                       0.995443 R Squared                   0.983545
No. of Observations                    8 No. of Observations                8
Degrees of Freedom                     6 Degrees of Freedom                 6

X Coefficient(s)  2.524147               X Coefficient(s)  2.324573
Std Err of Coef.  0.069719               Std Err of Coef.  0.122746
```

Table A3 Effect of Gypsum Salt mixed with Soil on Infiltration (small columns).

Time, (min)1/2	Check	1%	2%	3%	5%	10%
	Treatments(gypsum)					
	------ Depth to Wetting Front (cm) ---------					
0.65	2.10	1.80	2.30	2.00	2.60	2.30
1.29	3.40	2.80	3.70	4.00	4.40	3.80
1.94	4.50	4.50	5.00	6.30	5.80	5.50
2.58	5.80	6.20	6.00	7.50	7.10	7.00
3.23	7.00	7.70	7.40	8.80	8.40	8.40
3.87	8.10	9.00	8.60	10.30	9.60	9.80
4.52	9.00	10.30	10.20	11.60	10.80	11.00

```
 Check   Regression Output:               1%    Regression Output:
Constant                        1.042857 Constant                     0.171428
Std Err of Y Est                0.129835 Std Err of Y Est             0.204065
R Squared                       0.997784 R Squared                    0.996560
No. of Observations                    7 No. of Observations                 7
Degrees of Freedom                     5 Degrees of Freedom                  5

X Coefficient(s)  1.803703               X Coefficient(s)  2.273994
Std Err of Coef.  0.038011               Std Err of Coef.  0.059744


 2%      Regression Output:               3%    Regression Output:
Constant                        1.042857 Constant                     0.942857
Std Err of Y Est                0.145160 Std Err of Y Est             0.419438
R Squared                       0.997716 R Squared                    0.987381
No. of Observations                    7 No. of Observations                 7
Degrees of Freedom                     5 Degrees of Freedom                  5

X Coefficient(s)  1.986287               X Coefficient(s)  2.428913
Std Err of Coef.  0.042498               Std Err of Coef.  0.122798


  5%     Regression Output:                10%  Regression Output:
Constant                        1.585714 Constant                     0.971428
Std Err of Y Est                0.212468 Std Err of Y Est             0.166476
R Squared                       0.995549 R Squared                    0.997697
No. of Observations                    7 No. of Observations                 7
Degrees of Freedom                     5 Degrees of Freedom                  5

X Coefficient(s)  2.080345               X Coefficient(s)  2.268461
Std Err of Coef.  0.062204               Std Err of Coef.  0.048739
```

Table A4 Effect of Gypsum Solution on Infiltration (Average of duplicate determinations).

Depth to Wetting Front(cm)	Treatments(Gypsum Solution)		
	Check	1/2 Saturated	Saturated
---------	-----------Time(min)1/2	------------	
1.00	1.55	1.85	1.51
2.00	2.89	3.00	2.57
3.00	4.05	4.05	3.61
4.00	5.11	5.15	4.62
5.00	6.57	6.11	5.76
6.00	7.59	7.07	6.80
7.00	8.65	8.00	7.93
8.00		9.08	9.06

```
Check                                       1/2 Saturated
          Regression Output:                          Regression Output:
Constant                       -0.37795 Constant                     -0.92495
Std Err of Y Est               0.098418 Std Err of Y Est             0.083604
R Squared                      0.998270 R Squared                    0.999001
No. of Observations                   7 No. of Observations                 8
Degrees of Freedom                    5 Degrees of Freedom                  6

X Coefficient(s)  0.841476              X Coefficient(s)  0.979523
Std Err of Coef.  0.015664              Std Err of Coef.  0.012642

Saturated
          Regression Output:
Constant                       -0.36454
Std Err of Y Est               0.044482
R Squared                      0.999717
No. of Observations                   8
Degrees of Freedom                    6

X Coefficient(s)  0.929586
Std Err of Coef.  0.006381
```

Table A5 Effect of Gypsum Solution on Infiltration.

Depth to Wetting Front(cm)	Check		1/2 Satu.		Satu.	
	1	2	1	2	1	2
	Time(min)1/2					
1.00	1.90	1.20	1.65	2.06	1.65	1.37
2.00	3.07	2.69	2.79	3.21	2.62	2.52
3.00	4.42	3.69	3.82	4.29	3.63	3.59
4.00	5.40	4.81	4.97	5.33	4.55	4.69
5.00	6.85	6.29	5.96	6.26	5.64	5.89
6.00	8.00	7.18	6.96	7.19	6.58	7.03
7.00	8.88	8.41	7.74	8.27	7.64	8.21
8.00			8.97	9.18	8.84	9.28

