Fifth-Year Annual Report of the 1986-91 Mission on Water Penetration Problems in Irrigated Soils

Kearney Foundation of Soil Science
Division of Agriculture and Natural Resources
University of California

November 1991

FIFTH YEAR ANNUAL REPORT OF THE 1986-91 MISSION
on
WATER PENETRATION PROBLEMS IN IRRIGATED SOILS

KEARNEY FOUNDATION OF SOIL SCIENCE
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA

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FUNCTION OF THE FOUNDATION

The Kearney Foundation of Soil Science is an Organized Research Unit in the Agricultural Experiment Station of the University of California. The Foundation's function is to encourage and support research, as well as disseminate information on definitive research missions in soil, water, and plant sciences.

"Water Penetration Problems in Irrigated Soils" was approved as the 1986-91 mission for Kearney Foundation by the then Assistant Vice President for Agriculture and Natural Resources, Lowell N. Lewis. Previous five-year Foundation missions have addressed problems dealing with nitrogen, trace elements and salinity.

The Director of the Kearney Foundation of Soil Science receives policy guidance from an Advisory Committee, chaired by the Associate Director of the Agricultural Experiment Station (Dean of College) at the location where the Director of the Foundation resides and consisting of chairpersons, or designees, from departments on the Berkeley, Davis and Riverside campuses. The Foundation Director also receives assistance on identifying research priorities from a Technical Committee consisting of individuals having expertise in the subject matter of the mission and representing the campuses, cooperative extension, and external entities as needed. The Technical Committee also assists the Director in the competitive grant process. Tables 1 and 2 contain the current membership of the Administrative and Technical Committees.

GOALS

The goals of the 1986-91 mission of the Kearney Foundation of Soil Science are to encourage and support innovative field and laboratory research on water penetration problems principally in irrigated soils utilizing the expertise amongst the various campuses, field stations and cooperative extension; and to disseminate widely any new information and findings to potential users.

ACTIVITIES

The following administrative and research activities will help achieve the goals of the 1986-91 mission:

(1) Prioritize research needs for closely related field and laboratory research with an emphasis on fundamental soil and water properties, as well as mechanisms.

(2) Establish field and laboratory experiments representing the diverse contributing factors and conditions leading to slow water penetration, and potentially effective management practices.

(3) Develop diagnostic procedures to ascertain the nature of the water penetration problem and recommend appropriate management practices to ameliorate the problem.

(4) Hold seminars, workshops and field trips, in addition to annual conferences, to more fully evaluate research programs and disseminate findings to interested parties.

1990-91 RESEARCH PROGRAM

Table 3 contains a list of 17 projects supported by the Foundation in 1990-91. Table 4 describes the fifth year FTE commitment made to this research program.

* *

TABLE 1. 1990-91 ADVISORY COMMITTEE

Chairperson:

J.E. Kinsella, Dean, College of Agricultural and Environmental Sciences, UC Davis.

Members:

M. Hanemann, Professor, Department of Agricultural and Resource Economics, UC Berkeley.

A. A. Kader, Chairperson, Department of Pomology, UC Davis.

A. E. Läuchli, Chairperson, Department of Land, Air and Water Resources, UC Davis.

L. J. Lund, Chairperson, Department of Soil and Environmental Sciences, UC Riverside.

D. E. Ramos, Associate Dean, Cooperative Extension, College of Agricultural and Environmental Sciences, UC Davis.

H. E. Studer, Chairperson, Department of Agricultural Engineering, UC Davis.

H. E. Doner, Professor, Department of Plant and Soil Biology, UC Berkeley

* *

TABLE 2. 1990-91 TECHNICAL COMMITTEE

Chairperson:

K. K. Tanji, Foundation Director, UC Davis.

Members:

L. M. Carter, Supervisory Agricultural Engineer and Station Leader, Cotton Research Station, USDA-ARS, Shafter.

W. J. Chancellor, Professor of Agricultural Engineering, Department of Agricultural Engineering, UC Davis.

M. K. Firestone, Associate Professor of Soil Microbiology, Department of Plant and Soil Biology, UC Berkeley.

G. J. Hoffman, Supervisory Agricultural Engineer and Station Leader, Water Management Research Lab, USDA-ARS, Fresno.

J. D. Oster, Soil and Water Specialist, Cooperative Extension, UC Riverside.

M. J. Singer, Professor of Soil Science, Department of Land, Air and Water Resources, UC Davis.

G. Sposito, Professor of Soil Physical Chemistry, Department of Plant and Soil Biology, UC Berkeley.

* *

TABLE 3. 1990-91 RESEARCH PROJECTS

Proj. No.	Principal Investigators	Project Title
89-1	G. Sposito	Colloidal properties of soil illite influencing surface crust formation.
89-3	M.E. Grismer, F.E. Robinson	Infiltration management in cracking clay soils.
89-4	D.W. Grimes, D.A. Goldhamer, D. Munk	Cover crop management and modified drip irrigation for improved water infiltration.
89-5	J.W. Rumsey, W.J. Chancellor, D.J. Hills, S.K. Upadhyaya, G. Miyao	Effects of row crop cultural and irrigation practices on water infiltration characteristics
89-6	J.W. Hopmans, R.J. Southard, D.R. Nielsen	Effects of water quality on field-measured infiltration with an emphasis on infiltration measurement techniques.
89-7	M.J. Singer, R.J. Southard	Role of wetting and drying cycles in surface soil structure development in the Central Valley of California.
89-8	J. Letey, J.D. Oster, C. Amrhein, W.L. Peacock	Polymer-soil interactions as they affect soil dispersion, crust formation, infiltration rate and hydraulic conductivity.
89-10	W.T. Frankenberger, Jr., D.A. Martens, L.H. Stolzy	Interaction of microorganisms and organic amendments on water penetration in irrigated soils.
89-11	M.K. Firestone, M.J. Singer	Effect of soil characteristics on polysaccharide production and aggregate stability.
89-12	S.K. Upadhyaya, W.J. Chancellor, R.J. Southard	Detection and quantification of soil physical parameters which to slow water infiltration rates
89-13	T.L. Prichard, D.E. Rolston, M.J Singer, W.K. Asai, R.A. Dahlgren	The tendency of field soils to form surface crusts and their effects upon water infiltration characteristics.
89-15	J.W. Biggar, D.W. Grimes	Practical and theoretical investigations on the vertical mulch drip system for improving infiltration.
89-17	H.E. Doner, M.K. Firestone	The interactive effects of hydroxy-Al and polysaccharides on physical stabilization of clays.
89-18	M.K. Firestone	Management of polysaccharide-mediated aggregation in soil.
89-19	D.E. Rolston, T.L. Prichard, D.W. Grimes, M.J. Singer, W. Wallender	Relationships of crust and cracking characteristics to infiltration in field soils.
89-20	J.D. Oster	Water penetration handbook.

TABLE 4. FTE COMMITMENTS TO RESEARCH PROJECTS, 1990-91

	Number of Personnel	Full-Time Equivalent
UC Agricultural Experiment Station	26	3.57
UC Cooperative Extension	11	.60
External Research Collaborators	6	1.00
Postgraduate Researchers	13	9.15
Graduate Research Assistants	8	3.40
Staff Research Associates	5	.80
Undergraduate Student Assistants	0	0
Other Assistants	1	.25
Total	66	17.07

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ANNUAL PROGRESS REPORTS

CHEMISTRY AND MINERALOGY

PROJECT TITLE: Colloidal Properties of Soil Illite Influencing Surface Crust Formation

PROJECT NUMBER: 89-1

DURATION OF FUNDING: July 1989 - June 1991

PROJECT INVESTIGATORS:

Name: Garrison Sposito
Affiliation: Soil Science
University of California
Location: Berkeley Campus

FTE Commitment: 0.10

RESEARCH STAFF:

Research Assistant: Dean Heil 1 @ 0.5 FTE

ABSTRACT:

Domino loam and hydrogen-peroxide-treated Hanford sandy loam were studied in flocculation, cation-exchange, and electrophoresis experiments. These soil materials behaved similarly to the untreated Hanford soil, except that increasing pH caused decreasing flocculation and an increasing magnitude of the electrophoretic mobility. At pH 6 and a total electrolyte concentration of 5 $mol_c\ m^{-3}$ in mixed Na/Ca/K perchlorate solution, the degree of flocculation as measured by light scattering increased with decreasing organic carbon content of the soil material for any aqueous solution composition. These results were interpreted as evidence for the role of adsorbed organic matter on the soil particles in preventing flocculation by a steric mechanism which inhibits close particle approach, thereby weakening the attractive van der Waals forces between the particles.

KEYWORDS: dispersion, exchangeable cation effects, flocculation, Hanford sandy loam, illite, pH effects

PROJECT OBJECTIVES ADDRESSED:

To investigate the flocculation properties of California soils containing significant illite:

(a) Na-K-Ca-Mg exchange equilibria at ionic strengths below 10 mol m^{-3} and pH 6 to 8,

(b) soil suspension turbidity as influenced by exchange equilibria, pH, and ionic strength,

(c) effect of Ca^{2+} *vs*. Mg^{2+} as a flocculating cation.

RESEARCH PLAN AND PROCEDURES:

A stock suspension of Domino soil was prepared using a similar procedure as for the Hanford soil (Sposito et al., 1990), except for the following changes. After several washings with 100 mol m^{-3} $NaClO_4$ solution, the resulting supernatant solution was still darkly colored. This made it necessary to remove the top layer (mostly organic matter) with a spatula following each subsequent washing. This was done a total of 16 times, after which the coloration faded. When the soil was re-suspended in a 5 mol m^{-3} $NaClO_4$ solution, the supernatant solution became darkly colored again. The soil was washed 12 times with this $NaClO_4$ solution until the coloration again disappeared. The suspension was then washed with a 5 mol m^{-3} $NaClO_4$/0.1 mol m^{-3} $KClO_4$ solution. The pH of this stock suspension was 7.14 and its density was 0.106 kg soil kg^{-1}.

A Hanford stock soil suspension was prepared after treating the soil with hydrogen peroxide to remove organic matter. The silt and clay size-fractions were separated by adding 0.180 kg soil plus distilled water to make a total volume of 600 mL in a 1 L beaker. After stirring and then settling for 5 min, the remaining suspension was poured through a 53 μm sieve. This step was repeated until a total of 3.5 L of suspension had been collected. The electrolyte concentration of the suspension was adjusted to 50 mol m^{-3} $NaClO_4$. The volume of the suspension was then reduced by centrifugation until the suspension was contained in 250-mL centrifuge bottles. The soil was washed four times by adding 180 mL of 500 mol m^{-3} $NaClO_4$ to each bottle. In order to optimize the efficiency of the hydrogen peroxide treatment, the pH of the suspension was reduced to 5.0 by washing with a

50 mol m^{-3} $NaClO_4$ solution adjusted to pH 4.0 with $HClO_4$. The soil was then washed twice with 50 mol m^{-3} sodium acetate solution adjusted to pH 5.0 with acetic acid. The suspension was adjusted to a volume of 200 mL and then placed in a 1 L beaker. Hydrogen peroxide was added to the suspension in 10 mL increments until a total suspension volume of 400 mL was achieved. The beaker containing the suspension was then placed on a hot plate at 80°C to maximize the removal of soil organic matter. The hydrogen-peroxide-treated soil suspension was then transferred back into two 250 mL centrifuge bottles and washed twice with 500 mol m^{-3} $NaClO_4$. This was followed by three washings with a solution containing 5 mol m^{-3} $NaClO_4$ and 0.1 mol m^{-3} $KClO_4$. The pH of this stock suspension was 7.62, and the soil solids concentration was 0.116 kg kg^{-1}.

The identification of clay minerals was accomplished by X-ray analysis using a Rigaku Geigerflex X-ray diffractometer. Treatments included Mg-saturation at 54% RH; Mg-ethylene glycol; K-saturated and heated to 105°C; and K-saturated and heated to 550°C.

For electrophoresis experiments, a fresh stock suspension of the <53 μm fraction of the Na-saturated Hanford soil was prepared as described previously (Sposito et al., 1990). To facilitate accurate electrophoretic mobility measurements, the particle size range was narrowed to 0.1-1 μm effective settling diameter by centrifugation and selective sampling. The solids concentration of this stock suspension was then adjusted to 1 g kg^{-1} (0.1%) in a background of 10 mol m^{-3} $NaClO_4$ and 0.1 mol m^{-3} $KClO_4$. A H_2O_2-treated suspension of the Hanford soil was prepared with the same particle size range, solids concentration, and background electrolyte. Suspensions of Ca-Na-K and Mg-Na-K soil systems at a total electrolyte concentration of 10 mol_c m^{-3} and soluble bivalent cation charge fractions of 0, 0.1, 0.3, 0.5, 0.7, and 0.9 were prepared. One gram of the stock soil suspension plus 1 g of 10 molc m^{-3} $KClO_4$ was added to a 100 mL plastic bottle. The required amounts of stock solutions of $NaClO_4$ and $CaClO_4$ or $MgClO_4$ then were added, and the total suspension mass was adjusted to 0.100 kg by the addition of distilled water. The solids concentration of these suspensions was 0.01 g kg^{-1} (0.001 %). The effect of pH on electrophoretic mobility was studied in the pH range of 4 to 9. Suspensions of the Ca-Na-K soil systems at a solids concentration of 10 mol_c m^{-3} and soluble bivalent cation charge fractions of 0 and 0.5 were prepared. The pH of two sets of six 0.10-kg suspensions, one for each bivalent cation charge fraction, was then adjusted by addition of 5% (by volume) $HClO_4$ or 1% (by mass) NaOH to encompass the pH range of 4 to 9.

Following a 14 hr shaking period, the pH of each treatment suspension was measured. Electrophoretic mobility measurements then were made on a Pen Kem Laser Zee meter model 501 electrophoresis instrument at an applied voltage of 100 V and a corresponding electric field strength of 10 V cm^{-1}. Readings for each sample were taken six times.

Total organic carbon content of each suspension was measured on a Dohrmann DC-80 Carbon Analyzer. The <2 μm size fraction of each suspension was separated, and then analyzed for total organic carbon as a solid sample.

RESULTS:

Analyses of the X-ray diffraction patterns revealed that illite was the dominant clay mineral in both the Hanford and Domino soils. The presence of smectite and kaolinite was also established for both soils. The content of illite in each stock suspension, however, was greater than 90%, based on the method of Klages and Hopper (1982), which utilizes relative peak height in the diffraction pattern.

The Domino soil (Fig. 1-3) flocculated at a lower solution bivalent charge fraction ($\tilde{E}_{Biv}$) than did the Hanford soil at a comparable total electrolyte concentration (Sposito et al., 1990; Fig. 1-3). The Domino soil did behave similarly to the Hanford soil, however, in that Ca was more effective in causing flocculation than Mg. Increasing pH from 6 to 8 reduced the flocculation of the Domino soil, which was opposite to the relationship observed for the Hanford soil (Sposito et al., 1990).

The hydrogen-peroxide-treated suspension of the Hanford soil flocculated at a lower soluble bivalent cation concentration than both the untreated Hanford soil and the Domino soil. The removal of organic matter from the Hanford soil resulted in a reversal of the influence of pH on suspension stability (Fig. 4) and differences in flocculation effectiveness between Ca *vs*. Mg were reduced. The flocculation behavior of all four illitic materials used in this study was related to the total organic carbon content of the clay size-fraction of each soil (Fig. 5). An increase in organic carbon content corresponded to an increase in the soluble bivalent cation charge fraction ($\tilde{E}_{Biv}$) required to cause a given degree of flocculation, as measured by % T.

Exchange isotherms for Ca/Na and Mg/Na at pH 6 and 8 for the Hanford, Domino, and hydrogen-peroxide-treated Hanford soils were very similar (data not shown). However, close examination of the exchange isotherms revealed that Ca tended to be adsorbed to a greater extent than Mg, and the exchangeable charge fraction for either bivalent cation was increased as pH was increased from 6 to 8. (The percentage error in both E_{Biv} and $\tilde{E}_{Biv}$ was less than 2.5%, which was about the same magnitude as the separation of points on isotherm plots.)

The influence of Ca vs. Mg on the electrophoretic mobility (an estimate of net total particle charge) was nearly identical across a range of $\tilde{E}_{Biv}$ that corresponded to a change from a completely dispersed suspension of the Hanford soil to a completely flocculated state (Fig. 6). Also, the removal of organic matter from the Hanford soil had no significant effect on the electrophoretic mobility across a wide range of soluble bivalent cation charge fraction. (A representative standard deviation for the points in Figure 6 is 4 μm s^{-1} per V cm^{-1}.) Electrophoretic mobility (EM) did not provide a consistent indication of colloid stability for the Hanford soil (Fig. 7). The hydrogen-peroxide-treated sample in Ca/Na electrolyte flocculated at the most negative EM, followed by the untreated Hanford sample in Ca/Na solution, and then the sample in Mg/Na solution. The magnitude of EM *decreased* slightly as the pH was increased from 4.10 to 8.70 at $\tilde{E}_{Biv}$ = .50 for the Hanford soil (Table 1). Following the removal of organic matter, the magnitude of EM *increased* significantly as pH increased from 4.06 to 9.42.

TABLE 1. Electrophoretic mobility (EM) of Hanford soil particles in Na/Ca/K perchlorate solution at $\tilde{E}_{Biv}$ = 0.5 and 10 mol_c m^{-3} total concentration.

Untreated		H_2O_2-Treated	
pH	-EM x 10^8 $m^2 s^{-1} V^{-1}$	pH	-EM x 10^8 $m^2 s^{-1} V^{-1}$
4.10	1.39 + 0.03	4.06	1.29 + 0.04
4.68	1.37 + 0.04	5.48	1.40 + 0.05
5.59	1.28 + 0.04	6.72	1.43 + 0.07
6.38	1.33 + 0.03	8.60	1.42 + 0.05
6.64	1.27 + 0.04	9.13	1.55 + 0.05
8.70	1.25 + 0.04	9.42	1.66 + 0.08

DISCUSSION AND SUMMARY:

The differences in flocculation of the illitic materials studied that depended on organic matter content, Ca *vs.* Mg as the exchangeable cation, or pH, are likely the result of steric and/or electrostatic interparticle interaction mechanisms. The adsorption of organic matter onto mineral particles is expected to result in an increase in the magnitude of the negative charge of the particles, since organic matter in soils typically is negatively charged. However, the electrophoretic mobility data showed that particle charge was not altered by the presence of organic matter, suggesting that the stabilizing influence of adsorbed organic matter on the soil suspensions was the result of a steric mechanism, in which surface coatings act as physical barriers to close particle approach, thereby weakening the attractive van der Waals forces between the particles.

The influence of pH on flocculation was mediated by the amount of soil organic matter. At the relatively high soluble bivalent cation concentration needed to flocculate the Hanford soil, the adsorption of Ca evidently was sufficient to balance the dissociation of H^+ at the soil colloid surface, resulting in the net particle charge remaining nearly constant as pH was increased, as observed in the electrophoresis experiments. The net particle charge decreased, however, with increasing pH after the removal of organic matter, also as observed from electrophoresis. Thus, the variable influence of pH on flocculation may be attributed to electrostatic effects.

The effect of exchangeable Ca *vs.* Mg appears to be controlled by both steric and electrostatic mechanisms. The electrophoresis measurements showed that the significant difference in flocculation observed between Ca and Mg does not correspond to different electrophoretic mobilities. Apparently, Ca is more effective than Mg in altering the structure of organic matter, perhaps allowing a closer approach between soil colloids and thus enhancing the effectiveness of attractive van der Waals forces.

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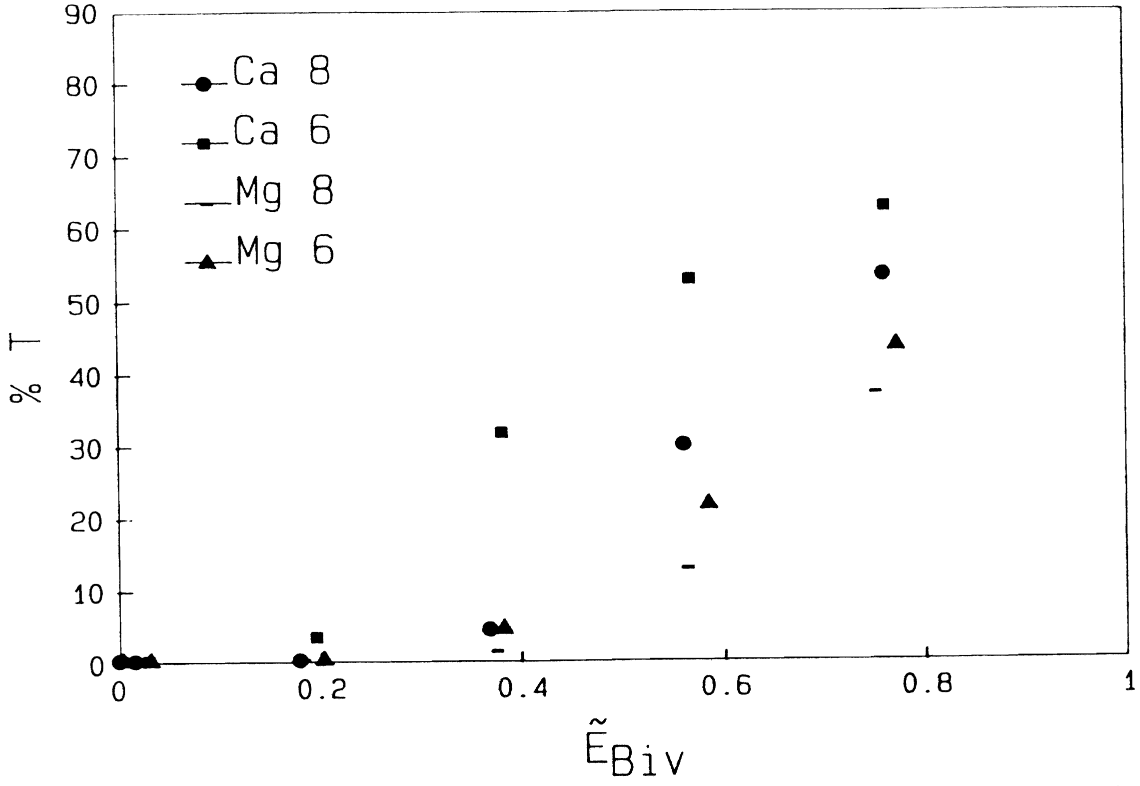


Fig. 1. % T versus the charge fraction of bivalent cations in solution at a total electrolyte concentration of 5 mol_c m^{-3} (Domino soil). The type of bivalent cation and pH are fixed variables for each curve.

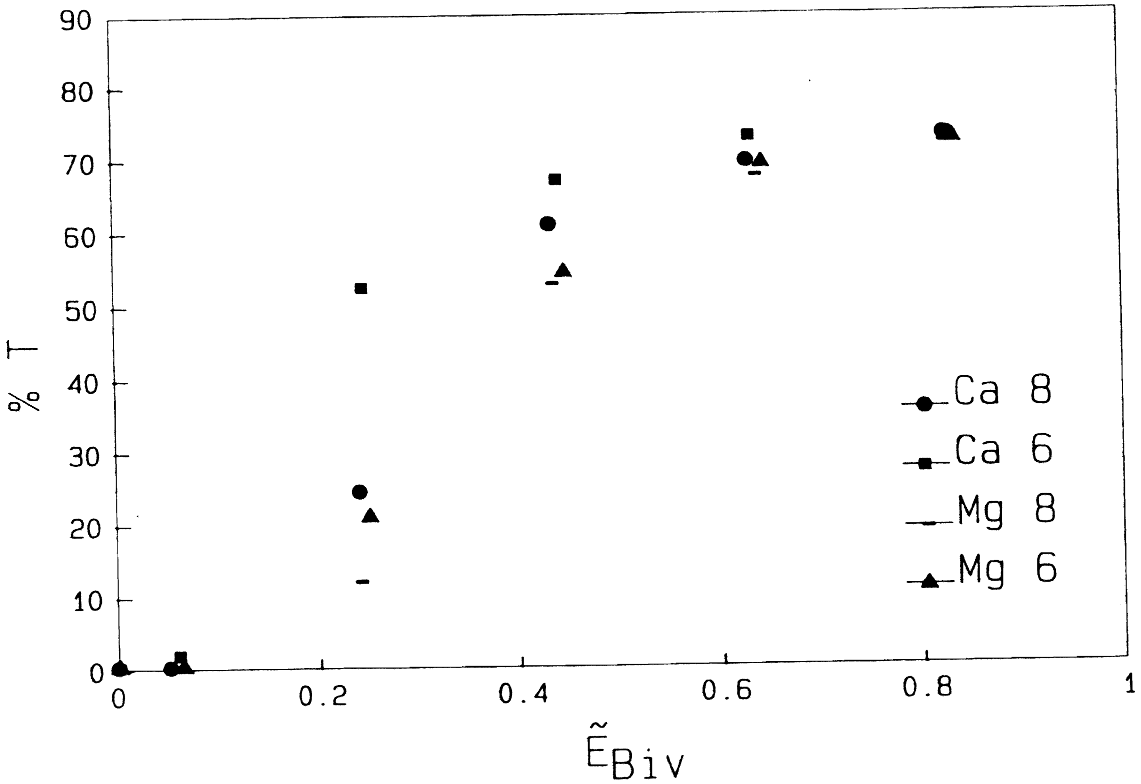


Fig. 2. % T versus the charge fraction of bivalent cations in solution at a total electrolyte concentration of 10 mol_c m^{-3} (Domino soil). The type of bivalent cation and pH are fixed variables for each curve.

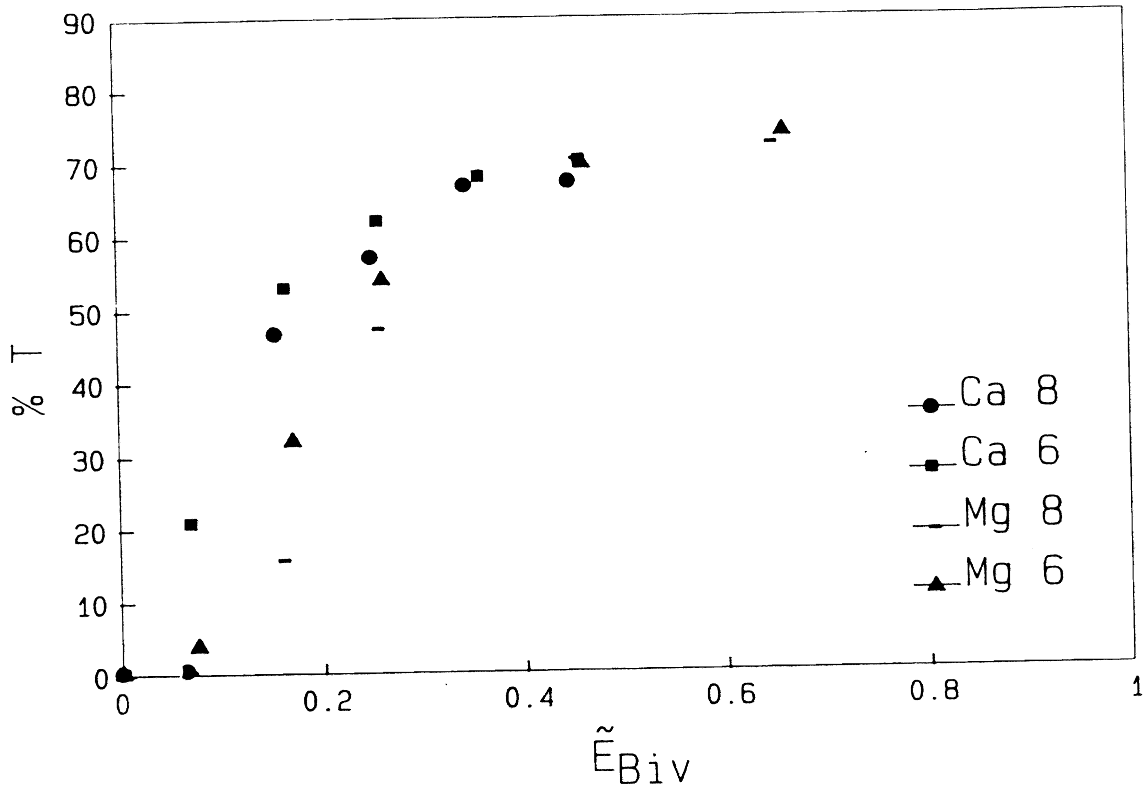


Fig. 3. % T versus the charge fraction of bivalent cations in solution at a total electrolyte concentration of 15 $mol_c\ m^{-3}$ (Domino soil). The type of bivalent cation and pH are fixed variables for each curve.

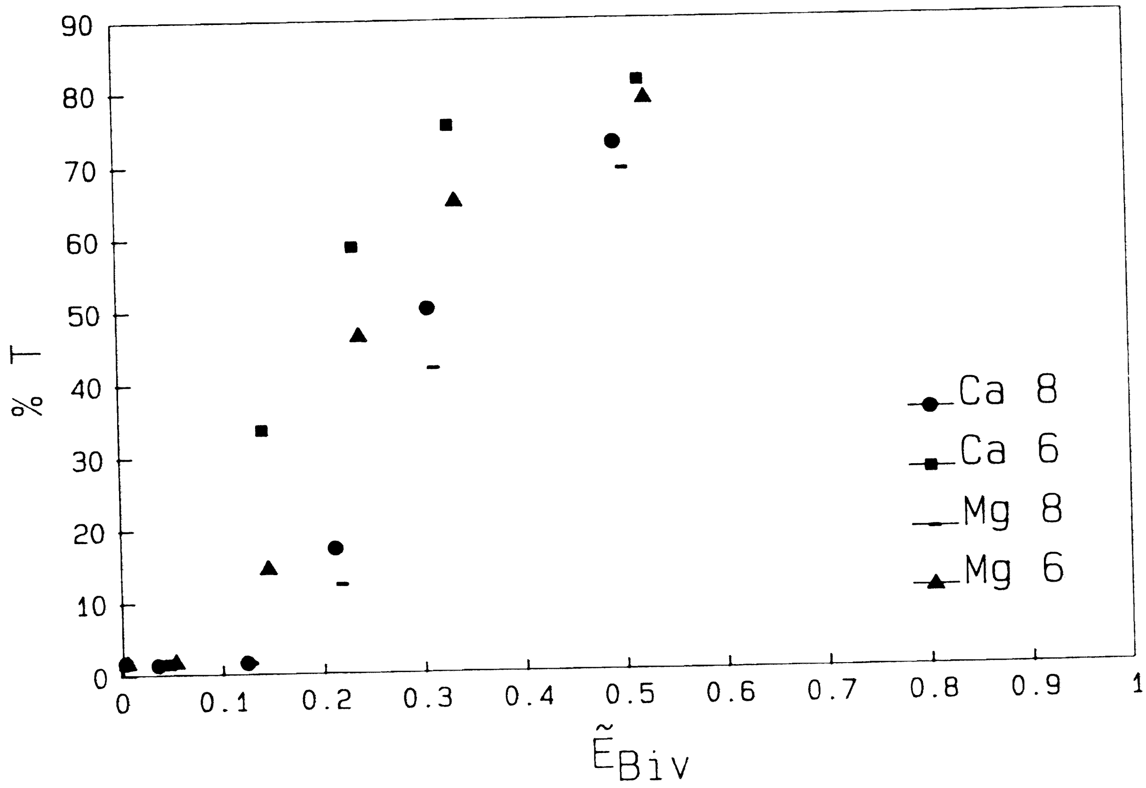
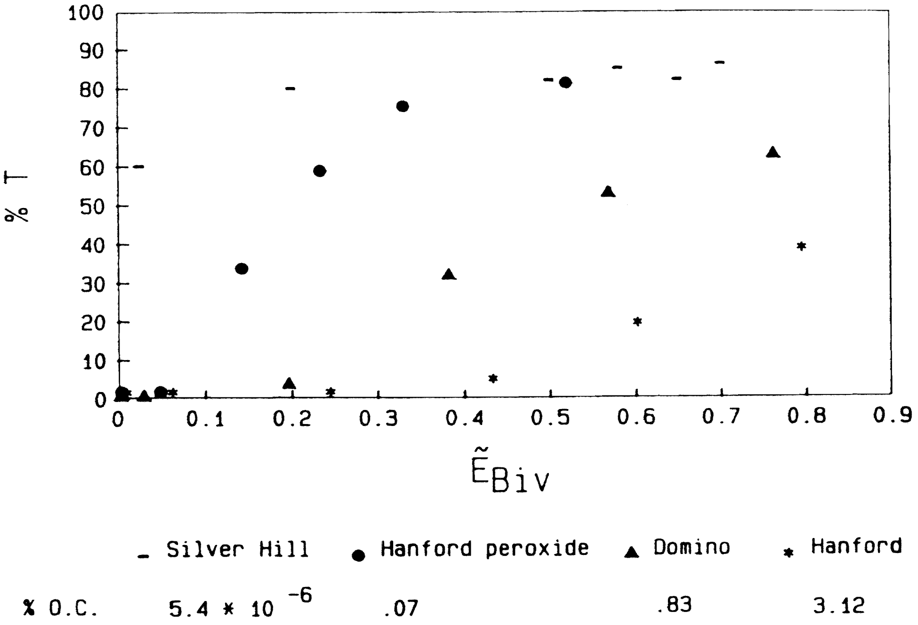
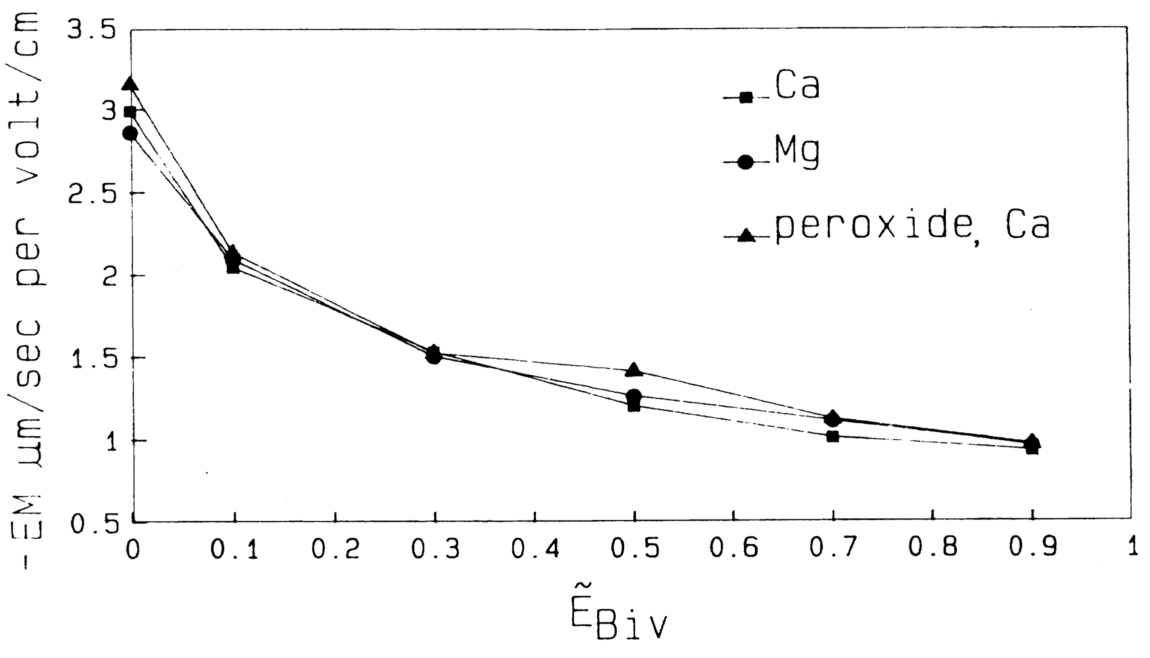


Fig. 4. % T versus the charge fraction of bivalent cations in solution at a total electrolyte concentration of 5 $mol_c\ m^{-3}$ (hydrogen-peroxide-treated Hanford soil). The type of bivalent cation and pH are fixed variables for each curve.



m^{-3}

Fig. 5. % T *versus* the charge fraction of bivalent cations in solution, at pH 6 and a total electrolyte concentration of 5 mol_c m^{-3} in mixed Ca/Na/K perchlorate background, for: Silver Hill illite, peroxide-treated Hanford soil, Domino soil, and untreated Hanford soil. Percentage organic carbon is given for each illitic material at the bottom of the figure.



m^{-3}

Fig. 6. Electrophoretic mobility (EM) versus the charge fraction of bivalent cations in solution at 10 mol_c m^{-3} in Ca/Na/K or Mg/Na/K electrolyte solution for the Hanford soil and in Ca/Na/K electrolyte solution for the hydrogen-peroxide-treated Hanford soil.

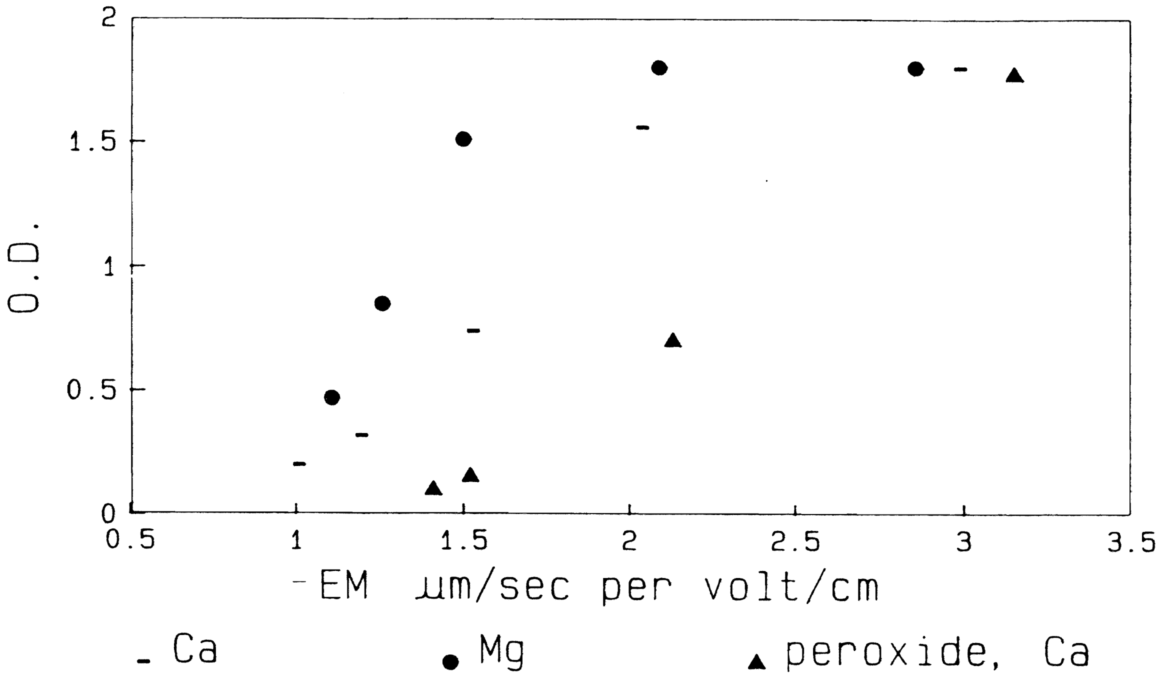


Fig. 7. Optical density (O.D.) *versus*. electrophoretic mobility (EM) for the untreated (Ca or Mg form) and hydrogen-peroxide-treated (Ca form) Hanford soil.

PROJECT TITLE: POLYMER-SOIL INTERACTIONS AS THEY AFFECT SOIL DISPERSION, CRUST FORMATION, INFILTRATION RATE AND HYDRAULIC CONDUCTIVITY

PROJECT NUMBER: 89-8

DURATION OF FUNDING: July 1989-June 1991

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ABSTRACT:

Polymers were found to be almost irreversibly adsorbed by soil materials and the strong bonding was enhanced by drying. The desorption results help explain the effectiveness of the various polymers on aggregate stability. A column leaching study was conducted to determine the effects of polymer treatments, gypsum and their combination on the hydraulic properties of a saline-sodic soil. The addition of polymer alone did not improve the hydraulic conductivity of the soil. A combination of polymers and gypsum increased the hydraulic conductivity of the soil more than four times as compared with the gypsum treatment without polymer. When soils with high ESP values were treated with polymer solutions and dried and checked for hydraulic conductivity to water, the polymer treatments significantly increased saturated hydraulic conductivity of soil samples with ESP values less than 15 but no significant effect on soils with ESP greater than 15. It was found in another study that soils which had high shrink-swell characteristics were most effectively treated with polymers by creating the cracks first and then applying the polymer solution. Polymer solutions applied in this manner significantly increased the hydraulic conductivity of these soils. The effect of polymers on solution viscosity was effectively greater for flow through porous medium than measured by standard viscometers. The apparent viscosity was also dependent on the pore size of the porous media. Measurements of mobility of polymers through columns in the laboratory suggest that the polymers investigated consist of two or more molecular groups with varying adsorptive capacities. A field experiment to investigate the effect of polymers on infiltration on furrow irrigation identified that PAM is more effective than the guar compounds. The culmination of the research is that a better understanding has been achieved on the procedures and polymers to use for improving hydraulic conductivity and infiltration rates.

KEYWORDS: Adsorption, polyacrylamide, guar, aggregate stability, viscosity

PROJECT OBJECTIVES ADDRESSED:

1. Conduct a detailed quantitative investigation on the interaction between polymer type and soil materials to elucidate polymer effects on soil dispersion, crust formation, infiltration and hydraulic conductivity.

2. Test the effectiveness of polymers for improving infiltration rates under field conditions.

RESEARCH ACCOMPLISHMENTS:

Desorption of Polymers from Soil Materials

A summary of adsorption results of various polymers on soil materials was reported last year. The study was extended to measure desorption. Three polyacrylamide (PAM) and three guar (polysaccharide) polymers were used in the study. The PAM polymers were designated as 2J, 21J and 40J with the number referring to the level of negative charges on the polymer. The guar compounds were higher cationic charge (T-4141), lower charge cationic (CP-14) and anionic (T-4246). These polymers were tritium labeled for quantitative analysis.

After 30 g of soil had been equilibrated with 20 mls of polymer solution, the supernatant was replaced by distilled water and the amount of polymer desorbed was calculated. Additionally, one soil was dried under the laboratory hood after decanting the supernatant before adding distilled water. Without drying the soil, the desorption of the various polymers was very low and almost zero in most cases. The overall low observed desorption percent supports the hypothesis that there is very low probability that large molecular size, multisegmented and flexible polymer segments can simultaneously become detached and move back into the bulk solution.

After the soil was dried and rewet with water, the polymer originally in solution was expected to become redissolved in the added water. The expected concentration of the redissolved polymer was calculated by dividing the amount of polymer left in solution before drying by the volume of water added to rewet the soil. Any measured concentration higher than this value would represent desorption. The measured concentration was considerably less than the expected concentration (Table 1) therefore drying the soil provided a bonding between the polymer and soil which was not completely displaced by water; indeed, no 2J was displaced by water.

TABLE 1. Polymer concentrations after drying and rewetting soil.

Polymer	Expected	Measured
2J	46	0
21J	25	10
T-4246	29	9
CP-14	29	11
T-4141	21	8

The largely irreversible bond between the polymer left in solution and the soil material upon drying the soil apparently affects aggregate stability. We had previously reported that 2J was more effective than 21J or T-4246 in providing aggregate stability by wet sieving technique. Note from Table 1 that all of the 2J left in solution was irreversibly absorbed upon drying. This is particularly significant because absorption of 2J was considerably less than 21J without drying the soil.

Polymers and Gypsum for the Reclamation of a Saline Sodic Soil

Soils were collected from the El Rico Ranch of J. G. Boswell Company near Corcoran, California in the Tulare Lake Basin. Soil was from an experimental field wherein plots had been irrigated for six years with six different waters made to vary in salinity by mixing high quality canal water and saline drainage water. The six salinity levels used for irrigation were approximately 1, 2, 5, 7, 9 and 12 dS m^{-1}. The soils were analyzed for soluble salts in a saturation extract, particle size distribution, cation exchange capacity and ESP.

One study was conducted on the soil sampled from the plots receiving irrigation water with EC = 9 dS m^{-1}. Polyacrylamide 21J and guar T-4141 were used in this study. The air-dried soil was treated with the two polymers to obtain a final soil polymer concentration of 50 mg kg^{-1}. A column leaching study was conducted to determine the effects of polymer treatments, gypsum and their combination on the hydraulic properties of this soil. The gypsum was added to the soil at a rate equal to the gypsum requirement (6.72 g kg^{-1}) with an additional 25% to insure complete reclamation. Addition of the gypsum significantly reduced the ESP value of the soil and increased the hydraulic conductivity by reducing soil swelling and dispersion. The addition of polymer alone did not improve the hydraulic conductivity of this soil. When the 21J polymer was added to the soil in the first pore volume of irrigation water, the infiltration rate dropped to zero, possibly because of apparent viscosity effects which will be discussed later in this report. Spraying and mixing the soil with polymers and adding gypsum increased the hydraulic conductivity of the soil more than 4 times as compared with the gypsum treatment without polymer. There was no difference between the two polymers when they were combined with gypsum addition. Drying cycles improved the hydraulic conductivity of the soil.

In another study, the soil samples from each of the field irrigated plots were used. The soil samples had exchangeable sodium percentages (ESP) of 8.0, 12.4, 20.0, 25.3, 31.5 and 35.1. The air dried soils were treated with PAM 2J and PAM 40J and guar T-4141. The final soil polymer concentration was 50 mg kg^{-1}. The polymers were added to the soil samples by spraying 1 kg of air dried soil with 100 ml solution with a concentration of 100 mg L^{-1} of polymer and distilled water. The polymer solutions were sprayed five times on each soil with drying and gentle hand crushing after each spraying.

A column leaching study was conducted to determine polymer treatment effects on hydraulic conductivity. This was done by packing the soil into glass columns in the laboratory. The soil in the columns was saturated by slowly introducing water to the bottom until complete saturation. The water used for measuring hydraulic conductivity was synthesized to simulate high-quality canal water used in the field experiment. Swelling of the soil in the column was determined by measuring the change in vertical height of the soil in the column. Soil swelling was also carried out using another test. Macroscopic swelling is defined as the total quantity of solution taken up per gram of soil. Two grams of soil were pressed onto a filter paper and placed on a sponge immersed in the irrigation water. The soil and filter paper were weighed every day until a constant weight for each replicate was reached.

The polymer treatments had a highly significant effect on increasing the saturated hydraulic conductivity of soil samples with ESP values less than 15 but no significant effect on soil with ESP greater than 15. None of the polymers reduced soil swelling on any of the soils. The improvement in hydraulic conductivity with polymer treatment at low ESP was attributed to reduction in soil slaking. At ESP values greater than 15, the dominant mechanism controlling hydraulic conductivity was swelling and the polymers had little or no benefit under these conditions.

Soils containing a large percentage of montmorillonitic clay have high shrink-swell characteristics. Upon drying in the field, these soils tend to form cracks which can extend to some depth within the profile. Irrigation of these soils results in water flowing into the cracks very rapidly until the soil swells and closes the cracks. After the cracks are closed, the infiltration rate drops to almost zero. A study was conducted to determine whether polymers could be effective in decreasing the rate and/or extent that cracks close soil wetting.

Soils collected from the field experiment which had ESP of 8 and 25 were used in this laboratory study. Five hundred grams of soil were packed 6 cm deep in a 9.6 cm i.d. plexiglass column over 1 cm coarse sand and a porous fiberglass sheet. The columns were sealed at the bottom with a plexiglass sheet with a drainage tube in the center. Tap water was applied to the soil until it was saturated and the water was left ponded for 24 hours to allow swelling and dispersion to occur. During this saturated period, the outlet from the column was stoppered. Later the stoppers were removed and the water allowed to drain. The columns were then dried and allowed to form cracks. After drying, four treatments were imposed by adding tap water containing 0, 25, 75 and 200 mg L^{-1} of 21J to the top of the columns. After 24 hours of ponding, the stoppers were removed and the excess solutions were allowed to drain and again the columns were dry and cracks formed.

Next, the columns were stoppered and tap water was applied to all columns. After 1, 6, 12 and 24 hours, the stoppers were removed and the water was allowed to percolate for half an hour while the water head was maintained constant. The average hydraulic conductivity over this one-half hour time period was calculated for each case.

To investigate the ability of the polymer treatment to maintain hydraulic conductivity, the sample with ESP = 8 was treated with 200 mg L^{-1} of the polymer and allowed to dry and the hydraulic conductivity measurements were made for two wetting and drying cycles. The experiment was also repeated, applying the polymer solution to the sieved soil which had not been previously wet and allowed to form cracks upon drying.

The hydraulic conductivity was very rapid while the cracks were visible. The hydraulic conductivity decreased with time and approached a steady state value. The average steady state hydraulic conductivity is plotted as a function of polymer concentration treatment in Figure 1. The steady state hydraulic conductivity increased with increasing polymer concentration when the polymer solution was applied to soil cracks. These data suggest that the polymer stabilized the cracks preventing their complete closure upon rewetting. When the polymer solution was applied directly on the soils without initially creating cracks, there was no increase in hydraulic conductivity of the soil with ESP = 8 and a small increase was observed on the soil with ESP = 25. The effectiveness of the polymer treatment on crack stabilization tended to decrease with each drying cycle.

Pore-size Dependent Apparent Viscosity of Polymer Solutions

The viscosity of solution would affect the infiltration rate and hydraulic conductivity. If the polymer altered the solution viscosity, the change in viscosity would affect the value of both infiltration rate and hydraulic conductivity. A crude technique was initially used to determine whether the polymer was causing a great change in solution viscosity. The time required for a 10 ml pipette to empty under free flow was measured for water and various polymer concentrations. There was only a very slight increase in apparent solution viscosity up to concentrations of 400 mg L^{-1}. It was assumed from this crude technique that the deviations of viscosity of polymer solution from water would be negligible. Nevertheless, observation during experimentation suggested that the polymer solution flow through soils was slower than might be expected based on soil properties. For example, the hydraulic conductivity of water through soils which had been previously treated with polymer solution was usually higher than the hydraulic conductivity of the polymer solution through the soil. This despite the fact that the polymer solution tended to keep the soil from slaking and dispersing. These observations prompted a study to determine whether the viscosity of polymer solution relative to that of water was different in porous media than those measured by various types of viscometers.

Soil materials subject to flocculation and/or dispersion could not be used in the study because these properties were likely altered by the polymer solution. In order to isolate fluid from porous media properties on the solution flow it was imperative to use a porous media with a fixed geometry such as quartz sand which was selected. Two size fractions of sand were used and will be referred to as fine ($r < 0.5$ mm) and coarse (0.5 mm $< r < 1$ mm). These sands were packed into glass columns and the hydraulic conductivity was measured.

PAM, 2J, 21J and 40J were dissolved in Riverside, California tap water to concentrations of 0, 25, 50 100, 200, 300 and 400 mg L^{-1}. The ratio of the hydraulic conductivity of water to that of solution would be inversely proportional to the viscosities of these two liquids. The relative viscosity (viscosity relative to water) was calculated from the relative hydraulic conductivities of the solutions.

The relative viscosity is plotted as a function of the polymer concentration in Figure 2. The relative viscosity increased with polymer concentration in each case. Noteworthy is the fact that the relative viscosity of a given polymer solution is much higher in the fine sand than in the coarse sand. The relative viscosity of a given polymer concentration should be independent of pore size. The data presented in Figure 2 clearly and unambiguously demonstrate that this is not the case.

Traditionally the equation $K = k\rho g/\eta$ where k is the permeability, η is the fluid viscosity, ρ is the fluid density and g is the gravitational constant, has been used to account for porous media and fluid properties on hydraulic conductivity (K). The results of our study indicates this equation is not valid for use for polymer solutions and possibly for other solutions containing organic compounds.

Mobility of Polymers through Soil Materials

Knowledge of polymer mobility in soil is useful in predicting effective depth of treatment. In this study, solutions containing six tritium-labeled polymers were flowed through columns of Arlington soil or acid washed quartz sands. The polymers were PAM, 2J, 21J and 40J and guar T-4246, T-4141, and CP-14. Breakthrough curves were determined in each case. The ratio of the leachate polymer concentration (C) to the input polymer concentration at the top (C_0) did not reach 1 even after about 20 pore volumes were allowed to flow through. Less than five pore volumes were expected to produced $C/C_0 = 1$ from the calculated retardation factor. The concentration of the polymer in the effluent dropped to undetectable levels within about 1 pore volume after the solution at the top was replaced with untreated water which indicted irreversible polymer absorption. This result is consistent with the other studies which were done specifically for measuring polymer desorption.

Three hypotheses were proposed to explain why C/C_0 did not reach 1: (1) slow penetration of polymers into soil aggregates, (2) multi-layer adsorption and (3) polymers consisting of two or more molecular groups with varying adsorptive capacities. Experiments were designed to support or reject each hypotheses. The first hypothesis was conclusively rejected. Although the second hypothesis could not be completely rejected, the third hypothesis was experimentally verified. A fraction of the polymers are highly mobile whereas a fraction had a very low mobility. The mobile fraction could be carried about as deep as water flow whereas the highly adsorbed fraction would be retained very near the soil surface. The effective depth of treatment from a soil physical condition point of view depends on the unknown effectiveness of the mobile polymer fraction in altering soil physical conditions.

Polymer Effects in Furrow Irrigation

A field study was conducted to investigate polymer effects on infiltration rate and other soil properties in furrow irrigation. A recycling furrow infiltrometer system was constructed and used for the experiment. Two studies were conducted. In the first study, all furrows were initially irrigated with regular water. After drying, the furrows were raked to a depth of about 25 mm to disturb the soil surface. Infiltration rate measurements were then made using untreated water and water containing 20 mg L^{-1} of guar CP-14, PAM 2J, and PAM 21J. Following the initial irrigation with polymer in solution, subsequent irrigations were run without polymer.

The infiltration rate was found to decrease with successive irrigations. There was no significant effect of polymer treatment on infiltration rate in the first study. Thus, either the polymer treatment did not significantly decrease crust formation or the limiting layer to water infiltration was greater than the 25 mm which was disturbed by raking. The second study was done on the same furrows except each furrow base was ripped to a mean depth of 19 cm using a single tine offset to one side of the tractor wheel to avoid trafficking the furrow base. The same polymer treatments were applied again and the infiltration rate and soil properties were monitored. Following the treatment application, two further sequential irrigation cycles were applied with untreated water.

After deeper disturbance of the soil by ripping, infiltration rates increased for all treatments and remained higher for PAM 2J and 21J over the two irrigation cycles following application of polymers. CP-14 was not significantly different from the untreated plot.

Numerous other measurements were made in addition to infiltration rate. These included soil strength measurements by various techniques and aggregate stability measurement. Results from these analyses have not been completely analyzed at this time.

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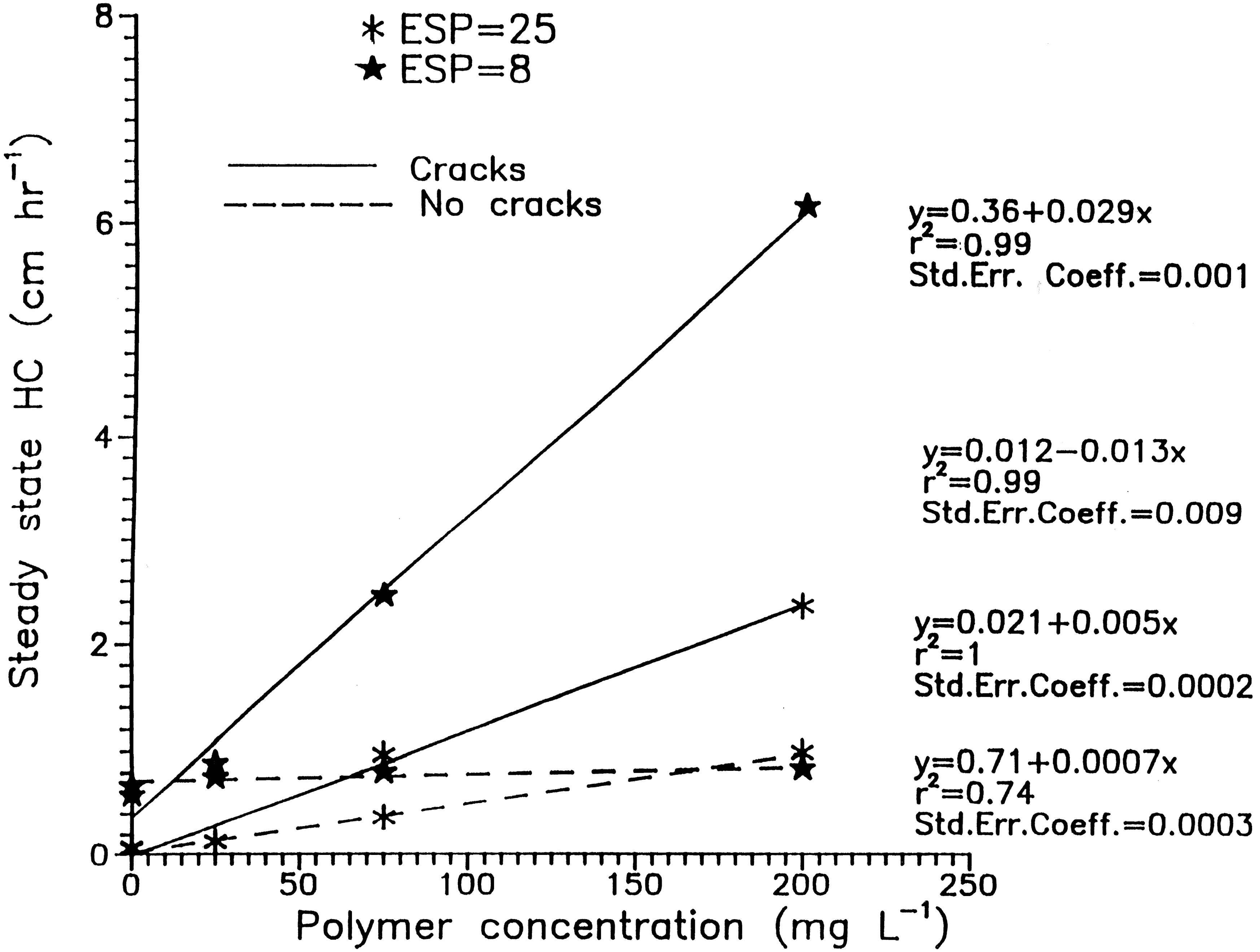
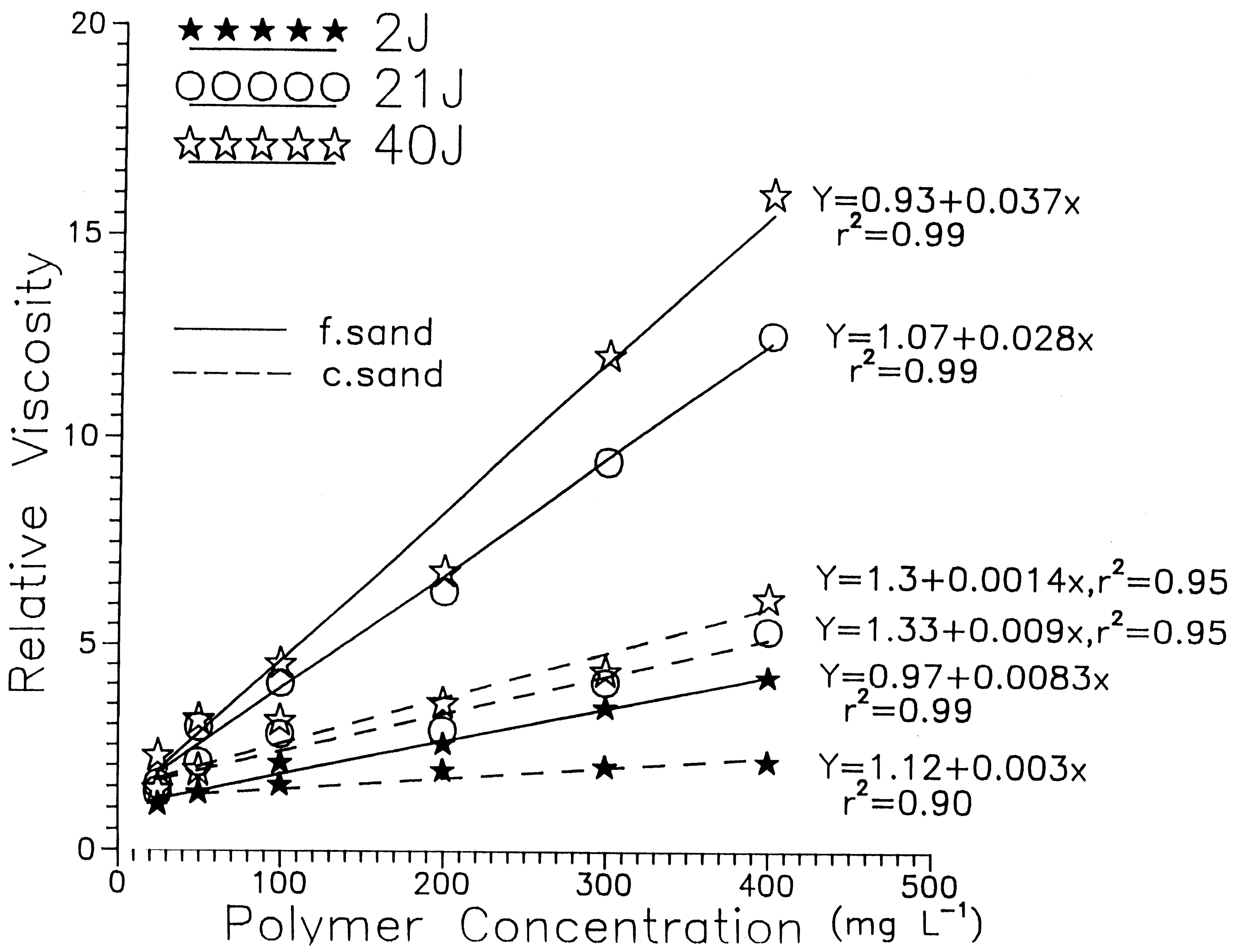

∗ ESP=25
★ ESP=8
Cracks
No cracks
$y=0.36+0.029x$
$r^2=0.99$
Std.Err. Coeff.=0.001
$y=0.012-0.013x$
$r^2=0.99$
Std.Err.Coeff.=0.009
$y=0.021+0.005x$
$r^2=1$
Std.Err.Coeff.=0.0002
$y=0.71+0.0007x$
$r^2=0.74$
Std.Err.Coeff.=0.0003
Steady state HC (cm hr^{-1})
0
2
4
6
8
Polymer concentration (mg L^{-1})
0
50
100
150
200
250


2J
21J
40J
f.sand
c.sand
Y=0.93+0.037x
r^2=0.99
Y=1.07+0.028x
r^2=0.99
Y=1.3+0.0014x,r^2=0.95
Y=1.33+0.009x,r^2=0.95
Y=0.97+0.0083x
r^2=0.99
Y=1.12+0.003x
r^2=0.90
Relative Viscosity
0
5
10
15
20
0
100
200
300
400
500
Polymer Concentration (mg L^-1)

PROJECT TITLE: THE INTERACTIVE EFFECTS OF HYDROXY-AL AND POLYSACCHARIDES ON PHYSICAL STABILIZATION OF CLAYS

PROJECT NUMBER: 89-17

DURATION OF FUNDING: July 1989 - June 1991

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ABSTRACT:

The combined addition of sesquioxides (Al hydroxy polycations, Alnf as reported here) and negatively charged polysaccharides (anionic PSS) was found to be the best treatment for maintaining both aggregate stability and hydraulic conductivity in soils that have been previously air dried. Illite and montmorillonite are probably the most important clay minerals active in aggregation and water infiltration problems of the Central Valley. In general, the independent and combined influence of Alnf and anionic PSS are very different depending on the clay mineral involved. Particle size distribution measurements of both clays showed that rapid and strong aggregates were formed in suspension when both Alnf and anionic PSS were included in the treatments in most cases.

KEYWORDS: Aggregation, adsorption, aluminum polycations, particle size distribution

PROJECT OBJECTIVES ADDRESSED:

1. To determine how the presences of sesquioxides (in this case hydroxy-Al polycations) in clays interact with polysaccharides in relationship to physical stability and aggregate formation.
2. To determine how changes in the chemical environment affect the interaction of the clay/aluminum hydroxy/polysaccharide system in relation to physical stability and aggregation.

RESEARCH PLAN AND PROCEDURES:

The detailed methods for determining soil aggregate stability by the wet sieving method and soil hydraulic conductivity (HC) are given by Doner (1989).

Montmorillonite (SWy-1) and illite (Le Puy, France) were sodium saturated and fractionated by sedimentation to collect the less than 2 μm fraction. Aluminum hydroxy polycations (Alnf) were prepared by the method of Bottero et al., 1980. This method consisted of adding 1.0 mol(NaOH) dm^{-3} to 0.5 mol($AlCl_3$) dm^{-3} at the rate of 3.33 ml min^{-1} with rapid mixing to give a product with an OH/Al ratio of 2.2. The anionic polysaccharide (T4246) (anionic PSS) was manufactured by Celanese Water Soluble Polymers, Louisville, Kentucky and obtained from J.Letey at U.C., Riverside.

The isotherms for the adsorption of anionic PSS to the clays were developed as follows. To 0.005 L of 4 g(Na-montmorillonite) L-1 suspensions, 0.005 L of either 1.6 mmol(Alnf) L^{-1} or 3.5 mmol(NaCl) L^{-1} were added and mixed. This treatment produced suspensions with approximately 0.3 mol_c(Alnf) kg^{-1} montmorillonite or a NaCl concentration with a chloride concentration equal to that of the Alnf treatment. Then 0.010 L of anionic PSS was immediately added to give a final, total concentration in suspension of 20, 40, 100, 150, 200, 300, 400, and 500 mg(PSS) L^{-1} or the same values in units of mg(PSS) kg^{-1} clay. The suspensions were immediately mixed, reacted for 3 hr., centrifuged, and total C determined in the supernatant. The amount of anionic PSS adsorbed was determined by the difference between what was added and the amount remaining in solution after reaction with the clay. Illite suspensions were treated in the same manner as the montmorillonite suspensions except that either 0.45 mmol(Alnf) L^{-1} or 1.8 mmol NaCl) L^{-1} was added to give 0.09 mol_c(Alnf) kg^{-1} or an equivalent chloride concentration in the NaCl treatments. Assuming the CEC of the montmorillonite is approximately 1.0 mol_c kg^{-1} and that of the Le Puy illite is 0.3 mol_c kg^{-1} this would give a theoretical 30% charge neutralization by Alnf.

Particle size distribution of montmorillonite and illite clays treated with Alnf, anionic PSS, or a combination of Alnf/anionic PSS was measured using a laser dispersion instrument (made by Malvern). The clay treatments for the particle size measurements were very similar to the method used for the adsorption isotherms with some noteworthy differences. It was necessary to reduce the concentration of the clay suspensions by 0.1 in order to be in the correct concentration range for the instrument. Subsequently, all Alnf, NaCl, and anionic PSS treatments were reduced amount by 0.1 to keep the same solid to treatment ratio. Additional Alnf and NaCl treatments were included to make the Alnf treatment equivalent to about 120% of the charge on the clays, i.e., 1.2 and 0.36 mol_c(Alnf) kg^{-1} for montmorillonite and illite, respectively. The NaCl concentration was increased to match the chloride concentration of the higher Alnf treatment. Anionic PSS added at the rate of 50 g kg^{-1} clay was the only treatment level tested. The reaction time before the particle size distribution was measured was between 1 to 3 minutes. There was vigorous agitation during the entire treatment and measurement period so that weakly associated particles would be dispersed.

RESULTS:

Figure 1 and Table 1 summarize the results of the soil aggregate stability tests by wetting sieving and soil HC tests as reported last year (Doner, 1990). The poignant points are that treatment of the soils with either anionic pss alone or with Al-p (Al-chlorohydrate, an Al_{13} product manufactured by Reheis Chemical Co., Inc.) in combination with anionic PSS resulted in a much improved aggregate stability. Treatment with Al-p alone provide some improvement in aggregate stability. The HC of both soils were increased initially for all treatments compared to the Na control. Anionic PSS treated soils initially had relatively high HCs of 45.36×10^{-6} and 11.99×10^{-6} m s^{-1} for the Hanford and Wyman soils, respectively, but final HC values after 5 days were close to the Na control. On the other hand, treatment of the soils with Al-p and Al-p/anionic PSS resulted in higher HC values over the 5 day test period (Table 1). It was concluded that the presence of Al-p was necessary with the anionic PSS treatment to maintain long term aggregate stability (Gu, 1991).

To provide more insight into the role of aluminum hydroxy polycations and anionic PSS in aggregate formation, adsorption isotherms and particle size distribution of clay suspensions were made. Results for either Na saturated or Alnf treated (30% CEC) montmorillonite and illite clays equilibrated with various amounts of anionic PSS are shown in Fig. 2a. More anionic PSS was adsorbed to the Alnf treated montmorillonite than the Na saturated form. This is in contrast to the results reported earlier (Doner, 1990). The difference is most likely due to the size of the Al polycation. The Al polycation used here was not size fractionated and no doubt contained large polymers that could not enter the interlayer region of montmorillonite to neutralize its surface charge. This would have left additional positive sites from the Alnf for electrostatic adsorption of anionic

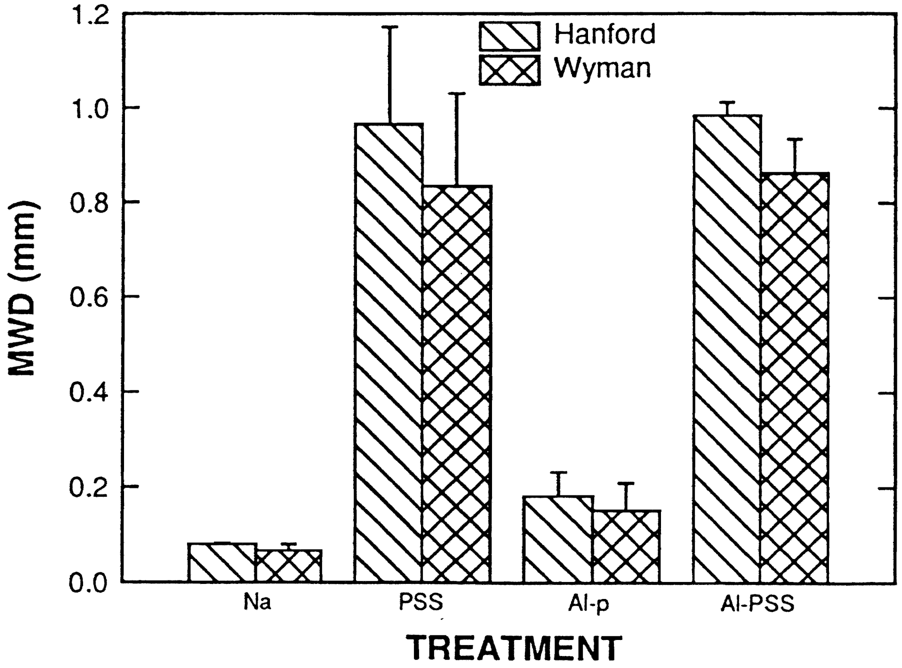


FIG. 1. The mean weight particle diameter (MWD) by wet sieving of the Hanford and Wyman soils after treatment with Na, Al-p (Al-chlorohydrate), anionic PSS or a combination of Al-p/anionic PSS.

TABLE 1. The initial (K_i) and final (K_f) hydraulic conductivities ($\times10^{-6}$ m s^{-1}) of soils after treatments with the anionic PSS, chlorohydrol (Al-p) and the combination of Al-p with PSS.

	HANFORD		WYMAN	
TREATMENT	K_i	K_f	K_i	K_f
Na	0.31	0.031	0.76	0.019
Anionic PSS	45.36	0.017	11.99	0.011
Al-p	44.75	11.5	70.83	1.04
Al-p + PSS	134.2	2.59	152.5	11.14

PSS. The illite (Le Puy) showed a slight increase in the adsorption of anionic PSS with the addition of Alnf (Fig. 2b). This is similar to that reported in previous studies with Silver Hill illite (Doner, 1990). The Na saturated illite showed no, or possibly negative, adsorption of anionic PSS.

Figure 3a and b shows the effect of Alnf, anionic PSS, and Alnf/anionic PSS treatment on particle size distribution. Anionic PSS produced no aggregation of the suspension and if anything had the effect of stabilizing the colloidal suspension. Addition of Alnf resulted in a skewed distribution to the 10 µm size fraction (Fig.3a). Since all the particle size measurements were taken within 1 to 3 minutes after the addition of Alnf and PSS the rate of reaction between the clay and Alnf was relatively fast. The addition of the combination of Alnf at a 30% CEC rate and anionic PSS produced no aggregation of the montmorillonite. When Alnf was added a rate of 120% CEC of the clay there was an immediate formation of particles greater than 100 µm in size (Fig. 3b). With the combination of Alnf/anionic PSS aggregation occurred with an apparent discrete particle size of approximately 100 Êm. Treatment of montmorillonite with only anionic PSS stabilized the colloidal suspension as described above.

Addition of Alnf at 30% CEC, anionic PSS, and the combination Alnf/anionic PSS to illite resulted in no aggregate formation after the first few minutes of treatment (Fig. 4a). On the other hand, treating the illite with Alnf at 120% CEC caused a significant increase in particle size distribution to the 2 to 30 µm size range. Including the addition of anionic PSS had the clear effect of increasing the particle size distribution to the 4 to 200 µm range (Fig. 4b).

DISCUSSION AND SUMMARY:

The role of drying soils on aggregate formation with Al-hydroxy-polycation/anionic PSS systems was demonstrated in an earlier report (Doner, 1990) and summarized here. In the colloidal suspensions experiments reported here no aggregation of either Na montmorillonite or illite was found with the addition of anionic PSS. This supports the observation that drying results in weak bonding of particles together if no polyvalent cations are present. Addition of Alnf at a level of 30% the CEC resulted in some aggregation of montmorillonite but not illite. This difference may be due to the more flexible nature of montmorillonite particles compared to the more rigid illite particles (Tessier and Pedro, 1982). The more rigid particles may be less likely to make contact to form bonds between particles. Under the conditions of the experiment the anionic PSS had no positive influence in promoting aggregation. The interactive role of Alnf added at 120% CEC and anionic PSS was especially obvious for illite by the formation of large stable aggregates. In the case of montmorillonite the Alnf/anionic PSS bonding interaction was not as clearly differentiated as with illite. This points out the importance of considering the mineralogical aspects in understanding aggregate formation and stability.

In order to get the maximum, long term benefit from the addition of organic matter for improving infiltration the presence of sesquioxides or other polyvalent cations are necessary. Aluminum hydroxy polycation (and most likely Fe hydroxy polycations) with organic matter would provide the best conditions for aggregate formation since it is not as easily leached from the soil by infiltrating irrigation waters.

Acknowledgements. Appreciation is extended to J.Y. Bottero and Fabien Thomas, Centre de Recherches sur la Valorisation des Mineraux, C.N.R.S., Nancy, France for their help in the particle size measurements.

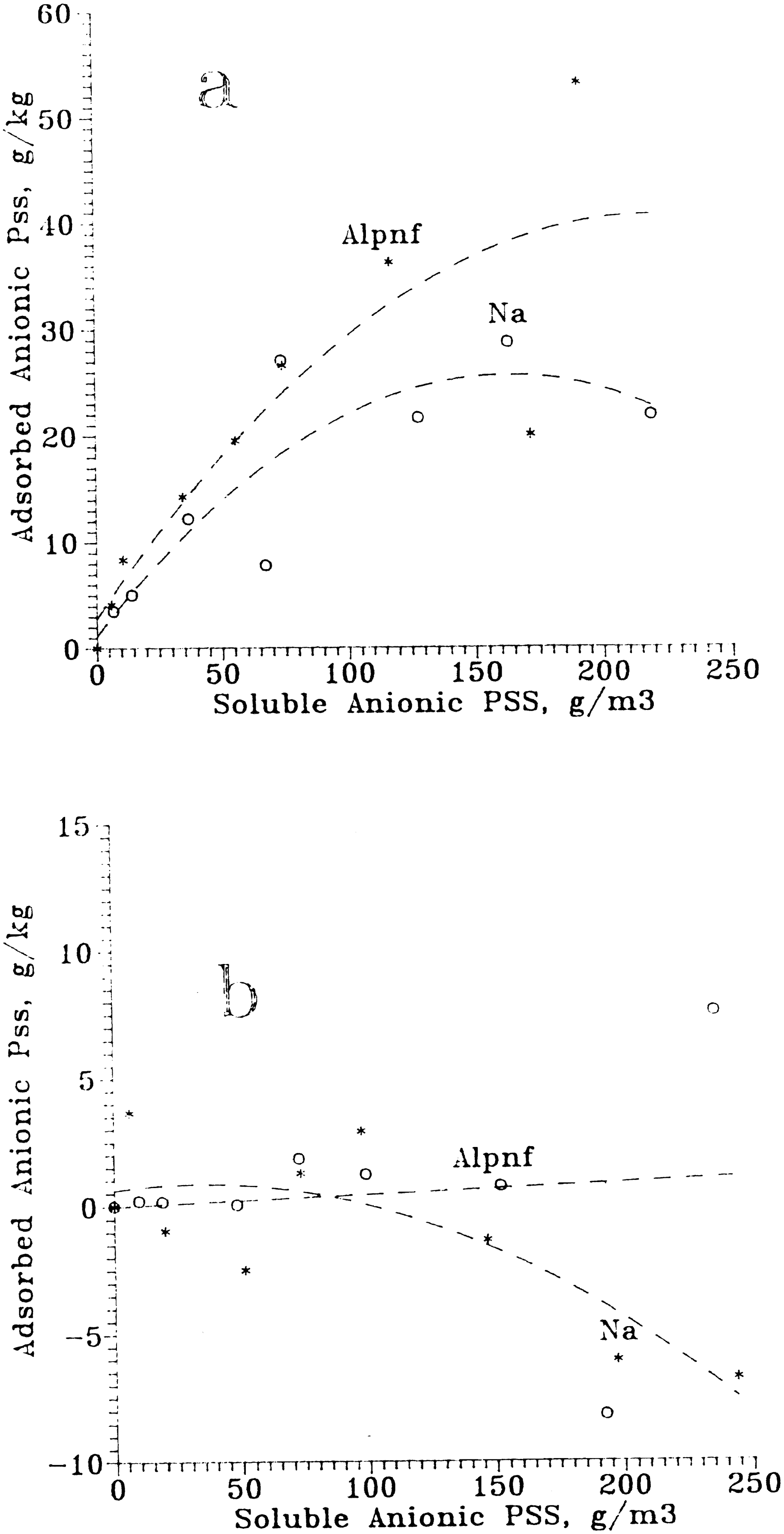


FIG. 2. The adsorption isotherms of anionic PSS on Na and Alnf treated montmorillonite (a) and illite (b).

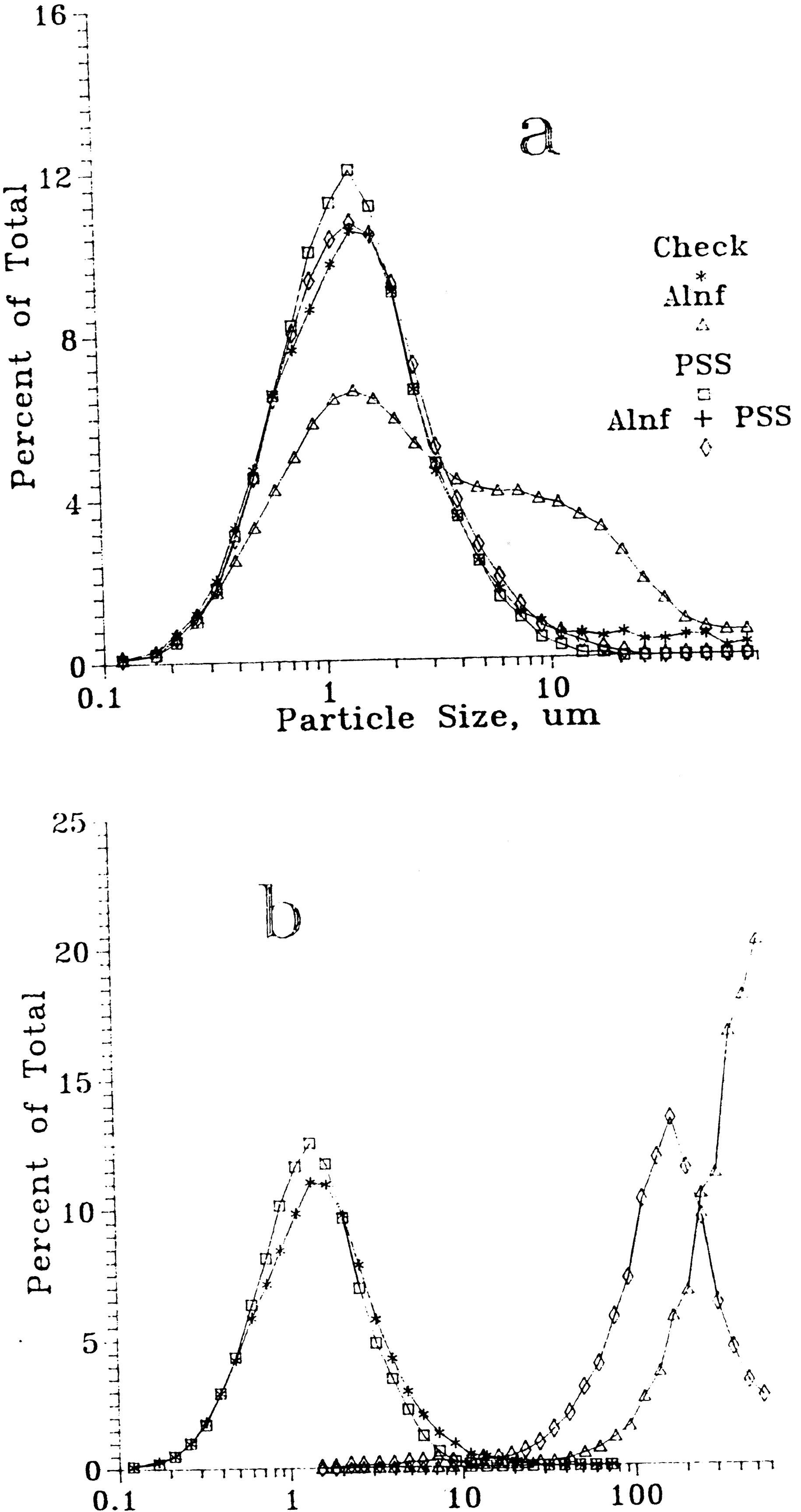
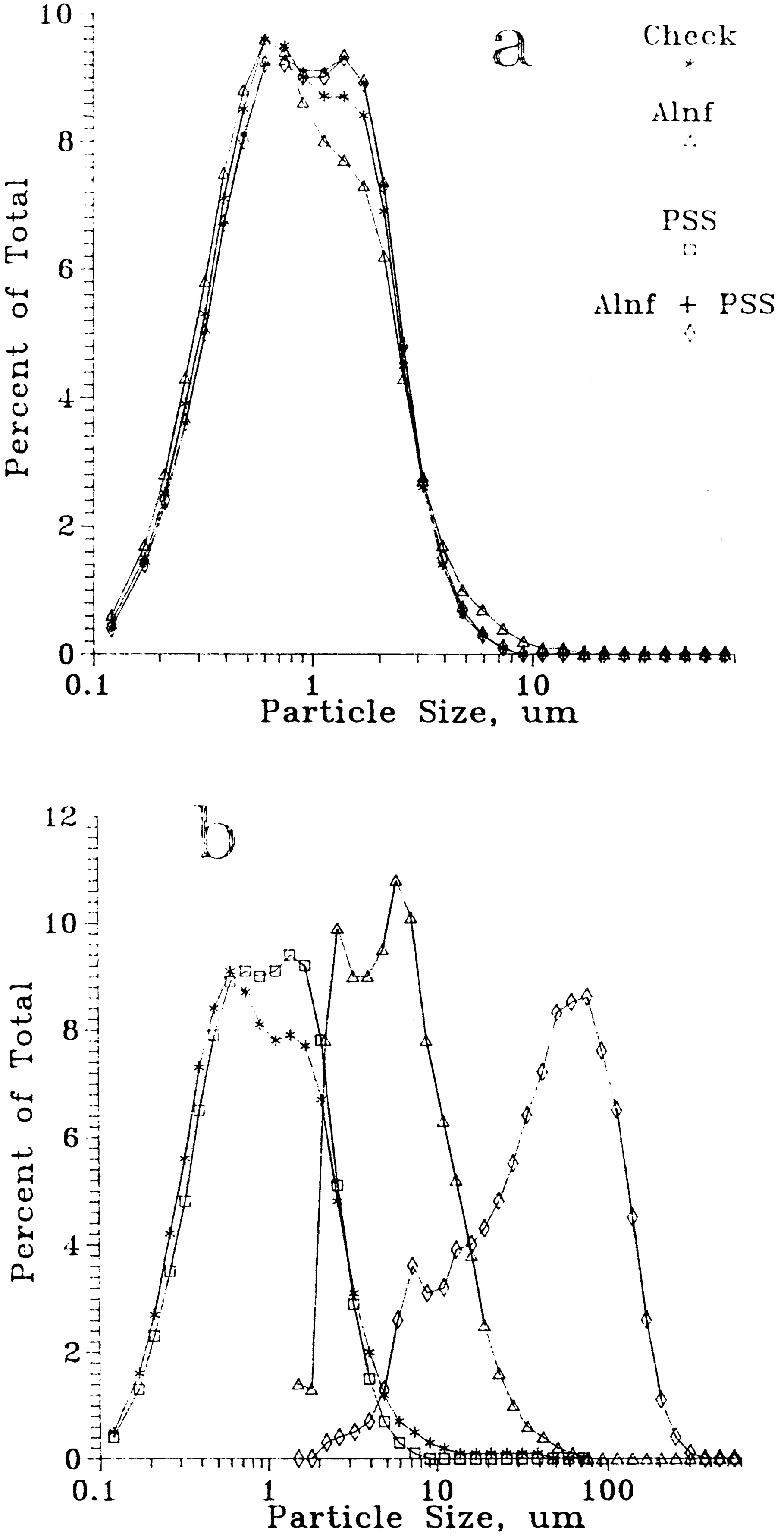


FIG. 3. Particle size distribution of montmorillonite after treatment with Na, Alnf, anionic PSS, or combined Alnf and anionic PSS. Alnf added at the rate of either 30% (a) or 120% (b) of the CEC.



anionic

FIG.4. Particle size distribution of illite after treatment with Na, Alnf, anionic PSS, or combined Alnf and anionic PSS. Alnf added at the rate of either 30% (a) or 120% (b) of the CEC.

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WATER MOVEMENT

PROJECT TITLE: INFILTRATION MANAGEMENT IN CRACKING CLAY SOILS

PROJECT NUMBER: 89-3

DURATION OF FUNDING: July 1989 – June 1991

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ABSTRACT:

Profitable crop cultivation on heavy clay soils can be difficult due to limited, or excessive soil moisture and adverse soil salinity conditions. These problems are the result of the low permeability and very slow rates of water movement through the clay. Soil cracking which occurs in these soils may provide the opportunity to adequately wet and leach the soil profile. From a water conservation and management perspective, it is important to devise different water application strategies that take advantage of soil cracking so as to enhance infiltration of applied water. For example, frequent, shallow depth irrigations may be more desirable than infrequent deep irrigations in which substantial applied water is lost deep in the profile due to deep cracks. The research reported herein describes (a) a procedure for eliminating surface runoff in border irrigated clay fields, and (b) results of preliminary efforts aimed at determining the effects of shallow groundwater on clay cracking.

KEYWORDS: surface irrigation, heavy clay, subsurface drainage, water conservation

PROJECT OBJECTIVES ADDRESSED:

Work has been completed towards the objective of developing a field usable water application management method which practically eliminates surface runoff from border-irrigated clay fields. Work towards the objective of measuring the effects shallow groundwater artesian pressure on infiltration into clay soil has been hampered by a number of field problems and is not yet completed.

RESEARCH PLAN AND PROCEDURES:

The original research plan and procedures for this project were described in the previous Kearney report of 1990 (Grismer and Robinson, 1990) on this project. Briefly, the field research directed towards the first objective involved application of a volume balance model of surface irrigation to the field such that the onflow cutoff time required for no surface runoff could be determined and the infiltrated crack volume could be estimated. This application requires that the surface irrigation advance trajectory is linear with time and that the flow depth can be successfully determined. Previous experience had shown that for a heavy clay field in the Imperial Valley, the advance trajectory was nearly linear. Thus, it was necessary to devise a procedure to estimate the flow depth.

Flow depth is a difficult parameter to measure in the field due in part to large variations in microtopography and the relatively small depths of flow. For three different irrigations, two rows of 10 flow depth measuring gages spaced 5 m apart near the border checks were used to measure flow depth. Each gage consisted of a measuring stick oriented in a vertical position on a circular plate anchored to the ground surface. Results of these measurements are summarized in Table 1. The large variations in the measurements are indicated by the values of the coefficient of variation (COV) in excess of 60%.

TABLE 1. Flow depth measurements for three different irrigations (n=20)

Irrigation Event	Mean Depth (mm)	Standard Deviation (mm^2)	COV (mm)
A	29.0	21.1	72.8%
B	17.5	13.5	77.1%
C	41.0	24.6	60.0%

Alternatively, flow depth can be estimated from Manning's equation when the onflow rate, field slope and surface roughness are known. We found that estimates of surface roughness on the order of n ~ 0.016 for newly cultivated fields and n ~ 0.28 for mature grass, cereal or alfalfa crops yielded better estimates of flow depth for the purposes of determining the onflow cutoff time. In order to make this method useful for field irrigators, we developed a simple worksheet that enables calculation of the cutoff time using a hand-held calculator. This worksheet is shown in Fig. 1. The calculated cutoff time is the total time that the irrigator should apply water to the field so as to have no surface runoff. This worksheet was then used to estimate cutoff times for several different irrigations and compared with the cutoff times estimated from the measured flow depths (Table 1).

Surface Irrigation Cutoff Time Calculations

Field Identification: ______________________ **Date:** ______________________

Border Number: ______________________

Field Characteristics:

Border length (ft), L = ____________

Border width (ft), w = ____________

Field slope (%), s = ____________

Crop & maturity, n = ____________

Surface Roughness (n)	
newly planted	$0.014 \le n \le 0.017$
crop nearing maturity	$0.023 \le n \le 0.031$

Measurements:

Onflow rate (cfs), Q = ____________

Advance time (min), t = ____________

Advance distance (ft), L_x = ____________

These measurements are taken when the surface wetting front has advanced 1/4 to 1/3 of the border length down the field.

Calculations:

Flow depth (ft), $d = \left[\frac{Q * n}{1.486 * w * \sqrt{s}}\right]^{0.6}$ = ____________

Total volume applied (ft^3), $TAW = Q * t * 60$ = ____________

Surface water volume (ft^3), $SW = L_x * w * d$ = ____________

Infiltrated (crack) water volume (ft^3), $IW = TAW - SW$ = ____________

Infiltrated water depth (ft), $z = \frac{IW}{L_x * W}$ = ____________

Cutoff time (min), $\frac{L * W * z}{Q} = \boxed{}$

Figure 1. Surface irrigation cutoff time worksheet.

RESULTS:

Cutoff times estimated from the mean of the measured flow depths were consistently low and resulted in under irrigating the field; that is, the surface wetting front failed to reach the end of the border. The measured flow depths were too large in addition to being difficult to measure. Irrigation cutoff times based on surface roughness values resulted in complete irrigation of the fields with little, or no runoff. Table 2 summarizes results of irrigation measurements for four different irrigations for which three used surface roughness based estimates of cutoff time and the fourth corresponded to irrigation event A of Table 1 in which the mean flow depth was used to estimate cutoff time. In general, cutoff times estimated from the simpler surface roughness factors resulted in satisfactory irrigation of the field and errors in infiltration volume of less than 10%.

TABLE 2

Irrigation Event	Flow Depth (in)	Advance Distances @ 90 min. (m)	Calculated Infiltrated Depth @ 90 min. (in)	Measured Infiltrated Depth @ Completion (in)	Infiltrated Depth Error (%) $\left[\frac{\text{calculated} - \text{measured}}{\text{measured}} \times 100\%\right]$
April (A)	1.14*	142	5.7	7.6	25.0
July	1.53	117	4.65	4.81	3.1
May	3.0	165	4.5	4.8	6.2
October	1.0	243	4.1	4.41	7.0

*Mean value of 20 measurements (Table 1).

Some work was completed on the well system described in the previous Kearney report. The bladder pump added to the system successfully developed the wells after pumping the fine sand for several hours. Unfortunately, mechanical breakdowns and limited sustained drawdown by the well system has not allowed our obtaining further results at this time. Work will continue on developing the well system for use in addressing the second objective of this study.

Results of the semi-empirical analysis of the effects of water table depth on infiltration suggest that shallow water tables at depths of a few meters, or less can reduce infiltration rates. Such large effects do not seem to occur in the field, however, perhaps this is due to the simplifying assumptions in the mathematical analysis. Additional field verification of these results is required.

DISCUSSION AND SUMMARY:

A simple field method has been devised for minimizing surface runoff from border irrigated clay fields. The method takes advantage of the cracking characteristics of these fields and enables irrigators to better manage their irrigation water supply. It appears that from an infiltration management perspective, frequent shallow irrigations applied after limited crack formation will improve soil moisture available to the plant and surface soil salinity. Additional field work is required to verify this observation, as well as to assess the impact of the depth of shallow groundwater on infiltration into cracking clay soils.

PROJECT TITLE: EFFECTS OF WATER QUALITY ON FIELD-MEASURED INFILTRATION WITH AN EMPHASIS ON INFILTRATION MEASUREMENT TECHNIQUES

PROJECT NUMBER: 89-6

DURATION OF PROJECT: July 1989 - June 1991

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PROJECT COLLABORATORS:

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ABSTRACT:

A field study was conducted to investigate the influence of soil chemical and soil physical characteristics on in-situ water infiltration. Differences in soil chemistry were established by increasing sodium contents of the irrigation water. Subsequent flooding with irrigation water of high quality indicated the effects of soil sodicity on dispersion and infiltration rate.

Earlier research in the same field has shown that soil subsurface heterogeneity exists on a small horizontal scale (1 - 2 m). That is, the presence of a sandy layer at about 1 m depth may influence infiltration rate and cause infiltration variability on that same small scale.

Variability and fluctuations in infiltration rate were only slightly correlated with soil layering and laboratory measured saturated hydraulic conductivity. More than 50% of the infiltration variability could be explained by exchangeable sodium percentages of the surface soils.

KEYWORDS: Infiltration, water penetration, soil heterogeneity, lateral flow, soil salinity, sodicity

PROJECT OBJECTIVES ADDRESSED:

(1) To study the soil chemical and physical factors that reduce infiltration rate under sodic soil-water conditions in a field setting,

(2) To investigate the influence of vertical soil heterogeneity and lateral flow on field-measured infiltration.

RESEARCH PLAN AND PROCEDURES:

Water infiltration was monitored within 16 plots in a four by four grid at the University of California's Campbell Tract research facility (Figure 1). The soil was Yolo silty clay loam, a stratified Typic Xerorthent with a water table well below 35 feet. In this research area, a 20-50 cm thick layer of silty clay loam overlies a silty loam. A about the 80-120 cm depth, a distinctive loamy fine sand layer occurs with thickness varying between 0 and 30 cm.

The plots were cultivated with a rototiller, turned over with a hand shovel to insure mixing to a depth of 30 cm, and leveled with a rake. In each plot square steel infiltrometers of 1.2 m by 1.2 m by 0.3 m were inserted approximately 10 cm into the soil in the center of each plot. Within each square infiltrometer, 21 smaller infiltrometers made of 15 cm diameter PVC tubing were installed. The PVC infiltrometers were arranged as shown in Figure 2. The square infiltrometers were initially lined with plastic and flooded with water. Infiltration measurements commenced when the plastic sheet was removed. PVC infiltrometers were installed within the first 10 minutes after wetting.

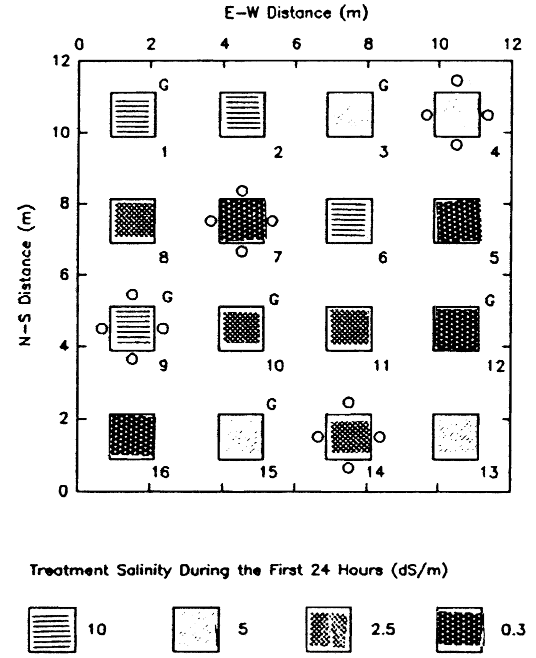


Figure 1. Locations of square infiltrometers in study plot. G's indicate plots which were treated with gypsum duing the second 24 hours of irrigation. Circles represent neutron probe access tubes.

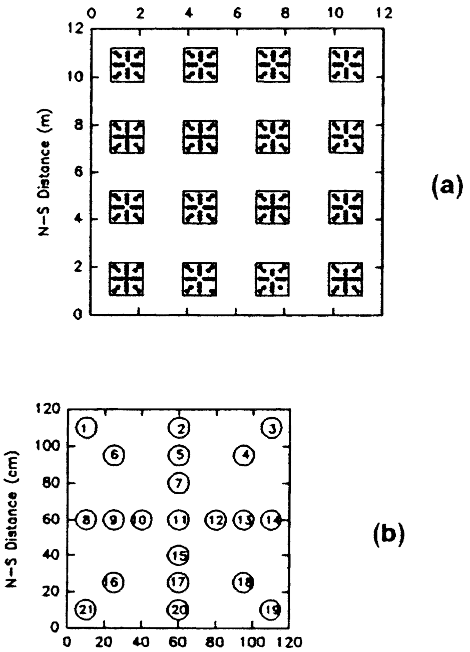


Figure 2. (a) Locations of 1.2·1.2 m square infiltrometers and (b) detail showing locations of 10.5 cm diameter PVC infiltrometers.

Philip's (1957) infiltration equation was fitted to infiltration data from both PVC and square infiltrometers.

$$I(t) = S\,t^{1/2} + A\,t \qquad (1)$$

where S ($LT^{-1/2}$) is sorptivity and A (LT^{-1})is related to the conductivity at the wetted soil surface. The infiltration rate, i(t), computed from Eq. (1) at 24 hours is referred to as the steady infiltration rate (IR). The two parameters, S and A, were estimated by fitting Eq. (1) to measured cumulative infiltration during the first 24 hours.

Changes in volumetric water content in the top 1.5 m soil were monitored with a neutron probe during the whole infiltration test period. Aluminum access tubes were installed at the center of each plot. At four plots (plot numbers 4, 7, 9, 14), four additional access tubes were installed 25 cm outside the square infiltrometers in the four major directions.

For the first 24 hours, each plot was flooded with either high quality water (Berryessa lake water) or one of three different saline water treatments. The three saline water treatments were achieved by dissolving NaCl into Berryessa lake water in a mixing tank. The four water treatments had electrical conductivities of 0.3, 2.5, 5.0, and 10 dS/m. Treatments were assigned to plots at random and each treatment was replicated four times (Figure 1). After 24 hours of ponding, all plots were flooded with high quality Berryessa water for an additional period of 24 hours.

Gypsum, a common soil amendment used to reduce clay dispersion, was applied to six of the plots (Figure 1) at the start of the second 24 hour flooding period. Gypsum slurry was applied with the high quality water at an application rate of 2 kg/m^2. Surface soil samples were taken at four locations in each plot prior to and after 24 and 48 hours of ponding. In addition, soil samples were also taken at the 21 PVC infiltrometer locations before and after 48 hours of flooding in plots 4, 7, 9 and 14. Surface soils were analyzed for CEC (cation exchange capacity), extractable Ca^{2+}, Mg^{2+}, Na^+, and K^+ and for salinity of saturation extracts (EC_e).

Continuous undisturbed soil samples of the upper 1.5 m of soil profile were obtained at 25 locations in plots 7 and 9 using a Madera sampler driven by a hydraulic press. Undisturbed soil cores in 8.2 cm diameter x 6 cm brass rings were collected to a depth of 1.5 m at two sites near the centers of plots 7 and 9, corresponding to PVC infiltrometer locations 7-10 and 9-12. These cores were analyzed in the laboratory for saturated hydraulic conductivity, bulk density and particle size distribution.

RESULTS:

The study field was known to have several textural layers in the top 1.5 m of the soil profile. Specifically, Hopmans et al. (1990) described a fine sandy layer at a depth of about 0.9 m which was thought to be responsible for much of the variability in infiltration rates. Madera core sampling revealed that textural layer thicknesses varied considerably over horizontal distances of tens of centimeters (Figure 3). Also, numerous small discontinuous sandy and loamy layers occurred in the profile at several depths.

Figure 4 shows the vertical variability in bulk density, percent sand, silt and clay, and saturated hydraulic conductivity in the upper 1.5 m of plots 7 and 9. Profiles of K_{sat} show that measured conductivities vary over about three orders of magnitude and that very low conductivities (<0.01 cm/hr) occurred at several depths. Also shown are the finer textured soil near the soil surface and the sandy soil layer between 90-120 cm depth.