```
 Check 1                               Check 2
         Regression Output:                     Regression Output:
Constant                      -0.62478 Constant                    -0.11707
Std Err of Y Est              0.117029 Std Err of Y Est            0.123612
R Squared                     0.997554 R Squared                   0.997271
No. of Observations                  7 No. of Observations                7
Degrees of Freedom                   5 Degrees of Freedom                 5

X Coefficient(s)  0.840404             X Coefficient(s)  0.840758
Std Err of Coef.  0.018609             Std Err of Coef.  0.019667


 1/2 Saturated 1                        1/2 Saturated 2
         Regression Output:                     Regression Output:
Constant                      -0.69841 Constant                    -1.16874
Std Err of Y Est              0.109469 Std Err of Y Est            0.088255
R Squared                     0.998288 R Squared                   0.998887
No. of Observations                  8 No. of Observations                8
Degrees of Freedom                   6 Degrees of Freedom                 6

X Coefficient(s)  0.970250             X Coefficient(s)  0.990244
Std Err of Coef.  0.016403             Std Err of Coef.  0.013492


Saturated 1                            Saturated 2
         Regression Output:                     Regression Output:
Constant                      -0.55714 Constant                    -0.18468
Std Err of Y Est              0.081711 Std Err of Y Est            0.034565
R Squared                     0.999046 R Squared                   0.999829
No. of Observations                  8 No. of Observations                8
Degrees of Freedom                   6 Degrees of Freedom                 6

X Coefficient(s)  0.983098             X Coefficient(s)  0.880285
Std Err of Coef.  0.012401             Std Err of Coef.  0.004695
```

Table A6 Effect of Gypsum Solution on Infiltration (small columns).

Check

1		2	
Time (min)1/2	Depth cm	Time (min)1/2	Depth cm
1.00	3.6	1.18	3.7
1.58	4.9	1.55	4.5
1.92	5.5	2.05	5.5
2.35	6.2	2.28	6.2
2.65	6.6	2.59	6.6
2.92	7.1	3.13	7.4
3.35	7.8	3.78	8.3
3.81	8.5	4.28	9
4.21	9.1		

1/2 Saturated

1		2	
Time (min)1/2	Depth cm	Time (min)1/2	Depth cm
1.30	5.3	1.00	4.9
2.17	7.4	1.48	6.5
2.65	8.3	2.12	7.6
3.00	8.9	2.65	8.7

Saturated

1		2	
Time (min)1/2	Depth cm	Time (min)1/2	Depth cm
1.22	4.2	1.00	3.8
1.73	5.4	1.30	4.5
2.17	6.3	1.58	5
2.95	7.9	1.92	5.8
3.27	8.5	2.24	6.3
		2.86	7.3
		3.61	8.5
		4.00	9
		4.47	9.5

Table A6 (continued)

```
 Check 1                                  Check 2
         Regression Output:                       Regression Output:
 Constant                       2.164960 Constant                      2.003634
 Std Err of Y Est               0.123761 Std Err of Y Est              0.241049
 R Squared                      0.995678 R Squared                     0.984946
 No. of Observations                   9 No. of Observations                  8
 Degrees of Freedom                    7 Degrees of Freedom                   6

 X Coefficient(s)  1.674829              X Coefficient(s)  1.687626
 Std Err of Coef.  0.041705              Std Err of Coef.  0.085174


  1/2 Saturated 1                         1/2 Saturated 2
         Regression Output:                       Regression Output:
 Constant                       2.600499 Constant                      2.885471
 Std Err of Y Est               0.157706 Std Err of Y Est              0.272172
 R Squared                      0.993320 R Squared                     0.981216
 No. of Observations                   4 No. of Observations                  4
 Degrees of Freedom                    2 Degrees of Freedom                   2

 X Coefficient(s)  2.138515              X Coefficient(s)  2.228609
 Std Err of Coef.  0.123997              Std Err of Coef.  0.218035


  Saturated 1                            Saturated 2
         Regression Output:                       Regression Output:
 Constant                       1.717735 Constant                      2.433803
 Std Err of Y Est               0.072490 Std Err of Y Est              0.202907
 R Squared                      0.998738 R Squared                     0.991473
 No. of Observations                   5 No. of Observations                  9
 Degrees of Freedom                    3 Degrees of Freedom                   7