Vertical infiltration rates should decrease with time as the hydraulic gradient decreases and a soil surface seal forms. Examples of measured infiltration curves for square infiltrometers at plot 7 (Figure 5a) and plot 9 (Figure 5b) show that infiltration rate was not a smooth continuously decreasing function of time for most ponded plots. Interestingly, infiltration rates rose steadily after about 30 to 40 hours of ponding in half of the measured plots. No commonly applied infiltration equation would satisfactorily describe the measured time-rate of change in infiltration for this plots. The fluctuations in infiltration rates could be explained if the soil is stratified. For example, in the presence of a sandy layer in a silt loam soil profile, infiltration rate will decrease as the wetting front encounters that sandy layer, but subsequently increases as water eventually has penetrated the sand and moves into the soil below the sandy layer.

Textural analysis showed the presence of a low density sandy horizon at the 75 cm depth in plot 7 (Figure 4a). The infiltration curve for plot 7 (Figure 5a) shows a distinct increase in IR beginning at about 5.5 hours, when the wetting front passed the 75 cm depth (Fig. 6a). IR decreased again after 7.5 hours, when the wetting front was near the 90 cm depth, the second sandy layer, and continued to decrease for the next several hours. Two sandy layers were also present in the soil profile of plot 9 between 85 and 120 cm (Fig. 4b). Plot 9 showed an increase in IR beginning at around 5 hours of infiltration (Figure 5b). After 4.52 hours, the piston-type wetting front in plot 9 (Fig. 6b, center) was at 90 cm. Until that time IR decreased due to the sandy interface, acting as a flow barrier. After the wetting front passed the sandy layer (after 6 hours) IR increased and remained high for 3 hours. If one of the layers in a stratified soil profile is much less permeable than the rest of the profile, the equivalent saturated conductivity, K_{eq}, may be approximated by (Terzaghi and Peck, 1967)

$$K_{eq} = z_t\left[\frac{K_1}{z_1}\right] \tag{2}$$

where K_1 and z_1 are the hydraulic conductivity and thickness of the most restrictive soil layer, and z_T is the profile depth. Two distinct soil layers were identified in the field plots: a silty clay loam layer near the soil surface and a loamy fine sandy layer at approximately 0.9 m depth. The approximate equivalent conductivities of the 1.5 m soil profile at PVC infiltrometer stations 7-10 and 9-12 after applying Eq. (2) were 1.0 and 0.025 cm/hr, respectively. The measured steady IR for these stations were 0.528 and 1.607 cm/hr, respectively. Thus, Eq. (2) provided a reasonable estimate of infiltration at station 7-10 but greatly underestimated infiltration rate at station 9-12. Clearly, the core samples used to measured the saturated hydraulic conductivity in the laboratory were not representative to infer infiltration rate from them, despite the fact that samples were taken at the same position as where the small infiltrometers were installed.

The IR and cumulative infiltration measured in a square infiltrometers should approximately be equal to the average measured IR and cumulative infiltration from the 21 small PVC infiltrometers within each square plot. A comparison for cumulative infiltration is shown in Fig. 7. An intercept close to zero and a slope smaller than one indicated that the PVC infiltrometers underestimated plot-average infiltration, and that differences increased with higher infiltration rates. Lateral flow is hypothesized to occur mostly at the edges of the large infiltrometers, where the number of PVC infiltrometers per unit area is the least. Therefore, the underestimation of plot infiltration is expected to be larger if lateral flow and thus cumulative infiltration is greater as well.

Water salinity did not have a clear effect on steady IR in PVC infiltrometers. Figure 8 seems to imply that soils flooded with the most saline treatment (10 dS/m) were associated with the highest infiltration rates and soils from the least saline treatment (0.3 dS/m) were associated with some of the lowest rates. However, Fig. 8 contains data from four plots only (plot numbers 4, 7, 9, and 14), where paired ESP and PVC infiltrometer data were available. Apparently, the relatively low salinity of the high quality treatment caused dispersion and reduced infiltration, irrespective of the initial ESP. Eight plots on the east side of the study area (Fig. 1, plots 3, 4, 5, 6, 11, 12, 13, and 14) were irrigated with Na-added irrigation water, two years prior to this study. Subsequent tillage operations caused a spatial distribution of Na in the study area, with higher levels of Na still present in the eastern part of the field plot. If the 0.3 dS/m treatment is omitted, increasing ESP appears to reduce steady IR. A linear function was fitted to PVC infiltrometer IR and initial ESP data (Figure 9). As expected, low ESP soils tend to have more stable aggregates than high ESP soils when wetted with water of the same salinity, thereby causing higher infiltration rates. The linear fit was reasonably successful as indicated by an R^2 value of 0.670, although the data appeared to be nonlinear.

For the second 24-hour period all plots were flooded with high quality (0.3 dS/m) Berryessa irrigation water. ESP was determined from samples collected at the surface after 24 hours of ponding, before flooding with the high quality water. In Fig. 10 we plotted 36-hour IR measured minus computed versus ESP at the end of the first 24-hour period. Computed IR was determined from extrapolation of Philip's infiltration equation from 24 to 36 hours (Table 2). Due to missing data, only the results of 12 plots are shown. The high ESP's are caused by the flooding with high sodium water in the first 24-hour infiltration period. A significant ESP effect is demonstrated in Fig. 10. Negative values for the ordinate indicate that the second 24-hour flooding period caused a further decrease in IR, presumably by soil dispersion.

Plot 7 E - W Transect

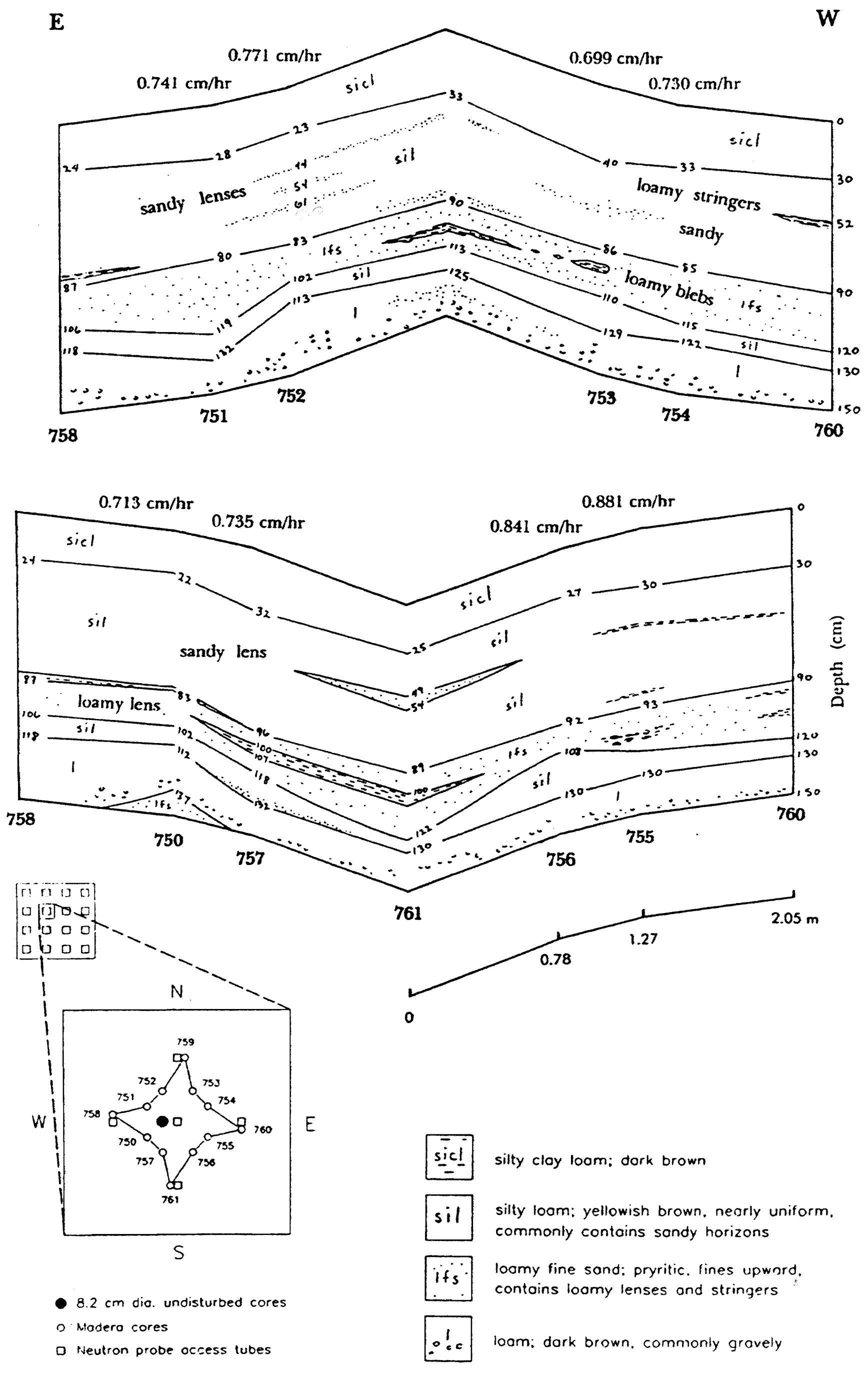
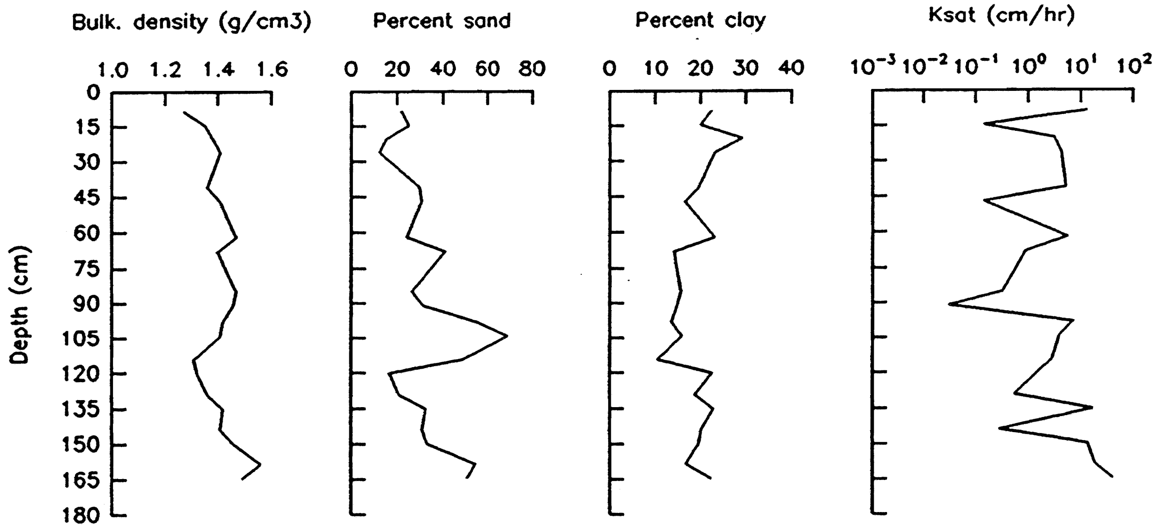
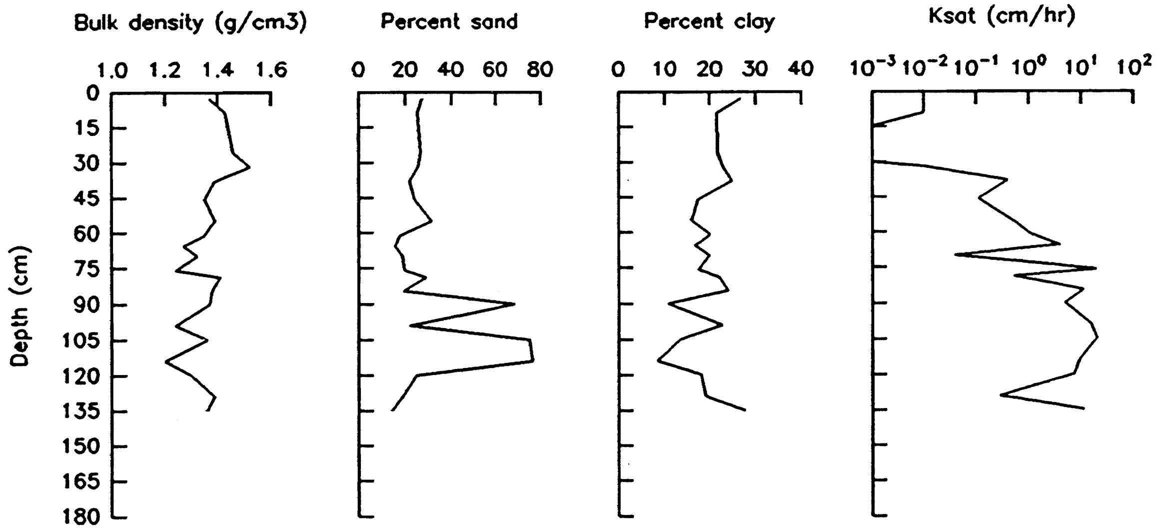


Figure 3. Soil textural variations within a 1.2 x 1.2 x 1.5 m soil volume in plot 7. Numbers at the top of the profile denote IR after 24 hours of ponding.



(a) Station 7



(b) Station 9

Figure 4. Bulk density, texture, and saturated hydraulic conductivity profiles for stations 7 and 9. Twenty core samples were collected to characterize each soil profile.

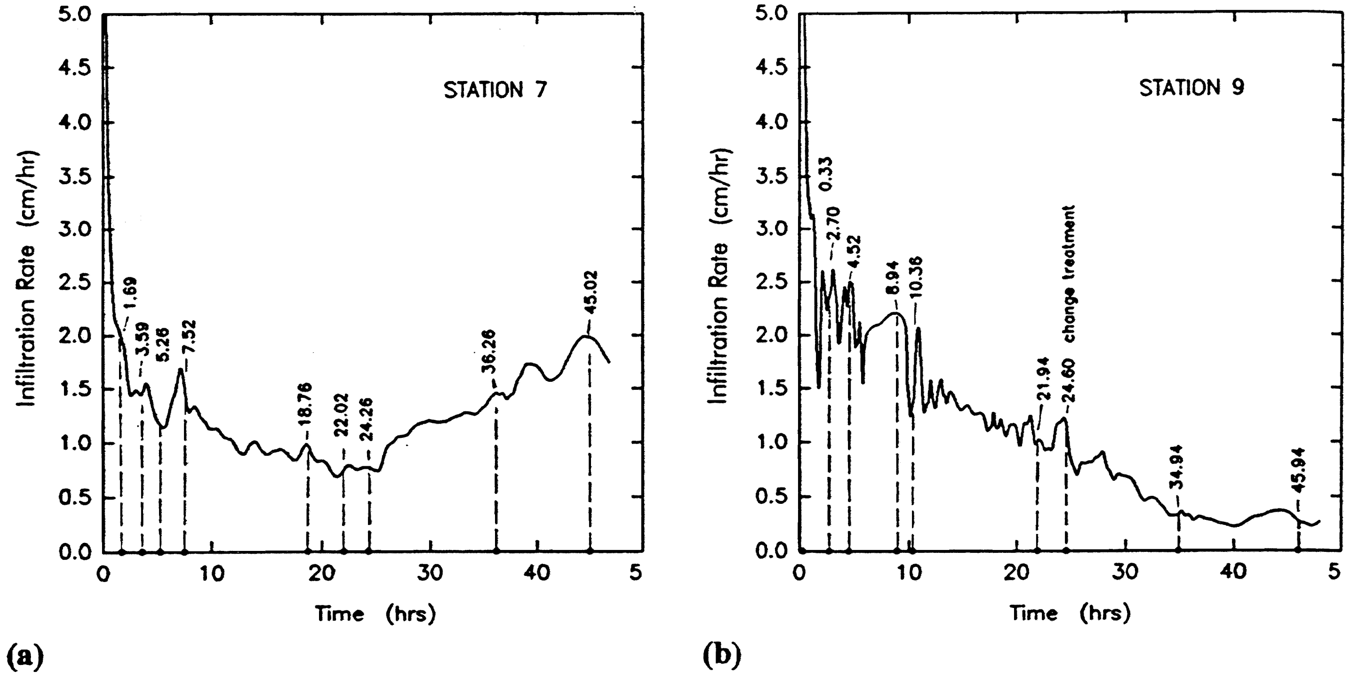


Figure 5. Time rate of infiltration curves for (a) plot 7 and (b) plot 9.

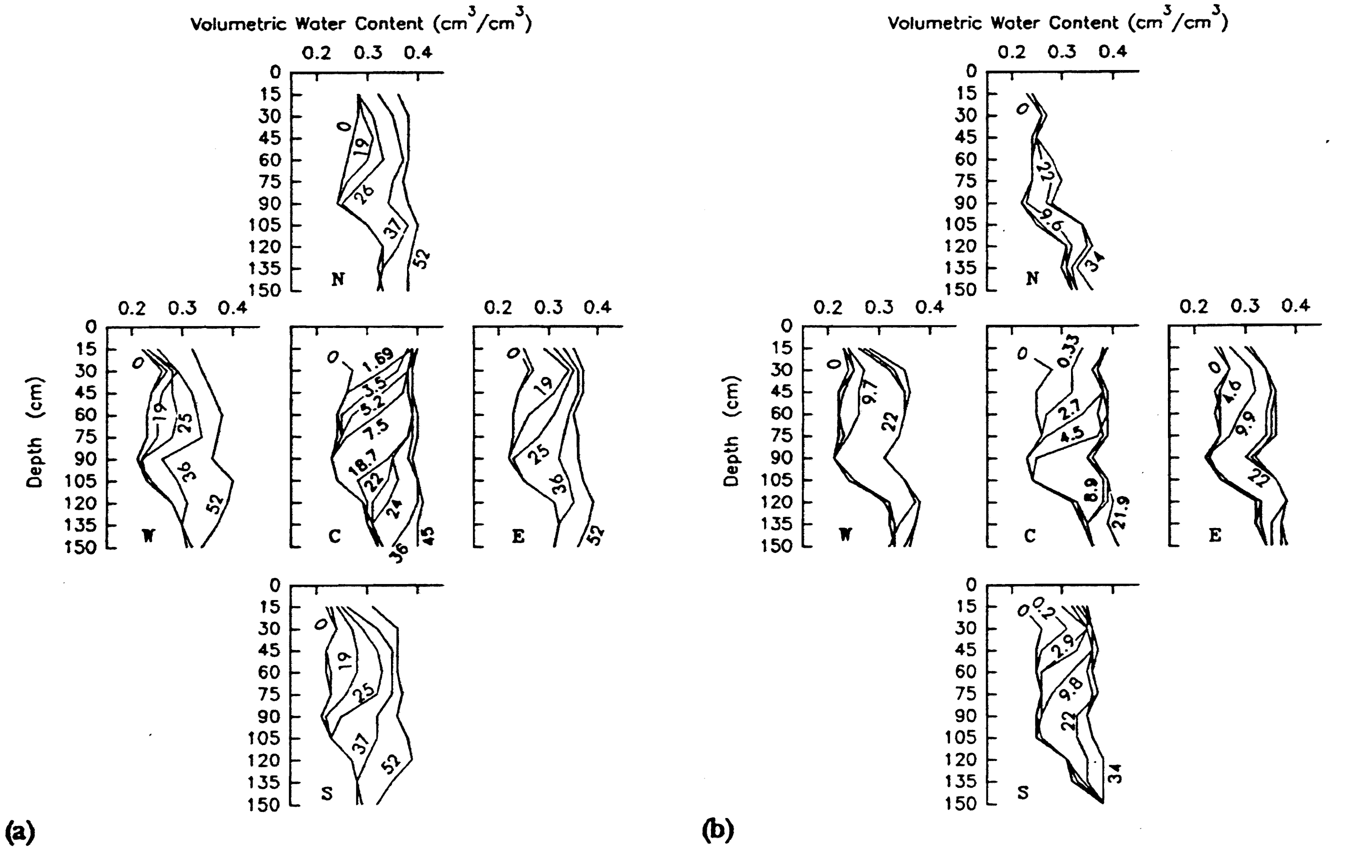
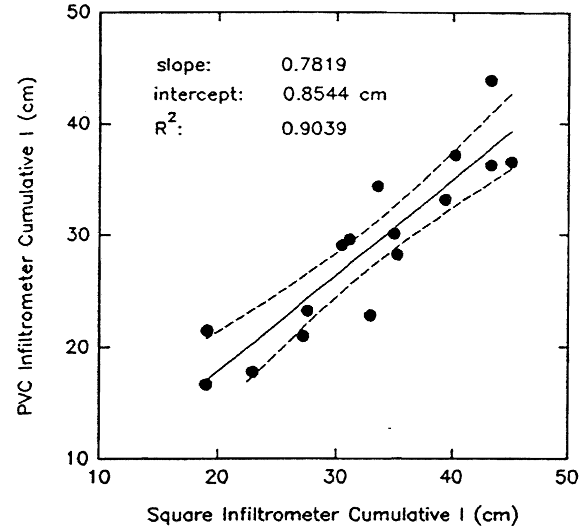


Figure 6. Volumetric water content measured using a neutron probe versus depth at (a) plot 7 and (b) plot 9 during approximately 48 hours of ponding. The five graphs correspond to five access tubes located in the center and to the north, south, east, and west of each plot.



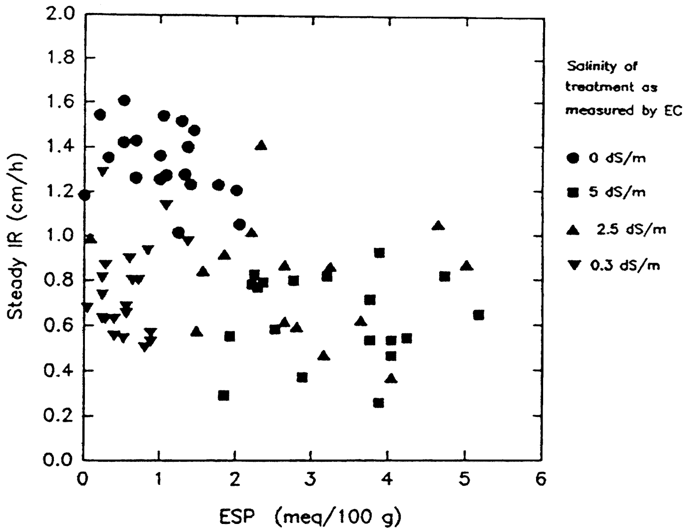
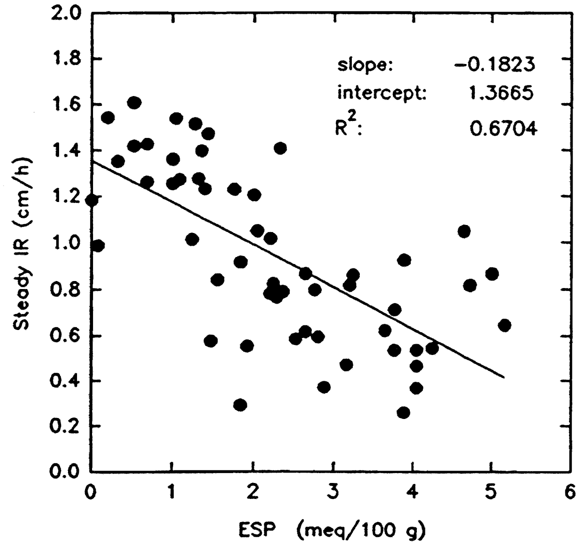


Figure 7. Cumulative infiltrated water at 24 hours measured in PVC inifltrometers versus cumulative in cumulative inifiltrated water in square inifltrometers.

Figure 8. Steady IR measured in PVC infiltrometers at plots 4, 7, 9, and 14 as a function of pre-irrigation ESP and water quality.



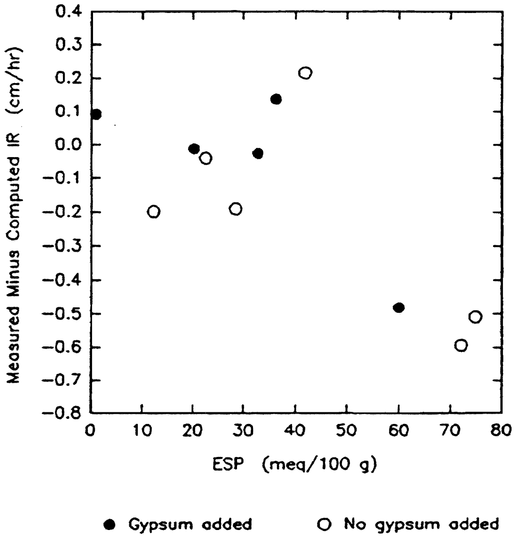


Figure 9. Steady IR measured in PVC infiltrometers at plots 4, 9, and 14 as a function of pre-irrigation soil ESP with linear regression. Data are pooled for three saline water treatments.

Figure 10. Infiltration rate measured in square infiltrometers after 36 hours as a function of ESP and water quality.

Figure 10 also demonstrates that the gypsum application treatments were not different from the untreated plots. Therefore, the application of gypsum was ineffective in reducing dispersion. Most likely, ESP values were too high for the gypsum to have an effect with the low IR's measured.

DISCUSSION AND SUMMARY:

Variability of infiltration was not affected by irrigation water quality in the first 24 hours of ponded infiltration. However, fluctuations in infiltration rate from individual infiltrometers could be correlated to subsurface soil layering through evaluation of water content profiles. Detailed soil sampling showed significant soil heterogeneity and variability in presence and thickness of soil layers within a 1.2*1.2*1.5 m soil volume. Nevertheless, we could not correlate the laboratory measured saturated hydraulic conductivities of the most restrictive soil layer to infiltration rate as measured from small size infiltrometers within the 1.2*1.2 m flooded plots.

In contrast, we could explain more than 50 percent of the infiltration variability after 24 hours of ponding by differences in initial ESP as brought about by sodium applications in the test area prior to the reported experiment. Subsequent flooding of the plots with high quality irrigation water after one day further reduced infiltration among most of the treatments. The magnitude of continued reduction in infiltration was highly dependent on the ESP of the surface soil after the first 24 hours of ponded infiltration. Application of gypsum after 24 hours did not alleviate the dispersion effect on infiltration reduction in the second irrigation period.

The field research has shown the difficulties encountered in correlating field infiltration measurements to soil properties. Although the concepts of infiltration into soils are clear and physically well understood, in reality water infiltration is controlled by other soil factors that are not well quantified as yet. For example, infiltration variability might well be caused by uneven distribution of macropores or other preferential flow paths between infiltration plots. Intensive soil sampling indicated the presence of soil layers with significant different textures, but the relation of their occurrence with variable depth and thickness to the infiltration process is still unclear.

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PROJECT TITLE: DETECTION AND QUANTIFICATION OF SOIL PHYSICAL PARAMETERS WHICH LEAD TO SLOW WATER INFILTRATION RATES

PROJECT NUMBER: 89-12

DURATION OF FUNDING: July 1989 to June 1991

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FTE Commitment: 0.02

ABSTRACT:

Extensive double-ring infiltration tests were conducted in a Yolo loam soil near UC Davis campus to study the effect of surface seals (thin soil crusts), depositional crusts (thick crusts), and soil compaction on infiltration rate. Results indicate that soil compaction and depositional crusts (both dry and wet) significantly reduce infiltration rate. The thin surface seals (both dry and wet up to six mm thick) do not affect infiltration rate significantly. Additional tests are currently being conducted to determine the effect of moderately thick surface crusts on infiltration rates. Moreover, we have developed a hand-operated micro-penetrometer to determine the strength of surface crusts.

KEYWORDS: Soil crusts, surface seal, soil compaction, depositional crust, infiltration, double-ring infiltrometer, Horton's equation, micro-penetrometer.

PROJECT OBJECTIVE ADDRESSED:

The main objective of this study was to determine the effect of surface crust and soil compaction on water infiltration. In addition, we have also addressed the need to develop a lightweight, portable, instrumented micro-penetrometer to determine crust strength.

RESEARCH PLAN AND PROCEDURES:

Field tests were conducted in the vicinity of UC Davis campus in a Yolo loam soil. Table 1 lists the soil texture data. Before conducting the experiments, the soil was deep-plowed, disced, packed and then rotary tilled.

The first set of tests were conducted during summer of 1990 using double ring infiltrometers. The inner ring had a diameter of 610 mm, and was gently placed in the soil to a depth about 50 mm. The outer ring had a diameter of 914 mm. During field tests it was inserted into the ground deep enough to avoid any leakage of water. At the beginning of tests the rings were filled with water to a depth of 50 mm. A plastic sheet was used to avoid the water from impacting the soil and minimize soil disturbance. The level of the water was kept constant at 50 mm using float valves. The outer ring was a buffer ring which minimized lateral movement of water off the inner ring. The outer ring was fed by a drum and the inner ring was fed by a plastic container which was suspended by a load cell.

A set of three identical double ring infiltrometers were used during these tests. The weight of inner rings were monitored by a Campbell Scientific 21X data logger at every 10 s intervals. The data logger controlled solenoid valves which automatically refilled the plastic containers whenever the container weight fell below a predetermined value. The data logger averaged 60 consecutive data points obtained over 10 minutes to obtain a single infiltration value at 10 minute interval. The data were subsequently analyzed on a Macintosh microcomputer.

Soil Compaction and Surface Crust experiments

Three levels of compaction: (a) no compaction, (b) heavy compaction using a loaded water truck with a tank capacity of 11,356 l (3000 gal) and a total load of 236 kN, and (c) medium compaction using an unloaded water truck (125 kN load) were used during this study. Table (2) shows the bulk density for the three levels of soil compaction.

For each level of compaction, three levels (thickness) of crust - (a) 10 pass, (b) 20 pass, and (c) 30 pass were created. A pass refers to spraying the soil with garden sprinkler once. Within each level of crust three types of crust were investigated. One set of double ring infiltrometer was tested in an undisturbed (no crust) soil. The second set of double infiltrometer was inserted in the soil and sprayed with desired pass of water and the crust so created was allowed to dry for two days (dry crust). The third set of rings were inserted into the ground and sprayed with desired pass of water just before the test to create a wet crust. Inserting the rings in the soil before spraying minimized the disturbance of crust due ring emplacement. The three rings were placed about three meters apart . This small strip of land is called a block. Within each block the types of crust were randomly assigned to the rings. Following Kenshi et al. (1989) these tests were replicated ten times (ten blocks) except in high compaction experiments. In high compaction experiments variability was observed to be low. Only five replicates were obtained in this case. This nested-crossed four factor experimental design consisted of 225 infiltration tests.

Depositional (Thick) Crusts

In order to study the effect of thick crusts on infiltration rate a 16.5 m x 30 m plot was deep plowed, disked, leveled and then flooded to create depositional crusts. The crust was allowed to dry before starting the double ring infiltration tests. As the crust dried several cracks were formed in the crust. Two other plots of the same size were similarly prepared except for flooding. One of these plots was considered as a control (no depositional crust). In the other plot, a double ring infiltrometer was installed the day before the test, and the rings and the surrounding area were flooded in the evening. This treatment created a wet crust next morning. On the day of test, double ring infiltrometers were installed in the dry crust plot and the control plot and the infiltration tests were conducted as described previously.

Portable, Hand Operated, Fully Instrumented Micropenetrometer

Figure 1 shows the lightweight, portable, fully instrumented micro-penetrometer. The device is similar to the fully automatic device developed by Upadhyaya et al. (1989). The major difference is that it is very light and it can be operated manually by a crank arm.

RESULTS AND DISCUSSION

Thin or Surface Crust

Figures 2, 3 and 4 are typical infiltration test results for no compaction, medium compaction and heavy compaction. Following Upadhyaya et. al (1989) the cumulative infiltration data was fitted to the integral of the Horton's equation using a nonlinear regression analysis technique. The form of the cumulative infiltration curve is:

$$Q = A(1- e^{(-Bt)}) + Ct. \qquad (1)$$

where

Q = cumulative infiltration, mm
A, B, C = regression coefficients.
t = time, h

The coefficient of multiple determination (R^2) ranged from 0.98 to 0.99. Table (3) lists the coefficients obtained through a regression analysis for all the 225 field tests.

Effect of Soil Compaction,Number of Passes, and Type of Crust

The infiltration coefficients A, B and C were analyzed using a nested-crossed statistical design given by:

$$Y_{ijkl} = \mu + \alpha_i + \beta_{j(i)} + \delta_l + (\alpha\delta)_{il} + (\beta\delta)_{jl(i)} + \xi_{ijkl} \qquad (2)$$

where

μ = overall mean
α_i = compaction effect
$\beta_{j(i)}$ = pass effect (nested with compaction)
$\gamma_{k(j)}$ = block effect
δ_l = crust effect
$(\alpha\delta)_{il}$ = the interaction between crust and compaction
$(\beta\delta)_{jl(i)}$ = the interaction between crust and pass nested with compaction
ξ_{ijkl} = the error term with mean 0 and variance s^2

Note that this particular experimental design resulted in the nesting of the pass effect within the compaction effect and the block effect within the pass effect.

The analysis of variance (ANOVA) results for this model are shown in Table 4. The results indicate that the compaction and pass are the only two significant factors at the 5% significance level. Block, crust type and all possible interactions are insignificant. The differences in infiltration due to compaction are evident from Figs. 2, 3, and 4. They are also evident from the Duncan's New Multiple Range Test which is presented in Table 5.

The differences in the pass effect seems to be somewhat confusing. Since a given pass effect contains a control (i.e. no spraying or no crust), the pass effect is most likely a representation of confounding of pass effect with the time and location differences between these tests. In order to investigate the pass effect in more detail, it is preferable to eliminate these confounding effects by subtracting the control from the dry crust and wet crust results. This transformation is possible within the design employed because dry crust, wet crust and no crust treatments were completely randomized within each block.

This modification leads to a more familiar split-plot design with a model of the form:

$$Y_{jkl} = \mu + \beta_j + \gamma_k + \varepsilon_{jk} + \delta_l + (\beta\delta)_{jl} + \tau_{jkl} \qquad (3)$$

where:

μ = overall mean

β_j = pass effect

γ_k = block effect

ε_{jk} = main plot error

δ_l = crust effect

$(\beta\delta)_{jl}$ = the interaction between crust and pass

τ_{jkl} = subplot error

Note that this model does not contain the compaction effect. The results of the ANOVA are presented in Table 6. The results clearly indicate that the main effect (pass), block, and the sub-treatment (type of crust (dry or wet)) are not significant. Also the interaction between crust and pass is not significant. A possible explanation for this rather surprising result is that the cracks that develop in these crusts compensate for the reduction in infiltration rate due to the presence of these surface layers. The average thickness of 10 pass, 20 pass, and 30 pass crusts were 1.8 mm, 4.1 mm, and 6.1 mm respectively. Even when the cracks swell shut when the soil is wetted, they still appear to provide reduced resistance to water intake. A similar effect was observed by Allen and Brand (1968) and Shainbergn and Singer (1985).

Depositional Crust

Table 7 lists the infiltration test results for the ten depositional crust tests conducted during 1991 spring. These tests were based on a randomized block design which can be expressed as:

$$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + \varepsilon_{ij} \qquad (4)$$

where:

μ = overall mean
α_i = compaction effect
$\beta_{j(i)}$ = block effect
ε_{ij} = the error term

The ANOVA table for this test is presented in Table 8. The results indicate that crust is significant at the 5% level whereas the block effect is insignificant. The new Duncan's Multiple Range test listed in Table 8 shows that the dry and wet crust treatments are significantly different than the no-crust treatment. However, there are no significant differences between WC and DC for the coefficient A and C. Fig. 5 indicates that the dry crust and wet crust behave differently in the beginning but become similar as the time goes on. In order to explore this possibility we tested the differences in initial infiltration rate. Differentiating Equation 1, we get:

$$dQ/dt = q = A*B*\, e^{(-B*t)} + C \qquad (5)$$

where

q = infiltration rate, mm/h

Equation (2) can be recast into the Horton's equation as follows:

where

$$q = i_f + (i_i - i_f)*e^{(-b*t)} \tag{6}$$

where

i_f = C = final or steady infiltration rate

i_i = A*B+C = initial infiltration rate

Table 9 lists the ANOVA and Duncan's New Multiple Range test results. As expected the crust effect was found to be significant. The Duncan's New Multiple Range Test showed that there were no significant differences between dry and wet crusts for final infiltration rate, but the differences in initial infiltration rate between the wet crust and dry crust were significant. There were no significant differences between the initial infiltration rate for the dry crust and no-crust treatments. This is mainly due to the presence of cracks which tend to fill up as soon as the test is started. However, as they fill up they swell shut and the water intake decreases unlike in the case of thin crusts. From these results it appears that although thin crusts do not impede water intake, thicker crusts significantly reduce infiltration rate. Moreover, presence of cracks tend to compensate the effect of thin crusts, but they are not as effective in compensating for the effect of thick crusts on the final infiltration rate. Cracks do, however, improve the initial infiltration rate even in thick crusts.

SUMMARY AND CONCLUSIONS

Extensive double-ring infiltration tests were conducted in a Yolo loam soil near UC Davis campus to study the effect of surface seals, depositional crusts and soil compaction on infiltration rate. The results of this investigation led to the following conclusions:

1) The cumulative infiltration can be represented by the integral of the Horton's equation in all cases, thus confirming the previous studies by Upadhyaya et al. (1988, 1989). This equation has the following form:

$$Q = A(1 - e^{(-Bt)}) + Ct. \tag{1}$$

where

Q = cumulative infiltration, mm

A, B, C = regression coefficients

t = time, h

2) Soil compaction reduces infiltration rate significantly.

3) Thin surface crusts (surface seals less than about 6 mm thick) whether dry or wet do not appear to reduce infiltration rates.

4) Thick depositional crusts reduce the final infiltration rate significantly. The initial infiltration rate depends on the type of crust. The initial infiltration rate decreases significantly for a wet crust. The presence of cracks in a dry crust compensate for any reduction in initial infiltration rate.

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TABLE 1. Texture of Test Soil*

Type: Yolo Loam

Depth	Particle Size Distribution (Percent)		
	Sand (>50 u)	Silt (50 u to 2 u)	Clay (<2 u)
0-50 mm	28.7	46.4	24.9
50-200 mm	26.1	46.8	27.1
200-480 mm	21.5	50.3	28.2

*Source: The Soil Survey. 1981. LAWR, University of California, Davis.

TABLE 2. Bulk Density and Moisture Contents*

Depth	Bulk Density(g/cm^3)			Moisture Content (%)		
in. (cm)	N.C.	M.C.	H.C	N.C.	M.C.	H.C.
4 (10.16)1.41	1.53	1.57	13.1	8.7	9.9	
8 (20.32)1.62	1.66	1.65	15.5	10.5	12.5	
12 (30.48)	1.65	1.56	1.60	5.2	11.8	14.3

*Average of three readings.

N.C.	no compaction
M.C.	medium compaction
H.C.	high compaction

TABLE 3: Infiltration Test Results.

Test #	Crust*	Block**	A	B	C	Pass***	Compaction****
1	DC	B1	33.169	.6213	.839	P10	L1
2	WC	B1	63.017	.5893	3.346	P10	L1
3	NC	B1	•	•	•	P10	L1
4	DC	B2	19.853	1.7963	5.590	P10	L1
5	WC	B2	38.438	.3284	3.054	P10	L1
6	NC	B2	101.086	.2707	6.093	P10	L1
7	DC	B3	28.565	.2445	2.313	P10	L1
8	WC	B3	100.786	.2454	6.319	P10	L1
9	NC	B3	76.833	.5882	4.084	P10	L1
10	DC	B4	74.993	.2684	5.692	P10	L1
11	WC	B4	75.714	.2563	9.872	P10	L1
12	NC	B4	149.001	.0995	3.658	P10	L1
13	DC	B5	65.815	.3068	4.111	P10	L1
14	WC	B5	45.034	1.2071	5.060	P10	L1
15	NC	B5	93.983	.3063	6.596	P10	L1
16	DC	B6	35.388	.6247	2.021	P10	L1
17	WC	B6	73.741	.2567	3.901	P10	L1
18	NC	B6	23.757	.7334	3.509	P10	L1
19	DC	B7	75.010	.5956	4.973	P10	L1
20	WC	B7	61.266	1.3188	3.071	P10	L1
21	NC	B7	32.259	.2924	1.241	P10	L1
22	DC	B8	75.745	.6697	2.510	P10	L1
23	WC	B8	89.384	.2787	5.623	P10	L1
24	NC	B8	33.873	.5214	1.551	P10	L1
25	DC	B9	74.456	.2916	2.536	P10	L1
26	WC	B9	70.432	.2208	3.062	P10	L1
27	NC	B9	50.406	.7438	5.577	P10	L1
28	DC	B10	71.985	.8968	2.830	P10	L1
29	WC	B10	85.940	.2715	6.839	P10	L1
30	NC	B10	53.518	1.1485	3.344	P10	L1
31	DC	B1	103.012	.1537	6.790	P20	L1
32	WC	B1	106.391	.2762	14.792	P20	L1
33	NC	B1	148.753	.2472	16.499	P20	L1
34	DC	B2	403.787	.0887	9.096	P20	L1
35	WC	B2	125.968	.2077	10.921	P20	L1
36	NC	B2	175.181	.1495	9.423	P20	L1
37	DC	B3	221.795	.1905	16.844	P20	L1
38	WC	B3	104.119	.2600	9.129	P20	L1
39	NC	B3	198.391	.0881	2.595	P20	L1
40	DC	B4	101.838	.1123	6.824	P20	L1
41	WC	B4	88.617	.2295	8.827	P20	L1
42	NC	B4	108.069	.2975	10.148	P20	L1
43	DC	B5	46.064	.2896	4.382	P20	L1
44	WC	B5	518.901	.0890	11.538	P20	L1
45	NC	B5	57.486	.1021	3.200	P20	L1
46	DC	B6	68.414	.2270	5.410	P20	L1
47	WC	B6	83.600	.2940	7.569	P20	L1
48	NC	B6	226.268	.1230	14.277	P20	L1
49	DC	B7	127.925	.3838	12.835	P20	L1
50	WC	B7	79.136	.4203	7.146	P20	L1
51	NC	B7	272.422	.1155	12.988	P20	L1
52	DC	B8	173.179	.0825	1.206	P20	L1
53	WC	B8	283.357	.1300	14.937	P20	L1
54	NC	B8	75.076	.2329	7.410	P20	L1
55	DC	B9	95.444	.1428	3.996	P20	L1

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* DC = Dry crust; WC = Wet crust; NC = No crust.

** B1 to B10 = Blocks 1 to 10.

*** P10 = ten passes; P20 = twenty passes; P30 = thirty passes.

**** L1 = No compaction; L2 = High compaction; 23 = Low compaction.

Test #	Crust*	Block**	A	B	C	Pass***	Compaction****
56	WC	B9	166.274	.1408	4.361	P20	L1
57	NC	B9	411.730	.1201	12.164	P20	L1
58	DC	B10	41.775	.1491	1.837	P20	L1
59	WC	B10	132.172	.1436	6.734	P20	L1
60	NC	B10	285.860	.1327	13.054	P20	L1
61	DC	B1	157.299	.1192	10.299	P30	L1
62	WC	B1	238.002	.0979	12.374	P30	L1
63	NC	B1	319.773	.1150	15.365	P30	L1
64	DC	B2	202.359	.1298	12.741	P30	L1
65	WC	B2	211.247	.1083	13.707	P30	L1
66	NC	B2	244.846	.0929	8.771	P30	L1
67	DC	B3	301.286	.1555	11.507	P30	L1
68	WC	B3	268.019	.1468	4.565	P30	L1
69	NC	B3	235.232	.1161	4.470	P30	L1
70	DC	B4	166.715	.3116	6.880	P30	L1
71	WC	B4	516.449	.1110	6.594	P30	L1
72	NC	B4	457.853	.1019	8.381	P30	L1
73	DC	B5	328.511	.1442	10.896	P30	L1
74	WC	B5	304.241	.2055	13.480	P30	L1
75	NC	B5	215.234	.1698	10.072	P30	L1
76	DC	B6	242.547	.1281	21.989	P30	L1
77	WC	B6	193.302	.1947	11.391	P30	L1
78	NC	B6	196.553	.1256	7.567	P30	L1
79	DC	B7	233.127	.1192	6.333	P30	L1
80	WC	B7	325.832	.1205	20.451	P30	L1
81	NC	B7	231.073	.1675	11.034	P30	L1
82	DC	B8	170.686	.1672	10.164	P30	L1
83	WC	B8	425.697	.0442	11.069	P30	L1
84	NC	B8	667.830	.0744	4.949	P30	L1
85	DC	B9	185.196	.1601	11.283	P30	L1
86	WC	B9	144.455	.2383	13.172	P30	L1
87	NC	B9	343.860	.0973	15.473	P30	L1
88	DC	B10	183.128	.1296	7.185	P30	L1
89	WC	B10	213.264	.1945	12.535	P30	L1
90	NC	B10	220.798	.2313	14.355	P30	L1
91	DC	B1	29.507	1.2355	1.067	P10	L2
92	WC	B1	18.911	1.2429	1.457	P10	L2
93	NC	B1	21.085	2.0425	1.668	P10	L2
94	DC	B2	23.202	1.6547	2.106	P10	L2
95	WC	B2	53.651	.2673	1.225	P10	L2
96	NC	B2	45.105	.1529	1.372	P10	L2
97	DC	B3	28.440	1.8776	2.781	P10	L2
98	WC	B3	22.845	.4285	1.969	P10	L2
99	NC	B3	25.946	1.4377	1.642	P10	L2
100	DC	B4	22.845	.4285	1.969	P10	L2
101	WC	B4	25.947	1.4377	1.642	P10	L2
102	NC	B4	28.440	1.8776	2.781	P10	L2
103	DC	B5	32.840	.2337	1.306	P10	L2
104	WC	B5	42.732	.2310	2.060	P10	L2
105	NC	B5	37.485	.2208	1.579	P10	L2
106	DC	B1	30.049	.5600	2.168	P20	L2
107	WC	B1	21.932	1.2189	1.777	P20	L2
108	NC	B1	33.336	.2727	4.471	P20	L2
109	DC	B2	24.437	.5049	3.401	P20	L2
110	WC	B2	21.791	.2907	1.209	P20	L2
111	NC	B2	23.683	.5239	1.491	P20	L2
112	DC	B3	26.251	.5222	4.365	P20	L2
113	WC	B3	31.235	.4160	2.491	P20	L2

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* DC = Dry crust; WC = Wet crust; NC = No crust.

** B1 to B10 = Blocks 1 to 10.

*** P10 = ten passes; P20 = twenty passes; P30 = thirty passes.

**** L1 = No compaction; L2 = High compaction; 23 = Low compaction.

Test #	Crust[*]	Block[**]	A	B	C	Pass[***]	Compaction[****]
114	NC	B3	30.304	.4022	2.413	P20	L2
115	DC	B4	50.824	.1674	.914	P20	L2
116	WC	B4	40.968	.2734	1.974	P20	L2
117	NC	B4	37.979	.4282	2.618	P20	L2
118	DC	B5	39.186	.3340	2.188	P20	L2
119	WC	B5	33.773	1.1823	2.288	P20	L2
120	NC	B5	42.856	.2254	2.021	P20	L2
121	DC	B1	38.907	.7207	2.942	P30	L2
122	WC	B1	23.083	.6809	2.745	P30	L2
123	NC	B1	21.598	1.1115	2.690	P30	L2
124	DC	B2	29.728	1.4920	2.838	P30	L2
125	WC	B2	41.563	.6689	3.529	P30	L2
126	NC	B2	30.290	.4262	2.982	P30	L2
127	DC	B3	27.688	.6360	3.230	P30	L2
128	WC	B3	32.902	.3432	2.561	P30	L2
129	NC	B3	32.400	.4043	2.683	P30	L2
130	DC	B4	31.921	.8505	2.100	P30	L2
131	WC	B4	34.457	.6569	2.570	P30	L2
132	NC	B4	31.980	.5228	2.030	P30	L2
133	DC	B5	28.687	.5148	2.607	P30	L2
134	WC	B5	28.374	.8440	2.977	P30	L2
135	NC	B5	23.822	.3806	1.743	P30	L2
136	DC	B1	42.062	.4924	3.745	P10	L3
137	WC	B1	53.748	.3748	2.586	P10	L3
138	NC	B1	42.665	.4433	3.134	P10	L3
139	DC	B2	48.252	.2859	5.197	P10	L3
140	WC	B2	57.712	.3509	3.925	P10	L3
141	NC	B2	54.413	.3231	2.998	P10	L3
142	DC	B3	33.643	.5144	4.262	P10	L3
143	WC	B3	51.805	.5026	2.744	P10	L3
144	NC	B3	53.356	.3652	3.691	P10	L3
145	DC	B4	17.276	1.4836	1.512	P10	L3
146	WC	B4	39.214	.6022	3.664	P10	L3
147	NC	B4	40.370	.5603	2.729	P10	L3
148	DC	B5	48.280	.4898	2.548	P10	L3
149	WC	B5	74.587	.2003	2.545	P10	L3
150	NC	B5	48.072	.4040	3.438	P10	L3
151	DC	B6	51.012	.2934	2.802	P10	L3
152	WC	B6	35.063	.3486	2.215	P10	L3
153	NC	B6	57.390	.2686	3.079	P10	L3
154	DC	B7	43.821	.3875	2.723	P10	L3
155	WC	B7	76.166	.2268	4.875	P10	L3
156	NC	B7	55.104	.2523	3.258	P10	L3
157	DC	B8	67.649	.2110	2.114	P10	L3
158	WC	B8	42.518	.4780	2.646	P10	L3
159	NC	B8	81.498	.2642	4.550	P10	L3
160	DC	B9	41.968	.4229	2.448	P10	L3
161	WC	B9	52.866	.4915	3.740	P10	L3
162	NC	B9	64.215	.2739	3.904	P10	L3
163	DC	B10	•	•	•	P10	L3
164	WC	B10	•	•	•	P10	L3
165	NC	B10	•	•	•	P10	L3
166	DC	B1	55.760	.4236	3.090	P20	L3
167	WC	B1	54.525	.2870	4.223	P20	L3
168	NC	B1	67.927	.2446	4.812	P20	L3
169	DC	B2	70.252	.1717	2.583	P20	L3
170	WC	B2	62.062	.3724	4.115	P20	L3
171	NC	B2	64.712	.3402	4.143	P20	L3

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[*] DC = Dry crust; WC = Wet crust; NC = No crust.

[**] B1 to B10 = Blocks 1 to 10.

[***] P10 = ten passes; P20 = twenty passes; P30 = thirty passes.

[****] L1 = No compaction; L2 = High compaction; 23 = Low compaction.

Test #	Crust*	Block**	A	B	C	Pass***	Compaction****
172	DC	B3	110.446	.1242	2.220	P20	L3
173	WC	B3	66.912	.3054	3.798	P20	L3
174	NC	B3	57.306	.4631	4.025	P20	L3
175	DC	B4	69.280	.2684	5.242	P20	L3
176	WC	B4	51.612	.3303	4.821	P20	L3
177	NC	B4	80.986	.2127	2.884	P20	L3
178	DC	B5	74.118	.2157	4.125	P20	L3
179	WC	B5	186.413	.0853	2.239	P20	L3
180	NC	B5	129.463	.1389	3.917	P20	L3
181	DC	B6	78.827	.1929	3.634	P20	L3
182	WC	B6	47.862	.4166	3.990	P20	L3
183	NC	B6	166.360	.1075	1.906	P20	L3
184	DC	B7	62.679	.2677	4.707	P20	L3
185	WC	B7	79.384	.2959	4.139	P20	L3
186	NC	B7	101.188	.2468	4.144	P20	L3
187	DC	B8	34.679	.3464	3.831	P20	L3
188	WC	B8	83.708	.1980	3.516	P20	L3
189	NC	B8	52.160	.3711	4.851	P20	L3
190	DC	B9	67.976	.2008	4.162	P20	L3
191	WC	B9	50.642	.2219	4.567	P20	L3
192	NC	B9	111.655	.1493	2.653	P20	L3
193	DC	B10	71.768	.2483	3.554	P20	L3
194	WC	B10	41.922	.3435	3.406	P20	L3
195	NC	B10	61.614	.1942	2.628	P20	L3
196	DC	B1	70.302	1.0347	4.777	P30	L3
197	WC	B1	62.644	.4168	5.554	P30	L3
198	NC	B1	32.691	.5781	2.997	P30	L3
199	DC	B2	137.124	.0922	1.517	P30	L3
200	WC	B2	49.437	.3436	5.506	P30	L3
201	NC	B2	70.667	.1965	5.191	P30	L3
202	DC	B3	171.662	.0811	1.818	P30	L3
203	WC	B3	265.906	.0624	2.092	P30	L3
204	NC	B3	60.889	.1983	4.899	P30	L3
205	DC	B4	115.881	.1180	6.106	P30	L3
206	WC	B4	85.662	.1585	3.315	P30	L3
207	NC	B4	91.359	.1573	2.687	P30	L3
208	DC	B5	63.058	.2308	5.249	P30	L3
209	WC	B5	60.329	.2387	2.501	P30	L3
210	NC	B5	57.122	.3060	4.550	P30	L3
211	DC	B6	46.992	.4012	3.660	P30	L3
212	WC	B6	75.251	.1762	5.110	P30	L3
213	NC	B6	74.274	.1594	2.326	P30	L3
214	DC	B7	42.937	.3007	5.600	P30	L3
215	WC	B7	75.465	.2893	5.451	P30	L3
216	NC	B7	93.282	.1572	2.954	P30	L3
217	DC	B8	45.786	.2489	7.850	P30	L3
218	WC	B8	42.338	1.2343	3.118	P30	L3
219	NC	B8	41.457	.3445	3.453	P30	L3
220	DC	B9	63.853	.2821	3.926	P30	L3
221	WC	B9	43.871	.3251	6.042	P30	L3
222	NC	B9	51.999	.2489	3.505	P30	L3
223	DC	B10	55.025	.2152	3.288	P30	L3
224	WC	B10	56.691	.3019	4.813	P30	L3
225	NC	B10	654.871	.2308	2.019	P30	L3

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[*] DC = Dry crust; WC = Wet crust; NC = No crust.

[**] B1 to B10 = Blocks 1 to 10.

[***] P10 = ten passes; P20 = twenty passes; P30 = thirty passes.

[****] L1 = No compaction; L2 = High compaction; 23 = Low compaction.

TABLE 7: Infiltration Test Results for Depositional Crust.

A	B	C	Crust*	Block**
-	-	-	DC	B1
7.017	1.5907	6.649	WC	B1
123.714	.2320	4.311	NC	B1
-	-	-	DC	B2
6.790	.1386	1.785	WC	B2
152.812	.1986	12.130	NC	B2
13.231	.7942	12.663	DC	B3
20.915	.0598	5.009	WC	B3
154.199	.1616	9.291	NC	B3
18.053	.3921	6.427	DC	B4
6.763	.2858	8.416	WC	B4
179.796	.1379	8.002	NC	B4
14.684	.5670	5.765	DC	B5
19.635	.0562	4.479	WC	B5
307.467	.1121	10.057	NC	B5
22.285	.3267	5.660	DC	B6
49.369	.0937	6.098	WC	B6
257.266	.1556	12.666	NC	B6
48.737	.3653	7.627	DC	B7
23.662	.1332	6.341	WC	B7
175.910	.2028	12.603	NC	B7
45.928	1.8720	6.663	DC	B8
31.975	.1155	4.963	WC	B8
119.057	.3335	15.364	NC	B8
70.155	1.1713	4.835	DC	B9
30.114	.1201	6.473	WC	B9
230.706	.1855	12.488	NC	B9
19.579	.3423	4.176	DC	B10
35.805	.1003	7.011	WC	B10
212.234	.1986	12.531	NC	B10

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[*] DC = Dry crust; WC = Wet crust; NC = No crust.

[**] B1 to B10 = Blocks 1 to 10.

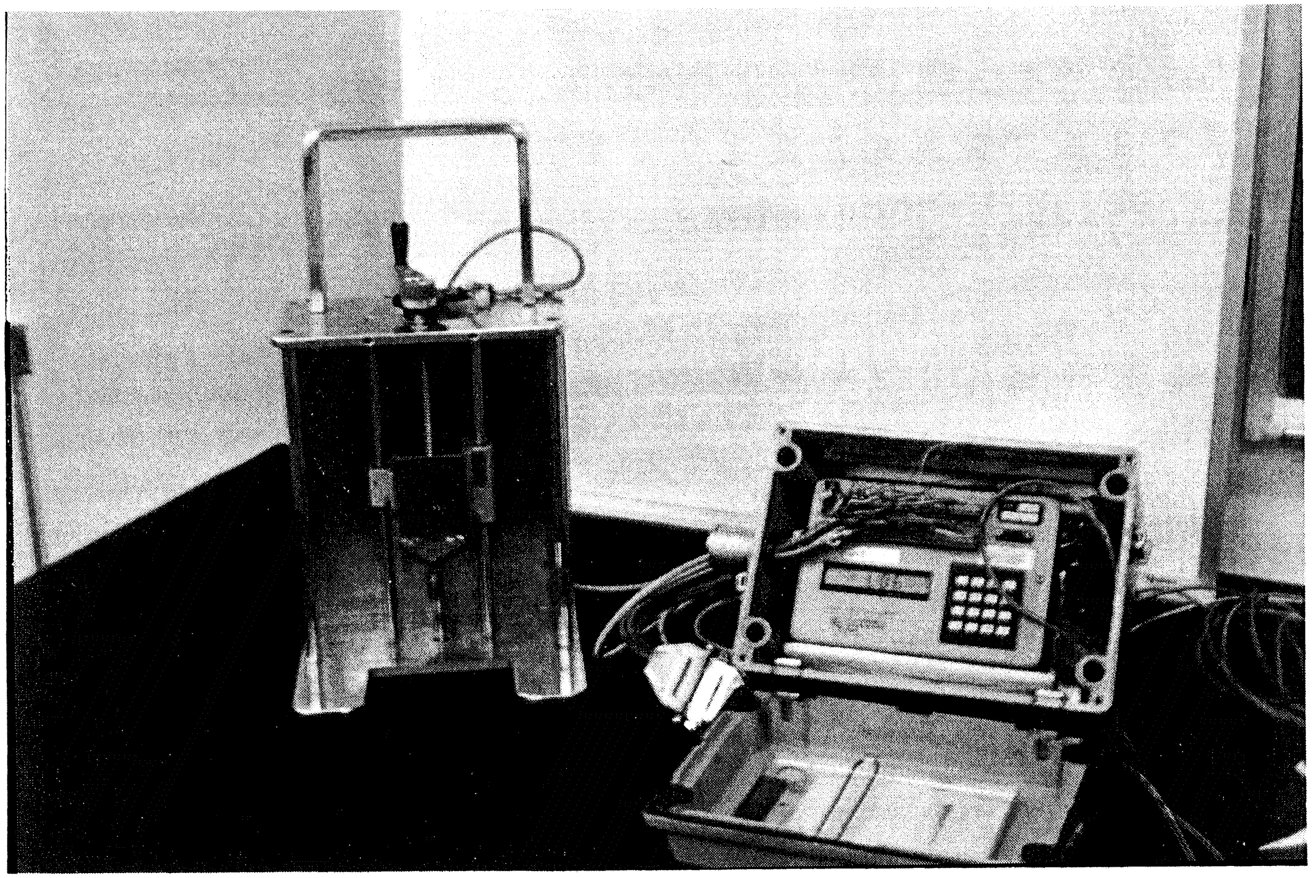

Fig. 1 Light weight, hand operated, instrumented micro-penetrometer.

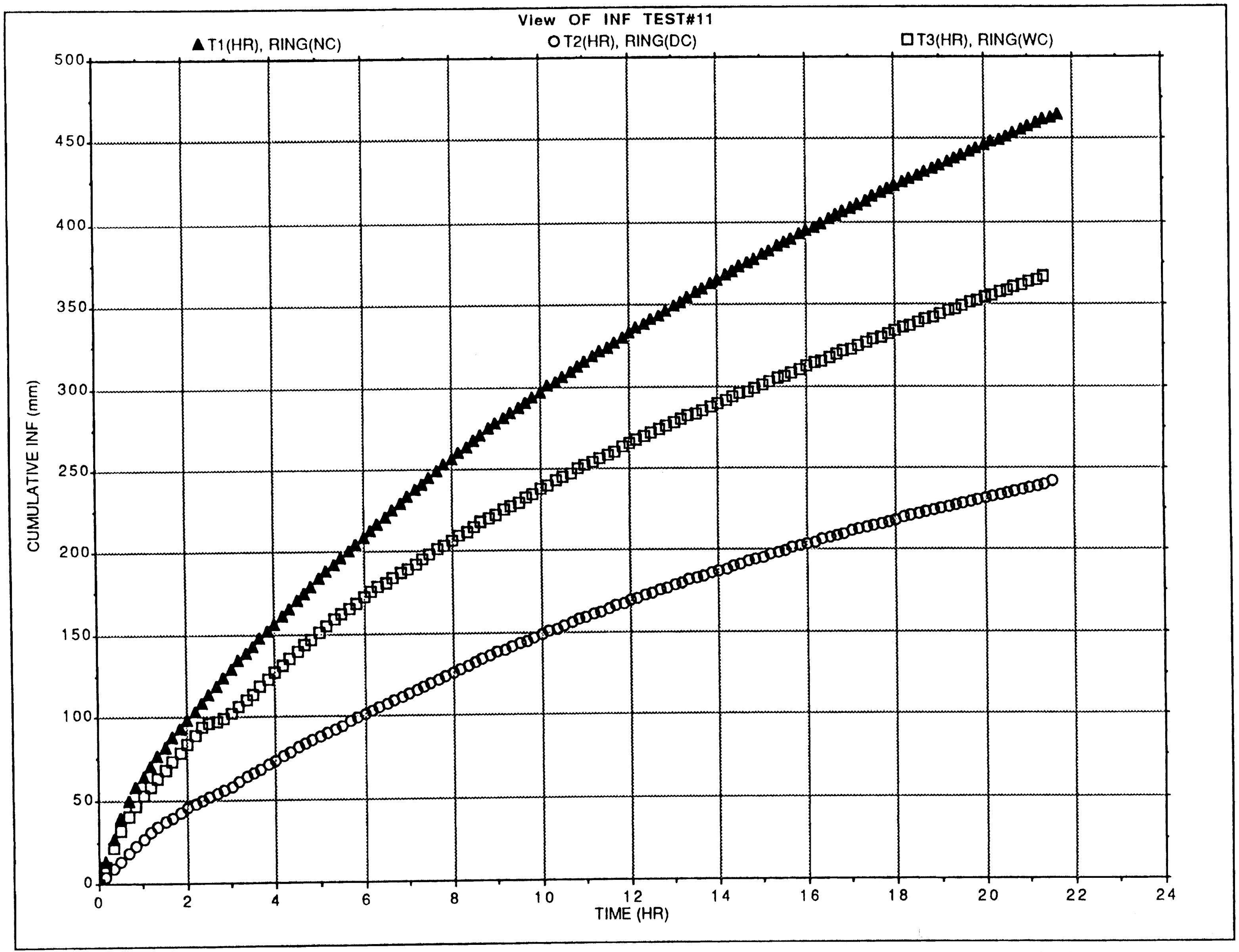

Fig. 2 Cumulative infiltration obtained using double ring infiltrometer as a function of time in tilled Yolo loam soil.

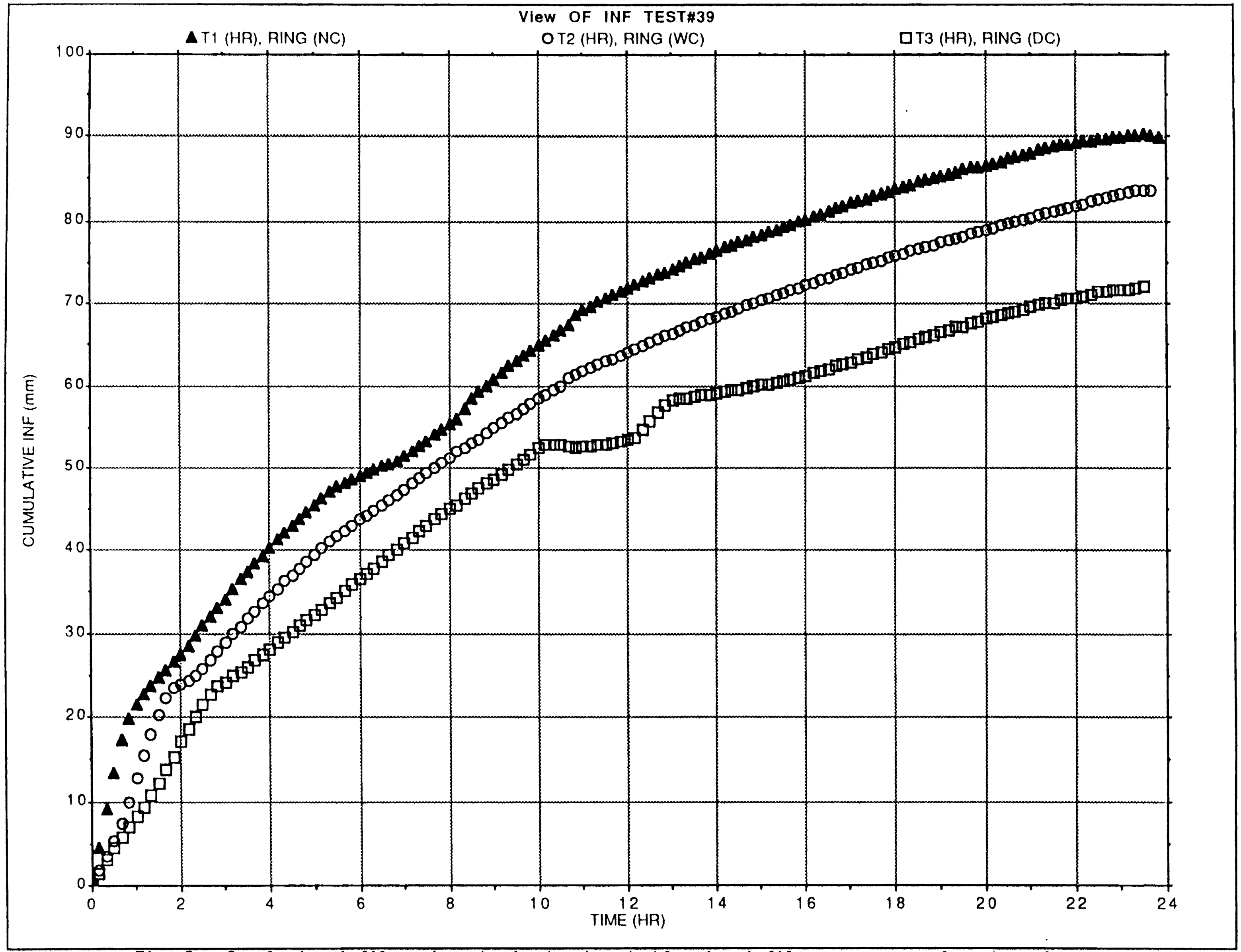

Fig. 3 Cumulative infiltration obtained using double ring infiltrometer as a function of time in a highly compacted Yolo loam soil.

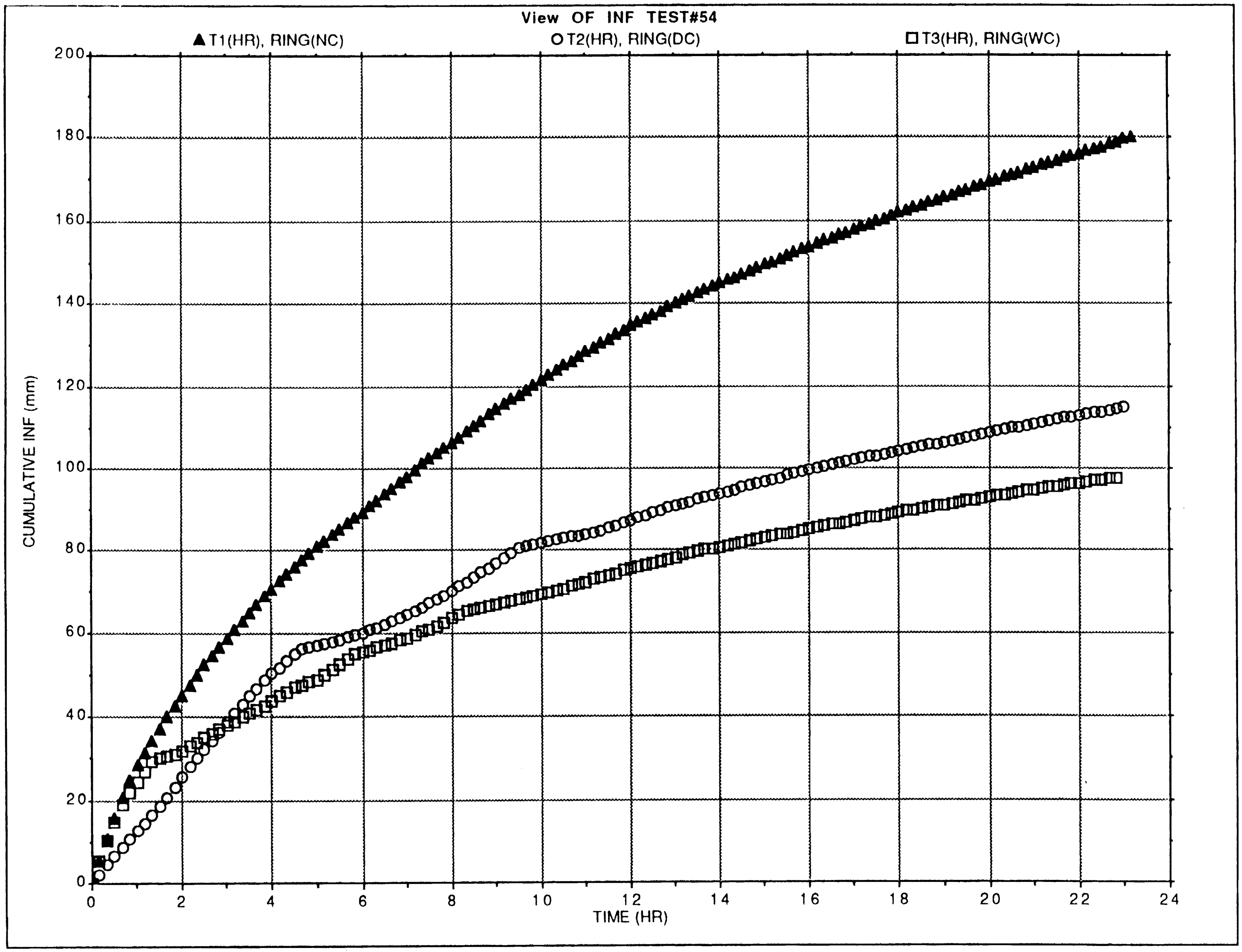

Fig. 4 Cumulative infiltration obtained using double ring infiltrometer as a function of time in a moderately compacted Yolo loam soil.

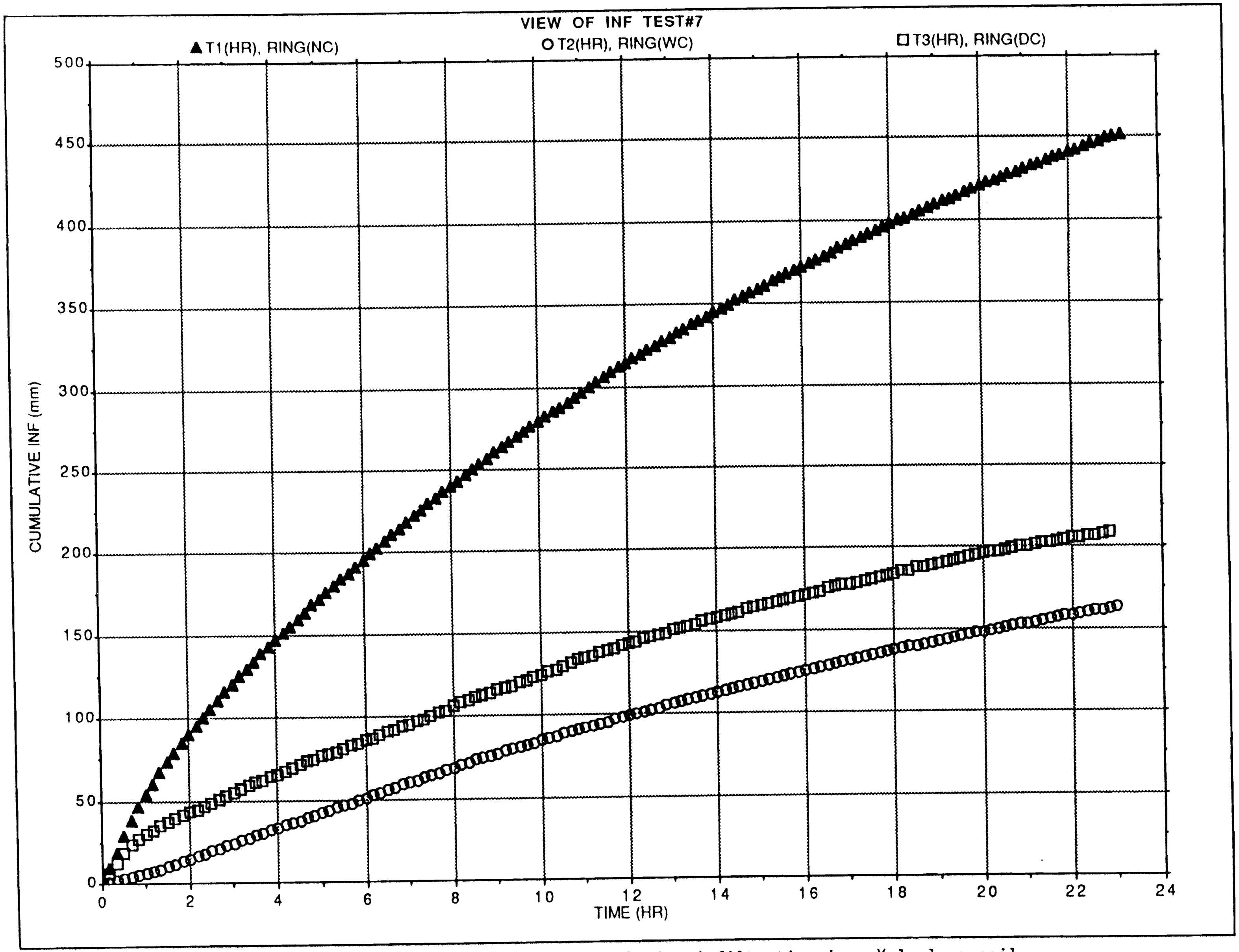

Fig. 5 Effect of depositional crusts on the cumulative infiltration in a Yolo loam soil.

PROJECT TITLE: THE TENDENCY OF FIELD SOILS TO FORM SURFACE CRUSTS AND THEIR EFFECTS UPON WATER INFILTRATION CHARACTERISTICS

PROJECT NUMBER: 89-13

DURATION OF FUNDING: July 1989 - June 1991

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Location: Glenn County

ABSTRACT:

A field study was conducted to evaluate the tendency of soils to form surface crusts and to diminish water infiltration measurements. Soils evaluated were located in the Sacramento-San Joaquin Valley of California from soil series representing sandy loam through clay loam textures. Water infiltration parameters were measured using a portable, rainfall simulator-type infiltrometer. Infiltration characteristics used for comparison included: initial and steady state infiltration rate and cumulative infiltrated water over 240 minutes. At each site, three surface treatments were evaluated: undisturbed, disturbed and disturbed-crusted. Significant differences in cumulative infiltrated water over 240 minutes were found between crusted and disturbed-crusted surfaces. Initial and steady state infiltration rates were affected by treatment within those soils of > and <27 percent clay. A fourth treatment evaluated the effect of a non-ionic guar polymer to stabilize the disturbed surface. No significant improvement in cumulative water over 240 minutes were found over the disturbed surface. The use of a ratio of disturbed to crusted infiltration

rate provided insight to the effects of crusting of "clayier" soils (>27 percent clay) over time. Initially, they have a ratio of 1.5-2.2, then decreases to near 1.0 by 240 minutes of water application. "Sandier" (<27 percent clay) soils do not improve in ratio over time, maintaining a ratio of near 1.4. Many soil physical and chemical properties of these were measured, and attempts were made to determine the effect on cumulative infiltrated water at 240 minutes. A step-wise linear regression found clay content to be the best for a model to estimate cumulative infiltration in these soils over 240 minutes.

KEY WORDS: water infiltration, infiltrometer, clay mineralogy, soil crusting, polymer, soil texture.

PROJECT OBJECTIVES ADDRESSED:

1. Determine the effects of structural and depositional crusts on the water infiltration of field soils.
2. Determine the effects of soil physical and chemical properties on crust formation of field soils.
3. Rate soil types as to their tendency to form crusts and decrease water infiltration rate.

RESEARCH PLAN AND PROCEDURES:

Chemical composition and soil mineralogy often influence the tendency of soils to form infiltration-limiting surface crusts. Additionally, agricultural practices such as irrigation and the presence of cover crops, have been shown to affect soil surface crust formation.

A method was developed to rate field soils as to their tendency to form surface crusts and diminish water infiltration. Eight soils, varying in texture and location within the Sacramento and San Joaquin Valleys of California (Table 1), were investigated to determine the effect of crusting on water infiltration. Emphasis was placed on soils with historically observed reductions in infiltration rates, reportedly due to soil surface crusting. All sites (except for Linden) were located in orchards.

TABLE 1.

Site	Soil Type	Texture
Ceres	Hanford	sandy loam
Merced	Delhi	sandy loam
Cortez	San Joaquin	sandy loam
Linden	Wyman	loam
Hamilton City	Wyo	silty clay loam
Crows Landing	Carbona	clay loam
Durham	Vina	silty clay loam
Farmington	Hollenbeck	silty clay

At each site, three soil surface treatments were evaluated: (1) undisturbed soil surface; (2) disturbed surface; and (3) disturbed-crusted surface. A fourth treatment was evaluated at a few sites in which a disturbed surface was polymer stabilized. Using a rake, the surface of all treatments (except the undisturbed) was mixed to a depth of 2-3 cm. In the third treatment, a depositional crust was formed using high energy droplets (Eigel and Moore, 1983). Water applied to the disturbed-stabilized surface contained a water soluble, non-ionic guar polymer at 15 ppm to test the effectiveness of this polymer in stabilizing the surface and preventing crusting. Use of the polymer can be expected to prevent physical destruction of the soil aggregates by the destructive forces of water drop impact (Letey 1988; Ben-Hur and Letey 1989).

Water infiltration characteristics of each treatment were determined once all treatments were at equal moisture content. Irrigation waters available for use on many of the soils evaluated are often low salinity (less than 0.1 dS/m), which contribute to reductions in infiltration rates. To eliminate this bias, a standard water, typical of surface irrigation waters in the San Joaquin Valley of California, was used in all tests (Table 2). The use of this water contributed to higher infiltration rates than experienced using the native waters.

TABLE 2. Chemical constituents of water used in infiltration studies.

pH	EC dS/m	Ca + Mg meq/L	Na meq/L	Cl meq/L	HCO_3 meq/L	SAR
7.65	0.69	2.6	4.3	1.0	7.0	1.8

Water infiltration characteristics of these field soils were determined using a portable, microcomputer-controlled, drop-forming infiltrometer as described in the Kearney Foundation Second-year Annual Report (Prichard, et al. 86-1). Water infiltration measurements were made by operating the infiltrometer at an initial rate (12.7 cm/hr) until ponding at the soil surface was noticed. The application rate was then incrementally decreased to maintain "incipient ponding" conditions for the term of the experiment (120-240 minutes). Data collected were used to obtain an infiltration rate characteristic curve by fitting the data to Equation 1 (Horton 1935) using non-linear regression techniques:

$$F(t) = f_c + (f_o - f_c)\, e^{-kt} \qquad (1)$$

where, $F(t)$ = the infiltration rate at some time t, (mm/hr)

k = a constant representing the rate of decrease in f

f_c = final infiltration rate, (mm/hr)

f_o = initial infiltration rate, (mm/hr)

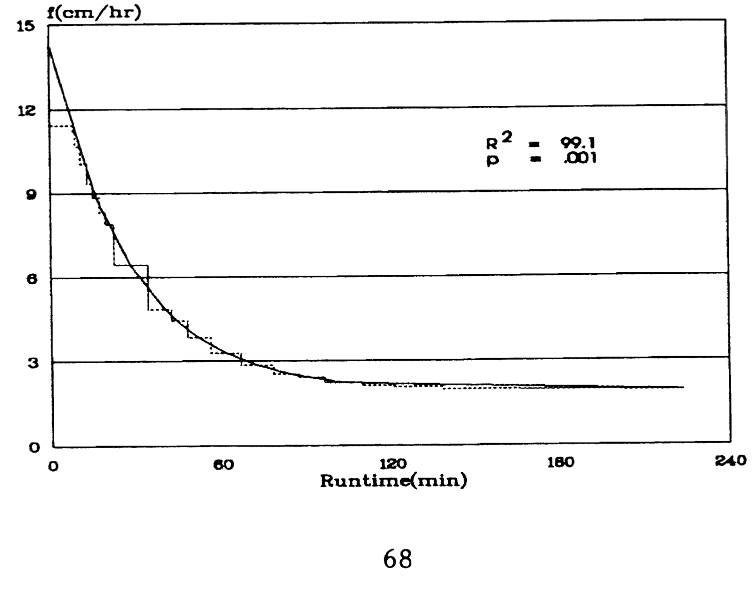
A typical fit is shown in Figure 1.

By integrating equation 1, an accumulated depth of infiltrated water can be determined for any time:

$$F(t) = \frac{1}{60}\left[f_c t + \frac{f_o - f_c}{k}(1-e^{-kt})\right] \qquad (2)$$

where, $F(t)$ = the depth of accumulated infiltration at time t, (mm)

FIGURE 1. Typical non-linear regression fit to infiltration data.



Infiltration characteristics of the soil in each treatment will be compared to determine the mechanism(s) and relative effect of the soil physical and chemical properties on infiltration reduction. Particle size analysis, clay mineralogy, organic matter, amorphous Al and Fe, salinity, exchangeable cations, aggregate stability and soil pH were determined at each site. Micro-penetrometer measurements of crust strength were made on the disturbed-crusted and undisturbed treatments as a part of a Kearney Project #89-19.

The formation of a surface crust which limits water infiltration was required to accomplish the objectives. An experiment was conducted to evaluate the level of energy necessary to form an infiltration rate limiting crust. Soils of approximately 0.10 cm/cm moisture content were raked to a depth of 3 cm to break up the existing structural crust. Water was applied utilizing a shower head to deliver pressurized water to the soil surface at increasing amounts of time to yield treatments of different energy levels: 0.34 kJ/m^2; 0.68 kJ/m^2; and 1.02 kJ/m^2. The results from a Hanford sandy loam and Wyman loam were similar in that accumulated infiltration at 240 minutes decreased from the 0.34 to 0.68 kJ/m^2 treated plots. An increased energy level of 1.02 kJ/m^2 resulted in no further decrease in the infiltration rate. In subsequent experiments, the 1.02 kJ/m^2 level was used to form a depositional crust used as the crusted treatment.

RESULTS:

The water infiltration characteristics of eight field soils were measured under the three soil surface treatments previously described. Significant differences between treatments in accumulated infiltrated water over the 240-minute measurement period were found to exist in all soils tested except for Wyo (Table 3). In each case where differences exist, the crusted infiltration rate was reduced when compared to the disturbed treatment. Figures 2 and 3 represent cumulative infiltration as a function of irrigation time for both disturbed surface and disturbed-crusted surface treatments, respectively. As the infiltration process proceeds, noticeable changes in slope occur prior to 120 minutes indicating different relative influences of the infiltration function variables. The initial infiltration rate (f_o) is significantly different between crusted and disturbed treatments containing greater than 27% clay content (Table 3), while the steady state of these same soils (f_c) is generally not significantly different. The opposite tends to be true for the soils with less than 27% clay content.

A non-ionic guar polymer was applied in the standard water as an additional treatment to three disturbed soils, Wyman, Hanford and Delhi. In each, the infiltrated water volumes over the 240-minutes measurement period were not significantly lower than the disturbed surface (Table 3). A possible explanation is that over the term of the measurements, the infiltrometer does not form a depositional crust, which is mitigated by the presence of the polymer. However, the use of polymer seemed to increase the variability in surface ponding within the 1.0 m^2 measurement area.

FIGURE 2. Cumulative infiltrated water (cm) over 240 minutes for eight soils; disturbed surface.

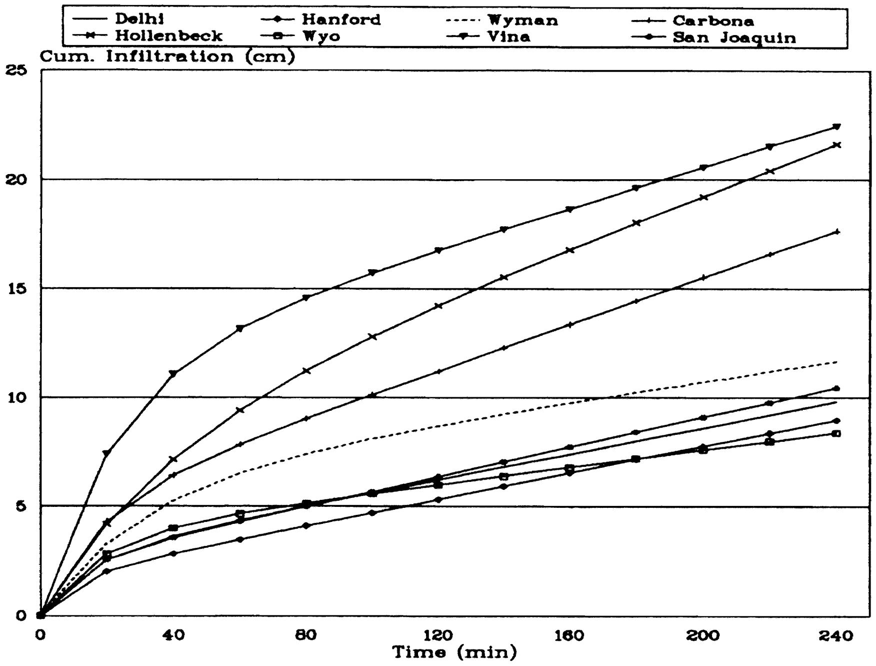


FIGURE 3. Cumulative infiltrated water (cm) over 240 minutes for eight soils; disturbed crusted surface.

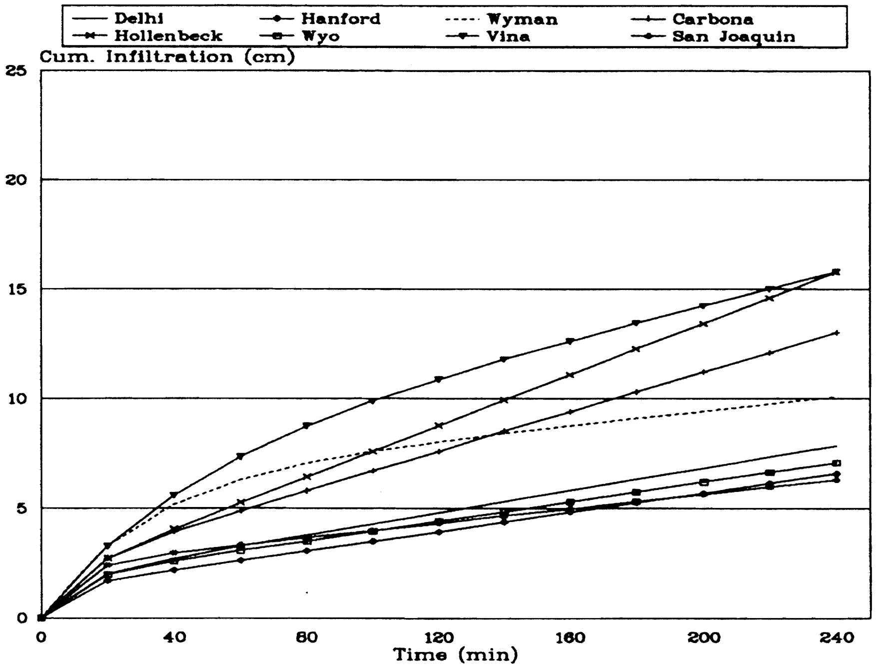


TABLE 3. Initial (f_0) and final (f_c) infiltration rates and the cumulative depth of infiltrated water after 240 minutes of irrigation

Soil Type	Treatment	f_o cm/hr		f_c cm/hr		Infiltrated Water 240 minutes (cm)	
Hanford	crusted	12.34	a*	1.30	a	6.58	a
	disturbed	10.97	a	1.83	a	8.97	b
	polymer	12.27	a	1.42	a	7.06	b
Delhi	crusted	11.71	a	1.52	a	7.85	a
	disturbed	11.86	a	1.80	a	9.86	b
	polymer	11.81	a	1.68	a	8.38	b
San Joaquin	crusted	14.35	a	0.98	a	6.30	a
	disturbed	13.64	a	2.04	b	10.44	b
Wyman	crusted	13.18	a	0.97	a	10.08	a
	disturbed	12.85	a	1.43	b	11.68	b
	polymer	12.01	a	1.27	b	10.82	b
Wyo	crusted	12.09	a	1.35	a	7.11	a
	disturbed	13.34	b	1.21	a	8.41	a
Carbona	crusted	14.27	a	2.69	a	13.00	a
	disturbed	19.63	b	3.23	b	17.65	b
Vina	crusted	11.68	a	2.26	a	15.82	a
	disturbed	31.70	b	2.82	a	22.43	b
Hollenbeck	crusted	12.17	a	3.51	a	15.77	a
	disturbed	14.99	b	3.53	a	21.62	b

* Common letters among means within columns denote no significant difference at $p \leq 0.05$.

Soil physical and chemical properties were determined on seven of the soils. Analysis included: exchangeable cations, 1:1 extract for major cations and anions, CBD Fe and Al, particle size analysis, clay mineralogy, organic fraction, and aggregate stability (Table 4). Using cumulative infiltrated water at 240 minutes as the dependent variable and soil properties as the independent variable, simple regressions were performed using all soils except for Wyo. Those with reasonable probability at $p = \leq 0.010$ are CDB aluminum, CEC, sum base cations, clay content, mica and pH (Table 5).

TABLE 4. Physical and chemical properties of soils at seven sites
(0.0 - 2.5 cm depth unless indicated)

	Soils						
Soil Property	Hanford	Delhi	Wyman	Wyo	Carbona	Vina	Hollen-beck
Organic Matter (%)	3.34	1.99	4.85	3.79	2.13	3.67	4.13
Organic Carbon (%)	1.94	1.16	2.82	2.20	1.24	2.13	2.40
Aggregate Stability (%) 0-2.5cm	76.1	24.7	14.3	60.2	23.6	52.3	60.9
Aggregate Stability (%) 0-15cm	24.7	20.1	17.4	69.3	33.9	15.1	41.3
CBD Fe (%)	0.38	0.41	1.68	0.91	1.25	2.07	0.98
CBD Al (%)	0.03	0.03	0.10	0.08	0.11	0.19	0.09
CEC (cmol/Kg)	6.16	5.18	13.22	17.67	20.59	33.81	23.75
pH	8.08	7.88	7.53	7.71	7.44	4.99	6.95
Exchangeable cations (cmol/Kg)							
K	0.57	0.00	1.04	0.49	0.49	0.53	1.56
Na	0.10	0.11	0.18	0.28	0.73	0.11	0.23
Ca	8.26	8.72	15.08	10.59	8.33	13.41	10.96
Mg	1.70	2.53	5.03	5.15	5.67	7.11	5.15
sum base	10.63	11.35	21.33	16.50	15.22	21.16	17.90
1:1 Soil Extract (mg/L)							
EC (dS/m)	1060	810	380	380	281	417	349
Ca	2791	1667	851	579	1495	1240	645
Mg	1628	1730	543	502	121	1010	401
K	1181	520	329	110	104	93	460
Na	219	298	338	699	1226	256	452
Cl	210	212	289	924	1464	72	408
NO_3	1200	2216	998	835	640	2464	1679
PO_4	98	41	22	18	24	0	32
SO4	182	150	221	316	256	1113	183
HCO_3	8367	4841	1706	561	1922	87	519
Sand (%)	76.8	76.8	35.0	12.5	29.2	5.0	15.0
Silt (%)	17.2	12.8	41.8	59.9	36.8	55.8	44.4
Clay (%)	6.0	10.4	23.2	27.6	34.0	39.2	40.6
Mica*	4	4	1	3	0	0	2
Vermiculite*	3	3	0	1	1	0	2
Smectite*	1	1	1	2	1	3	0
Kaolinite*	2	2	1	1	2	1	1

* Clay Legend: 0 = None
1 = Trace
2 = Minor
3 = Moderate
4 = Major

TABLE 5. Simple linear regression analysis of cumulative infiltrated water versus CBD Al, CEC, sum exchangeable base of cations, clay, mica and pH

Independent Variable	Cumulative Infiltrated Water at 240 Minutes (Dependent Variable)							
	Disturbed				Crusted			
	P value	r^2	Coef.	Constant	P value	r^2	Coef.	Constant
CBD Al	0.049	66.21	38.35	2.72	0.037	70.22	26.12	2.27
CEC	0.005	88.27	0.18	2.83	0.008	85.57	0.12	2.44
sum base	0.153	43.69	0.29	1.07	0.104	52.30	0.22	0.93
Clay	0.001	94.39	0.15	2.18	0.000	98.44	0.10	1.92
Mica	0.115	50.17	-0.91	7.22	0.085	56.45	-0.64	5.70
pH	0.052	65.31	-1.69	18.15	0.065	61.45	-1.09	12.30

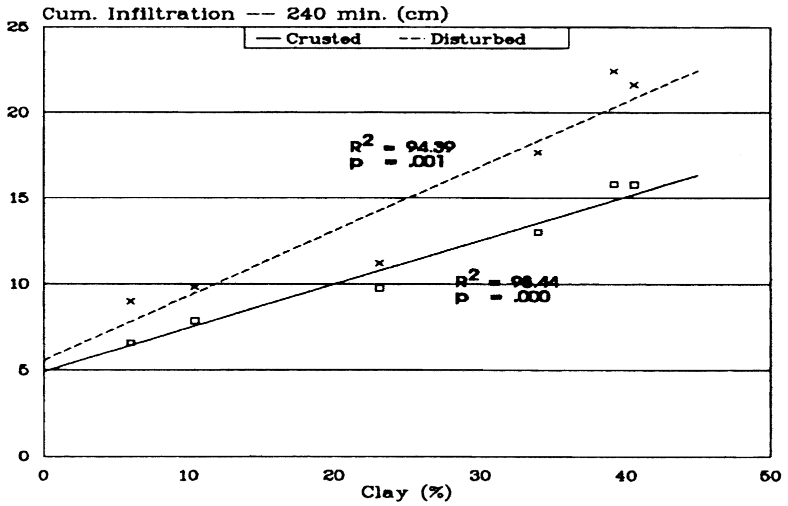
Using cumulative infiltrated water at 240 minutes as the dependent variable, a step-wise multiple regression technique was performed at the 95% confidence level using the independent variables in Table 4. Both the undisturbed and crusted surface regressions showed clay content to be the significant independent variable with respect to cumulative infiltrated water at 240 minutes. The disturbed surface treatment resulted in a linear model:

$$Y = 2.18 + 0.148 \times clay.$$

The crusted surface resulted in the model:

$$Y = 1.92 + 0.100 \times clay.$$

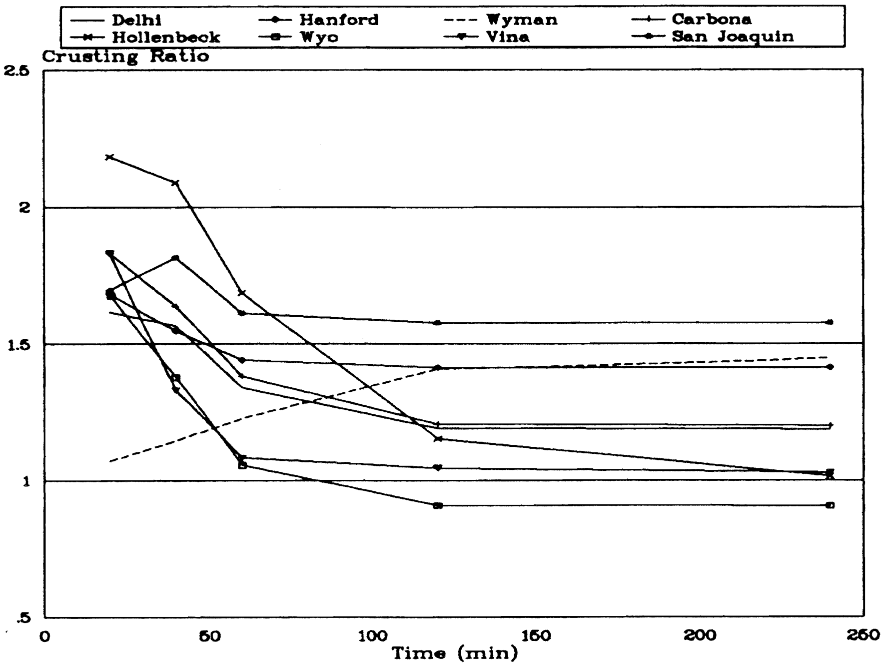
FIGURE 4.



Crusting Ratio

Crusting ratio is a ratio of disturbed to disturbed-crusted infiltration characteristics. It can be determined from either rates or cumulative infiltrated water at sometime as the irrigation proceeds. This ratio can be viewed as the susceptibility or tendency of soils to form depositional surface crusts and impede water infiltration. Unfortunately, this ratio is not constant, changing over time. Figure 5 shows crusting ratio calculated using infiltration rates as a function of time. Soils with higher clay content (Vina, Wyo and Hollenbeck) are initially affected by the formed crust having ratios exceeding 1.5. By 240 minutes, however, they are little affected. The "sandier" texture soils (San Joaquin, Hanford) are affected more uniformly over time by the crusted surface resulting in nearly a 50% reduction in infiltration rate in three soils.

FIGURE 5. Crusting ratio calculated using infiltration rates as a function of time for eight soils.



DISCUSSION AND SUMMARY

The infiltration characteristics of eight filed soils were measured under three conditions: (1) undisturbed, (2) disturbed, and (3) disturbed-crusted. Three soils were evaluated with the water containing a non-ionic guar polymer. Soil chemical and physical characteristics were measured on seven of the eight soils.

Different methods of evaluating treatment infiltration characteristics are presented: 240 minutes cumulative infiltrated water and initial and steady state infiltration rates. Significant differences were found to exist between disturbed and disturbed-crusted soil surfaces in seven of the eight soils when compared by cumulative infiltrated water at 240 minutes. Initial (f_0) and steady state (f_c) is not well correlated to the presence of a crust across all soils but seem to be within groups of > or <27 percent clay. Those with >27 percent clay have initial rates, which are significantly different and steady state generally not significant. In general, the opposite is true of the <27 percent clay soils examined.

A ratio of disturbed to crusted infiltration rates (crusting ratio) provides insight to the relative effects of surface crusting. When viewed over time, the infiltration rate of the "clayier" soils (>27 percent) have a ratio of 1.5 - 2.2 early in the irrigation. The ratio declines to near 1.0 over a 240-minute period. This phenomenon may be a result of additional factors reducing the infiltration rate in the disturbed treatment to near that of the crusted treatment. The most likely is that after the 2-3 cm depth of disturbed soil becomes fully wetted, the infiltration characteristics of the undisturbed soil become dominant. The sub-surface characteristics are similar in the two treatments. The crusting ratio of the "sandier" soils (<27 percent clay) (in contrast to the "clayier" soils) does not improve as the irrigation proceeds, maintaining approximately a 1.4 ratio. The surface crust effects remain as the dominant factor influencing infiltration rate.

When considering a normal 12-36 hour irrigation, it is apparent from this work that the "clayier" soils are not significantly impacted from depositional crusts. Initially the infiltration rate of the disturbed surface is higher than that of the crusted surface, but by 120 minutes, the infiltration rate of the lower undisturbed soil becomes dominant. The "sandier" soils are affected for the term of the tests. The practical implication of this is that soil surface manipulation of these soils to disrupt a depositional crust may significantly increase infiltrated water over the term of an irrigation.

The non-ionic polymer applied in the evaluation water at 15 ppm did not result in increased cumulative infiltration over the disturbed surface. It is speculated that over the term of the measurements, the infiltrometer did not form a depositional crust, which was mitigated by the polymer.

Many soil physical and chemical properties of the soils were measured and attempts were made to determine their effect on cumulative infiltrated water at 240 minutes. A relationship was found to exist for clay content, CBD aluminum, cation exchange capacity, sum of the exchangeable cations, mica, and pH. Many of these variables are inter-correlated. A step-wise linear regression found clay to be the best for a model to estimate cumulative infiltration in these soils over a 240-minute period.

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BIOLOGY

PROJECT TITLE: INTERACTION OF MICROORGANISMS AND ORGANIC AMENDMENTS ON WATER PENETRATION IN IRRIGATED SOILS

PROJECT NUMBER: 89-10

DURATION OF FUNDING: July 1989-June 1991

PROJECT INVESTIGATORS:

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FTE Commitment:	0.1	FTE Commitment:	0.1

RESEARCH STAFF:

Postgraduate Researcher: 1.0 FTE
Dean A. Martens

ABSTRACT:

The adherence of soil particles into stable aggregates by the synthesis of microbial saccharides from decomposing organic materials has been speculated to be the mechanism for increased soil aggregate stability from addition of organic amendments. This project evaluated the validity of this hypothesis in field, glasshouse and laboratory studies. Field studies found that amino-, monosaccharides and uronic acids added as organic amendments were rapidly decomposed by soil microorganisms. Statistical analyses indicated that the saccharides extracted from organic amended soil was significantly correlated with short-term soil aggregation (<9 months) but with continued incubation was not correlated with long-term stability (>1 year). Glasshouse and laboratory experiments showed that monosaccharides such as glucose or polysaccharides such as complex microbial polymers were quickly decomposed in soil and most of the decomposed C was accounted for in the flask headspace as CO_2. The saccharide materials evaluated possess the potential to promote soil aggregation but were not found to be directly responsible.