 X Coefficient(s)  2.089949              X Coefficient(s)  1.644306
 Std Err of Coef.  0.042891              Std Err of Coef.  0.057634
```

Table A7 Effect of PAM Solution on Infiltration (Average of duplicate determinations).

Depth to Wetting Front(cm)	Check	7.5ppm	15ppm	30ppm
	-----	time(min)1/2	-------	
1.00	0.30	0.61	0.64	0.70
2.00	0.62	1.50	1.79	1.58
3.00	1.09	2.69	2.67	2.53
4.00	1.34	3.68	3.85	3.76
5.00	1.80	4.78	5.04	4.92
6.00	2.25	6.03	6.36	6.15
7.00	2.95	7.34	7.61	7.44
8.00	3.60	8.64	9.11	8.83
9.00		9.90		

```
Check                                   7.5ppm
         Regression Output:                     Regression Output:
Constant                      0.792192 Constant                      0.725955
Std Err of Y Est              0.379896 Std Err of Y Est              0.156996
R Squared                     0.979382 R Squared                     0.997124
No. of Observations                  8 No. of Observations                  9
Degrees of Freedom                   6 Degrees of Freedom                   7

X Coefficient(s)  2.126341             X Coefficient(s)  0.851799
Std Err of Coef.  0.125949             Std Err of Coef.  0.017289


 15ppm                                  30ppm
         Regression Output:                     Regression Output:
Constant                      0.651689 Constant                      0.678950
Std Err of Y Est              0.169880 Std Err of Y Est              0.173887
R Squared                     0.995877 R Squared                     0.995680
No. of Observations                  8 No. of Observations                  8
Degrees of Freedom                   6 Degrees of Freedom                   6

X Coefficient(s)  0.830475             X Coefficient(s)  0.851426
Std Err of Coef.  0.021814             Std Err of Coef.  0.022894
```

Table A8 Effect of PAM Solution on Infiltration

Depth to Wetting Front(cm)	Treatments(PAM) Check 1	Check 2	7.5ppm 1	7.5ppm 2	15ppm 1	15ppm 2	30ppm 1	30ppm 2
	------- Time(min)1/2 --------							
1.00	0.25	0.35	0.50	0.71	0.48	0.80	0.59	0.28
2.00	0.55	0.70	1.50	1.50	1.99	1.59	1.58	1.16
3.00	1.10	1.07	2.90	2.48	2.78	2.56	2.50	2.30
4.00	1.30	1.38	3.71	3.65	3.99	3.71	3.81	3.52
5.00	1.70	1.91	4.78	4.78	5.29	4.79	5.05	4.89
6.00	2.15	2.33	5.98	6.08	6.70	6.03	6.27	6.43
7.00	3.00	2.91	7.10	7.58	8.06	7.17	7.71	7.82
8.00	3.65	3.56	8.44	8.84	9.66	8.57	9.09	8.91
9.00			9.67	10.12				

Table A9 Effect of PAM mixed with Soil on Infiltration (Average of duplicate determinations).

Time, (min)1/2	Check	120ppm	240ppm
	Treatments(PAM)		
	Depth to Wetting Front (cm)		
1.00	2.90	5.65	5.25
1.73	4.85	8.50	8.00
2.00	5.80	10.15	9.90
2.24	6.55	12.25	
2.45	7.20		
2.65	7.75		
2.83	8.20		
3.00	8.90		
3.16	9.50		

```
  Check                                      120ppm
         Regression Output:                          Regression Output:
Constant                        -0.26747 Constant                      0.263391
Std Err of Y Est                0.110125 Std Err of Y Est              0.648096
R Squared                       0.997558 R Squared                     0.963917
No. of Observations                    9 No. of Observations                  4
Degrees of Freedom                     7 Degrees of Freedom                   2

X Coefficient(s)  3.041657               X Coefficient(s)  5.092745
Std Err of Coef.  0.056871               Std Err of Coef.  0.696726


  240ppm
         Regression Output:
Constant                        0.676257
Std Err of Y Est                0.508600
R Squared                       0.976337
No. of Observations                    3
Degrees of Freedom                     1