Addition of 125 mg ha^{-1} soil of poultry manure, sewage sludge, barley straw and fresh alfalfa over a four-year time frame significantly increased water sorptivity, water infiltration rates and hydraulic conductivity in the Arlington soil used. The additions of organic amendments not only improved water infiltration rates, they were responsible for increasing aggregate stability from an initial 80 kg water-stable aggregates kg^{-1} soil to >550 kg aggregates kg^{-1} amended soil, and decreased bulk density in the tillage zone from 1.65 g cm^{-3} to 1.32 g cm^{-3} amended soil. This research mission showed that the incorporation of available animal manures or plant residues on a regular basis should be a part of a successful management plan to improve and sustain soil physical conditions and high crop productivity.

KEYWORDS: sorptivity, infiltration rates, hydraulic conductivity, microbial saccharides, organic amendments.

PROJECT OBJECTIVES ADDRESSED:

1. Determine if the production of specific saccharides by soil bacteria from the decomposition of organic amendments is related to increased aggregate stability and decreased bulk density?
2. Determine the effects of organic additions incorporated into the tillage zone of soil on the sorption of water, the rate of infiltration, and the hydraulic conductivity of the irrigated Arlington soil.

RESEARCH PLAN AND PROCEDURES:

Field Study

A detailed description of the field plot design and metholodgy used for saccharide analysis, aggregate stability measurements, water infiltration measurements and bulk density determinations have been previously described in the December 1987 and in the August 1988, 1989 and 1990 Kearney Foundation of Soil Science reports.

RESULTS:

Effects of saccharides on aggregate stability

The physical properties of a soil (e.g., aggregation, bulk density, etc.) influence plant growth through their effects on soil moisture, soil air, soil temperature and mechanical impedance to root development and shoot emergence (Shaw 1952). Intensive agricultural practices usually results in the degradation of soil aggregation while an improvement in soil structure usually follows with the addition of organic materials to soils. Although aggregate formation and stabilization are often discussed together, the two processes involve formation and stabilization forces which may or may not be occurring at the same time (Allison, 1968). Aggregate forming forces (e.g., wetting and drying, freezing and thawing, etc.) involves the orientation of soil particles so that physical forces between them will hold them firmly when allowed to dry.

Two aggregate-stabilizing mechanisms have been proposed for the improvement in soil aggregation and structure following organic additions to soil (Martin et al. 1955). They include a physical entanglement of soil particles with living bacteria and fungal hyphae, and(or) the binding of soil particles with gelatinous organic materials produced by microbial decomposition of the added organic materials. Scanning electron micrographs showing the extent of physical entanglement of a microbial hyphae and soil particles on the surface of an alfalfa-treated soil was presented in the Kearney Foundation of Soil Science 1990 report (Project 89-10). This surface entanglement reduced the dispersion of trapped soil particles during irrigation events. Persistent soil polysaccharides which are largely extracellular products of soil microbes have been hypothesized to be the gelatinous organic material. Results presented in the Kearney Foundation of Soil Science Reports dated August 1989 and 1990 showed that organic amendments were responsible for an increase in the total saccharide content of the Arlington soil by 0.5 to 1.2 mg g^{-1} soil over 2 years time.

To determine if gelatinous organic materials such as microbially-produced saccharides were responsible for the increased aggregate stability noted in the mission results, the fate of 13 purified microbial polymers (characterization presented in the 1990 Kearney Report) added to the Arlington soil was monitored by high performance anion chromatography (HPAC) with pulsed amperometric detection (PAD) (Martens and Frankenberger, 1990a). The potential of ion exchange chromatography for the analysis of saccharides has been previously reported (Kearney report 1989, 1990). In all cases, saccharides added to the Arlington soil as microbial polymers (ECPs) were rapidly decomposed and within one to two weeks the monosaccharide concentration in the treated soil was not significantly different from the soil check (no ECP added). Saccharide concentrations did not change with continued incubation. Oades and Wagner (1971) reported that after 12 days, soil incubated with ^{14}C-glucose and a ^{14}C-dextran polymer (*Leuconostoc mesenteroides* ATCC 10830a) contained amounts of glucose and other saccharides similar to the original soil (no saccharide added) and these levels did not change with continued incubation suggesting little or no conversion to microbial saccharides. Statistical analyses indicated that the extracted monosaccharide concentrations of the 13 ECP-treated soils were not significantly correlated with the increased aggregate stability measured after polymer addition. Glucose additions showed the same decomposition pattern as was found with the ECP-saccharides. The glucose concentration in the glucose-treated soil was approximately the same as the soil check after only one week of incubation. Short-term analyses indicated that little glucose (<20 *u*g g^{-1} soil) remained in the soil after incubation for only five days. The extremely rapid loss of glucose added to soil has also been noted by previous research (Chahal, 1968; Persson, 1968; Cheshire et al., 1969; Oades and Wagner, 1971).

Carbon dioxide evolution studies showed that most of the ECP-saccharides metabolized could be accounted for by elevated CO_2 concentrations in the headspace of the flask (Table 1). The non-*Pseudomonas* ECPs and guar had an average of 62% of the 1 mg ECP-C g^{-1} soil recovered as CO_2-C after incubation for four weeks. This is compared with the addition of glucose and the *Pseudomonas* ECPs which averaged 75% of the added ECP-C recovered as CO_2-C during the same time period. Oades and Wagner (1971) reported that after incubation for 28 days, 75% of the glucose label and 66% of the dextran label were recovered as CO_2. Their research suggested that the lower recovery of CO_2 for the dextran label was due to inaccessibility of the polymer to the soil microorganisms. Our inability to account for all of the added C as saccharides or evolved CO_2-C suggests that the ECP-saccharides, in addition to providing an energy source for soil organisms, may have been transformed into new biomass in the treated soil.

There are two contrasting views on the role of soil organic compounds in stabilizing soil aggregates. One view is that water-soluble carbohydrates as measured by anthrone-sulfuric acid analysis (Brink et al., 1960) correlates with aggregate stability in sewage sludge-amended soil (Kinsbursky et al., 1989) and in soils with varying cropping histories (Haynes and Swift, 1990). Another view presented by Capriel et al. (1990), Ma'shum et al. (1988) and Dormaar (1984) suggests that hydrophobic aliphatic soil fraction, particularly long chain fatty acids produced by microorganisms have a considerable influence on the stabilization of soil aggregates. Chaney and Swift (1986) noted that soil adsorbing humic acid materials resulted in long-term aggregation effects that is in contrast to the transient effects on aggregation observed with extracellular polysaccharides.

TABLE 1. Recovery of CO_2-C From the Arlington Soil After Treatment With 1 mg ECP-C g^{-1} Soil.

	Week				
Microbial polymers	0.5	1	2	3	4
	CO_2-C Recovery (%)^a				
1	13	32	51	55	59
2	11	23	33	52	57
3	33	37	53	61	68
4	14	21	32	56	62
5	37	61	68	70	72
6	36	65	70	71	73
7	33	63	69	72	73
8	34	68	73	76	77
9	29	64	69	72	75
10	31	59	63	69	74
11	21	41	51	59	63
12	17	29	40	54	59
13	2	13	31	33	65
Hyroxyethyl guar	33	41	59	63	66
Glucose	49	69	73	75	77

^{a}Values are corrected for CO_2-C evolved from the control soil (no ECP added).

The conclusions of Kinsbursky et al. (1989) and Haynes and Swift (1990) are questionable because of the method of carbohydrate analysis employed. Doutre et al. (1978) reported that anthrone-sulfuric acid analysis of soil saccharides is subject to serious interference problems. This was confirmed by Martens and Frankenberger (1990b) who also noted that water extracts ($80^{\circ}C$ or $25^{\circ}C$) of field moist soil contain very low levels of carbohydrates when compared with carbohydrate recovery with mild acid hydrolysis (0.5 M H^+). The recovery of CO_2 in the headspace and the lack of saccharide recovery in the ECP-treated soils suggests that the bacterial polymers tested were rapidly decomposed in the soil within one to two weeks and not directly involved in the aggregate stabilization processes. These results support the research presented by Mehta et al. (1960) who reported that although soil polysaccharides had the capacity to promote aggregation, they were not the responsible agent. Capriel et al. (1990) found that supercritical hexane extracts of soils with varying cropping histories had high correlation coefficients between the extracted aliphatic fraction and soil biomass ($r = 0.91$) and soil aggregate stability ($r = 0.91$). The hydrophilic fraction of soil organic matter (OM) such as polysaccharides have received much recognition on their effects in stabilization of soil aggregates, but the role of the hydrophobic aliphatic fraction of OM in soil stabilization has received little attention.

Effects of organic amendments on water sorptivity, hydraulic conductivity and infiltration rates

During the early stages of the infiltration process, water transmittance is nearly uniform in all directions, independent of both the gravity and the geometry of the soil (Philips, 1969). This one-dimensional absorption or sorptivity (S) of water into a medium at time t is described by the equation (Philips, 1969):

$$S = I\,t^{-1/2}$$

where I = cumulative infiltration (cm water cm^{-3}) at t = 10 min.

Incorporation of the four organic amendments significantly increased the sorptivity of the Arlington soil (Fig. 1). In general, the first and fourth organic applications resulted in the greater increase in sorptivity in the amended soil except for the poultry manure amendment when compared to the second or third organic application. Over a 33-month study the organic amendments more than doubled the sorptivity of the Arlington soil at selected infiltration events when compared to the tillage only treatment (unamended plot). Sorptivity estimates at the 10 min measurement were correlated with decreased bulk density ($r = 0.54^{***}$) and increased organic carbon ($r = 0.51^{**}$) but not significantly correlated with increased aggregate stability during the study. Water sorptivity is influenced by both soil structure and the antecedent water content of a soil (Bouwer, 1978). Dry soils have a higher water sorptivity than wet soils. In this study, gravimetric or volumetric water contents (gravimetric moisture x bulk density) were not found to be significantly correlated with sorptivity measured during the study. The lack of significant correlations between sorptivity and water contents may have been due to the observations that the soil was maintained in a damp state by irrigating weekly and may not have dried sufficiently to show significant sorptivity effects during infiltration measurements. Incorporation of the organic amendments increased the mean sorptivity 25%, 56%, 78% and 67% for the poultry manure, sewage sludge, barley straw and alfalfa, respectively, when compared to the tillage only treatment during the study.

The movement of irrigation water into soil is governed by the nature of the pore spaces, the deterioration of soil aggregates and the changes in the volume of entrapped air (Poulovassilis, 1972). Previous research has shown that soil hydraulic conductivity (K) is strongly influenced by soil aggregate stability and bulk density (Frankenberger et al., 1979). The aggregate stability and bulk density determinations made during this aspect of the study are shown in Figs. 2 and 3. Saturated hydraulic conductivity (K) and infiltration rates, i (i = cm H_2O infiltrated h^{-1}) in a vertical soil column can be calculated by the two-parameter equation proposed by Philips (1969):

$$i = 1/2\ St^{-1/2} + K$$

where S = sorptivity as calculated above.

Addition of the four organic amendments significantly increased infiltration rates (cm H_2O infiltrated h^{-1}) in the Arlington soil when compared to the unamended soil (Fig. 4). Statistical analyses showed that the infiltration rates in the amended and unamended Arlington soil were correlated with the sorptivity factor (r = 0.70***) during the study. The infiltration rates were not correlated with aggregate stability or bulk density measured (r = 0.29 and -0.15, respectively) in the tillage zone during the study. The organic additions resulted in a 38%, 43%, 59% and a 53% increase in the infiltration rates for the poultry manure, sewage sludge, barley straw and the alfalfa treatments, respectively, when compared to the unamended plots during the study. Increased infiltration rates resulting from applications of organic materials have been previously reported to be closely associated with the processes in the upper portions of the soil (Pillsbury and Huberty, 1941a,b).

The effects of the additions of organic amendments on the hydraulic conductivity in the irrigated Arlington soil are shown in Fig. 5. In the reported study, infiltration rates did not reach a saturated hydraulic conductivity steady state at the end of the four h infiltration event. The hydraulic conductivity measurements were estimated from the infiltration rates during the last hour of the infiltration event. The estimated hydraulic conductivity rates (cm water sec^{-1}) were significantly increased 53%, 76%, 118% and 88% by the addition of the poultry manure, sewage sludge, straw and alfalfa additions, respectively, when compared to the soil controls during this study. Statistical analyses showed no significant correlations were determined between the measured aggregate stability (r = 0.06) and bulk density (r = -0.13) and the estimated hydraulic conductivity in the Arlington soil.

To summarize the study, incorporation of plant residues, animal manures or sewage sludge had a benifical influence on the Arlington soil tested. The applications stimulated the soil biota and resulted in increased soil aggregate stability, organic C content, soil saccharide content, infiltration rates, soil sorptivity, hydraulic conductivity and decreased soil bulk density. The incorporation of organic amendments on a regular basis should be a part of a successful management plan to improve soil structure.

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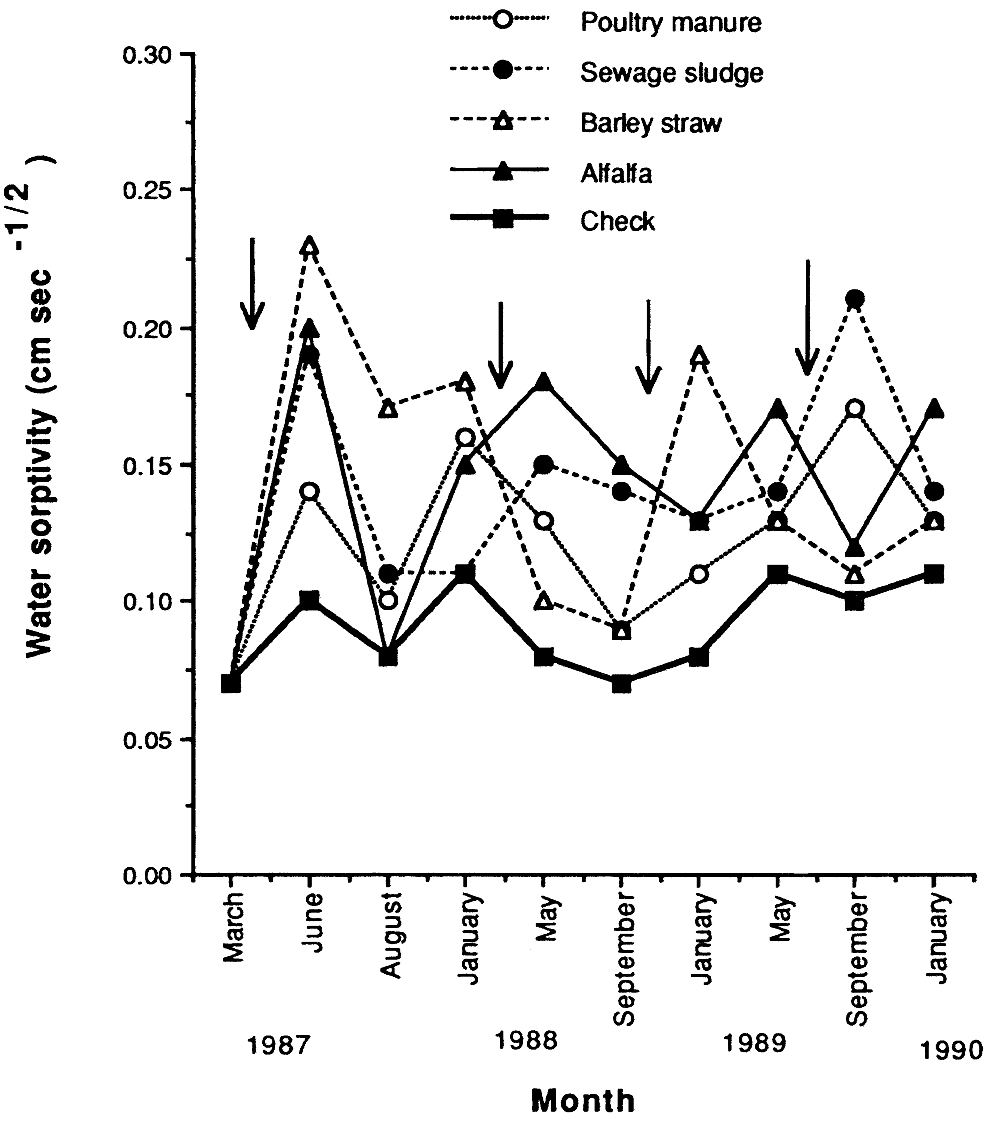

Fig. 1. Influence of organic amendments on soil sorptivity. $LSD_{0.05} = 1.1 \times 10^{-2}$. Arrows indicate addition of organic amendments.

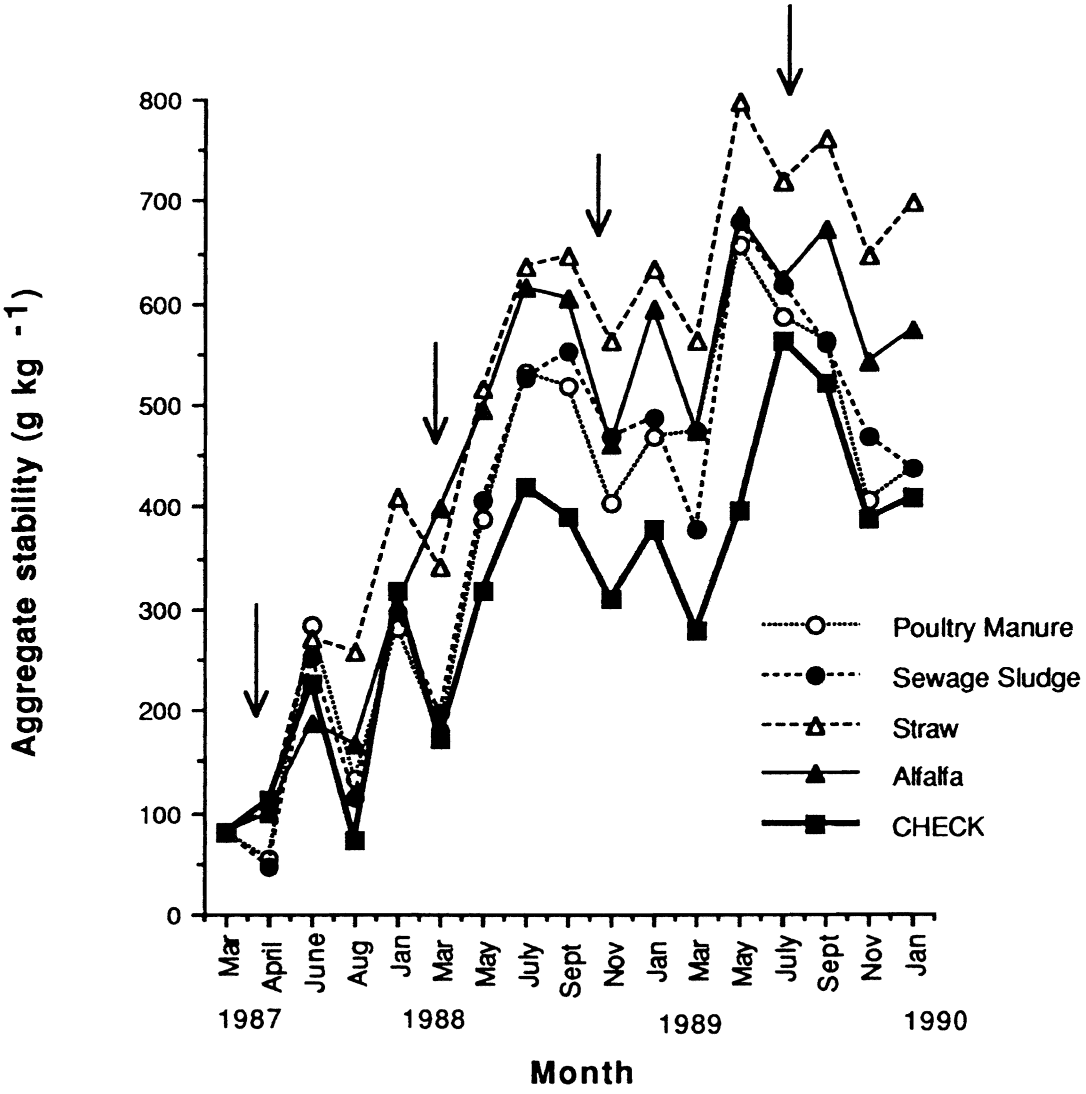

Fig. 2. Influence of organic amendments on soil aggregate stability. $LSD_{0.05} = 69.60$. Arrows indicate addition of organic amendments.

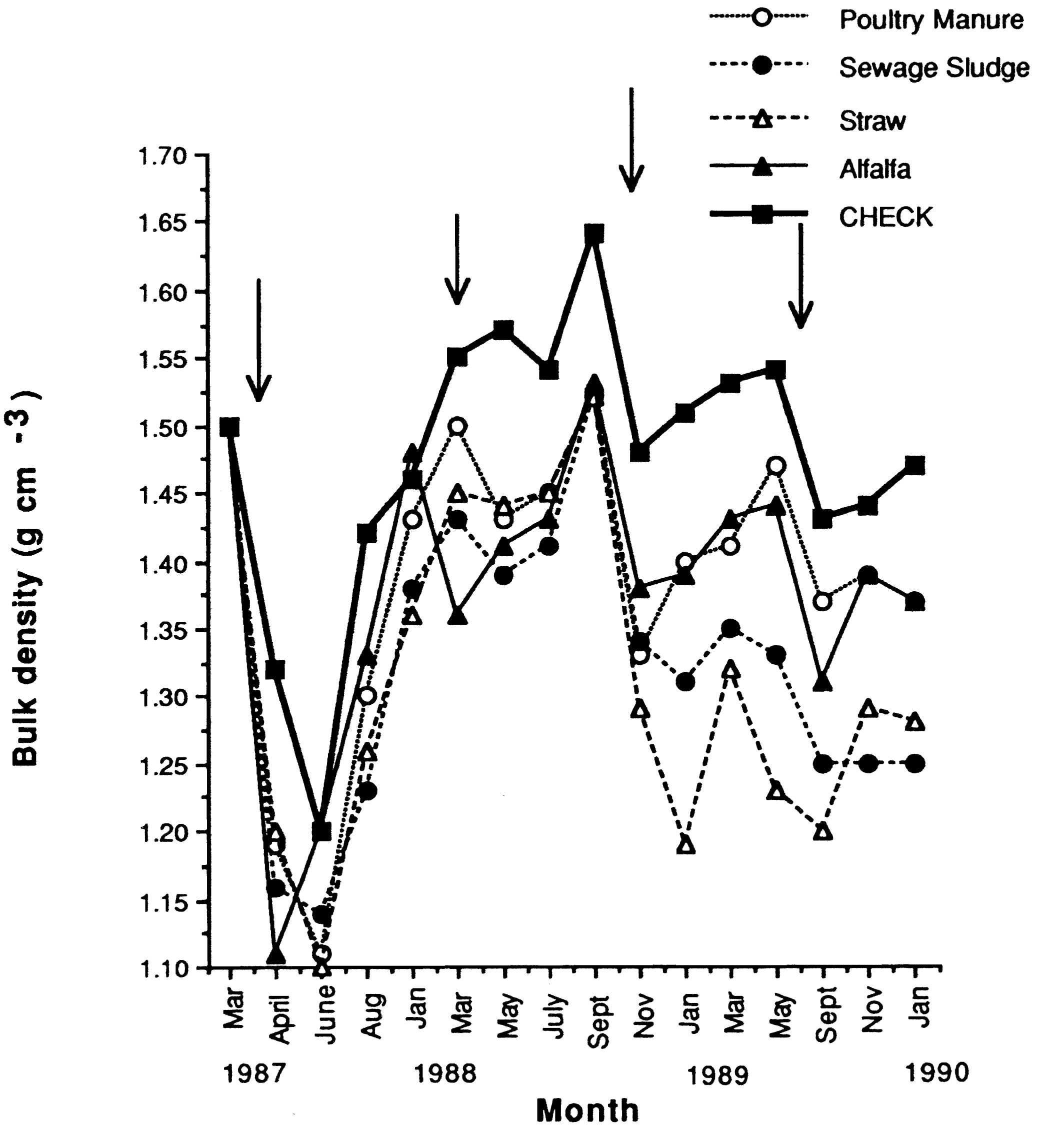

Fig. 3. Influence of organic amendments on soil bulk density. $LSD_{0.05} = 0.05$. Arrows indicate addition of organic amendments.

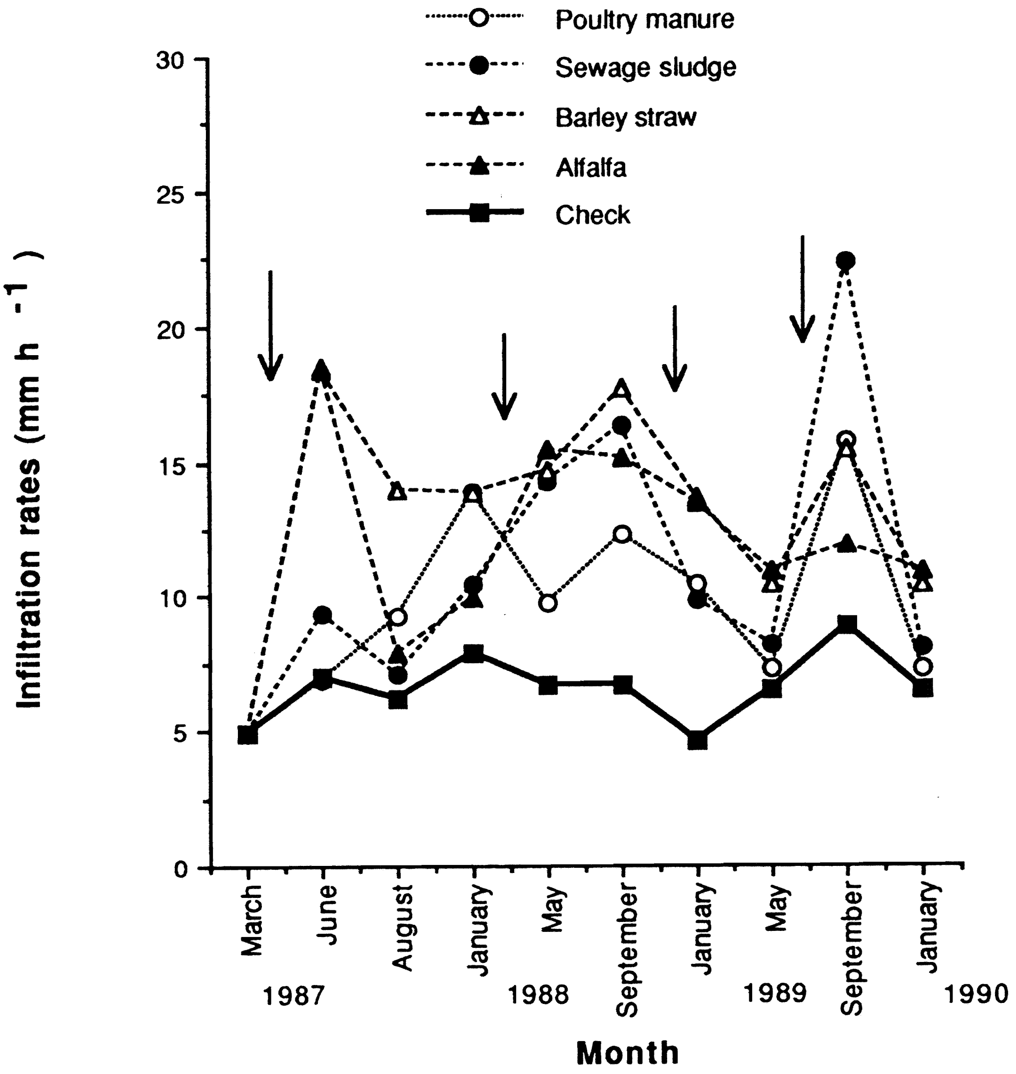

Fig. 4. Influence of organic amendments on infiltration rates (cm H_2O infiltrated h^{-1}). $LSD_{0.05}$ = 8.30. Arrows indicate addition of organic amendments.

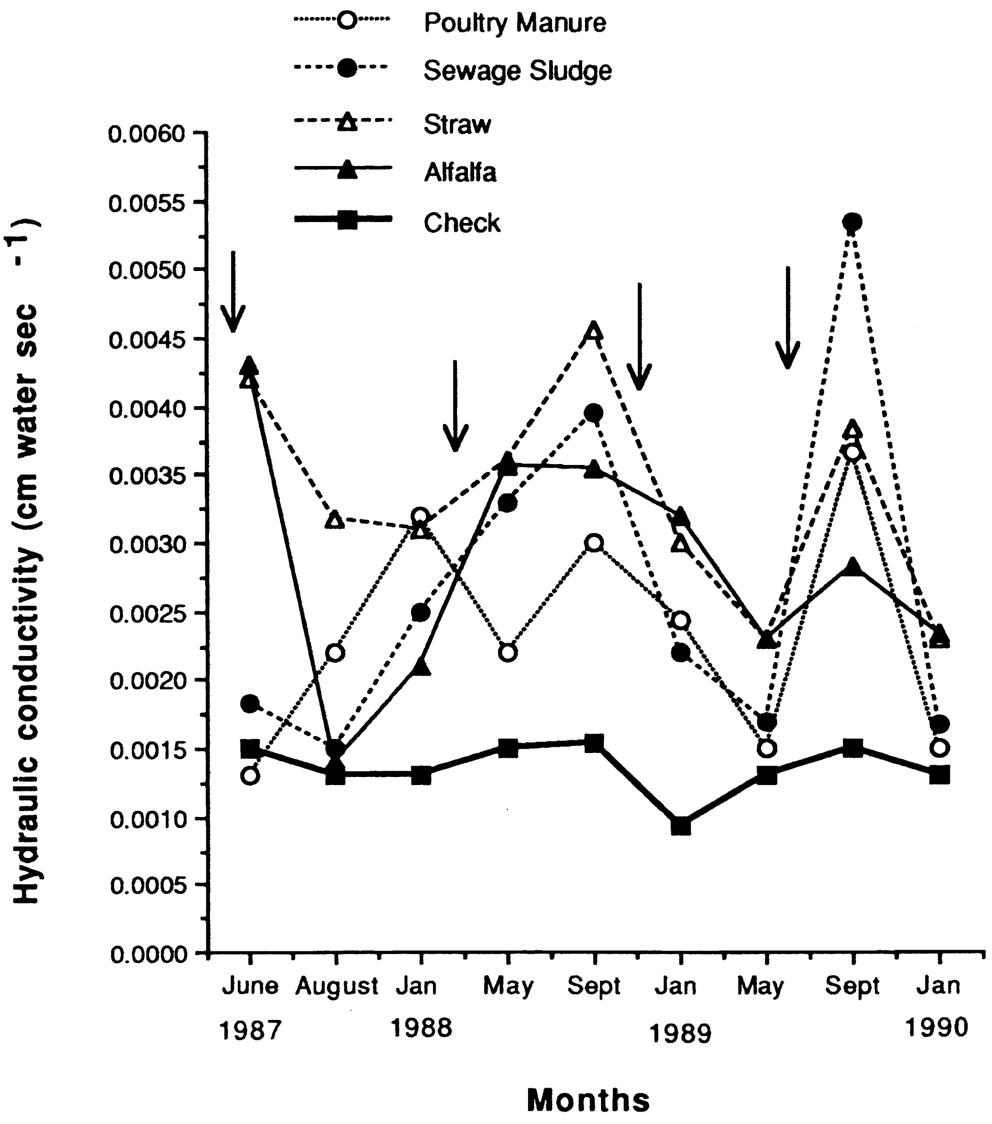

Fig. 5. Influence of organic amendments on soil hydraulic conductivity. LSD$_{0.05}$ = 1.3 x 10^3. Arrows indicate addition of organic amendments.

PROJECT TITLE: EFFECT OF SOIL CHARACTRERISTICS ON POLYSACCHARIDE PRODUCTION AND AGGREGATE STABILITY.

PROJECT NUMBER: 89-11

DURATION OF FUNDING: July 1990 - June 1991

PROJECT INVESTIGATORS:

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ABSTRACT:

The relationship between desiccation and the production of extracellular polysaccharides (EPS) by soil bacteria was investigated using a Pseudomonas species isolated from soil. Cultures subjected to desiccation while growing in a sand matrix contained more EPS and less protein than those growing at high water potential, suggesting that resources were allocated to EPS production in response to desiccation at the expense of other metabolites. Wetting and drying significantly affected the recovery of EPS from sand-clay mixtures, but not from pure sand, suggesting that desiccation facilitated adsorption of EPS to clay surfaces. Purified EPS produced by the Pseudomonas culture contained several times its weight in water at low water potential. Sand amended with EPS held significantly more water and dried significantly more slowly than unamended sand, implying that an EPS matrix may buffer bacterial colonies from some effects of desiccation and that EPS may improve that water retention characteristics of soil. The affect of EPS and commercial polysaccharides on water stable aggregation during wetting and drying is not clear. Alginate at 0.1% concentration did not maintain or increase aggregate stability over 40 wetting and drying cycles.

KEYWORDS: Desiccation, polysaccharide, Alginate, adsorption, water holding capacity.

PROJECT OBJECTIVES ADDRESSED:

We addressed the questions of what conditions optimize extracellular polysaccharide production by soil bacteria and of how extracellular polysaccharides modify the water retention characteristics of the soil environment.

The affect of EPS and a commercial polysaccharide (Alginate) and wetting and drying on aggregate formation and stability was investigated.

RESEARCH PLAN AND PROCEDURES:

Bacteria

The strain used was isolated from an agricultural soil in the Sacramento Valley of California. The strain was selected for mucoid colony appearance. It is a yellow-pigmented, gram-negative, oxidase-positive rod, and has been identified as a Pseudomonas species by its fatty acid profile (MIDI, Inc., Newark, Delaware). The EPS produced by this strain contains both neutral monosaccharide and uronic acid subunits. The ratio of neutral to uronic acid subunits in the EPS varies depending on media composition (data not shown).

Two series of experiments were performed. The first group followed bacterial protein and EPS production during one cycle of wetting and drying. The second group examined the water retention characteristics of the EPS produced by the bacteria and the effect of EPS on drying rate.

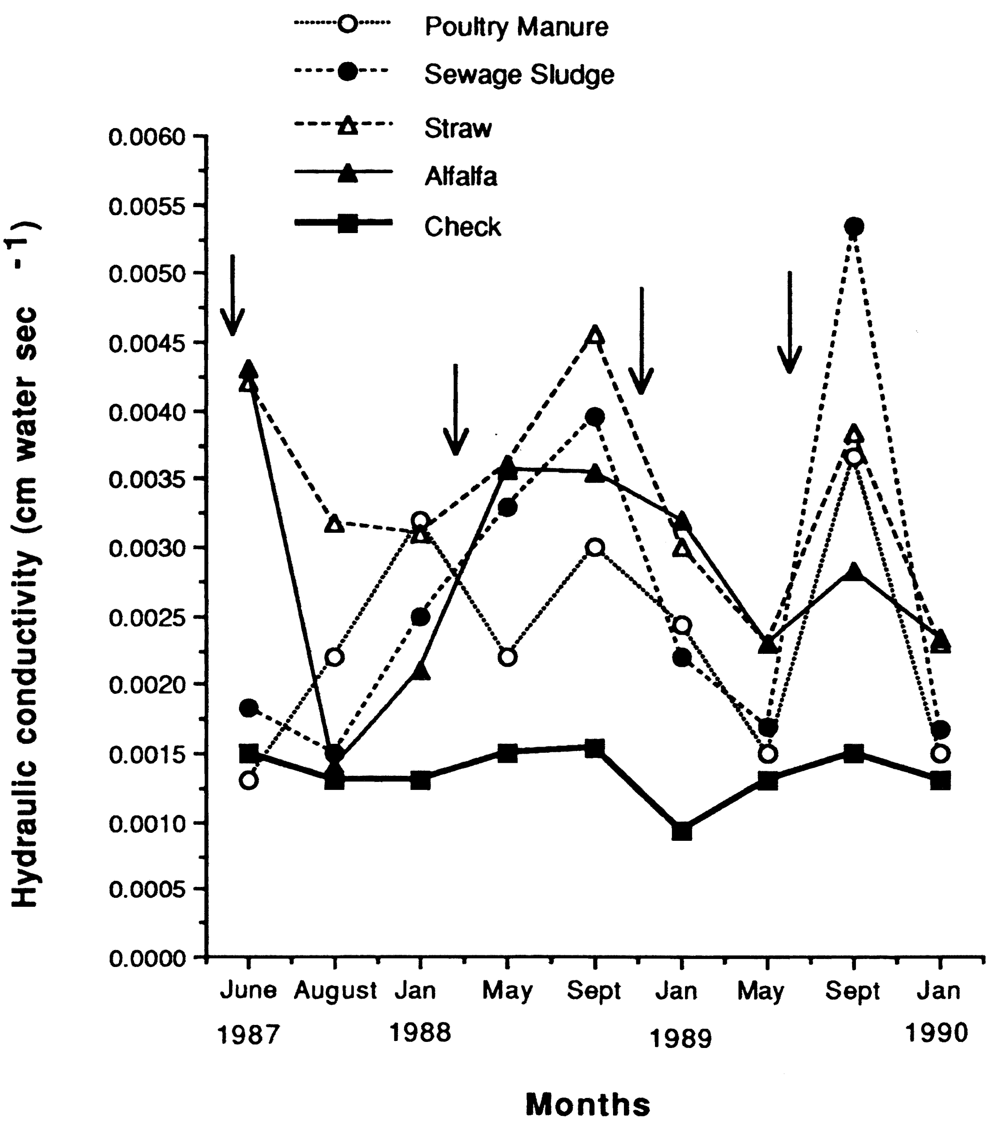

Fig. 5. Influence of organic amendments on soil hydraulic conductivity. $LSD_{0.05} = 1.3 \times 10^3$. Arrows indicate addition of organic amendments.

Metabolic response of bacteria to wet/dry cycle.

A sand matrix and mineral salts growth medium was chosen for this experiment so that nutrient supply could be tightly controlled and monitored and bacterial protein and polysaccharide production could be precisely measured. Bacteria were grown to mid log phase (about 2 x10^8 cells/ml) in a mineral salts medium consisting of 4 g NH_4Cl; 6.98 g $Na_2HPO_4 \cdot 7H_2O$; 5.58 g KH_2PO_4; 20 g glucose; and 40 ml Hunters Mineral Supplement (Guirard and Snell, 1981) per liter. The initial pH was adjusted to 6.8. Sand cultures were grown in 99 mm diameter pyrex petri dishes. Fifty grams of sterile quartz sand which had been acid washed, rinsed with deionized water, and equilibrated with growth medium, were inoculated with sufficient unwashed culture to bring the total water potential to -0.025 MPa, 130 µl culture/g sand. All petri plates were placed in sterile desiccators containing solid LiCl to produce a relatively constant low relative humidity and to dry the plates reproducibly. The cultures were allowed to dry to -1.5 MPa, then readjusted to -0.025 MPa with 1/4-strength growth medium. Three plates were collected for day-0 measurements after this wetting. The bacteria were exposed to this drying and wetting cycle before the experiment in order to acclimatize them to growing in the presence of surfaces.

On day 0, after wet-up, half the remaining plates were replaced in the LiCl containing desiccators and half were placed in desiccators containing sterile distilled water. Distilled water maintained a high relative humidity in the desiccators. The water potential in cultures in the water-containing desiccators remained roughly constant during the experiment, and this was used as a control treatment.

Three petri plates were collected from the LiCl chambers and three from the control chambers each day, weighed to determine water content, and sampled for protein, total carbohydrates, and glucose. A moisture release curve was used to convert sand water content to water potential. The experiment was terminated when the average water potential in the desiccated treatment reached -1.5 MPa, a water potential which has been reported to limit bacterial activity (Harris, 1981; Soroker, 1990; Rosacker and Kieft, 1990).

The protein content of the cultures was determined using the coomassie blue method (Biorad Laboratories, Richmond, CA). Cultures were heated to 100C for 10 minutes in 1 N NaOH to release cell contents, filtered, and protein measured in the filtrate. Lysozyme in 1N NaOH was used as the standard. Results are reported as µg lysozyme equivalents per g sand.

Polysaccharides were extracted from the sand using a method similar to that of Oades et al. (1970). Cultures were heated to 120°C with 5N H_2SO_4 for 30 minutes and filtered through a glass fiber filter. Samples were further extracted once with boiling water. Extracts were pooled and neutral and uronic acid carbohydrates were determined using anthrone and *m* -hydroxydiphenyl, respectively (Brink, *et al.*, 1960; Blumenkrantz and Asboe-Hansen, 1973). Results are reported as µg glucose and glucuronic acid equivalents/g sand, respectively. Residual glucose was determined using the glucose oxidase assay (Keston, 1956). Glucose was subtracted from total neutral carbohydrates to calculate neutral polysaccharides.

Microscopy

A separate but identical experiment was performed to produce samples for examination by scanning electron microscopy. We used a cryoscan device (Oxford Cryotrans Temperature and Preparation Controllers) which makes it unnecessary to dry samples before they are placed in the microscope. Conventional SEM preparation techniques such as alcohol dehydration and critical point drying have been found to severely affect the structure and apparent quantity of bacterial EPS (van Doorn *et al.*, 1990).

Small samples were collected from both desiccated and control treatments each day, frozen to -180°C in a N_2 slush, and transferred into a liquid N_2 cooled Phillips 525 M Scanning Electron Microscope (SEM). Ice was removed from the surface of the samples by 20 minutes of sublimation at -80 °C, the samples were coated with gold and observed at -180°C. By using Cryo-

SEM, we were able to observe qualitative changes in both the amount and the hydrated structure of the EPS in the cultures as water potential changed during desiccation.

EPS adsorption to surfaces

Bacteria were grown to late log phase in mineral salts medium and the culture was sterilized using an autoclave. Sufficient sterile culture was added to sterile mixtures of acid washed quartz sand and Wyoming bentonite (Na, K saturated) in petrie dishes to bring the water potential to -0.025 MPa as above. Three levels of clay were used 0% (100% sand), 5% (95% sand), and 50%. Eight replicate dishes were prepared containing each mixture. Half the petrie dishes from each clay level were placed in LiCl-containing desiccators and subjected to four wetting and drying cycles. Each cycle consisted of desiccation to -1.5 MPa, and then re-wetting to -0.025 MPa with sterile distilled, deionized water. The remaining plates were placed in water-containing desiccators and kept at -0.025 MPa as a control treatment. After the mixtures in the LiCl-containing chambers had been exposed to four wet/dry cycles, polysaccharide was extracted and carbohydrates were determined as above.

EPS water retention characteristics

Polysaccharide Moisture Release Curve. Bacteria were grown to late log phase in mineral salts medium and separated from EPS in solution by two 14-minute centrifugations at 10,000 X g at 4 C. Polysaccharides in the supernatant were extensively dialysed against distilled water using Spectra/Por 1000 dalton molecular weight cut-off dialysis membranes (Spectrum Inc., Los Angeles, California) to remove residual growth medium. They were then concentrated approximately 5 fold by further dialysis against solid polyethylene glycol (PEG) 8000 and finally evaporated to dryness using a Speedvac Concentrator (Savant Medical Industries, Farmingdale, New York). The absence of protein contamination in the concentrated solution was confirmed by the coomassie blue method (Biorad Laboratories, Richmond, CA). A range of volumes (30 - 400 µl) of distilled water was added to approximately 40 mg of dry polysaccharide in gas-tight 1.5 mL microcentrifuge tubes. The mixtures were vortexed and then centrifuged at 14,000 X g for 2 minutes to thoroughly mix the water with the polysaccharide, and allowed to equilibrate overnight at 4 C. Water potential was determined at each water content.

Effect of EPS on drying rate

Polysaccharides were purified and concentrated by dialysis as above but were not lyophilized. Sufficient concentrated polysaccharide solution (100 mg EPS/ml) was added to three replicate petri plates containing 50 g sterile acid-washed sand to bring the water potential to -0.2 MPa. Concentrated EPS solution was used in order to approximate the immediate bacterial microenvironment, which is essentially pure polysaccharide. Three control plates were brought to -0.2 MPa with sterile deionized water. Both solutions contained 0.2% sodium azide to maintain sterility. Pairs of sand filled petri plates, one containing EPS solution and one containing water, were placed in desiccators containing LiCl and allowed to evaporate. Samples were taken from each dish each hour and water content and water potential were measured.

In all experiments, water potentials below -0.2 MPa were determined using an HR33T microvoltmeter with a C32 thermocouple psychrometer sample chamber (Wescor Co., Logan, Utah, U.S.A.) using an equilibration time of 50 minutes before measurement. Water content at water potentials above -0.2 MPa were measured using a pressure plate apparatus (Soil Moisture Equipment Corporation, Santa Barbara, California). Sand and media were sterilized using an autoclave.

All statistical analyses were performed using StatView and SuperANOVA software (Abacus Concepts, Inc. Berkeley, CA).

Wetting and drying cycles

To mixtures of 5% smectite and 95% acid washed sand were added Alginate at 0.1% and 1.0% (by weight). Aggregates were prepared and wet and dried as described in the report of project 89-7. Two methods of maintaining sterility of the samples was investigated. Samples were either autoclaved or treated with mercuric chloride. The mercuric chloride results are reported here.

RESULTS:

Metabolic response of bacteria to wet/dry cycle. The change in water potential in the two treatments is shown in Figure 1. All points in the figures represent means of three replicates. Drying in the desiccated treatment began immediately and by day 2, water potential in the cultures averaged -0.47 MPa. On day three, the desiccated cultures had reached a water potential of -1.46 MPa, which was close to their water potential after the pre-experiment drying cycle on day 0. Water potential in the control treatment remained relatively constant after initial wet-up.

Figure 2 shows the change protein during the experiment. Desiccation significantly reduced the amount of protein in the cultures. The amount of protein in the control cultures increased between day 0 and 3, but in the desiccated treatment, protein concentration increased for only one day after wetting and then declined. The number of colony forming units was also significantly lower in the desiccated treatment than in the control (data not shown).

Figure 4 shows the amount of neutral,uronic acid, and total polysaccharide in the cultures each day. There was a sharp decrease after wetting on day 0 in both treatments, possibly the result of EPS consumption by the growing cultures. The amount of polysaccharides in the control cultures remained low throughout the experiment. The amount in the desiccated treatment, however, began to increase immediately as the water potential decreased and continued to increase until day 3. As was found for protein, the quantity of polysaccharides in the desiccated cultures at the end of the experiment was similar to that on day 0, at the end of the pre-experiment desiccation. There was no significant difference between the proportion of uronic acid in the EPS in the desiccated and control treatments (data not shown).

Micrographs. The micrographs (Figure 5) show bacteria and EPS on sand after wet-up on day 1, when the water potential in the cultures was -0.025 MPa, (plates a-c) and after the cultures had dried to approximately -1.0 MPa (plates d-f). Fibres of EPS are visible in plates (b) and (c), but bacteria without obvious EPS can also be seen in plate (a). Plates (d) - (f) show that the amount of EPS in the cultures substantially increased after exposure to desiccation. Thick layers of EPS covered bacteria and sand surfaces. Before desiccation, the edges of the bacteria appear sharp (Plates a-c); while after desiccation, the bacteria appear to be partially embedded in EPS. The hydrated structure of the EPS also changed after exposure to desiccation. Instead of an open network of fibres, it appears to be a dense amorphous layer on the sand surface after desiccation.

Adsorption of polysaccharide to surfaces. Wetting and drying did not affect the recovery of polysaccharide from 100% sand (Figure 3). Recovery decreased from both the control and wet-dry cycle treatments as the amount of montmorillonite in the mixture increased, however. Wetting and drying significantly lowered polysaccharide recovery, relative to the control, when clay was present.

EPS water retention characteristics

Polysaccharide Moisture Release Curve. The moisture release curve (Figure 6) shows the relationship between water potential and water content for the purified EPS. The EPS showed a high affinity for water at all water potentials. At -1.5 MPa, the EPS held approximately 5 times its weight in water. At -0.5 MPa, it contained 10 times its weight in water. These values are similar to those reported for the neutral fungal polysaccharide scleroglucan (Chenu, 1989). For comparison, a medium textured soil holds between 0.04 and 0.1 g water/g soil at -1.0 MPa.

Figure 6 also shows the effect of EPS on the moisture release curve of quartz sand. The addition of a small amount of EPS greatly increased the amount of water held by the sand at all water potentials. The points fit a curvilinear function overall, but in order to analyze the effect of EPS, they can be split at -0.9 MPa into two linear portions, and each linear portion analyzed separately by linear regression. This approach has the advantage of allowing a test of the statistical significance of the effect of EPS using an analysis of covariance (ANCOVA) (Table 1) (Snedecor and Cochran, 1980). Table 1 shows the slopes of the regressions between water potential and water content for the control and EPS-amended sand. Table 1 also shows the significance level (P value) for the hypothesis that the slopes differ between the control and EPS-amended sand. Over both water potential ranges, the slope of the regression line was significantly ($P < 0.1$) greater for the control sand than for the EPS-amended sand. This means that water potential decreased more with decreasing water content in the control sand. In other words, an identical decrease in water content caused a smaller decrease in water potential in the EPS-amended sand than in the control sand.

TABLE 1. The linear relationship of water potential with time and water content in drying sand, with and without extracellular polysaccharide (EPS) added, over two water potential ranges.

	Water Potential	Slope[a]		
		Control	EPS added	p value[b]
Water Content(%)	> -0.9 MPa	0.28	0.11	0.07
	< -0.9 MPa	3.55	1.25	<0.01
Time (hour)	> -0.9 MPa	-0.09	-0.04	0.03
	< -0.9 MPa	-1.15	-1.30	0.74

[a] The slope of the regression of water potential against time or water content in the given water potential range using the data in Figures 6 and 7.

[b] Significance level for the difference between the slopes of the control and EPS amended sand.

Effect of EPS on drying rate. The effect of EPS on the decrease of water content and water potential with time of drying is shown in Figure 7. EPS had no effect on the rate of decrease of water content in the sand. This rate was constant throughout the experiment in both the EPS-amended and the control sand. However, EPS did have a significant effect on the rate of decrease of water potential above - 0.9 MPa (Table 1). The slope of the regression of water potential against time was significantly smaller in the EPS amended sand. The rate of water potential decrease in the sand was therefore significantly slowed by the addition of EPS above -0.9 MPa, even though the rate of water content decrease was not. The effect of this is that the control sand dried to a water potential of -0.9 MPa in approximately 5 hours while roughly double that time was required for EPS amended sand. Below -0.9 MPa, the slopes for the two treatments were not significantly different.

Effect of Alginate on stability. Although incomplete, the data indicate that wetting and drying of Alginate treated aggregates did not have increase stability over 40 wetting and drying cycles compared to treated aggregates that were not wetted and dried. the initial stability of 1 to 2 mm aggregates was 56% (about the same as untreated sand clay aggregates of the same size). After 40 wetting and drying cycles the aggregate stability decreased to 25%. Insufficient data are available for the 1.0% Alginate treated samples to make conclusions about the affect at this higher concentration.

EPS treatment of aggregates was not successful. The material proved to be difficult to handle and was too impure to make meaningful interpretation. At present, a "cleaning-up" procedure is being developed so the material can be added to the aggregates.