X Coefficient(s)  4.465375
Std Err of Coef.  0.695171
```

Table A10 Effect of PAM mixed with Soil on Infiltration

Time, (min)1/2	Check 1	Check 2	120ppm 1	120ppm 2	240ppm 1	240ppm 2
	-------- Depth to Wetting Front -------					
1.00	2.80	3.00	5.60	5.70	5.00	5.50
1.73	4.90	4.80	8.50	8.50	7.90	8.00
2.00	5.60	6.00	10.00	10.30	9.80	10.00
2.24	6.50	6.60	12.00	12.00		
2.45	7.10	7.30				
2.65	7.80	7.70				
2.83	8.10	8.30				
3.00	8.80	9.00				
3.16	9.50	9.50				

Table A11 Effect of PAM on Aggregate Stability (%).

Rep.	Check	15ppm	30ppm	60ppm
1	68	87	90	88
2	57	77	86	89
3	70	90	88	90

ANOVA

Source	df	SS	MS	F	F .01
Total	11	1343			
Treat.	3	1142	381	15.23**	7.59
Error	8	201	25		

Coefficient of Variation: 6.12%

Mean Stability(%) of soil aggregates treated with different concentrations of polyacrylamide.

source	check	15ppm	30ppm	60ppm	S.E
Stability (%)	65	85	88	89	3

Treat-ments	Stability (%)	Difference
Check	65	
15ppm	85	20
30ppm	88	3
60ppm	89	1

LSD: 9.63(5%)
13.70(1%)

Table A12 Effect of Soil Amendments on Stability of Aggregates Sampled in the Field.

1		11		111		1V	
(1)	(4)	(1)	(4)	(1)	(4)	(1)	(4)
62	54	57	89	61	80	71	89
(7)	(10)	(7)	(10)	(7)	(10)	(7)	(10)
62	82	86	87	68	62	74	69
(5)	(2)	(5)	(2)	(5)	(2)	(5)	(2)
77	70	84	75	64	70	78	75
(8)	(11)	(8)	(11)	(8)	(11)	(8)	(11)
89	76	85	87	79	84	93	83
(9)	(12)	(9)	(12)	(9)	(12)	(9)	(12)
83	87	65	72	89	86	87	93
(3)	(6)	(3)	(6)	(3)	(6)	(3)	(6)
67	75	78	87	62	89	78	83

Description of the symbols.

T: Traffic
N: Non-Traffic
F: Furrow Irrigated
O: Check
G: Gypsum
P: Polyacrylamide
U: Upper Part of Furrow
L: Lower Part of Furrow

Treatments.

TFOU -(1)
TFGU -(2)
TFPU -(3)
NFOU -(4)
NFGU -(5)
NFPU -(6)

TFOL -(7)
TFGL -(8)
TFPL -(9)
NFOL -(10)
NFGL -(11)
NFPL -(12)

1-1V: Replications.

ANOVA

Source	df	SS	MS	F	$F_{.05}$
Total	47	5028			
Blocks	3	473	158	2.11^{ns}	2.92
A	2	625	313	4.17^{*}	3.82
B	1	358	358	4.77^{*}	4.17
AB	2	206	103	1.37^{ns}	3.32
C	1	488	488	6.51^{*}	4.17
AC	2	104	52	0.69^{ns}	3.32
BC	1	276	276	3.68^{ns}	4.17
ABC	2	16	8	0.11^{ns}	3.32
Error	33	2484	75		

A: Amendments.
B: Traffic.
C: Part of furrow.

ns: Not significant.
*: Significant at 5% level

Table A12 (continued)

Mean stability (%) of soil aggregates treated with different soil amendments.

Check	Gypsum	PAM	S.E
72	79	80	3.06

Mean stability (%) of soil aggregates taken from traffic plots.

Traffic	Non-traffic	S.E
74	80	2.50

Mean stability (%) of soil aggregates taken from different parts of furrow.

Upper part of furrow	Lower part of furrow.	S.E
74	80	2.50

Table A13: Depth of Wetting. Regression equation of best fit line for plots of accumulative time (hours) vs square root infiltration (cm). (from Prather et al., 1978). Y= Sq. root of infiltration.

Treatment	Regression equation
Check	$Y= 1.047X + 1.084$
$CaSO_4$	$Y= 4.866X + 8.727$
$CaCl_2$	$Y= 13.096X + -1.556$
$CaCl_2$ and $CaSO_4$	$Y= 11.119X + 0.109$
H_2SO_4 and $CaSO_4$	$Y= 7.144X + 5.088$
H_2SO_4	$Y= 10.472X + -6.772$