DISCUSSION AND SUMMARY

Metabolic response of bacteria to wet/dry cycle. Water availability strongly controlled the production and consumption of protein and polysaccharide by the bacteria. The wetting event caused an initial decrease in the amount of polysaccharide in all cultures between day 0 and day 1 (Figure 4). This may have been the result of consumption of polysaccharides by bacteria growing in response to the increase in water availability. The concurrent increase in protein concentration (Figure 2) suggests that some polysaccharide C may have been used for protein production. Conversely, after day 1 in the desiccated treatment, the amount of polysaccharide increased while protein decreased, implying use of protein, and possibly other cellular components as well, for polysaccharide production in response to desiccation.

The polysaccharide:protein ratio (Figure 8) shows the pattern of C allocation by the bacteria more clearly. The ratio increases when C is allocated to polysaccharide production rather than protein production. The ratio decreased in both control and desiccated cultures after the wetting on day 0, reflecting consumption of EPS and production of protein. The ratio in the control cultures changed little after day 1. In the desiccated cultures, however, the ratio increased as water potential decreased after day 1, showing consumption of protein and synthesis of EPS. By day 3, the polysaccharide:protein ratio was similar to the day-0 value. Changes in water potential, therefore strongly controlled allocation of resources between synthesis of EPS and synthesis of other cellular components.

Adsorption of polysaccharide to surfaces. Wetting and drying significantly decreased the recovery of polysaccharide from sand-clay mixtures (Figure 3). This may be the result of stronger adsorption of polysaccharides to the surfaces of the clay in response to wetting and drying cycles. As the volume of water decreases in a system during drying, the probability of contact between EPS and clay increases. Contact facilitates the development of H-bonds and Van der Waals interactions as well as other bonding mechanisms. Sand did not show an effect of wetting and drying which suggests that adsorption of polysaccharide to sand was low or that the adsorption mechanisms for polysaccharides differ between sand and clay surfaces.

EPS water retention characteristics

The EPS produced by this bacteria held several times its weight in water at low water potential (Figure 6), so the EPS-rich microenvironment surrounding bacteria in the first experiment contained water even when the culture as a whole was dry. The EPS therefore has the ability to retain water in the bacterial microenvironment during desiccation. By maintaining a high water content, EPS may also increase diffusional availability of nutrients to the bacteria.

The effects of the water holding capacity of the EPS can be seen in the effect of EPS on the moisture release curve of sand (Figure 6). The EPS amended sand held more water at all water potentials than the unamended sand. The ANCOVA results in Table 1 show that in addition to quantitatively holding more water, the EPS amended sand also could loose significantly more water than the control before experiencing the same decrease in water potential. The EPS, therefore, can protect bacteria against drying in two ways. It holds a reservoir of water in the microenvironment surrounding bacteria, and it can loose substantial amounts of water from this reservoir during desiccation with relatively little change to the internal water potential in the microenvironment. An EPS-rich microenvironment surrounds bacteria like a protective sponge, buffering them against external changes in water potential.

The presence of EPS substantially slowed the rate of water potential decrease in the sand (Figure 7, Table 1). The drying rate within a matrix of pure polysaccharide, such as in a bacterial colony in soil, would be slower than that of the EPS-sand mixture shown in Figure 7. Bacteria must maintain equilibrium with the water potential of their surroundings. The production of EPS in response to desiccation may provide significant additional time in which to make metabolic adjustments this environmental stress.

Desiccation stimulated EPS production by a soil bacteria and increased EPS adsorption to clay. A small amount of EPS significantly affected the water holding capacity and rate of water potential decrease in sand in this study. The production of EPS may increase the water holding capacity of soil in the same way.

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Roberson, E.B. and M.K. Firestone. The effects of desiccation on activity, biomass, and polysaccharide production by soil bacteria. Applied and Environmental Microbiology. Submitted.

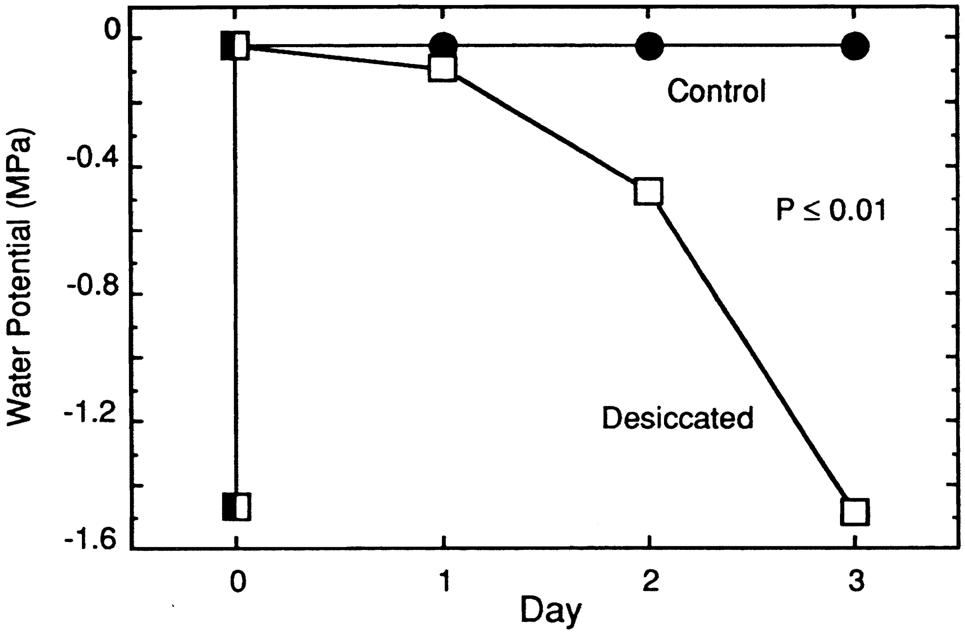

Figure 1. Water potential changes in the two treatments. P value shows level of significance for difference betweeen desiccated and control treatments across days 1 to 3. ◧ indicates that treatments were not separated until after day 0 measurements.

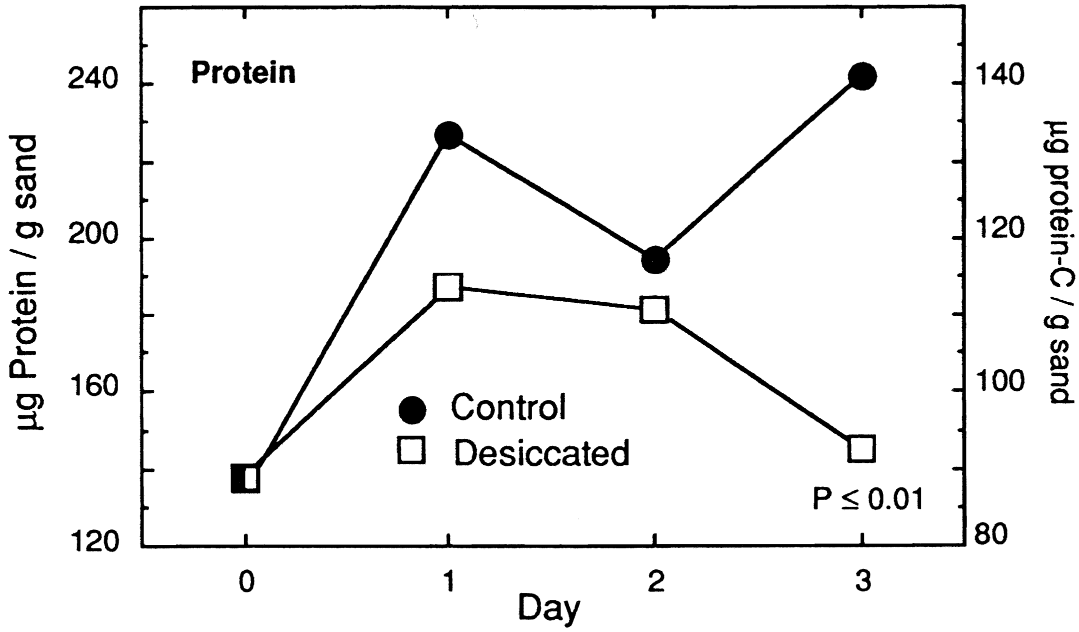

Figure 2. Changes in the amount of protein in the cultures each day. P values show level of significance for differences between desiccated (☐) and control (●) treatments across days 1 to 3. ◧ indicates that treatments were not separated until after day 0 measurements.

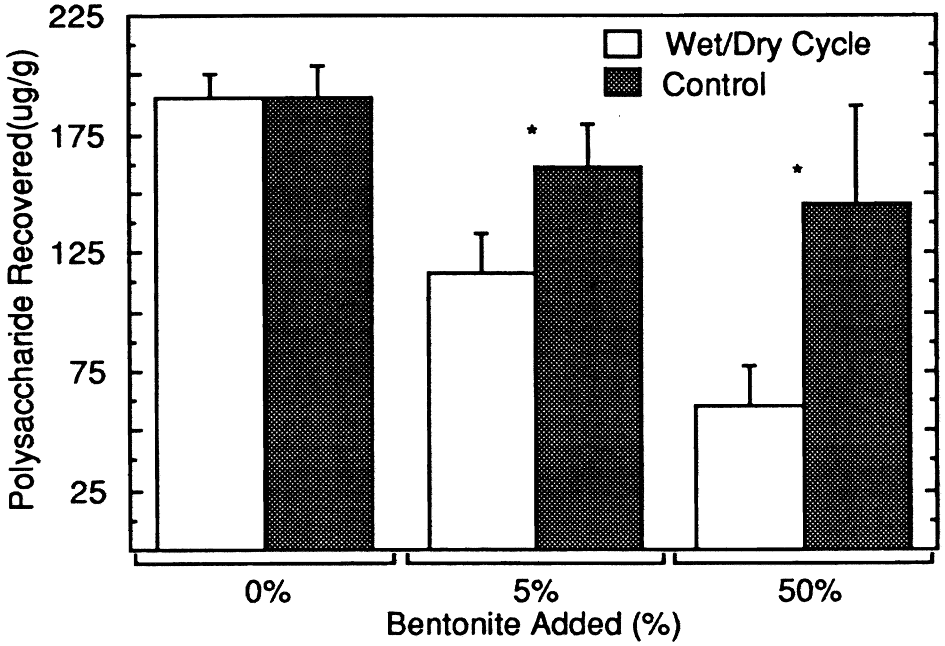

Figure 3. The effects of clay addition and of wet-dry cycles on polysaccharide recovery from sterile sand and sand-clay mixtures. * show treatment effects significant ($p \leq 0.05$) within a clay level.

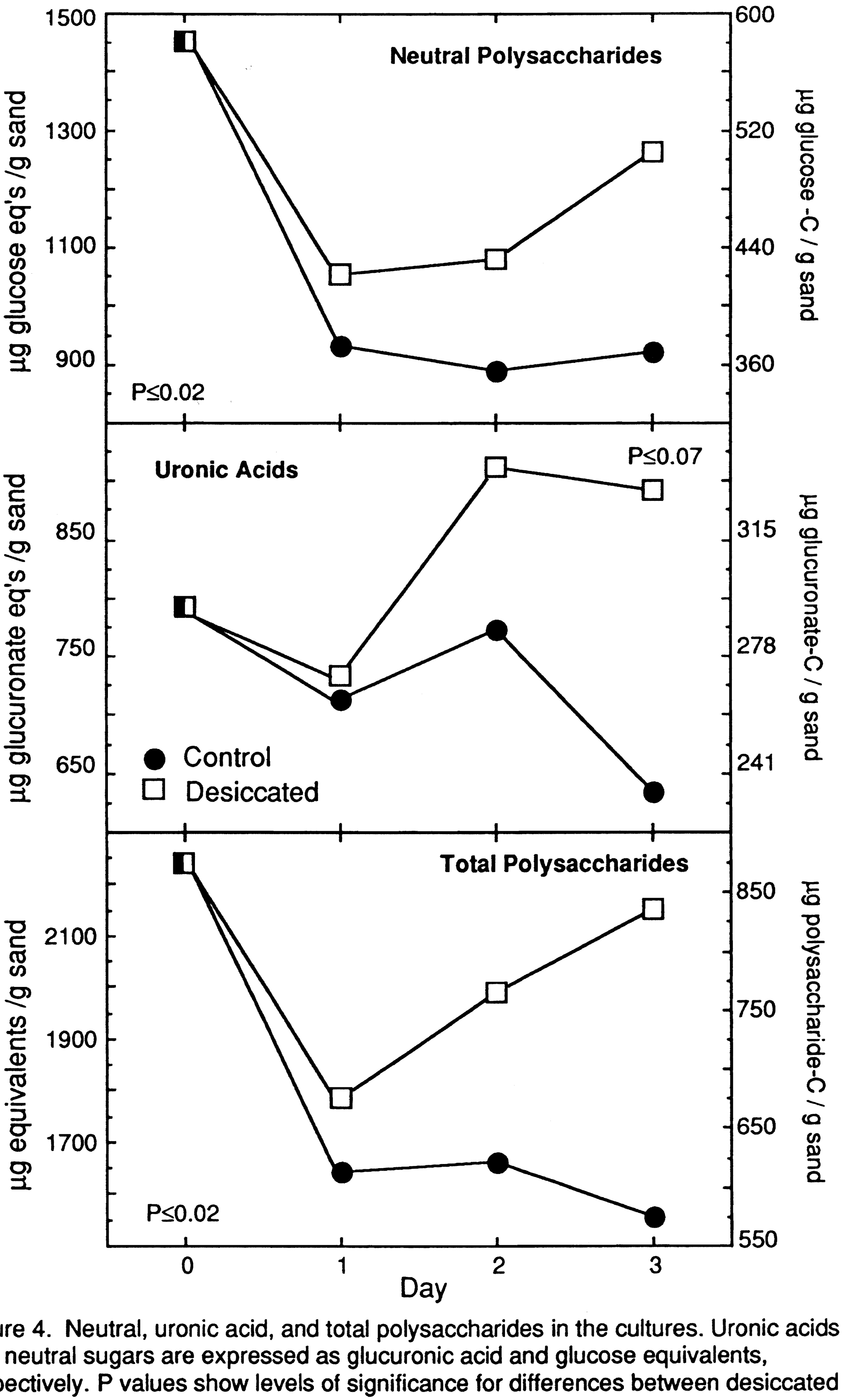

Figure 4. Neutral, uronic acid, and total polysaccharides in the cultures. Uronic acids and neutral sugars are expressed as glucuronic acid and glucose equivalents, respectively. P values show levels of significance for differences between desiccated (☐) and control (●) treatments across days 1 to 3. ◧ indicates that treatments were not separated until after day 0 measurements.

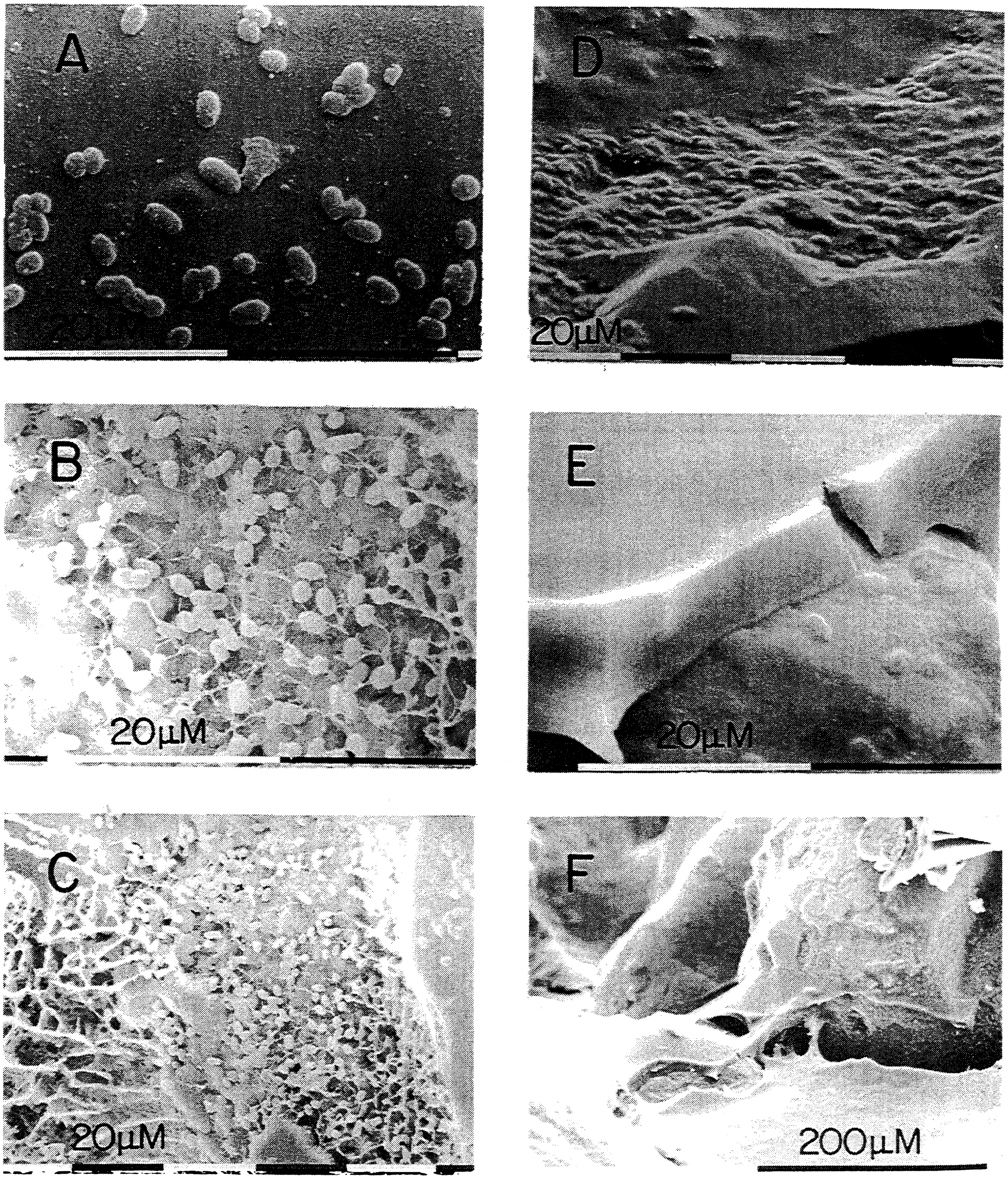

Figure 5. Scanning electron micrographs showing changes in the amount and hydrated structure of extracellular polysaccharide in cultures of Pseudomonas growing on quartz sand at -0.025 MPa (a-c) and after desiccation to -1.0 MPa (d-f).

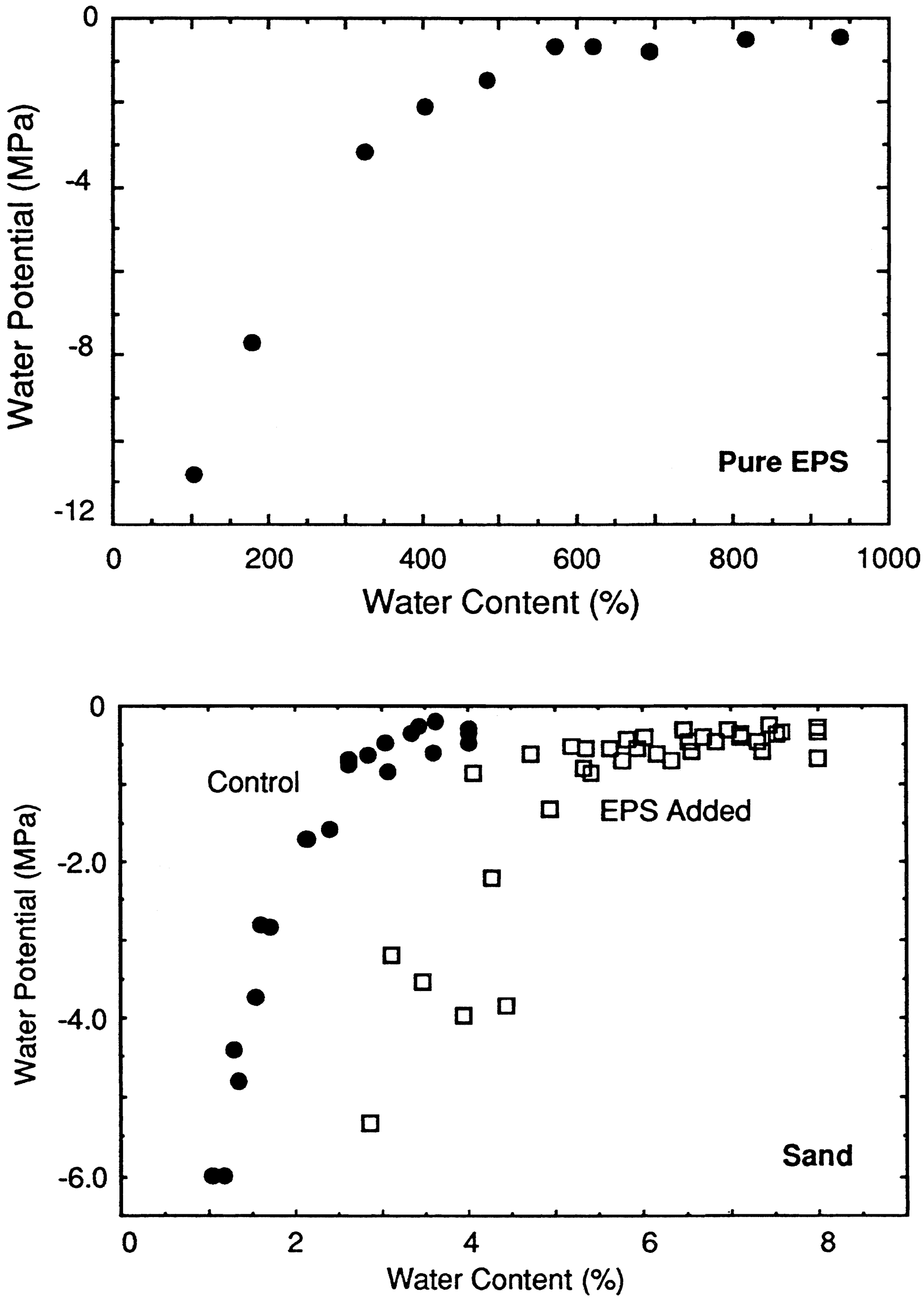

Figure 6. The relationship between water potential and water content in purified exopolysaccharide (EPS) (above) and in sand with (□) and without (●)EPS added.

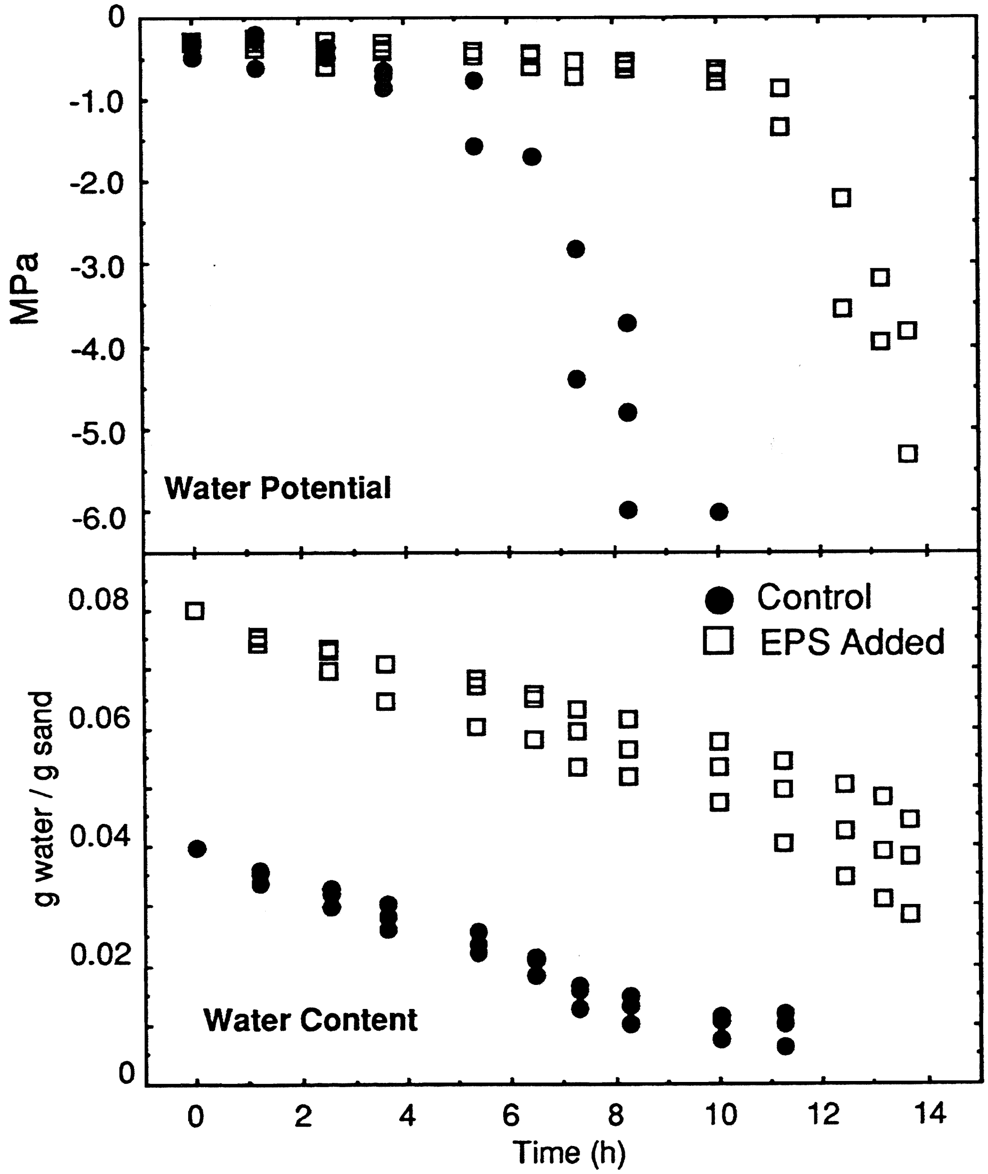

Figure 7. Changes in water potential (above) and water content during 14 hours of drying in sand with (□) and without (●) EPS added.

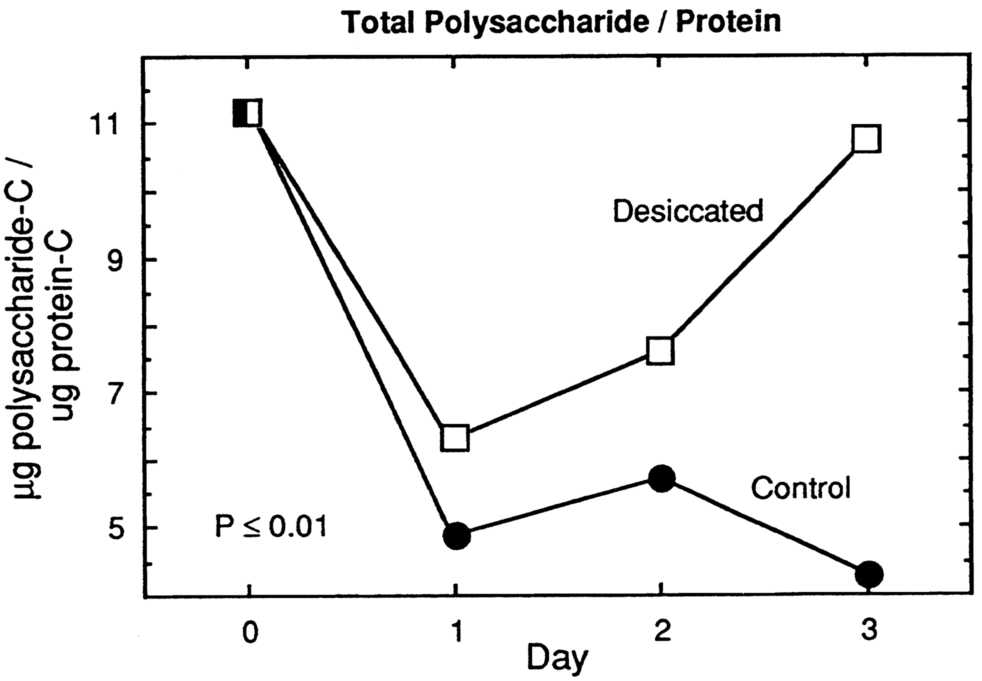

Figure 8. Changes in the ratio of total (uronic acid + neutral) polysaccharide to protein. P value shows level of significance for difference betweeen desiccated and control treatments across days 1 to 3. ◧ indicates that treatments were not separated until after day 0 measurements.

PROJECT TITLE: MANAGEMENT OF POLYSACCHARIDE-MEDIATED AGGREGATION IN SOIL.

PROJECT NUMBER: 89-18

DURATION OF FUNDING: JULY 1989 - JUNE 1991

PROJECT INVESTIGATORS:

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FTE Commitment:	0.10	FTE Commitment:	0.05

RESEARCH STAFF: 2 persons, 1.0 total FTE

Postgraduate Researcher	S. Sarig	0.50 FTE
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ABSTRACT:

Carbon and nitrogen inputs to a tomato field were managed using two winter cover crops, vetch and oats, an N-fertilizer treatment, and a control. In the soils from these four treatments, the heavy fraction carbohydrates (in the soil fraction heavier than 1.76 g/ml) were correlated with "improvements" in soil structure reflected by increased aggregate staking resistance and saturated hydraulic conductivity. The heavy fraction carbohydrates appeared to be dominantly of microbial origin. Nitrogen availability strongly controlled microbial polysaccharide production in this soil, and the N fixing cover crop performed better than either the non N fixing cover crop or N fertilizer in stimulating microbial polysaccharide production and improving soil structure. Measurements of heavy fraction carbohydrate may be useful in assessments of short term effectiveness of agricultural management practices.

KEYWORDS: polysaccharide, microbial, aggregation, bacterial, nitrogen

PROJECT OBJECTIVES ADDRESSED:

1. To understand the nutritional control of microbial polysaccharide production in soil.
2. To determine whether polysaccharide-mediated aggregation can be managed by fertilization in agricultural soils.

RESEARCH PLAN AND PROCEDURES:

Field Methods

The experimental plots are on the Student Farm at the University of California, Davis. The field experimental design was conceived by and is maintained by C. Shennan and colleagues. The soils are Yolo fine sandy loam (fine-silty, mixed, nonacid, thermic Typic Xerorthent) and Rieff sandy loam (coarse-loamy, mixed, nonacid, thermic, Mollic Xerofluvent). All plots were planted to a summer crop of tomatoes Lycopersicon esculentum Mill. in May.

We collected soil from four treatments: two cover crop treatments, a nitrogen fertilized treatment, and a control. Treatments were laid out in complete randomized block design with two blocks to account for the effects of the two soil types, and two replications per block. The fertilized plots, designed to receive only N inputs, were fertilized with 168 kg $(NH_4)_2SO_4$ - N per hectare in two split applications, one before planting and one 3 weeks after seedling emergence. The control plot received neither fertilizer nor cover crop inputs. Fertilized and control plots were left fallow over winter. Plant cover on these plots was discouraged by applications of herbicide (glyphosate). The winter cover crop treatments were planted to either vetch (Vicia sativa L.), which fixes N and added both N and C to the soil, or oats (Avena sativa L.), which supplied predominantly C, in October. Crops were plowed into the soil before planting. Cover crop plots received no fertilizer.

All plots were cultivated once with a chisel plow, twice with a sled cultivator, and sprinkle irrigated before the tomato crop was planted. Tomatoes were grown in raised beds and furrow irrigated at one to two week intervals during the growing season. There was no cultivation during the growing season; weeds were controlled by hand.

Pooled bulk soil samples, from both furrows and raised beds, and duplicate intact cores were taken from the upper 10 cm soil in each plot on two sampling dates in 1990, the fifth season of the experiment. The first sampling was in March, before winter cover crop incorporation or fertilizer application. The second was in July, during the growing season for the summer tomato crop. Samples for microbial biomass, respiration, saturated hydraulic conductivity, and N mineralization were stored field moist at 4C and were processed within 3 days. Samples for total C and N, carbohydrate, aggregate stability and mean weight diameter were dried over LiCl before measurement.

Laboratory Methods

Field moist soil samples were pooled and sieved to pass a 4 mm mesh. Subsamples were brought to a uniform water content of 25% (w/w) and assayed for microbial biomass, potential N mineralization, and microbial respiration. Microbial biomass C was estimated using the chloroform fumigation-incubation method (Voroney and Paul, 1984). Fumigated and control samples (20g each) were incubated for 10 days at 21°C in sealed mason jars equipped for gas sampling. Production of CO_2 was measured using a gas chromatograph. Control samples were incubated for an additional 10 days for soil respiration measurement. Potential N mineralization was measured using a modification of the method of Stanford and Smith (1972). The availability of N was estimated using potential N mineralization during a 20 day aerobic incubation. Soil NH_4^+ and NO_3^- pools were extracted from separate samples before and after the incubation with 2N KCl (20 g moist weight in 100 ml solution) and production or consumption determined by difference. Analysis for N species was performed using a Lachat flow-injection autoanalyzer (Lachat Chemicals, Inc., Mequon, Wisconsin).

Dry soil was sieved into four aggregate size fractions, 0.15 to 0.3, 0.3 to 1.0, 1.0 to 2.0, and 2.0 to 4.0 mm, and dry aggregate mean weight diameter (MWD) was calculated after Kemper and Rosenau (1986). Mean weight diameter is the weighted average of soil mass in each aggregate size fraction. It is an index of aggregate size distribution in each treatment. Saturated hydraulic conductivity was measured in intact cores, from the summer sampling date only, according to the method of Klute and Dirksen (1986).

Slaking resistance of aggregates in the 0.3 to 2.0 mm diameter fraction, dried over LiCl, was measured as described previously (Roberson et al., 1991). Five grams of aggregates were placed in a 10 by 4 cm cylinder on a 0.3 mm sieve, and covered by a filter paper to minimize disruption by drop impact. Water (2.5 L) was poured through them so that a constant head of 10 cm of water was maintained in the cylinder. Soil remaining on the sieve was oven dried and weighed. Aggregate slaking resistance is expressed as the percent oven dried soil remaining on the sieve after treatment.

Soil from the <0.3 mm and the 0.3 to 2 mm fraction was ground to powder using a rolling ball mill before determination of total organic C, light and heavy fraction carbohydrates. Management had little effect on organic matter content of soil <0.3 mm. This result is consistent with other reports (Tisdall and Oades, 1980; Elliott, 1986; Weill et al., 1988). For this reason, results are reported only for the 0.3 to 2 mm fraction. Total organic C was measured using a wet oxidation technique (Snyder and Trofymow, 1984). Neutral carbohydrates were measured in acidic soil hydrolysates of both the heavy fraction and whole soil. The LF was determined by difference. Heavy fraction carbohydrate was defined as material denser than 1.74 g/mL. Lighter material was removed by densimetric flotation and centrifugation using NaI (Strickland and Sollins, 1987; Roberson et al., 1991). Soil was hydrolyzed using a method similar to that of Oades et al. (1970). Soil was heated to 120 °C with 2.5M H_2SO_4 for 30 minutes and filtered through a glass fiber filter. The soil was further extracted once with boiling water. Extracts were pooled and total neutral carbohydrates were determined using the anthrone method (Brink, et al., 1960) and are reported as g glucose equivalents/kg soil.

Monosaccharide Distribution

The distribution of monosaccharides was analyzed in extracts of soil from the two cover crop treatments and from soil from the same experimental field but from plots fertilized with 280 kg $(NH_4)_2SO_4$ - N per hectare. Extracts were neutralized to pH 4.0 with 10 M KOH and precipitate was removed by filtration though a glass fiber filter. Samples were then analyzed on a Dionex Liquid Chromatograph (Dionex, Inc. Sunnyvale, Calif.) using pulsed amperometric detection (Martens and Frankenberger, 1990a, b).

Statistical Analysis

With the exception of saturated hydraulic conductivity which was only measured in the summer and so was analyzed by randomized complete block analysis of variance (ANOVA), treatment responses were analyzed using randomized complete block repeated measures ANOVA (Weiner, 1971) with sampling date as the within factor. Analyses of variance were performed on untransformed data, again with the exception of saturated hydraulic conductivity which has been found to be lognormally distributed (Biggar and Nielsen, 1976). Means comparisons were made using the single degree of freedom contrast method. Relationships among soil properties were investigated with linear and multiple regression techniques (Draper and Smith, 1981). Sampling date, treatment, and block were included as factors in the multiple regression to eliminate their effects from the analysis. All statistical analyses and graphics were performed using StatView II and SuperANOVA software (Abacus Concepts, Inc., Berkeley, CA).

RESULTS:

Table 1 shows the (galactose + mannose)/(xylose + arabinose) ratios in soil from three treatments. In all three treatments, the ratio is significantly higher in the HF carbohydrates than in the LF. The difference between the ratios for the HF and LF was not significantly affected by treatment. This result implies that carbohydrates in the HF are predominantly of microbial origin while the LF contains mainly plant carbohydrates (Cheshire, 1977; Oades, 1984).

The effects of the treatments on soil carbohydrate is shown in Figure 1. The figure also shows the effect of sampling date on the response to treatment. The plots that received N inputs, vetch and fertilized (N treatments), contained more HF carbohydrate in both the spring and summer samplings than the oats and control plots. Significantly more HF carbohydrate was measured in the summer in all treatments. More LF carbohydrate, on the other hand, was present in the soil in the spring sampling than in summer. No significant differences were found between LF carbohydrate in the treatments in the spring. In summer, LF carbohydrate followed the same pattern as the HF: the N treatment plots contained more LF carbohydrate than the other plots.

Soil aggregate slaking resistance, mean weight diameter, and saturated hydraulic conductivity are shown in Figure 2. Saturated hydraulic conductivity was greatest in the vetch treatment, followed by the fertilized treatment. Aggregate slaking resistance was higher in the vetch and fertilized plots in the spring and significantly higher in all treatments compared to the control in the summer. Slaking resistance increased significantly in the fertilized and oat treatments between the spring and summer samplings. Mean weight diameter was not affected by the treatments, but it was significantly decreased in all treatments in summer.

The amount of C and N in the 0.3 to 2.0 mm fraction is shown in Figure 3. On both sampling dates, the vetch plots contained more organic C and N than any other treatment. In the spring, little difference was found in organic C between the plots with the exception of the higher C content of the vetch plots relative to the control. Soil N content was significantly higher in both N treatments than in the oats or control in the spring sampling date. In summer, however, the main effect was of cover crop rather than N supply. The cover crop treatments significantly increased the amount of both C and N in the soil over the control and fertilized treatments. The cover crops also significantly increased the amount of C and N in the soil in the summer sampling relative to spring.

Figure 4 shows the response of microbial biomass, respiration, and potential N mineralization to the treatments. No significant treatment effects were found for microbial biomass or respiration in the spring. On the summer sampling date, however, the vetch plots contained significantly more microbial biomass than the other plots, and respiration was higher in both N treatments. On both sampling dates N mineralization was stimulated by the N treatments. Microbial biomass was lower in the summer than in the spring, but N mineralization was higher in the summer. Respiration did not show a clear effect of sampling date.

Tables 2 and 3 show correlation matrices for the spring and summer sampling dates. In the spring, HF carbohydrate was most closely correlated with aggregate stability, followed by organic N, and N mineralization. No organic fraction was shown to be related to mean weight diameter. Saturated hydraulic conductivity was not measured in the spring. On the summer sampling date, HF carbohydrate was again most closely related to slaking resistance and saturated hydraulic conductivity. LF carbohydrate, organic N, N mineralization, and respiration were also significantly correlated with saturated hydraulic conductivity, however, and N mineralization and respiration were correlated with aggregate stability. In contrast to the spring sampling, summer mean weight diameter was correlated with total organic C, N, and microbial biomass.

Multiple regression was performed (Table 4) to rank these different soil organic fractions as controllers of aggregate stability and saturated hydraulic conductivity. No organic fraction was significantly related to mean weight diameter by multiple regression (data not shown). HF carbohydrate was the only organic component found by multiple regression to be significantly related to aggregate stability. No organic fraction was significantly ($p \leq 0.05$) related to saturated hydraulic conductivity, but HF and LF carbohydrate were the variables most closely related to it ($p \leq 0.1$).

DISCUSSION:

The difference between the monosaccharide ratios (Table 1) of LF and HF carbohydrate supports the hypothesis that HF carbohydrate, as defined in this study, is enriched in microbial polysaccharides. Of the organic fractions we measured, HF carbohydrate was also the most closely related to soil structure. These data are consistent with other studies (e.g. Clapp et al., 1962; Lynch, 1981), and conceptual models of soil structure, including that of Tisdall and Oades (1982), that show microbial polysaccharides to play an important role in stabilizing soil aggregates. They are also consistent with the idea that the HF fraction of soil carbohydrate is closely associated with soil minerals.

In a previous study (Roberson et al., 1991), we found that cover crop inputs of microbially available C stimulated rapid production of HF carbohydrate and improved soil structure. In this study, where both N and C availability were varied by management, N availability appears to have controlled microbial activity and microbially mediated changes in soil structure more than C availability. The N treatments clearly outperformed the oat and control treatments in increasing soil HF carbohydrate content, saturated hydraulic conductivity and aggregate stability. The N treatments also showed higher microbial respiration and N mineralization rates. Some of these effects are the result of increased C as well as N availability in the N treatments, however. Plants deposit a substantial portion of the C that they fix into the soil as root exudates and dead roots (Barber and Martin, 1976; Norton, 1991). The vetch treatment therefore added C to the soil both through root exudation and turnover during winter and spring and through decomposition of residues during the summer growing season. The fertilized treatment also increased C availability indirectly by stimulating growth (Shennan, pers. commun.) and therefore root exudation and and root turnover by the summer tomato crop.

The stimulation of C availability by fertilization can be seen by comparing the fertilized treatment with the control on the summer sampling date (Figures 1,2,4) when the tomato crop was in the plots. Microbial respiration rate, soil HF carbohydrate content, and aggregate stability were all significantly higher in the fertilized plots than in the control plots in summer. In spring, when fertilized and control plots were bare and rhizodeposition negligible, no significant differences were measured between the two treatments. The data from the fertilized treatment do not, therefore, reflect the effects of N addition alone.

Vetch was as effective as or more effective than N fertilizer in increasing HF carbohydrate, microbial biomass, soil organic C and N contents, N mineralization, and improving soil structure, particularly on the summer sampling date. The vetch treatment also significantly increased aggregate stability and HF carbohydrate content in both sampling dates while the effect of N fertilizer was more important in the summer. In the oat treatment, C was the major addition to the soil, and HF carbohydrate production and saturated hydraulic conductivity were not significantly different from the control. The oat treatment did increase aggregate stability relative to the control in the summer. The non N fixing cover crop alone was generally comparable to N fertilization in controlling changes in soil carbohydrates, soil structure, or microbial activity in this system. The maximum response was obtained when both N and C availability were increased by the N fixing cover crop.

Soil structure and soil organic matter content and composition changed significantly between the two sampling dates. The amounts of microbial biomass and LF carbohydrate in the soil were lower in the summer than in the spring. The higher summer temperatures, tillage and irrigation caused a portion of these materials to be broken down. The dry aggregate MWD was also significantly lower in the summer, possibly because some larger aggregates were broken by cultivation. On the other hand, HF carbohydrate content and aggregate stability both increased in summer relative to the spring sampling date. Some of the microbial biomass or LF carbohydrate that was broken down between spring and summer may have been resynthesized as EPS by soil microorganisms, although some of the increase in HF can also be traced to rhizodeposited C from the tomato crop, as discussed above.

Correlation analyses (Tables 2,3) show that HF carbohydrate was the organic fraction most highly correlated with aggregate stability for both sampling dates, and with saturated hydraulic conductivity in the summer. Other organic fractions, however, were also significantly correlated with aggregate slaking resistance and saturated hydraulic conductivity. Multiple regression (Table 4) confirmed that HF carbohydrate was most closely related fraction to both aggregate stability and saturated hydraulic conductivity. The amount of LF carbohydrate was as important as HF carbohydrate in controlling saturated hydraulic conductivity, but not aggregate stability. LF carbohydrate may participate in stabilizing macropores between aggregates which are important in saturated hydraulic conductivity, while HF carbohydrate stabilizes aggregates which also contributes to hydraulic conductivity.

Extracellular polysaccharides are immediate byproducts of microbial metabolism; so that changes in management practices may be quickly reflected in changes in microbial EPS production. The carbohydrate fraction of soil organic matter has been found to be associated with rapid changes in soil structure in response to management (Greenland et al.,1962). Other organic aggregating agents, such as humic acids, may take more time to form. The plots in this study had been conventionally tilled for five years. Tillage disrupts aggregates and exposes organic aggregating agents to microbial attack (Adu and Oades, 1978; Reganold et al., 1987). The loss from the soil of these aggregating agents may increase the importance of more rapidly synthesized substances such as EPS. The increase in HF carbohydrate content and aggregate stability in the four months between the spring and summer sampling dates, combined with the high correlation between the two, appears to confirm the rapid production of microbial EPS and its effectiveness in aggregate stabilization.

Microbial biomass was not well correlated with aggregate slaking resistance or saturated hydraulic conductivity in this study. This suggests that fungal hyphae are not important aggregating agents in this system. Biomass was better correlated with aggregate slaking resistance on the spring sampling date, after several months without cultivation, than in the summer (Tables 2,3). In our previous work, using less intensively tilled soil, microbial biomass was highly correlated with aggregate stability. These results are consistent with other research which has found that fungi are more important in reduced tillage systems than in conventional tillage (Hendrix et al., 1986; Dormaar and Lindwall, 1989).

CONCLUSIONS:

We have found that heavy fraction carbohydrate is enriched in microbial EPS and can be important in rapid improvements in structure in agricultural soils. Nitrogen availability strongly controlled microbial EPS production in this soil, and an N fixing cover crop performed better than either a non N fixing cover crop or N fertilizer in stimulating microbial EPS production and improving soil structure. Measurements of HF carbohydrate may be useful in assessments of short term effectiveness of agricultural management practices.

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TABLE 1. Monosaccharide ratios in acid extracts of the light (LF[†]) and heavy (HF[‡]) fraction of soil from selected treatments.

Treatment	Fraction	$\frac{\text{galactose + mannose}}{\text{xylose + arabinose}}$	Standard Error
Fertilized*	HF†	1.03a§	0.09
	LF‡	0.24b	0.06
Vetch	HF	1.15a	0.12
	LF	0.20b	0.03
Oats	HF	1.17a	0.13
	LF	0.18b	0.03

† Carbohydrate in the heavy fraction of soil (density > 1.74 g/cm^3)

‡ Carbohydrate in the light fraction of soil (density < 1.74 g/cm^3)

§ Mean of 4 replicates per treatment. Means within each treatment followed by different letters are significantly different at the $p < 0.$ level.

* Fertilized with 280 kg $(NH_4)_2SO_4$ - N / ha.

TABLE 2. Correlation matrix (n=20) for organic components and structural characterisitics of the soil for the spring sampling date.

	Slak. Res.	MWD	HF Carb.	LF Carb.	Org. C	Org. N	N min.	Resp.	Biomass
Slak. Res.	1								
MWD	-0.04	1							
HF Carb.	0.72	0.32	1						
LF Carb.	-0.23	-0.12	-0.25	1					
Org. C	0.34	-0.26	0.33	0.19	1				
Org. N	0.65	-0.02	0.58	0.04	0.65	1			
N Min.	0.63	0.31	0.62	0.01	0.32	0.67	1		
Resp.	-0.01	0.22	0.08	0.10	0.46	0.51	0.22	1	
Biomass.	0.56	-0.01	0.53	0.15	0.40	0.51	0.63	-0.18	1
Resp. / N min.	-0.50	-0.07	-0.41	0.15	0.13	-0.14	-0.57	0.63	-0.52

TABLE 3. Correlation matrix (n=20) for organic components and structural characterisitics of the soil for the summer sampling date.

	Sat. K	Slak. Res.	MWD	HF Carb.	LF Carb.	Org. C	Org. N	N min	Resp.
Sat. Hyd. Cond.	1								
Slak. Res.	0.62	1							
MWD	0.01	-0.23	1						
HF Carb.	0.88	0.73	0.09	1					
LF Carb.	0.67	0.25	-0.01	0.48	1				
Org. C	0.44	0.27	0.51	0.41	0.57	1			
Org. N	0.60	0.36	0.48	0.55	0.63	0.96	1		
N Min.	0.51	0.54	-0.26	0.52	0.50	0.45	0.45	1	
Resp.	0.57	0.59	-0.37	0.56	0.43	0.36	0.38	0.95	1
Biomass.	0.37	0.17	0.60	0.25	0.44	0.51	0.55	-0.06	-0.20
Resp./N min.	0.51	0.55	-0.50	0.47	0.17	0.02	0.13	0.42	0.66

TABLE 4. Summary of slopes of linear regressions and probability values obtained by multiple regression analysis# ranking fracti of the soil organic matter and microbial activity as controllers of aggregate slaking resistance and saturated hydrau conductivity.

	Dry slaking resistance†		Sat. hydraulic conductivity ¶	
Fraction	P value	Slope	P value	Slope
H.F. Carbohydrate‡	<0.01	15.31	0.10	2.4×10^{-5}
L.F. Carbohydrate§	0.91	-1.88	0.11	1.3×10^{-5}
Organic C	0.91	0.64	0.85	5.5×10^{-7}
Organic N	0.69	16.10	0.18	1.5×10^{-5}
N Mineralization	0.33	1.5×10^{3}	0.16	1.0×10^{-2}
Respiration	0.80	496.52	0.23	1.0×10^{-3}
Biomass C	0.72	13.84	0.88	8.7×10^{-7}

† Slaking resistance of air dried aggregates between 0.3 and 2 mm in diameter. Spring and summer sampling dates combined.

‡ Carbohydrate in the heavy fraction of soil (density > 1.74 g/cm^3)

§ Carbohydrate in the light fraction of soil (density < 1.74 g/cm^3)

¶ Values from summer sampling date only.

\# Treatment, sampling date, and block factors were also included in the multiple regression.

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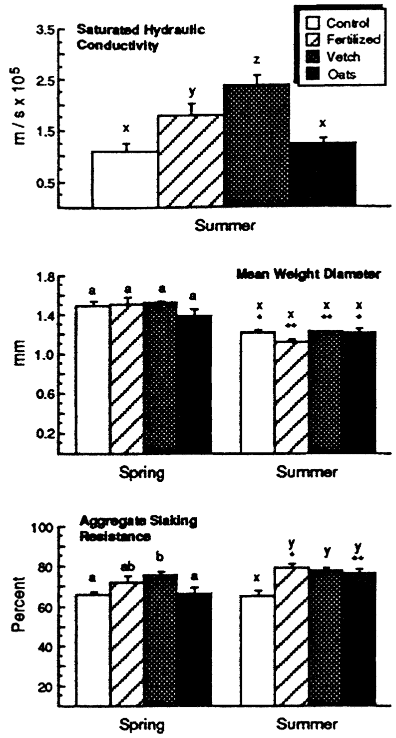

Figure 2. Treatment responses for saturated hydraulic conductivity (summer only), dry mean weight diameter, and aggregate slaking resistance for the two sampling dates. Treatments labeled with the same letter did not differ at the $p \leq 0.05$ level within a sampling date. *, ** indicate that the effect of sampling date was significant for that treatment at the $p \leq 0.05$, and $p \leq 0.01$ significance levels, respectively.

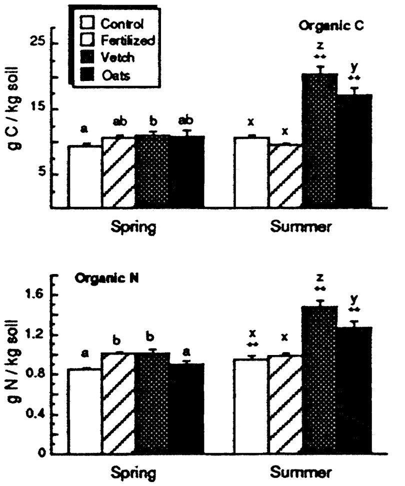

Figure 3. Treatment responses for total organic C and N for the two sampling dates. Treatments labeled with the same letter did not differ at the $p \leq 0.05$ level within a sampling date. *, ** indicate that the effect of sampling date was significant for that treatment at the $p \leq 0.05$, and $p \leq 0.01$ significance levels, respectively.

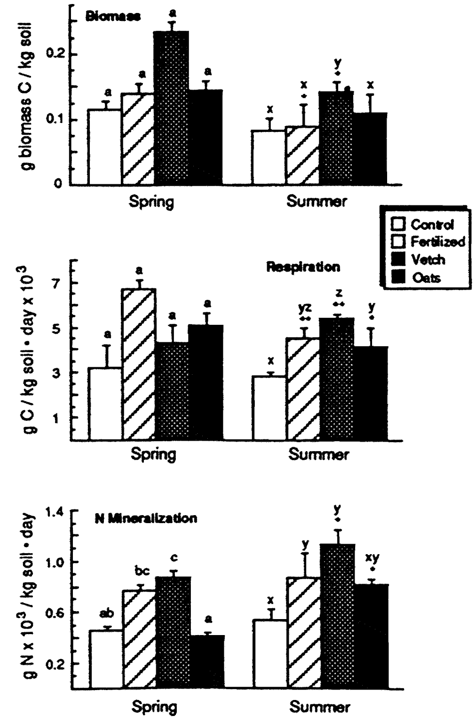

Figure 4. Treatment responses for microbial biomass, potential respiration, and potential N mineralization for the two sampling dates. Treatments labeled with the same letter did not differ at the $p \leq 0.05$ level within a sampling date. *, ** indicate that the effect of sampling date was significant for that treatment at the $p \leq 0.05$, and $p \leq 0.01$ significance levels, respectively.

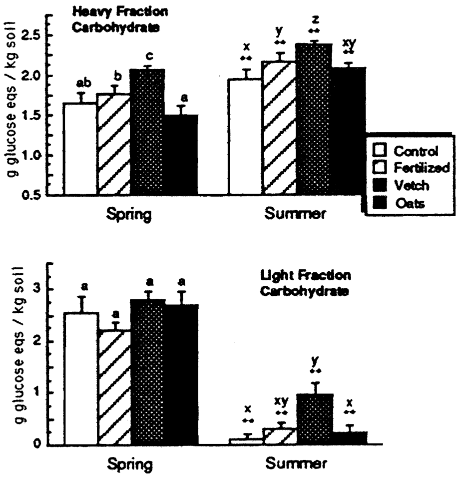

Figure 1. Treatment responses for light and heavy fraction carbohydrate for the two sampling dates. Treatments labeled with the same letter did not differ at the $p \leq 0.05$ level within a sampling date. *, ** indicate that the effect of sampling date was significant for that treatment at the $p \leq 0.05$, and $p \leq 0.01$ significance levels, respectively.

PHYSICS AND ENGINEERING

PROJECT TITLE: ROLE OF WETTING AND DRYING CYCLES IN SURFACE SOIL STRUCTURE DEVELOPMENT IN THE CENTRAL VALLEY OF CALIFORNIA

PROJECT NUMBER: 89-7

DURATION OF FUNDING: July 1990 - June 1991

PROJECT INVESTIGATORS:

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Location:	Davis Campus	Location:	Davis Campus
FTE Commitment:	0.20	FTE Commitment:	0.20

RESEARCH STAFF:

Postgraduate Researcher	1 @ 1.00 FTE 1 @ 0.25 FTE

ABSTRACT:

We continued to study soil aggregate stability by constructing synthetic aggregates by drying a slurry of 0.1 to 0.5 mm diameter acid washed quartz sand and pure clay at 40°C. The resulting dry mixture was sieved and the <0.5, 0.5-1.0 and 1.0-2.0 mm diameter aggregates were subjected to up to 80 wetting and drying cycles. In addition to varying the amount and type of clay, iron oxides and silt were added to the mixtures to determine the influence of these additives to the aggregate stability. The wet stability (Yoder method) of 1 to 2-mm diameter aggregates with 5% clay decreased, regardless of clay type, as the number of wetting and drying cycles increased. The smectite and illite 0.5 to 1-mm diameter aggregate stability did not change significantly over 32 cycles. Following an initial decrease, wet stability for the 0.5 to 1-mm 5% kaolinite aggregates increased to equal the 0 cycle stability as the number of cycles increased. Increasing smectite clay content from 5 to 25% increased the initial wet aggregate stability, but decreased the kaolinite and illite wet aggregate stability for both aggregate size fractions. Only the kaolinite aggregate stability increased regularly with an increasing number of wetting and drying cycles. We attribute the variation in response to wetting and drying cycles to variation in clay-clay and clay-sand interactions. The effect of wetting and drying on natural soil aggregates was to decrease the stability.

KEYWORDS: smectite, kaolinite, illite, Yoder wet sieving.

PROJECT OBJECTIVES ADDRESSED:

We addressed three questions during the past year. 1. How do wetting and drying cycles influence the aggregate stability of artificial aggregates consisting of sand and three reference clay minerals, smectite, kaolinite and illite. 2. How does the addition of Fe and organic polymers affect the stability during wetting and drying and 3. How do wetting and drying cycles affect the aggregate stability of natural soils.

RESEARCH PLAN AND PROCEDURES:

Commercial quartz sand was sieved to separate the 0.1 to 0.5 mm fraction followed by washing in hot 1N HCl and rinsing in distilled water. The sand was then cleaned of clay and silt by repeated sedimentation in distilled water . Smectite, kaolinite and illite were prepared from commercial material using standard sedimentation techniques to remove all but the <2 μm fraction from the sample. The clean Na-clay was then saturated with calcium using $CaCl_2$, excess salt was removed by washing with ethanol and the clay was dried by freeze drying.

For the first experiment, slurries of each clay type consisting of 95g sand and 5g of clay were dried at 40°C. Each mixture was stirred at intervals during the drying to insure intimate contact between sand and clay. The mixture was stirred more frequently as it approached the plastic limit. In a second experiment the proportions of sand and clay in the mixture were varied to produce aggregates consisting of 10, 15, and 25% smectite, and 25% kaolinite or illite. The same slurry and drying procedure used in experiment 1 was repeated in experiment 2. In experiment 3, smectite and kaolinite in equal proportions were mixed with sand, and in experiment 4, 10% smectite and 15% silt sized quartz were mixed with sand using the same techniques.

After drying, the mixture was gently crushed through square hole sieves of 2.0, 1.0 and 0.5 mm diameter. The resulting particles are referred to as "aggregates" . Four grams of each size material was placed on a filter paper disk in a small aluminum dish for the wetting and drying procedure. Each cycle started with wetting the edge of the filter paper disk with 3.0 mL of distilled water and allowing the aggregates to absorb the water. After about five minutes, the wet aggregates in their aluminum dishes were placed in the ≈40 ∞C oven for a minimum of 2.5 h. The dry aggregates were removed from the oven and cooled in the air before the start of the next cycle. Three dishes were selected after various numbers of cycles and the stability of the synthetic aggregates was measured using the wet sieving technique (Yoder, 1936). A fourth set of samples was treated in the same way, but instead of measuring aggregate stability, samples were saved for scanning electron microscopy.

RESULTS:

Aggregates of 1.0 to 2.0 mm and 0.5 to 1.0 mm diameters were studied for all three clay types and different clay percentages. Originally, we put the aggregates through 80 wetting and drying cycles. We found that 40 cycles was sufficient in most cases to see the effect of the number of cycles on stability.

Aggregate Stability of 5% Mixtures

Smectite. Stability of the 1.0 to 2.0-mm diameter aggregates made with 5% smectite decreased from 38% to 31% after eight cycles, increased through 24 cycles, after which there was no significant change through 60 cycles (Figure 1, Table 1). The final stability was nearly 33% after 60 wetting and drying cycles. Although not tested statistically, there did not appear to be differences between the behavior of the 1 to 2 mm and the 0.5 to 1.0 mm aggregate stability. No significant differences were found among the initial, first or final cycle for the 5% 0.5 to 1.0-mm smectite aggregates. For these aggregates there was little change in stability through 40 cycles. The minimum stability was reached after 8 cycles and the maximum after 24 cycles. The maximum stability was not significantly different from the initial stability (Table 1). It should be noted that the original mass of aggregates was used in the calculation rather than the actual weight of material on the sieve. Some of the original clay eluviated into the filter paper during the wetting and drying. This is discussed later in this report.

Kaolinite. Initial stability of the 1 to 2-mm 5% kaolinite aggregates was 39%. The stability remained at 39-40% through four cycles then decreased to approximately 33% stability after 60 cycles (Table 2). No replicates were run for this treatment because the yield of aggregates from dry sieving was very low. The initial and final absolute stability of the 1 to 2 mm kaolinite aggregates was lower than the stability of the 0.5 to 1 mm aggregates (Table 2). Stability of the 0.5 to 1.0-mm aggregates decreased from 46% to 37%, after eight cycles, followed by a steady increase in stability. After 60 cycles, the final wet aggregate stability (47%) was not significantly different from the initial stability.

Illite. Aggregate stability decreased from 23% to 20% after one cycle and remained approximately constant through 32 cycles for the 5% illite 1.0 to 2.0-mm aggregates (Table 3). The final stability of the 1.0 to 2.0-mm illite aggregates was significantly less than the initial stability, but not significantly different than the stability after one wetting and drying cycle. There were no significant differences among the measured aggregate stabilities of the 0.5 to 1.0-mm illite aggregates between 0 and 32 cycles.

Aggregate Stability of >5% Clay Mixtures

Smectite. The initial aggregate stability of the 1 to 2-mm diameter smectite aggregates increased significantly (0.05 level) from 38 to 58% when the smectite content was increased from 5 to 10%. Stability did not increase with a further 5% increase in smectite, but the 25% smectite aggregates had a significant increase in initial aggregate stability to 74% (Table 1). At each smectite content, aggregate stability decreased after one wetting and drying cycle. Aggregate stability decreased the most for the 10% smectite treatment, but was followed by nearly complete recovery of the original aggregate stability after 60 cycles. The 15% and 25% smectite aggregate stability generally decreased through 32 cycles.

The behavior of the 0.5 to 1.0-mm aggregates was similar to that of the 1 to 2-mm aggregates. Initial aggregate stability was lowest (36%) for the 5% smectite aggregates, intermediate for the 10 and 15% smectite aggregates (56 to 58%), and highest (75%) for the 25% smectite aggregates. Stability of the 5, 15 and 25% smectite aggregates decreased slightly after 1 cycle and the stability either remained nearly constant through the remaining cycles (5% clay) or continued to decline through the cycles (15 and 25%). Only the 10% smectite aggregates had the large decrease in stability followed by a return to the original stability.

Kaolinite. Stability of both the 0.5 to 1.0 and 1.0 to 2.0-mm 25% kaolinite clay aggregates increased significantly as the number of wetting and drying cycles increased up to 80 wetting and drying cycles. The final stability of the 0.5 to 1.0-mm aggregates (25%) was more than twice the initial stability (12%). In contrast to the results with smectite, initial aggregate stability of the 25% kaolinite aggregates was one-third to one-fourth that of the 5% aggregates.

Illite. Initial 1 to 2-mm aggregate stability decreased from 23 to 13% when percent illite increased from 5 to 25%, but there was little affect of wetting and drying on stability of the 25% illite aggregates (Table 3). A minimum stability of 11% was measured after 4 cycles. The final stability after 32 wetting and drying cycles was not significantly different than the initial stability, but was significantly higher than the first cycle stability.

The 0.5 to 1.0-mm, 25% illite aggregate stability decreased after one cycle followed by an increase in stability. Similar to the 1 to 2-mm aggregates after 32 wetting and drying cycles, stability of these illite aggregates was not significantly higher than the original stability but the stability was significantly higher than after one wetting and drying cycle.

Stability of 1 to 2 mm 5% smectite plus 5% kaolinite aggregates increased from an initial stability of 25% to approximately 32% after 80 wetting and drying cycles. The yield of 0.5 to 1.0 mm aggregates was too low to allow for many measurements, but the trend and magnitude of stability appeared to be the same for the smaller aggregates.

The experiment with aggregates made from 10% smectite, 15% silt sized quartz and sand is incomplete but the initial behavior of the aggregates indicates that the addition of silt produces an unstable aggregate. This seems to be in agreement with field studies that have identified increased silt plus very fine sand as contributing to decreased aggregate stability and increased crusting.

Experiments with natural soil aggregates are also incomplete, but preliminary observations indicate that wetting and drying decreases the stability of the aggregates. The rate of decrease appears to be a function of drying temperature. Stability of aggregates dried at 40°C decreases more rapidly and to a lower final stability than aggregates dried at room temperature (~22 °C).

DISCUSSION AND SUMMARY:

We would not expect a soil with 5% clay and 95% sand to have stable structure, yet the artificial aggregates did cohere under the standard test procedure. This demonstrates the efficacy of small amounts of clay. Higher clay contents increases the stability as expected. The aggregate stability data suggest that wetting and drying cycles have an effect on the stability of these artificial aggregates and that the effect is dependent on the clay type. Because no significant differences were found between the two aggregate sizes, the following discussion is based on the behavior of the 1 to 2-mm diameter aggregates.

We suggest three processes account for changes in wet aggregate stability with increased wetting and drying cycles:

(i) The clay particles become oriented into more face-to-face associations, as described by Quirk (1978). If, in the dry state, the clay particles are initially in a random pattern of face-to-face, face-to-edge and edge-to-edge contact, they will be less stable than when they are more ordered. Differences between the behavior of smectite and kaolinite aggregates subjected to the Yoder method can be accounted for by considering these face to face associations in the presence of agitated water. The kaolinite particles can form strong hydrogen bonds between the oxygen atom in the outer hexagonal sheet of one layer and the hydroxyl groups in the outer sheet of the other layer. In water, these bonds remain strong and the kaolinite neither swells nor disperses. Smectite, however, does not form hydrogen bonds between the layers and swelling occurs as water enters between the clay layers. Subjected to mechanical forces, dispersion can occur, even within a calcium saturated system (Keren, 1990). Edge-to-edge and edge-to-face contacts are actually more likely to survive the wet sieving process. This was suggested as a mechanism for the instability of soils studied by Imeson and Jungerius (1976).

(ii) There is an increase in the number of sand-clay interactions as the clay is distributed across the surface of the sand grains. An increase in the uniformity of clay distribution over the surface of the sand grains was observed in smectite aggregates under SEM. Neither the kaolinite nor illite aggregates have been examined with the SEM. If the kaolinite particles are stacked in a more stable manner, it would be reasonable to speculate that clay redistribution across the surface would be less likely.

(iii) Free clay platelets migrate to and from the aggregates with the filter paper acting as a reservoir. During such movement the clay has the opportunity to become part of the aggregate in either of the two processes described above. We noticed that illite became more associated with the filter paper with increased wetting and drying cycles. Because of the experimental set-up, the clay could interact with the filter paper as well as the sand grains. The filter paper is behaving in a manner similar to lower layers of aggregates. Of the three clays, kaolinite would probably have the greatest ability to move in and out of the filter paper because of its lower charge.

Smectite. The low stability of the 5% clay aggregates, and the insignificant changes in stability with wetting and drying cycles is due to the small amount of clay present. Decreased stability caused by the orientation of the clay particles, is compensated for by the increased numbers of sand-clay interactions, so no net loss of stability was noted.

With increasing clay content, there is an increase in aggregate stability because there is more clay adhering to the sand grains. In both the 15% and 25% clay aggregates there exists the potential for thicker clay layers. Increasing particle orientation results in a steady decline in stability over 32 cycles and is the dominant process.

With smaller amounts of clay, the orientation of the particles is likely to be more readily achieved. This would account for the sharper fall in stability observed in the 10% clay aggregates. Recovery of stability is attributed to increasing uniformity of clay distribution, and stronger clay-sand linkages, with increased numbers of wetting and drying cycles.

Kaolinite. Both the 5% kaolinite and illite aggregates were fragile in the dry state, indicating the clay did not adhere well to the sand grains. Nor did the clay particles cohere well. All three processes would lead to increased aggregate stability when the amount of clay is not a limiting factor. In the 5% clay aggregates, a slight decrease was observed in the stability of the 1 to 2-mm aggregates, while that of the smaller aggregates remained constant with increased numbers of wetting and drying cycles. With more clay present, significant increases in stability were measured.

Illite. Illite was expected to behave more like kaolinite. For illite, swelling and dispersion should not be too important since 2:1 units are held together by tightly bound interlayer K+. Illite aggregates were very unstable, however. The illite itself dispersed readily on contact with water. This was not expected and may have been due to the preparation of the clay by freeze-drying. At least one report in the literature suggests that illite becomes much more susceptible to dispersion when it has been freeze-dried (Green et al., 1978).

Additional studies are currently underway to determine the effect of initial particle size distribution, organic matter type and amount, and oxide mineralogy on aggregate stability as the number of wetting and drying cycles increases. It is apparent from the first results from this study that the number of cycles is important in determining aggregate stability, but it is not a simple relationship.

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TABLE 1. Aggregate Stability of 1 to 2-mm and 0.5 to 1.0-mm Diameter Smectite Plus Sand Artificial Aggregates After 0 to 60 Wetting and Drying Cycles.

	1 to 2-mm diameter				0.5 to 1.0-mm diameter			
Clay %	5	10	15	25	5	10	15	25
Cycle	Aggregate stability (%)							
0	38.1 a	57.8 f	55.3 a	74.2 a	35.9 bc	56.5 cd	58.5 a	74.9 a
1	34.3 abc	36.8 a	51.2 a	70.1 b	33.0 ab	35.7 a	55.1 a	69.7 b
4	33.2 bc	40.1 a	43.4 bc	63.1 c	32.6 ab	36.5 a	46.5 b	62.3 c
8	30.6 c	46.2 b	43.3 bc	59.1 d	32.0 a	51.2 b	43.9 b	57.5 d
16	32.4 bc	52.8 de	41.8 bc	48.0 e	34.3 ab	57.9 d	41.9 b	47.3 e
24	35.8 ab	50.5 cd	42.0 bc	54.7 f	38.8 c	48.7 b	40.3 b	55.9 d
32	34.0 bc	48.8 bc	38.4 c	47.3 e	33.6 ab	49.9 b	nm	48.2 e
40	34.3 bc	nm	48.1 ab	nm	33.1 ab	53.2 bc	nm	nm
50	32.5 bc	nm	nm	nm	nm	nm	nm	nm
60	32.6 bc	56.1 ef	nm	nm	nm	56.1 cd	nm	nm

nm = no measurement

Means in a column followed by the same letter are not significantly different by Fisher's protected least significant difference at 0.05 level of significance.

TABLE 2. Aggregate Stability of 1 to 2-mm and 0.5 to 1.0-mm Diameter Kaolinite Plus Sand Artificial Aggregates After 0 to 80 Wetting and Drying Cycles.

	1 to 2-mm diameter		0.5 to 1.0-mm diameter	
Clay (%)	5	25	5	25
Cycles	Aggregate stability (%)			
0	39.4	14.4 a	45.7 b	12.1 a
1	nm	17.3 ab	nm	17.0 ab
4	40.4	18.3 bc	41.0 ab	18.7 b
8	36.3	20.1 bcd	37.3 a	17.9 b
16	36.8	21.6 cd	38.4 a	19.9 bc
32	32.1	21.2 cd	42.5 ab	21.8 bc
60	32.7	nm	46.6 b	nm
80	nm	22.8 d	nm	24.6 c

nm = no measurement

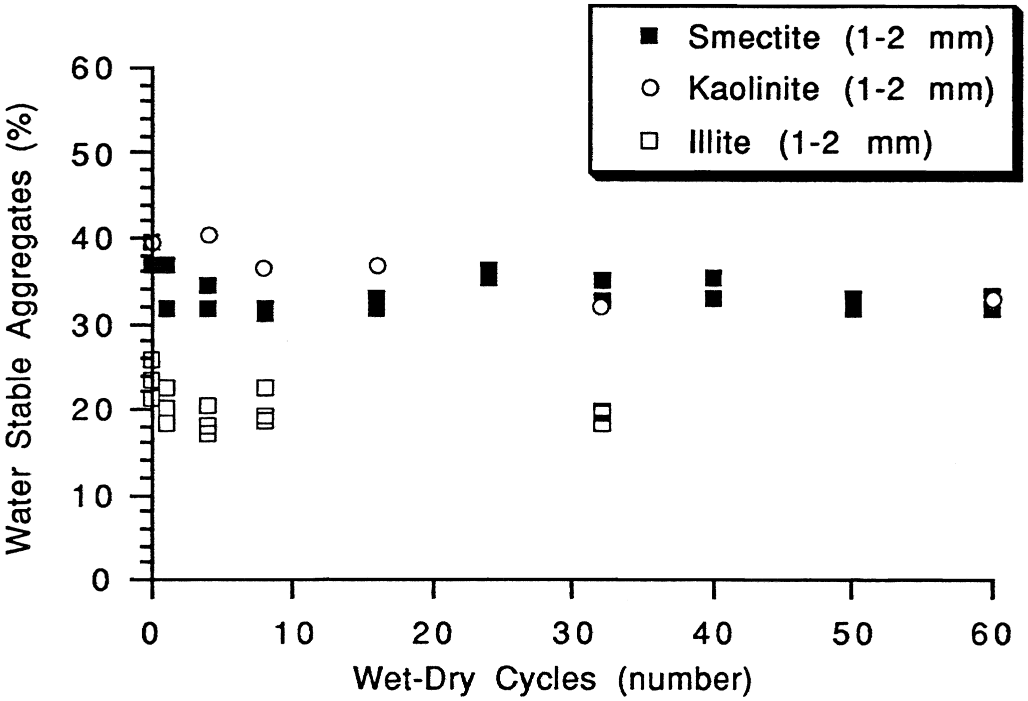
Means in a column followed by the same letter are not significantly different by Fisher's protected least significant difference at 0.05 level of significance.

Table 3. Aggregate stability of 1 to 2-mm and 0.5 to 1.0-mm diameter illite plus sand artificial aggregates after 0 to 32 wetting and drying cycles.

	1 to 2-mm diameter		0.5 to 1.0-mm diameter	
Clay (%)	5	25	5	25
Cycles	Aggregate stability (%)			
0	23.5 a	12.6 abc	22.8 a	12.5 bc
1	20.4 ab	12.0 ab	20.5 a	9.7 ab
4	18.6 b	10.9 a	17.2 a	8.7 a
8	20.3 ab	13.5 bc	19.5 a	11.2 ab
16	nm	13.5 bc	nm	10.6 ab
24	nm	14.4 c	nm	14.0 c
32	19.3 b	13.5 c	18.2 a	14.2 c

nm = no measurement

Means in a column followed by the same letter are not significantly different by Fisher's protected least significant difference at 0.05 level of significance.



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PROJECT TITLE: PRACTICAL AND THEORETICAL INVESTIGATIONS ON THE VERTICAL MULCH DRIP SYSTEM FOR IMPROVING INFILTRATION

PROJECT NUMBER: 89-15

DURATION OF FUNDING: July 1989 – June 1991

PROJECT INVESTIGATORS:

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Affiliation:	Land, Air & Water Resources Hydrologic Science Section University of California	Affiliation:	Land, Air & Water Resources Hydrologic Science Section University of California
Location:	Davis Campus	Location:	Kearney Agricultural Center
FTE Commitment:	0.20	FTE Commitment:	0.05

RESEARCH STAFF:

Postgraduate Researcher:	1 @ 0.20
Staff Research Associate:	1 @ 0.20

PROJECT COLLABORATORS:

Name: L. Williams
Affiliation: Viticulture
University of California
Location: Davis Campus

ABSTRACT:

No significant difference in yield and berry weights was observed for the surface drip and VMD systems in 1990 but the sugar content of berries was significantly greater in the VMDS. Observations not documented in the report suggest preferential flow paths exist in this area from old root channels, etc. These in conjunction with the restricting layer at 50 cm and the VM trench could result in wider lateral water movement than anticipated. Dye experiments and excavation will be conducted in 1991 o further investigate the phenomenon. Computer modeling of VMDS provides information on the operational design of the system and the potential for its use. Some improvements in the model have been made this year.

KEYWORDS: vines, infiltration, vertical mulch, drip

PROJECT OBJECTIVES ADDRESSED:

1. Investigate in the field the potential of the Vertical Mulch Drip System for improving the infiltration of water into coarse textured compact soils and other soils of low infiltration.
2. Develop a computer model of the VMDS to compliment field and laboratory experiments for the purpose of establishing design criteria and identifying potential.

RESULTS AND DISCUSSION:

Yields, berry weight and sugar content were measured for the 1990 crop year for the vertical mulch and surface drip configuration of water application. The subsurface drip system was converted to a surface drip system prior to this season because the subsurface drip system became plugged with roots and it appeared that efforts to unclog the system would be unsuccessful. In order to provide water for the vines in this treatment the system was replaced with one similar to the other surface system. The two surface drip systems cannot be considered equivalent until the roots pruned in the installation of the subsurface system are re-established. As results indicate this year, based on yield and other data, these differences may have been eliminated but to confirm this fact an additional year's data may be required.

As noted in previous reports the number of vines and replications available for observation in this experiment are considered too few to establish statistical differences in plant response although some indication is available from trends. A difficulty has been experienced in obtaining established plantings for experimentation because of the reduction in yield as a result of root pruning when the systems are installed. This has been particularly evident when seeking private cooperators. In addition, the limited length of project period precludes establishing new plantings with the irrigation systems initially installed before planting occurs and collection of data for sufficient times for analyses.

For reference it is noted that yields of vines in general at the Kearney Agricultural Center were lower in 1990 as compared with 1989. Irrigation applications were started on May 10, 1990, and harvest occurred on September 14. Table 1 gives the applied water, ET_O, crop ET and precipitation for the season.

Table 1. Irrigation and crop water use in the VMDS irrigation of vines at KAC.

	SD	SS	VMDS	ET_O	Crop ET	Precipitation
	Inches					
Rep 1	22.7	22.8	23.4	29.9	22.2	2.1
Rep 2	23.1	22.8	23.0			
Mean	22.9	22.8	23.2			

The amount of water applied by the VMDS was constrained by the amount applied in the SD and SS treatments although more could have been applied. In 1990 yield from the VMDS was less than that observed for the surface drip systems but the differences were not significant at the 95% confidence level. Neither was there a significant difference in berry weights for the treatments. However, as in 1989, the sugar content of the berries in 1990 was significantly higher in the VMDS over surface drip methods. The results are summarized in Figure 1. Some of these differences may be caused by irrigation timing. The SS and SD (both surface irrigation) treatments were irrigated daily while the VMDS was irrigated weekly. The apparent similarity between the SD and SS treatments suggest that the SS (previous subsurface drip) treatment has re-established its rooting system.

The low infiltration rate and sometimes low hydraulic conductivity of the soil types on the Kearney Agricultural center have been generally recognized for sometime. These properties have been related to the clay mineral type, electrical conductivity of the irrigation water and the high bulk density of the soils as a result of their natural textural characteristics. The soils would therefore seem to be a good choice for examining methods for improving infiltration rates. An additional complication is the cemented layer that exists at various shallow depths in the soil profile. That condition is expected to impede the drainage of water from the profile if sufficient water reaches the layer. Based on soil moisture measurements this appears to be the case for the VMDS. The impedance of downward flow causes the water to move laterally and that condition can result in wider horizontal distribution of the water, providing the water introduced at the surface reaches the layer. Since the infiltration of water is slow for surface irrigation methods sufficient water to cause accumulation and horizontal movement may not occur. However, that is not the case for the VMDS which places water in the zone where surface methods do not provide water. That fact could be significant in the present experiment if vines from the other treatments can utilize water introduced by the VMDS.

An additional factor must also be considered. Recent observations indicate the presence of channels in the soil profile that result from previously existing roots. The extent of these channels is unknown as in their effectiveness in conducting the water horizontally as well as vertically, particularly above the impeding layer. If that system is extensive, the VMDS would intersect a wider array of channels and where saturation develops water movement could be more extensive than anticipated. Such movement could increase the potential for water extraction by vines from the other treatments thereby confounding the yield relative to water application when comparing the two (or three) methods of water application. These extenuating conditions and their implication was not known when the site was selected. But it is also evident that water measurement due to this more complex spatial distribution of flow paths is likely to be more demanding.

In the current crop year, soil moisture measurements are being attempted with the TDR as well as the neutron probe in order to obtain additional information on water distribution. At the conclusion of the current year dye will be introduced into the water infiltrating from the VMDS and the SD system portion of the soil profile will then be excavated to examine the extent and nature of the water distribution system.

Other factors to be examined will be the condition of the trench fill material, the water distribution system, and the root distribution.

Modeling the VMDS

Development of a compute model to simulate water distribution from the VMDS was continued following last years initial results. While the representative simulations presented here may not adequately reflect the conditions of the preferential flow that could exist in the VMDS experiment at the KAC, they do demonstrate the differences in water distribution that develop over a 7-day period for different soil and trench configuration. The depth of surface soil over the trench is 20 cm for all cases but the width and depth may be different and layering is present in some cases. The transpiring vine row is located at distance 150 and the center of the trench at 205 cm in the figures.

Two recharge periods occur in the 7-day period with the length of irrigation being 0.25 days. Figure 2A, 2B, 3A, 3B are the same except the trench is 25 cm and 40 cm deep for Figure 2 and Figure 3 respectively. The soil hydraulic conductivity is 5 cm per day. For A figures, the water content is after 2 days and B figures after 7 days. The influence of the trench depth is clearly evident by the larger water contents with depth. Figure 4 presents an example of water content for a 5 cm W x 40 cm D trench with an irrigation of 0.5 days and other factors as in Figure 2A and 3A. Notice water has moved farther laterally than with previous cases.

An example of the influence of layering is shown in Figure 5. Conditions are similar to those for Figure 3A (2 days) (10 cm W x 40 cm D trench) except the top layer is sand with an H.C. of 100 cm per day and the lower layer of clay with an H.C. of 5 cm per day. The lateral movement in the sand is greatly influenced by the absorption of water into the clay.

PUBLICATIONS AND REPORTS:

Biggar, J. W. and D. W. Grimes. 1990. Practices and theoretical investigations on the Vertical Mulch Drip System for improving infiltration. In: Fourth Year Annual Report of the 1986-1991 Mission on Water Penetration in Irrigation Soils. Kearney Foundation of Soil Science, DANR, University of California.

Chang, Wen Lian, J. W. Biggar, and D. R. Nielsen. 1990. Fractal analysis of wetting front instability in layered soil. Water Resources Research (submitted).

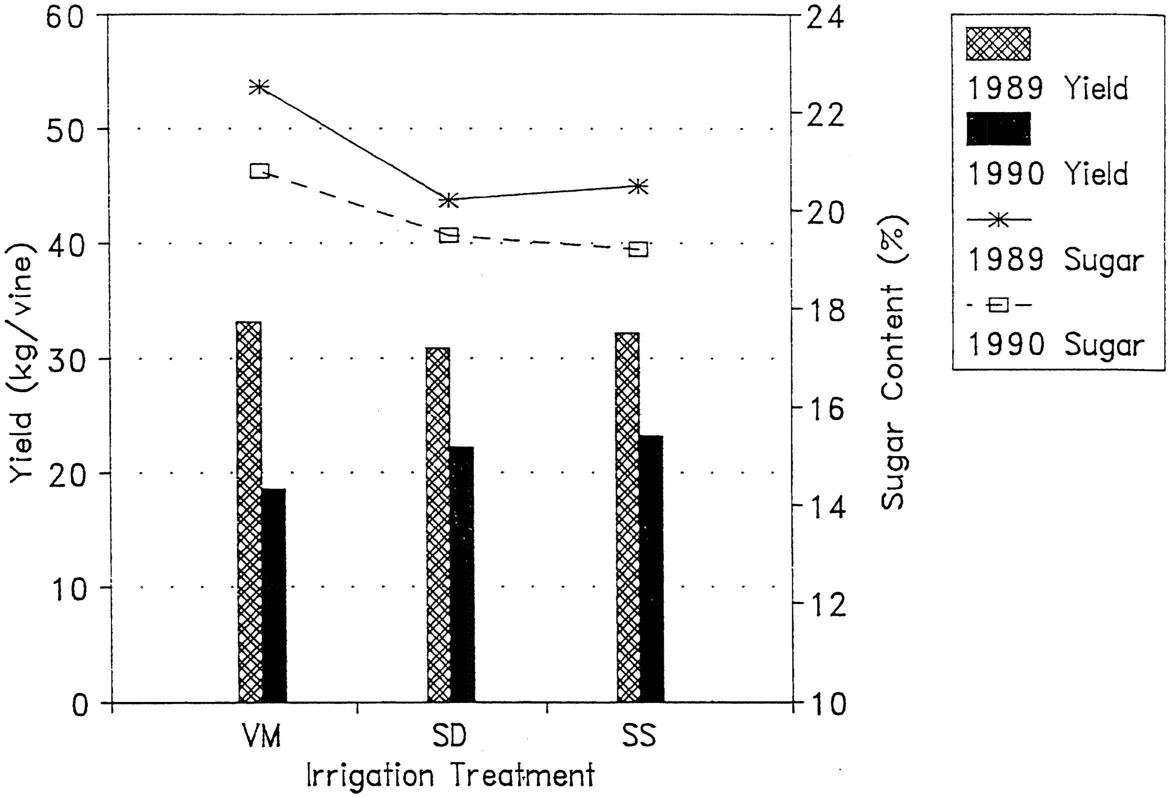

Figure 1. Yield, sugar content of grapes for 1989 and 1990 seasons irrigated by SD and VMDS.

Figure

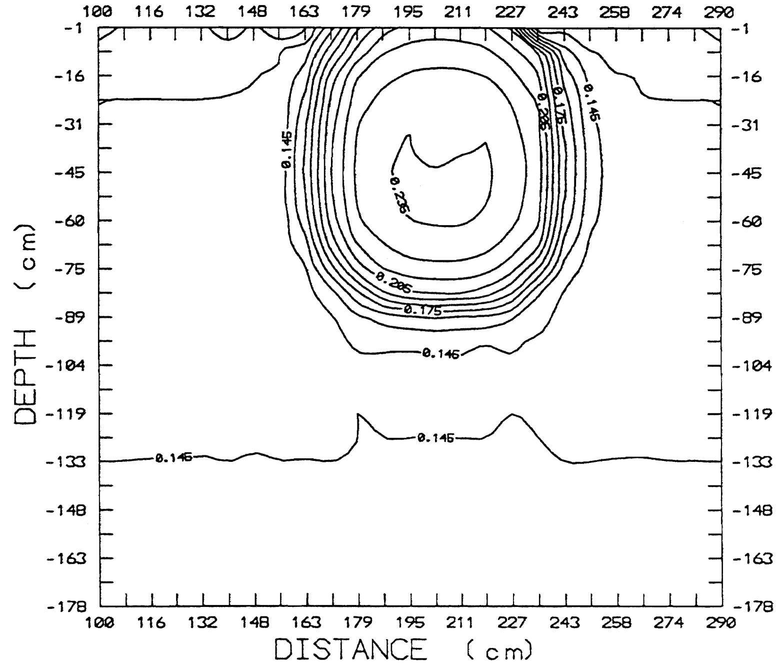

Figure 2A. Simulated water content distribution after 2 days (A) and 7 days (B) for 10 cm W × 25 cm D trench and H.C. of 5 cm per day.

Figure

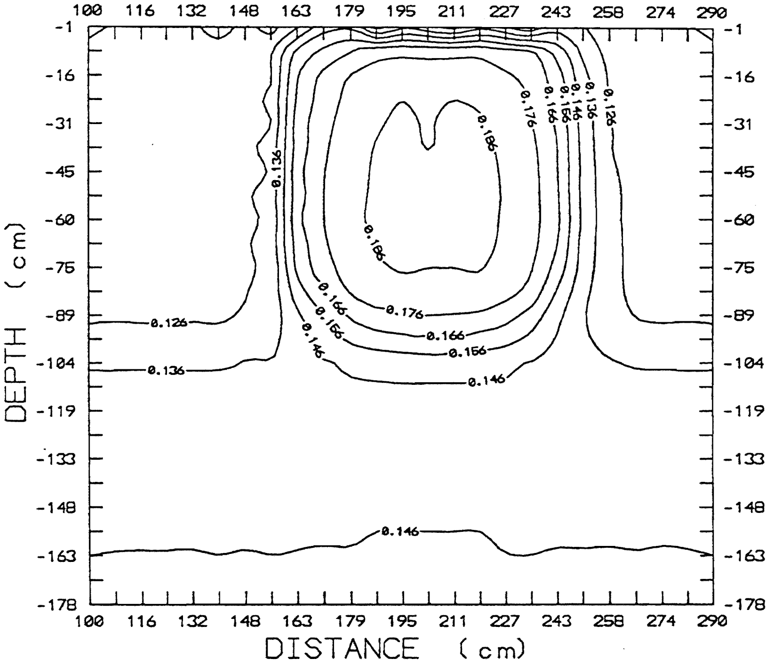

Figure 2B. Simulated water content distribution after 2 days (A) and 7 days (B) for 10 cm W × 25 cm D trench and H.C. of 5 cm per day.

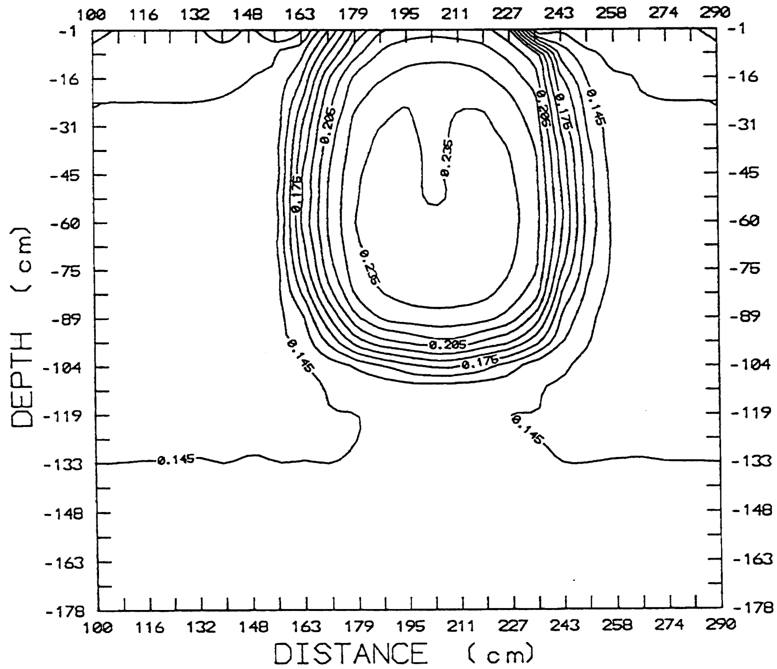

Figure 3A. Simulated water content distribution after 2 days (A) and 7 days (B) for a 10 cm W × 40 cm D trench and H.C. of 5 cm per day.

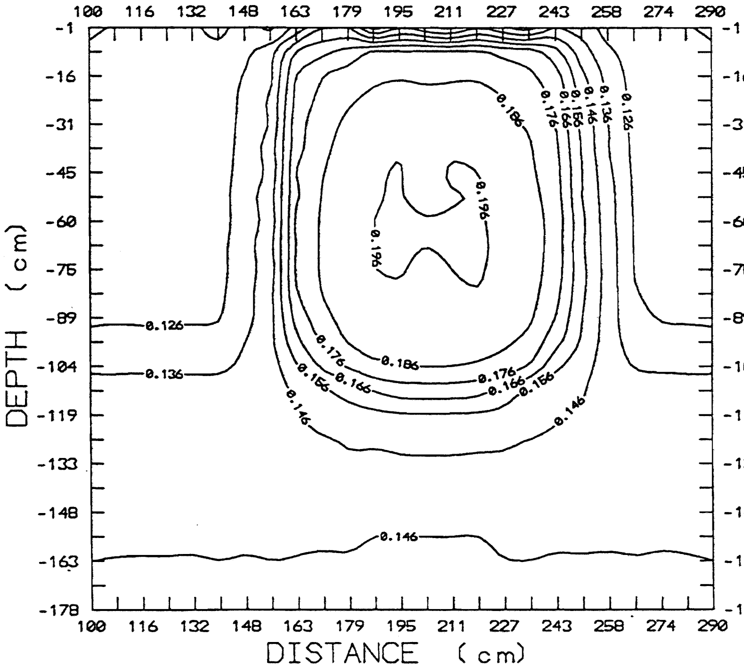

Figure 3A. **Simulated water content distribution after 2 days (A) and 7 days (B) for a 10 cm W × 40 cm D trench and H.C. of 5 cm per day.**

Figure

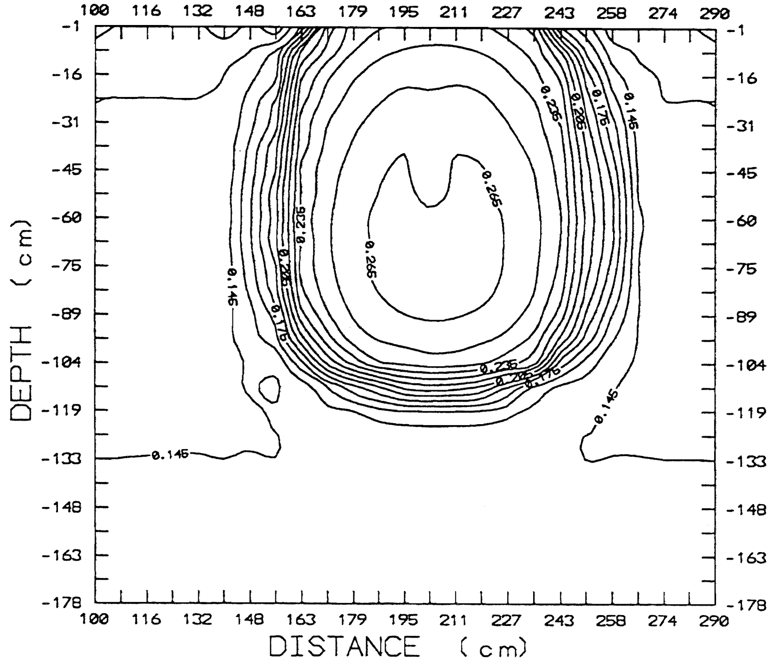

Figure 4. **Water content distribution for a 5 cm W × 40 cm D trench and 0.5 day irrigation.**

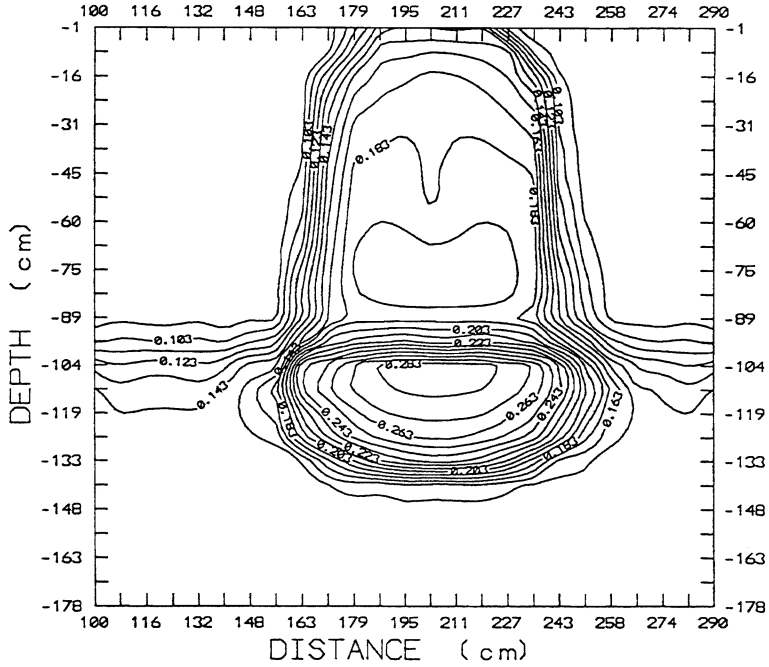

Figure 5. Water distribution in a 2-layer VMDS. Upper layer sand with H.C. of 100 cm per day and lower layer clay with H.C. of 5 cm per day.

MANAGEMENT

PROJECT TITLE: COVER CROP MANAGEMENT AND MODIFIED DRIP IRRIGATION FOR IMPROVED WATER INFILTRATION

PROJECT NUMBER: 89-4

DURATION OF FUNDING: July 1989 - June 1991

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FTE Commitment: 0.05

RESEARCH STAFF:

Postgraduate Researcher: Dan Munk prior to June 30, 1990
Steve Gulick after July 1, 1990
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Staff Research Associate: Paul Wiley; not funded by project.
1 @ 0.1 FTE

PROJECT COLLABORATORS:

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Location: University of California, Davis

Name: W. W. Wallender
Affiliation: Land, Air and Water Resources
Location: University of California, Davis

ABSTRACT:

Water infiltration is frequently observed to become severely restricted as the growing season progresses for many eastern San Joaquin Valley soils. Plant water deficits develop during periods of moderate to high potential evapotranspiration and monetary losses result.

Extensive field studies at the Kearney Agricultural Center on Hanford sandy loam soils revealed substantial improvement in subsoil water distribution with a drip/trickle subsurface water release position compared with a surface release in a Thompson Seedless vineyard. This was associated with a consistent 4 to 7 percent yield increase for subsurface water release treatments. Low subsoil K and increased root activity at lower depths with subsurface irrigation, required K-fertilization by chemigation to meet K plant requirements.

With furrow irrigation vineyard studies, a continuous brome grass cover crop (*Bromus mollis*) increased cumulative infiltration over an 8 hour period by a factor of 2.5 compared with clean no till conditions. However, increased infiltration came at a cost with seasonal ET_c increased by 31 percent for the cover crop system.

KEYWORDS: furrow irrigation, drip/trickle irrigation, water intake functions, crusting

PROJECT OBJECTIVES ADDRESSED:

The central objective of this study is to develop water management systems that sustain optimum water infiltration for coarse-textured, compact soils of eastern San Joaquin Valley; specific objectives are:

1) develop a brome grass cover crop system that sustains water infiltration and is practical to manage in furrow irrigated vineyards and

2) modify conventional surface drip irrigation placement to subsurface configurations.

RESEARCH PLAN AND PROCEDURES:

Two field experiments were conducted at the U.C. Kearney Agricultural Center on a Hanford sandy loam soil (coarse-loamy, mixed, nonacid, thermic Typic Xerorthents). Study site soils are typical of eastern San Joaquin Valley soils having restrictive water infiltration characteristics. The Hanford soil represents both the magnitude of water infiltration restriction and the site specific mechanisms responsible for poor infiltration. Both studies were concluded with the 1990 harvest and late fall and early winter observations of root development characteristics.

Drip/trickle study

The study utilized a 1.14 ha vineyard described in previous Kearney Foundation reports. 1989-90 treatments were:

1) control; above ground emitters (no K added).

2) buried system; entire lateral/emitter system buried 30 cm below the surface (+K),

3) bury; spaghetti tube only from the above-ground emitter with the outlet into a cylindrical mulch (5 cm diam. x 10 cm ht.) 25 cm below the soil surface (+K),

4) above ground emitters (+K), and

5) bury; spaghetti tube only from above-ground emitter with outlet into a cylindrical coarse sand volume (5 cm diam. x 10 cm ht.) 25 cm below the soil surface (+K).

The treatments were replicated three times in a randomized complete block design. Required water additions to meet nonstressed crop ET (ET_{crop}) were determined as previously described (Grimes et al, 1990; Grimes and Williams, 1990).

Differential K additions according to treatments and required nitrogen were added through the irrigation system. Potassium was added to treatments 2 through 5 in eight weekly increments to obtain a total annual addition of 168 kg K per ha as KCl. Thirty- nine kg N per ha (as urea) were added to all treatments.

Detailed root and soil K distribution throughout the soil profile were determined following harvest in 1990.

Furrow irrigated vineyard

The 19 rows of a two ha vineyard were alternately designated guard and treatment rows, as depicted in Fig. 1, so that each plot contained one treatment row, two alleys (one on each side of the treatment row), and four furrows (one on each side of the treatment row and one on the near side of each adjacent guard row). Three treatments were established that consisted of:

CNT; clean, no-till control treatment--herbicidenoncultivated,

C/HT; cover, herbicide treated--bromegrass winter/spring covercrop--herbicide treated after seed set, and

CC; continuous cover--bromegrass winter and spring--resident vegetation in summer.

Treatments were replicated three times in a randomized complete block field design.

Blando bromegrass was seeded in early January, 1989, in alleys and furrows of both bromegrass treatments at a rate of 7 kg/ha. After seed shattering commenced in May, a natural transition to summer resident vegetation was permitted in treatment CC, whereas all surface vegetation was killed by contact herbicide spray (paraquat) in treatment C/HT, leaving a bromegrass surface mulch through the summer. Bromegrass and resident vegetation were mowed as necessary to keep cover crop canopy height below approximately 0.3 m.

A "two-point method" described by Elliott and Walker (1982) was used to develop a furrow water advance function and the modified Kostiakov-Lewis function was used to characterize infiltration of a volume balance procedure. The impact of treatment on grapevine plant-water relations was evaluated according to the criteria established by Grimes and Williams (1990).

Steady-state infiltration for the Kostiakov-Lewis function was measured with a recirculating furrow infiltrometer. Furrow section ends were dammed with hemispherical metal plates and furrow inflow was preset to a constant rate. The return flow hose at the lower furrow end was set at a fixed elevation of 0.1 m above the furrow bottom (Bautista and Wallender, 1985).

Soil water content was measured with a neutron probe immediately before and three to five days after each irrigation. Each plot was monitored with four neutron probe access tubes. The neutron probe was site calibrated and volumetric water content was measured at the midpoints of 0.3-m depth increments to a total depth of 1.8 m, except for the 0.23-m reading in the surface increment to avoid surface effects.

Root excavation trenches were dug in the two treatments exhibiting the greatest differences in yield and infiltration rate during the course of the study; this was accomplished in blocks one and two. Pits were excavated by backhoe after the 1990 harvest for root observations.

RESULTS:

Drip/trickle study

The distribution of root-zone soil water for Thompson Seedless grapevines was improved substantially by subsurface water release from a drip irrigation system in soil that undergoes surface sealing. Grape production consistently reflected a 4 to 7 percent increase for subsurface water release treatments, except for the initial year of root pruning experienced by a treatment trenched for placement of a subsurface irrigation lateral. Increased root activity at lower profile depths, associated with subsurface water release, required that K-fertilization be accomplished through the water delivery system for soils of the study site that were low in subsoil K.

Furrow irrigated vineyard

Furrow advance times and modeled cumulative infiltration were greatest in the continuous cover (CC), intermediate in cover/herbicide-treated (C/HT), and lowest in clean no-till (CNT) treatments (Table 1). Infiltration was significantly different among treatments the first year of the study (1989), but differences were amplified considerably the second year (1990).

Cumulative infiltration curves, generated from the modified Kostiakov equation, illustrate treatment differences for each year when data from separate irrigation events were averaged (Fig. 2) and when the first and last irrigation events of each season were compared (Fig. 3). Figure 3 shows that while infiltration decreased slightly through the irrigation season both years in the CNT treatment, it increased during the first season and then decreased during the second season in the CC treatment. Steady-state infiltration values (C in Table 1) determined from recirculating furrow infiltrometers exhibited the same relative treatment trends as did cumulative infiltration.

Vines were slightly less water-stressed in the CC treatment as indicated by second-year midsummer determination of crop water stress index and leaf water potential (Table 1) measurements.

Soil water depletion was greatest in CC and least in CNT (Table 2). Continuous cover substantially improved water infiltration, but maintaining bromegrass and native vegetation throughout the growing season increased ET_{crop} by 31 percent. Herbicide treating the bromegrass cover after seed development increased ET_{crop} by 16 percent for the growing season.

DISCUSSION AND SUMMARY

Drip/trickle study

Observed trends in soil water content were consistent with that expected if increased surface area wetting, associated with surface water release, resulted in a higher evaporation (E) component of ET when compared with subsurface water release treatments. Although applied water was constant for all treatments, more water was available at lower rooting zone depths for subsurface water release treatments. Midday measured leaf water potential for surface water release control treatment typically was -0.92 MPa compared with -0.86 MPa for subsurface water release treatments.

The Hanford soil of the test site is substantially lower in exchangeable K at depths below 20 cm than in the surface soil; this phenomenon is fairly typical of eastern San Joaquin Valley soils (Kasimatis and Christensen, 1976). Subsurface water release encouraged increased root activity at lower depths; this response, coupled with lower exchangeable soil K in subsoils, resulted in marginal K uptake by the vineyard. This problem was easily corrected by injecting 168 kg K/ha annually, as 8 weekly additions during the growing season. Plant K uptake was elevated in subsurface water release treatments by K chemigation such that all subsurface treatments were equal to or higher than the surface water release control.

Furrow irrigated vineyard

Cumulative infiltration and steady state infiltration were substantially increased by a blando bromegrass cover crop. The benefit associated with the cover crop was substantial during the first year of establishment, but became even more pronounced during the second year where, cover maintained throughout the growing season, resulted in a 2.5 factor increase in cumulative water infiltered over an 8-hr period compared with clean no-till conditions.

Root count density of a CNT treatment relative to CC varied according to the depth of a restrictive layer observed in the vineyard. Where the restrictive layer was less than one meter deep, root count density was higher in the CNT treatment; where it was below one meter, the trend was reversed. This trend held true for all depths of the soil profile and in both row and middle zones.

Although water infiltration in cover crop treatments was improved substantially, production was reduced during the second year by cover crop treatments compared with CNT. This occurred even though vines were slightly less water stressed in the cover crop treatments. We hypothesize that transient periods of low oxygen availability resulted during irrigation events for the high infiltration conditions afforded by the cover crop.

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PUBLICATIONS AND REPORTS:

Grimes, D. W., D. A. Goldhamer, D. Munk, and P. Wiley. 1990. Cover crop management and drip irrigation for improved water infiltration. p. 128-135. In Fourth-year Annual Report of the 1986-91 Mission on Water Penetration Problems in Irrigated Soils. Kearney Foundation of Soil Science, DANR,University of California.

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Munk, D. S., D. W. Grimes, and D. A. Goldhamer. 1992. Management to enhance water infiltration of a slowly permeable soil. Ms. in preparation -- to be submitted to Soil Sci. Soc. Am. J.

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Gulick, S., D. W. Grimes, D. S. Munk, and D. A. Goldhamer. 1992. Cover crop enhanced water infiltration of a slowly permeable sandy loam soil. Ms. in preparation -- to be submitted to Soil Sci. Soc. Am. J.

TABLE 1. Treatment effects on grape production, water stress levels, furrow advance, and infiltration.

	Yield		CWSI	LWP	C	†Furrow advance time (182.8 m)		††Cumulative infiltration (8 hours)	
Treatment	1989	1990	Jul 1990	Jul 1990	Oct. 1990	1989	1990	1989	1990
	--------- mg/ha -------			MPA	mm/hr	------------ hr -----------		----------- mm -----------	
CNT	22.48 a*	23.30 c	0.44 a	-1.00 a	2.9 a	3.03 a	2.75 a	69 a	74 a
C/HT	20.85 a	19.96 b	0.42 a	-0.98 a	3.7 a	5.12 b	7.02 b	106 b	122 b
CC	20.93 a	15.68 a	0.34 a	-0.96 a	5.5 b	6.03 c	11.52 c	116 c	182 c

* Means in the same column not followed by a common letter differ at the 0.05 probability level according to Duncan's multiple range test.

† Data from separate irrigation events are averaged.

†† Cumulative infiltration was derived from furrow advance data by the two-point and modified Kostiakov procedures.

TABLE 2. Soil water depletion by treatment at row and middle positions.

Depth range	Treatment	Row	Middle	X̄	Ratio: Row/Middle
m		------------------------------ mm		------------------------------	
0-1.8	CNT	427 a*†	274 a	351 a	1.6
	C/HT	447 a	386 ab	417 ab	1.2
	CC	531 a	493 b	511 b	1.1
0-0.3	CNT	226 a	109 a	168 a	2.1
	C/HT	218 a	147 ab	183 a	1.5
	CC	267 a	236 b	251 b	1.1

* Values in the same depth increment and column not followed by the same letter differ at a 0.05 probability level according to Duncan's multiple range test.

† Each entry is the sum from eight depletion periods (four in each of two irrigation seasons).

PROJECT TITLE: EFFECTS OF ROW CROP CULTURAL AND IRRIGATION PRACTICES ON WATER INFILTRATION CHARACTERISTICS

PROJECT NUMBER: 89-5

DURATION OF FUNDING: July 1990- June 1991

PROJECT INVESTIGATORS:

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FTE Commitment: 0.25

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Affiliation: Agricultural Engineering
University of California
Location: Davis, California

FTE Commitment: 0.05

Name: S.K. Upadhyaya
Affiliation: Agricultural Engineering
University of California
Location: Davis Campus

FTE Commitment: 0.05

Name: D.J. Hills
Affiliation: Agricultural Engineering
University of California
Location: Davis, California

FTE Commitment: 0.10

RESEARCH STAFF:

Research Assistant: 1 @ 0.50 FTE

ABSTRACT:

An 11 acre field on the U.C. Davis campus has been utilized to produce processing tomatoes and field corn in rotation under conventional and reduced post-harvest tillage practices. Reduced post-harvest tillage in the rotation represents not only an opportunity for reduced costs of production, but may have effects upon agronomic performance of the crops as well as field water infiltration characteristics. A special reduced tillage implement reduced field tillage passes from two or three as compared to upwards of 9 field passes with conventional post-harvest tillage practices.

A linear move irrigation system was utilized to provide furrow (drop-tube), drop sprinkler and boom sprinkler irrigation treatments.

Previous years data indicate greater post-tillage time and planting time water infiltration rates in the reduced tillage field plots as compared to water infiltration rates in the conventionally tilled field plots. This trend was not sustained in 1990 as data indicated no significant differences in fallow (January, 1990) or growing season (August, 1990) water infiltration rates attributable to reduced tillage practices.

KEYWORDS: water infiltration, soil penetration resistance, soil moisture profiles, irrigation practices, reduced tillage, processing tomatoes, field corn.

PROJECT OBJECTIVES ADDRESSED:

1. Determine the effects of conventional and reduced tillage on water infiltration in a field utilized for a processing tomato and field corn rotation.

   a. Also, determine the effects of conventional and reduced tillage on soil penetration resistance and bulk density in a field utilized for a processing tomato and field corn rotation.

2. Determine the effects of furrow, drop sprinkler and boom sprinkler irrigation on water infiltration in a field utilized for a processing tomato and field corn rotation grown under conventional and reduced tillage.

a. Also, determine the effects of furrow, drop sprinkler and boom sprinkler irrigation on soil penetration resistance and bulk density in a field utilized for a processing tomato and field corn rotation grown under conventional and reduced tillage.

RESEARCH PLAN AND PROCEDURES:

An 11 acre field on the U.C. Davis campus has been used to grow approximately 5.5 acres each of processing tomatoes and field corn. One-half of the 11 acre field has been treated with reduced post-harvest tillage practices and the other half treated with conventional post-harvest tillage practices. Field corn and processing tomatoes were rotated on each field half from year to year. The 1990 season represents the final year that crops were grown and harvested after reduced tillage. The first cycle of reduced tillage was accomplished immediately after the 1987 harvest.

Irrigation for the two crops was provided by a 500 foot linear move irrigation system. The linear move system was set-up to provide furrow (drop tube), drop sprinkler and boom sprinkler irrigation treatments.

Reduced tillage practices used were based upon growing the processing tomatoes and field corn on essentially the same 60 inch beds from year to year. A special tillage tool was designed and was used to perform reduced tillage on the processing tomato and field corn fields. Design of the special tillage tool was based in part upon the first years measurement of soil penetration resistance. The post-harvest reduced tillage sequence on field corn consisted of mowing, subsoiling down the furrows and use of the special tillage tool which chisel plowed the beds tops while reforming rough furrows. The post-harvest reduced tillage sequence on processing tomatoes consisted of subsoiling down the furrows and use of the special tillage tool which chisel plowed the beds tops while reforming rough furrows.

Conventional post-harvest tillage practices are typical of those used in the area. For field corn, conventional post-harvest tillage consisted of mowing, plowing, discing two times, subsoiling twice, landplaning twice and listing up rough beds. For processing tomatoes, the tillage practices consisted of discing three times, subsoiling twice, landplaning twice and listing up rough beds.

Water infiltration measurements were taken with double ring infiltrometers placed on the top of the crop bed. Water was allowed to run into the infiltrometer set-up for at least 24 hours during which time the water was weighed and recorded on a datalogger. Information from the datalogger was processed to provide a plot of the rate of inches of water infiltrated vs. time. Water infiltration information during this reporting period has been taken at post-fall tillage time (January of 1990) and during the 1990 growing season (August, 1990).

RESULTS:

Water Infiltration:

Water infiltration data was accrued in order to determine the effects, if any, of tillage and irrigation practices upon the field water infiltration rate. It was also deemed of importance to understand the persistence of any effects upon water infiltration rate over the growing and fallow seasons.

Table 1 presents the 1990 winter infiltration rates at 24 hours for reduced and conventional tillage plots in the north field of the 11 acre plot. A two-factor analysis of variance on infiltration rate indicates no significant difference in infiltration rate at 24 hours between conventional and reduced tillage treatments as well as between the the three irrigation treatments at the 95% level.

Table 2 presents the 1990 growing season infiltration rates at 24 hours for conventional and reduced tillage plots in the north field. A two-factor analysis of variance on infiltration rate indicates no significant difference in infiltration rate between conventional and reduced tillage treatments as well as between the three irrigation treatments at the 95% level.

Crop Agronomic Performance:

1990 represents the fourth year that crop agronomic factors such as yield, maturity and quality measures have been available. For processing tomatoes, crop yield, crop maturity in terms of percent grass green tomatoes, Brix, pH and fruit per kilo measurements were taken. Measurements of crop agronomic performance of field corn were not taken in 1990 as the farmer providing the combine came in a day early and harvested the crop which precluded collection of yield, quality and maturity data.

Yield. A two-factor analysis of variance on processing tomato indicates no significant difference in yield attributable to the three irrigation treatments. However, a significant difference in yield was attributed to the tillage treatments at the 95% level. Specifically, in 1990, the yield of processing tomatoes grown under reduced tillage was only 59% of that of processing tomatoes grown under conventional tillage.This is the first year that a significant difference in the yield of processing tomatoes was shown to be attributable to the reduced tillage practice.

Maturity. The percent green (on a weight basis) of processing tomatoes at harvest time was used as a measure of crop maturity. A two-factor analysis of variance on percent green readings indicates no significant difference in maturity between processing tomatoes grown under the two tillage systems at the 95% level. A significant difference in maturity was noted between the three irrigation treatments at the 95% level. Specifically, the maturity of processing tomatoes grown under furrow irrigation was significantly greener than the yield of processing tomatoes grown under either of the two sprinkler irrigation system treatments.

Quality. Degrees Brix (the percent of soluble solids calculated as sugar) is an important quality and payment factor for processing tomatoes. Because many of the products of processing tomatoes are sold on a soluble solids basis, the higher the soluble solids of processing tomatoes the better. A two-factor analysis of variance on Brix readings indicates no significant difference in Brix readings between processing tomatoes grown under the three irrigation systems or under the two tillage systems at the 95% level.

PH of the processing tomato juice is a quality factor of interest to the food processor. Generally speaking, processors desire pH readings of 4.4 or less to inhibit the growth of bacterial spores after proper sterilization of the canned product. A two-factor analysis of variance on pH readings indicated a significant difference in pH readings between processing tomatoes grown under the three irrigation systems as well as between the two tillage treatments at the 95% level. Specifically, the pH of tomatoes grown under conventional tillage was higher than that of tomatoes grown under reduced tillage.

The number of tomato fruit per kilo, i.e., fruit size, is a quality factor of interest to both growers and processors of tomatoes. Fruit which is too small may in fact fall through the tomato harvester. Fruit which is too large may not meet processor peeling standards. A two-factor analysis of variance on fruit per kilo readings indicates no significant difference in fruit per kilo readings between processing tomatoes grown under the three irrigation systems or under the two tillage treatments at the 95% level.

DISCUSSION AND SUMMARY:

Water Infiltration. Previous years work has shown an increase in water infiltration rates when comparing the reduced tillage plots to the conventionally tilled plots right after fall tillage. This is logical in that the reduced tillage plots were subsoiled along the furrows and chiseled along the bed tops just prior to the fall post-tillage infiltration readings. As such, chisel slots on the bedtop where infiltration readings were taken allowed for much greater water infiltration. Conventionally tilled plots did not have a similar chisel slots in the bedtop. Thus, it had been previously postulated that improvements in over-winter water infiltration rates would improve the storage of winter rainfall in the root zone. Enhanced recovery of winter rainfall could lessen the need for springtime pre-plant irrigations. In the winter of 1990, however, for the first time, post-tillage infiltration tests conducted in January indicate no statistical differences in the infiltration rates at 24 hours between conventional and reduced tillage plots.

The spring pre- or post-plant water infiltration test information represents any advantages of a reduced or conventional tillage system toward the field's ability to accept irrigation waters. Previous years work had shown improvement of water infiltration rates attributable to reduced tillage during this time period. No infiltration tests were taken at planting time in 1990 as it was assumed that the no significant differences measured in the preceding winter would persist through to the spring period.

In 1990, water infiltration rates were measured during the latter part of the growing season (August, 1990). These tests indicated the persistence of no significant differences in water infiltration rates in 1990 attributable to reduced tillage practices.

Crop Agronomic Factors. In 1990, there was a statistically significant reduction in crop yield of processing tomatoes attributable to the reduced tillage treatment. Overall, processing tomato crop yield was reduced in two of the three crop years. Crop yield of processing tomatoes was not affected by irrigation treatment.

Maturity of processing tomatoes was not affected by tillage treatment but was affected by irrigation treatment.

On an overall basis, there were no differences in either soluble solids or count per pound measurements of processing tomatoes attributable to the reduced or conventional tillage treatments. Ph, however, for the first time was slightly lower in the reduced tillage treatment when compared to the conventional treatment.

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TABLE 1. 1990 Post-Tillage Infiltration Rate at 24 Hours (cm/min)

TREATMENT	FURROW	DROP SPRINKLER	BOOM SPRINKLER	AVERAGE
CONVENTIONAL				
NORTH FIELD	0.0081	0.0099	0.0041	0.0074
REDUCED				
NORTH FIELD	0.0119	0.0079	0.0076	0.0091

Tillage LSD @ 5% = NS

Irrigation LSD @ 5% = NS

TABLE 2. 1990 Growing Season Infiltration Rate at 24 Hours (cm/min)

TREATMENT	FURROW	DROP SPRINKLER	BOOM SPRINKLER	AVERAGE
CONVENTIONAL				
NORTH FIELD	0.0612	0.0409	0.0437	0.0485
REDUCED				
NORTH FIELD	0.0099	0.0561	0.0622	0.0470

Tillage LSD @ 5% = NS

Irrigation LSD @ 5% = NS

PROJECT TITLE: RELATIONSHIPS OF CRUST AND CRACKING CHARACTERISTICS TO INFILTRATION IN FIELD SOILS

PROJECT NUMBER: 89-19

DURATION OF FUNDING: July 1989 through June 1991

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ABSTRACT:

Studies were conducted at nine locations within the Central Valley to investigate the relationship between surface soil strength as characterized by penetration resistance and infiltration rate. In separate experiments, the effects of cover crop (Brome grass) and salinity on soil strength and infiltration rate were investigated. Although the relationship between soil surface strength and infiltration rate observed in the various studies was not very consistent, there appeared to be a general negative correlation between soil strength and infiltration rate. Spatial analysis revealed that the sampling interval beyond which the force measurements were no longer autocorrelated ranged between 0.02 and 0.04 m. The use of several realizations as well as the combined use of geostatistical and conventional time-series techniques in obtaining a reliable "range" for force measurements were found to be very desirable. Surface soil strength increased with increased sodicity. Cover crop reduced soil strength by 51% while increasing infiltration rate by 61%.

KEYWORDS: Crust, micropenetrometer, soil strength, infiltration

PROJECT OBJECTIVE ADDRESSED:

a. Measure crust strength with a micropenetrometer on soils known to have differing infiltration properties. Spatial and fractal statistical techniques will be used to establish spatial characteristics and scale dependence of the soil surface strength measurements.

b. Correlate crust strength and cracking frequency with soil physical, chemical, and mineralogical characteristics and with infiltration properties of field soils.

RESEARCH PLAN AND PROCEDURES:

High surface soil strength has been implicated in reduced water intake rate in soils susceptible to crusting and surface sealing. The relationship between surface soil strength and infiltration rate was investigated at several field locations within the Central Valley in a series of field studies. The surface strength was characterized in terms of penetration resistance as measured by the micropenetrometer earlier described (Rolston et al., 1991). All measurements were made using a cylindrical, flat-tipped probe with a diameter of 1.59 mm (1/16 in.). The penetration rate was set at 8 mm/min and force measurements were taken at every 0.1 mm depth interval to a desired depth at air-dry water content in order to minimize the effect of water content on penetration resistance (Tackett and Pearson, 1965; Callebaut et al., 1985; Rolston et al., 1988).

Effect of Depositional Crust on Soil Strength and Infiltration Rate. Five sites with soils known to have reduced infiltration rates were chosen to evaluate their tendency to form surface crusts. Four of the sites were in almond orchards and one was in a walnut orchard. At each site, six plots were established between two trees. The surface of four of the plots were raked to a depth of 2-3 cm to break up any existing crust. On two of the raked plots, a depositional crust was formed by impact energy of water drops supplied by a shower head at the rate of 276 cm^3/sec for a total of 150 seconds (equivalent to energy level of 1.02 kJ/m^2). The other two plots were left undisturbed. Penetration resistance measurements were taken when all the plots were at air-dry water content. Four transects of 15 measurements spaced 50 mm apart and to a depth of 5mm were taken on the crusted and undisturbed plots. An additional two transects of 5-7 measurements were taken to a depth of 30 mm to provide soil strength readings for a deeper soil profile. After the penetration resistance measurements were taken, measurements of infiltration were conducted using a portable, rainfall simulator-type infiltrometer (Kearney Project #86-13).

Soil Strength as Affected by Salinity. The El Rico Ranch in Corcoran was chosen to study the effect of salinity on soil strength. This site has had five years of application of six different levels of saline drain water. The three salinity levels selected were 400, 4500, and 9000 ppm. The current crop is cotton and the soil type is Tulare clay, a swelling clay soil prone to cracking. Large islands up to 20 cm in length often result upon drying. A transect of 30 points spaced 5 mm apart were taken on four islands of at least 15 cm in length in two replicates of each treatment. Penetration depth was set at 5 mm.

Cover Crop Effect on Soil Strength and Infiltration Rate. Penetration resistance measurements were taken in a mature furrow-irrigated Thompson seedless vineyard located at the UC Kearney Agricultural Center. Soil type is a Hanford sandy loam. This site is being used in a study to improve infiltration by using a cover crop, brome grass, and comparing infiltration rate to a clean till control treatment (Kearney Project #89-4). In two replicates of each treatment, penetration resistance measurements were taken on two transects of 60 points spaced 15 mm apart and to a depth of 8 mm. Measurements were taken in the furrow, and transects were located between two vines. The brome grass was clipped to the soil surface prior to measurements.

Relationship Between Soil Strength and Infiltration Rate at Undisturbed Sites. Nine different locations having varying soil textures within the Central Valley were selected. The locations were Durham, Hamilton City, Turlock, Crows Landing, Ceres, Kearney Ag. Center, Farmington, Hilmar, and Davis. All the sites except Davis were located in orchards.

At each site, six parallel transects (5-10 cm apart) of different lengths were sited parallel to a row of trees within an area free from vehicular traffic with weeds being mainly controlled by herbicides. Measurements within each transect were made at equal intervals to permit spatial analysis.

At each site, steady infiltration rate was measured at two soil depths (0-15 and 15-30 cm) using the pressure infiltrometer described by Reynolds and Elrick (1990) with a 10 cm depth of ponding. Measurements were replicated four times at each depth.

RESULTS AND DISCUSSION:

Effect of Depositional Crust on Soil Strength and Infiltration Rate. The average maximum force values and cumulative infiltration depth at 240 minutes at the five sites are given in Table 1. Soil strength data is for points that were not in cracks. No penetration resistance measurements were taken on the raked surface because the soil surface was too loose for accurate measurements. For the raked and subsequently crusted sites, the order of increasing soil strength was Crows Landing, Durham, Farmington, Turlock, and Hamilton. The order of increasing soil strength for the undisturbed sites was different than that of the intentionally crusted sites: Crows Landing, Turlock, Farmington, Durham and Hamilton. In all cases, soil strength in the crusted plots was lower than for the undisturbed plots (Fig. 1). The consolidation resulting from the formation of the depositional crust was not as great as that associated with the natural, undisturbed surface. Figure 2 shows typical 30 mm deep force-depth curves for crusted and undisturbed plots.

There is no simple direct correlation between soil strength and infiltration rate. For example, the average soil strength of the undisturbed plot at Durham was three times higher than that of the crusted plot, but the cumulative infiltration data were virtually the same for both treatments (Table 1). As mentioned earlier, the average soil strength was higher for the undisturbed plots than for the crusted plots, but the cumulative infiltration depth at 240 minutes and the steady-state infiltration rate were generally higher for the undisturbed plots than the crusted plots. In undisturbed soils, deep and wide cracks that develop over long periods of time possibly enhanced infiltration rate. When the soil surface is raked, the resulting loose soil may tend to fill existing cracks and subsequently decrease the infiltration. The decreased infiltration rate of the crusted plots may be partially attributed to the disruption of the soil aggregates upon application of the high energy water droplets. As the soil dries, a smoother surface with small cracks develop. On the other hand, most of the undisturbed plots had soil surfaces that were partially aggregated.

The relationship between soil strength and cumulative infiltration at 240 minutes for the undisturbed plots at the various sites was not as consistent as for the crusted plots (Fig. 3). This could possibly be due to differences in preferential water flow caused by different cracking patterns and intensities not accounted for in the strength measurements. Analysis of chemical and physical properties for the five soil types were recently completed. That information may help explain the observed relationships between soil strength and infiltration rate.

The difference in soil strength readings between the crusted and undisturbed sites for the 30-mm deep measurements were not as pronounced (Table 1). The raked depth ranged from 2-3 cm and many penetrations of the crusted plots extended down to the undisturbed soil.

Soil Strength as Affected by Salinity. Figure 4 shows the average strength readings for the 5-mm deep measurements for the three salinity treatments. Deeper penetration measurements were not possible because the soil was so dense that soil resistance exceeded the capacity of the load cell of the micro-penetrometer. Soil strength measurements were lowest in the 400 ppm treatment, followed by the 9000 ppm treatment, and highest in the 4500 ppm. The overall soil strength in the 4500 treatment is actually higher than reported since measurements were only possible on two islands. Soil strength of other islands exceeded the limit of 200 Newton. Chemical data are not currently available for the soils measured, but saturated extracts of soils sampled in 1988 in the 400, 4500 and 9000 treatments had EC values of 1.46, 9.10, and 15.24 mmhos/cm, respectively, and Na concentrations of 8.45, 110.35 and 186.09 meq/l, respectively. It appears that the higher level of Na in the 4500 ppm treatment caused soil dispersion, but the increased Na and overall salt concentration in the 9000 ppm may have led to soil flocculation.

Cover Crop Effect on Soil Strength and Infiltration Rate. Table 3 summarizes the results of penetration resistance measurements taken in the clean-till and brome grass treatments. The infiltration rate given here was obtained by a recycling furrow infiltrometer over a 2 meter furrow segment (Kearney Project 89-4). The average maximum strength for the clean till treatment as 13.64 and 12.86 N for the two replicates. For the brome grass treatment, the average strength was 9.80 and 3.23 N. The average for the clean-till and brome grass was from 120 measurements, with the exception of the brome grass, replication 2. Due to computer problems, only 48 measurements were taken. In many of the measurements of the brome grass treatments, the penetrometer probe would penetrate into the thatch before force measurements were initiated. It is hard to distinguish where the actual "soil surface" would be in areas where there is plant debris. In some cases, penetration measurement would be initiated when the probe contacts a grass part. In a clean, no crop surface, soil surface strength measurements are more accurate. In spite of the uncertainties in the brome grass measurements, the overall soil strength was lower in that treatment than the clean-till treatment. This lower soil surface strength was reflected in the increased infiltration rate. This is consistent with previous reported effects of cover crops on infiltration rate.

Relationship Between Surface Strength and Infiltration Rate at Undisturbed Sites.

Spatial properties of strength measurements. Data for two of the nine sites (Farmington and Hilmar) are presented in this report. Information for the other sites are being processed. Farmington site was located in a walnut orchard on silty clay soil while the other sites were located in almond orchards. Hilmar site was located on a loamy sand soil. The mean force measurement appeared insensitive to the length of transect sampled at both Farmington and Hilmar sites except for the 50m long transect at Farmington (Tables 3 and 5). Although it is not very clear why the mean force of the 50m long transect at Farmington was much higher than for the other transects at the site, it is suspected that the transect possibly extended across a part of the field that had suffered some form of compaction in the past.

The magnitude of spatial variation as quantified by the coefficient of variation (c.v.) was generally less than one order of magnitude at the two sites (Tables 3 and 5). It is interesting to note that the strength measurements were normally distributed at 5 mm sampling interval but log-normally distributed at the other intervals. This observation suggests that the frequency distribution of force measurements could be scale-dependent. As would be expected, higher coefficients of spatial variation were associated with the log-normal distributions and longer sampling intervals.

Force measurements at both sites revealed spatial autocorrelation at lags 1 and 2 within the 1.0, 1.5 and 2.0 m long transects (Tables 4 and 6). Little or no autocorrelation was observed within the 5.0, 25.0 and 50.0 m long transects. This observation suggests that the sampling interval beyond which the force measurements are no longer autocorrelated lies between 0.01 and 0.05 m. This interval only encompasses the ranges corresponding to the lowest nugget variances at both sites (Tables 4 and 6). Consequently, the estimated ranges for the Farmington and Hilmar sites are 0.02 and 0.04 m respectively. The nugget variances associated with larger sampling intervals were too high to allow for any reliable estimate of the range from the variogram model. Caution should be used in using variogram models of single realizations to estimate the range of soil properties. It is not only desirable to have several realizations, it is equally important to use estimated autocorrelation coefficients (Box and Jenkins, 1970) as a check.

The concept of fractals (Mandelbrot, 1977) has recently been found useful by soil scientists to study the nested, autocorrelated, and scale dependent nature of unresolved variations referred to as the white noise component of spatial variability. The force measurements obtained in this study are considered fractals in view of the fact that increasing the scale of observation continued to reveal more details (Figure 5). Consequently, the Hausdorf-Besicovitch fractal dimension, D, (Mandelbrot, 1977; Burrough, 1983) was calculated as $D = 1/2\ (4-m)$ where m is the slope of the logarithm of semivariance plotted against the logarithm of the separation distance.

For linear fractal curves used in this study, the value of D may range between 1 and 2. Values of D closer to 1 imply the importance of long-range variation while values closer to 2 imply that the curve is so "noisy" that it effectively takes up the whole of a two-dimensional space (Burrough, 1983) suggesting the dominance of short-range effects. The D values obtained for the various sampling scales at both sites range between 1.899 and 1.990, reflecting the importance of short range variation. The D value remains large even at the smallest sampling interval of 0.005 m used for the 1.0 and 1.5 m long transects. The obvious dominance of the short-range effects suggested by the D values is very much in agreement with the low values of range (0.02 and 0.04 m) estimated for the two sites.

Effect of surface strength on infiltration rate. Surface strength at the Farmington site was more than five times higher than that at the Hilmar site (Fig. 6). Although steady ponded infiltration rate of the soil surface (0-15 cm) at Farmington site was more than four times higher than at the Hilmar site, the sub-surface (15-30 cm) infiltration rates at the two sites were not very much different (Fig. 7). Surface and subsurface infiltration rates at Farmington appeared similar. Surface infiltration rate at Hilmar was more than three times higher than the subsurface permeability. Although appropriate correlation between surface strength and infiltration rate (if any) cannot be sought until data from all the sites have been processed, the relative magnitudes of surface and sub-surface permeabilities will no doubt play a significant role in this effort. Based on the data from the two sites, there appeared to be a negative correlation between surface strength and infiltration rate. However, no definite conclusions can be made until information from all the sites have been processed.

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TABLE 1. Summary of soil surface strength measurements and cumulative depth of infiltration at 240 minutes.

		5 MM DEEP MEASUREMENTS		30 MM DEEP MEASUREMENTS		
Site	Soil Type	Ave. Maximum Force (N)	Sample Number	Ave. Maximum Force (N)	Sample Number	Cumulative Infiltration (cm)
CRUSTED PLOTS						
Crows Landing	Carbona	3.22 a*	105	27.69 a	23	13.05
Durham	Vinaloam	7.18 b	88	32.68 a	20	15.80
Farmington	Hollendeck	7.66 b	93	70.40 b	19	15.73
Turlock	San Joaquin Sandy Loam	10.73 c	116	56.04 b	20	6.30
Hamilton	Wyo silt loam	18.19 d	104	57.75 b	21	7.09
UNDISTURBED PLOTS						
Crows Landing		8.63 a	110	26.43 a	20	14.43
Durham		23.66 bd	116	53.05 b	18	16.21
Farmington		19.96 b	119	98.04 d	17	17.73
Turlock		15.73 c	120	82.00 cd	20	6.88
Hamilton		25.79 d	120	67.91 bc	15	9.25

*Different letters within each group of treatment indicate significant differences (t-test, alpha = 0.05).

TABLE 2. Soil strength and infiltration rate as affected by cover crop.

Treatment	Rep	Ave. Maximum Soil Strength (N)	Infiltration rate (cm/hr)
Clean till	1	13.64a	0.29 **
	2	12.86a	0.20
Brome grass	1	9.80b	0.43
	2	*3.23c	0.36

* Only 48 measurements were taken. Others were an average of 120 points.

** No infiltration rate was available at the exact site of penetration measurements. Infiltration rate given is the average of 6 measurements in the clean till treatment.

TABLE 3. Descriptive statistics for strength measurements at Farmington

Length of transect sampled (m)	Sampling Interval	Sample size	Mean ± S.E. (N)	C.V. (%)	Frequency Distribution
1.0	0.005	200	21.63 ± 0.77	51.41	Normal
1.5	0.005	300	22.67 ± 0.70	53.20	Normal
2.0	0.010	200	19.59 ± 0.97	70.09	Log-Normal
5.0	0.50	100	21.30 ± 1.57	73.85	Log-Normal
25.0	0.500	50	24.97 ± 2.36	66.76	Log-Normal
50.0	0.500	100	32.33 ± 2.23	68.91	Log-Normal

TABLE 4. Spatial statistics for strength measurements at Farmington.

Length of Transect sampled (m)	Autocorrelation†		Variance§ (%)	Range‡ (M)	Fractal Dimension	Variogram Model
	Lag 1	Lag 2				
1.0	0.51*	0.25*	27.27	0.02	1.987	Spherical
1.5	0.60*	0.30*	71.74	0.27	1.982	Spherical
2.0	0.46*	0.22*	82.31	0.73	1.968	Spherical
5.0	0.22^{NS}	0.05^{NS}	80.56	1.15	1.955	Linear/Sill
25.0	0.01^{NS}	0.32*	85.05	3.50	1.990	Spherical
50.0	0.18^{NS}	0.28*	74.28	28.00	1.931	Linear/Sill

† Autocorrelation function (Box and Jenkins, 1970)

‡ Based on Variogram model

* Significant (p <0.05)

NS Not significant

§ Expressed as percentage of total variance.

TABLE 5. Descriptive statistics for strength measurements at Hilmar.

Length of Transect Sampled (m)	Sampling Interval (m)	Sample size	Mean ± S.E. (N)	C.V. (%)	Frequency Distribution
1.0	0.005	200	4.43 ± 0.10	38.83	Normal
1.5	0.005	300	3.93 ± 0.10	34.35	Normal
2.0	0.010	200	4.47 ± 0.30	93.96	Log-Normal
5.0	0.050	100	4.55 ± 0.29	63.52	Log-Normal
25.0	0.500	50	3.73 ± 0.32	61.66	Log-Normal
50.0	0.500	100	4.96 ± 0.35	69.56	Log-Normal

TABLE 6. Spatial statistics for strength measurements at Hilmar.

Fig.

Length of transect samples (m)	Autocorrelation †				Nugget Variance§ (%)	Range‡ (m)	Fractal Dimension	Variogram model
	Lag 1	Lag 2	Lag 3	Lag 4				
1.0	0.60*	0.52*	0.47*	0.35*	67.80	1.12	1.925	Spherical
1.5	0.65*	0.54*	0.30*	0.20NS	15.47	0.04	1.980	Spherical
2.0	0.32*	0.22*	0.17NS	0.16NS	81.24	0.72	1.899	Linear/Sill
5.0	0.28*	0.30*	0.23NS	0.02NS	62.47	0.34	1.986	Periodic
25.0	0.20NS	0.21NS	0.22NS	0.24NS	72.30	37.50	1.915	Gaussian
50.0	0.20NS	0.30*	0.30*	0.19NS	77.50	44.70	1.936	Periodic

† Autocorrelation function (Box and Jenkins, 1970)

‡ Based on variogram model

* Significant ($p < 0.05$)

NS Not significant

§ Expressed as percentage of total variance

Fig.

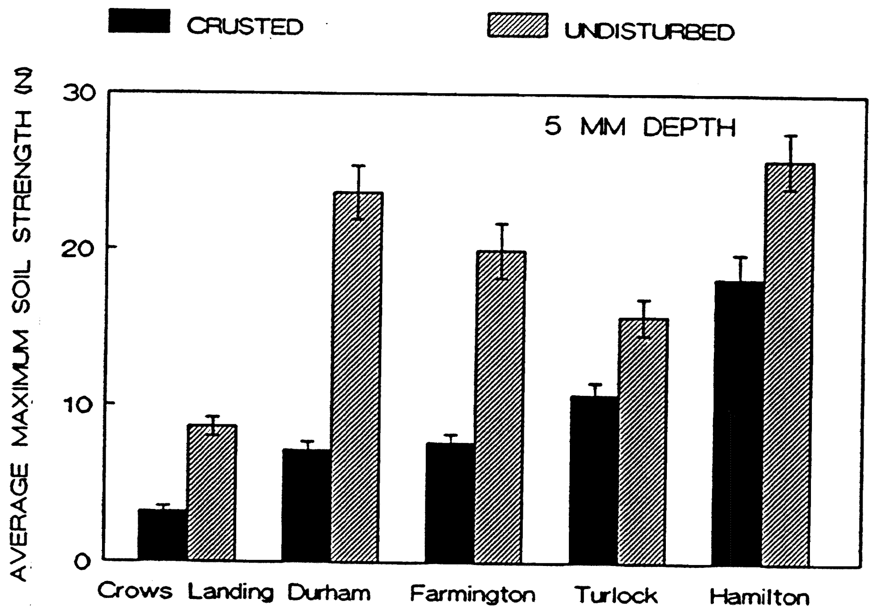

Fig. 1 Comparison of average maximum soil strength for the crusted and undisturbed plots.

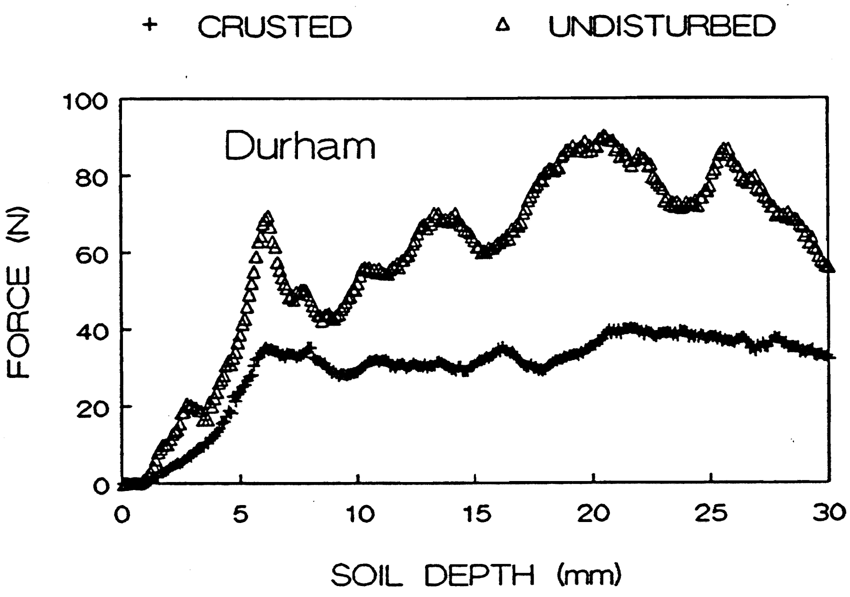

Fig. 2 Typical force depth curves for crusted and undisturbed soil surfaces.

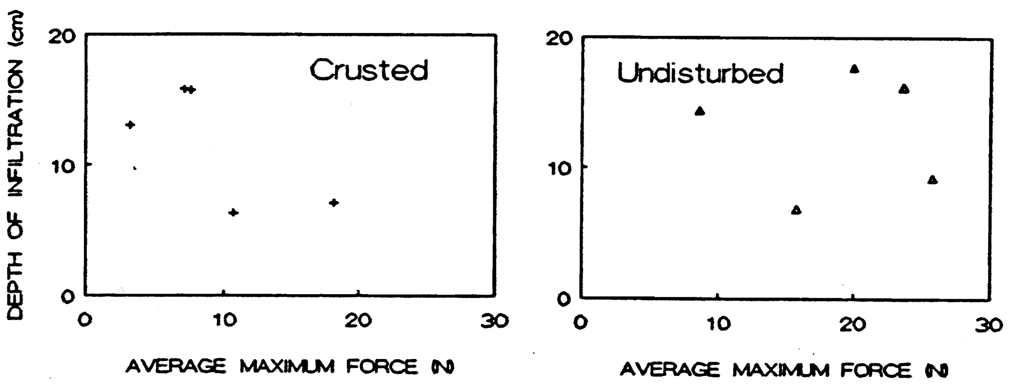

Fig. 3 Relationship between average maximum force values and cumulative depth of infiltration at 240 minutes for 5 mm deep measurements.

Fig.

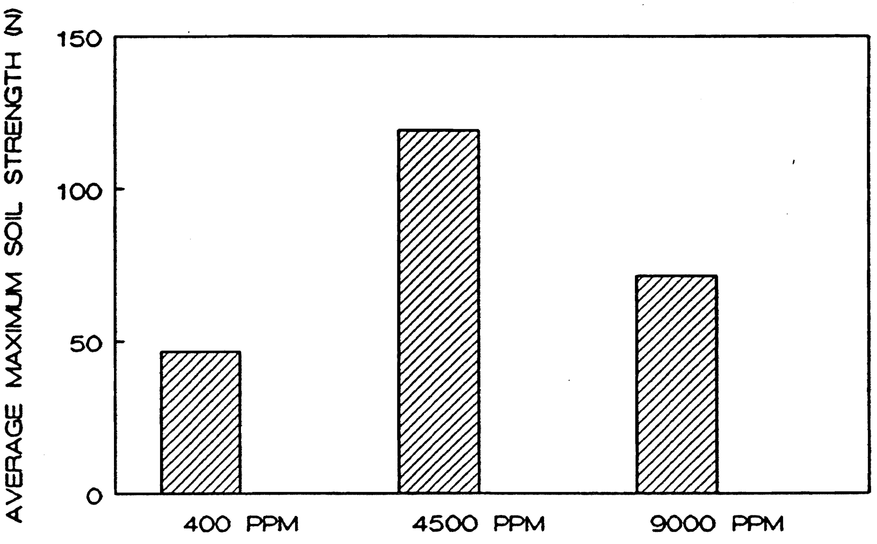

Fig.

Fig. 4 Average maximum force for the 400, 4500 and 9000 ppm treatments.

mm deep

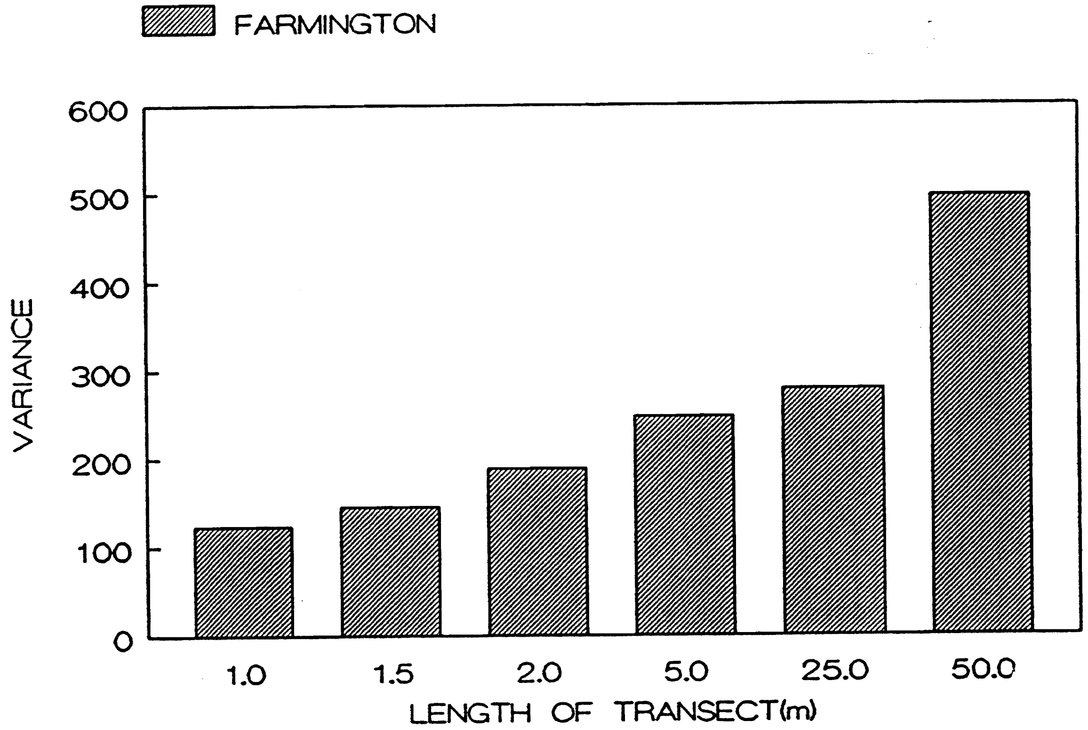

Fig. 5 Comparison of variances of penetration resistance at different sampling scales.

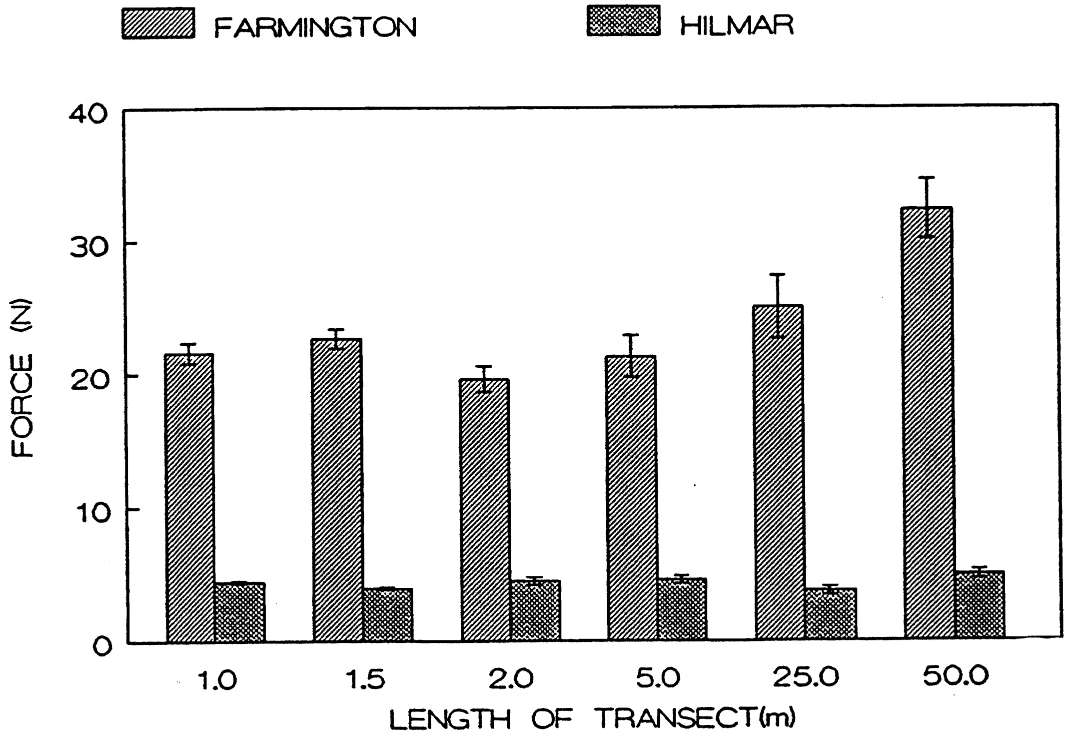

Fig. 6 Mean force measurement in relation to length of transect sampled at Farmington and Hilmar sites.

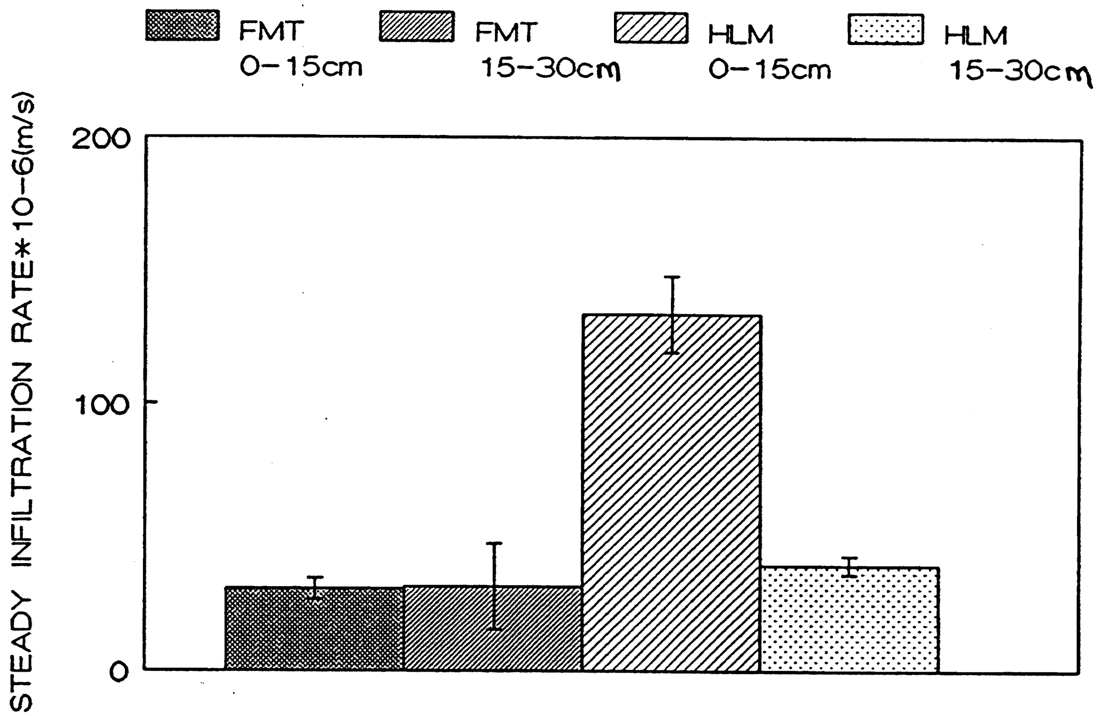

Fig. 7 Comparison of surface and sub-surface steady infiltration rates at Farmington (FMT) and Hilmar (HLM) sites.

PROJECT TITLE: WATER PENETRATION HANDBOOK

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ABSTRACT:

A draft of the manual has been reviewed twice by the Collaborators. The target date for completion is January 1, 1992. It will be in the form of a dichotomous key. The reader will be directed to one of three sections, Avoidance, Diagnosis, or Remediation, based on the reader's answers to questions given in the Introduction. The target audience includes growers, farm managers, farm advisors, and consultants who are trying to manage soils with infiltration problems.

KEYWORDS: Water content profiles, infiltration rates, soil characteristics, soil survey reports, water quality, irrigation systems, irrigation management, chemical amendments, tillage, crop selection, water quality, cover crops, crop residue management.

PROJECT OBJECTIVES ADDRESSED:

The objective is to produce a practical handbook on water penetration problems. It is to include management options and guidelines to avoid water penetration problems in unaffected soils, and methods to diagnose and improve water penetration in affected soils.

PROCEDURES:

A workshop was held in Davis on February 21, 1990 to review results of projects funded by the Kearney Foundation and an outline of the manual. Attendees included researchers, specialists, and farm advisors. One recommendation was to develop a manual, using a dichotomous key, with three sections: avoidance, diagnosis, and remediation. Using this suggestion, review comments obtained on previous outline, and a review of research and extension literature, two drafts of the manual have been prepared and reviewed. With another revision and review, the manual should be ready for final editing by about October of 1991 and publication by about January 1992.