IMPROVING EFFICIENCY IN AGRICULTURAL WATER USE

by

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Colorado Water Resources Research Institute

Completion Report No. 20

Colorado State University

IMPROVING EFFICIENCY IN
AGRICULTURAL WATER USE

Completion Report

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Title: EVAPORATION FROM SOIL AS AFFECTED BY SALT, STRUCTURE, AND TEXTURE.

July 31, 1970

by

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INDEX-ABSTRACT WORKSHEET

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IMPROVING EFFICIENCY IN AGRICULTURAL WATER USE

Salinity is a factor in most of the western soils. Evaporation of water in the soils leaves the salt concentrated in the remaining solution, building up large concentration gradients even in soils containing relatively low concentrations of total soluble salts. These salt gradients can affect water movement both by acting osmotically and by changing the soil structure and water absorption capabilities. The mechanisms of osmosis were delineated, hydrodynamic dispersion coefficients were determined, and effects of these salt gradients on evaporation were determined. NaCl decreased evaporative $CaCl_2$ tended to increase evaporation. Thin dease crusts of the type formed by raindrop action tended to reduce evaporation when overlying looser soil with larger pores.

The mechanisms of osmosis are so involved with ion type, mineral type, structure, and texture that much more work is needed to sort out all the interactions and develop predictive criteria.

DESCRIPTORS--
evaporation, soil salinity, soil texture, surface crusts, salt gradients, osmosis, electro-osmosis, anomalous osmosis,

IDENTIFIERS--
hysteresis of wetting and drying, dispersion coefficients, Onsager reciprocal relations, gravel mulches, wetting methods.

APPENDIX C--INDEX-ABSTRACT WORKSHEET

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ABSTRACT

Salinity is a factor in most of the western soils. Evaporation of water in the soils leaves the salt concentrated in the remaining solution, building up large concentration gradients even in soils containing relatively low concentrations of total soluble salts. These salt gradients can affect water movement both by acting osmotically and by changing the soil structure and water absorption capabilities. The mechanisms of osmosis were delineated, hydrodynamic dispersion coefficients were determined, and effects of these salt gradients on evaporation were determined. NaCl decreased evaporative $CaCl_2$ tended to increase evaporation. Thin dense crusts of the type formed by raindrop action tended to reduce evaporation when overlying looser soil with larger pores.

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KEYWORDS -- Evaporation/ soil salinity/ soil texture/ surface crusts/ salt gradients/ osmosis/ electro-osmosis/ anomalous osmosis/ hysteresis of wetting and drying/ dispersion coefficients/ Onsager reciprocal relations/ gravel mulches/ wetting methods.

I. <u>The OBJECTIVES of This Project Were</u>:

A. To determine the degree to which salt concentration gradients are effective in causing water to move through the liquid and vapor phases in soils with low water content.

B. To use the information gained in (A) to check and refine theory from which the osmotic efficiency of soils may be evaluated.

C. To determine, and develop theory for, the effect of salt concentration gradients, which normally form at the evaporation surface, on the rate at which a dry soil layer is formed and evaporation is reduced.

D. To evaluate the influence of structure and texture, and their interactions with salt content, on the rate at which the dry surface crust forms and evaporation is reduced.

II. <u>Project Findings by Objectives:</u>

A. To determine the degree to which salt concentration gradients are effective in causing water to move through the liquid and vapor phases in soils with low water content.

The efficiency with which osmotic "pressure" moves solution through soils and clays was found to be directly related to the degree to which salt is sieved from solution as it is drawn through the soil or clay by a hydraulic pressure gradient. (Letey and Kemper, 1969). This relation is one of the "Onsager reciprocal relations" which was suspected from the theoretical thermodynamic considerations, but had never been properly verified in clays or soils.

Water movement, in response to osmotic pressure gradients, was measured in clay loam soils at water suctions from 0.08 to 15 bars. Movements in response to osmotic pressure gradients were compared to movements in response to hydraulic pressure gradients on soil in which the water suction ranged from 0.08 to 0.65 bars. At suctions less than 0.5 bars the amount of water moved was generally less than 4% of the water moved by hydraulic gradients of equal magnitude. Details of the procedure and findings in this paragraph are reported by Letey, Kemper, and Noonan, 1969. In general, it was concluded that salt gradients would seldom be an important factor causing water to move in moist (less than 0.5 bar suction) soils, but might be an important factor in dryer soils (suctions from 1 to 25 bars).

B. To use the information gained in (A) to check and refine theory from which the osmotic effiency of soils may be evaluated.

Some of the measurements of osmotic movement indicated that the movement was actually reversed (solution going from zones of high to zones of low salt concentration. At first these were considered to be the result of spurious hydraulic pressure gradients which were overcoming the osmotic gradient forces. However, despite careful elimination of such hydraulic pressure gradients such observations continued. This led to an intensive experimental study and reevaluation of osmotic movement theory conducted by W. D. Kemper during his sabbatic leave at the University of Western Australia. While he was not supported by OWRR funds during this study, the impetus for the study originated in the OWRR sponsored project. The findings of this sabbatic year study are presently being reviewed for one publication in Science and two publications in the Soil Science Society of America Proceedings. Basically they contend that the osmotically induced solution movements observed at salt concentrations less than 1 N are essentially electro-osmotic phenomena, actuated by electric potential differences in soils. These electrical potential differences are generated by rates of cation diffusion exceeding anion diffusion when "positive" or normal osmotic movement is observed toward zones of high salt concentration, or by rates of anion diffusion exceeding cation diffusion when "negative" or anomalous osmotic movement is observed. At salt concentrations greater than about 1 N, the diffuse layer adsorbed cations essential to electro-osmotic movement are repressed to such close proximity to the mineral surfaces that the action of the electrical potential gradients on these ions causes little effective force on the solution. At these high salt concentrations osmotic efficiency is very low and the positive osmotic movement can be explained in terms of the partial geometrical restriction by the small pores of the large hydrated cations and the general theory discussed by Kemper and Evans (1963, Soil Sci. Soc. Amer. Proc. 27:485-490).

While the above findings greatly clarify the mechanisms of osmotic movement, they also point out the complexity of the movement and its dependence on amount and nature of cation exchange capacity, type of ions in the system and their mobilities, along with previously acknowledged factors such as salt concentration gradients and solution phase geometry.

C. To determine, and develop theory for, the effect of salt concentrations gradients, which normally form at the evaporation surface, on the rate at which a dry soil layer is formed and evaporation is reduced.

As a result of the complexity of the effect of salt gradients on osmotic movement, which was not realized when this project was proposed, this objective was not attained as quantitatively as originally planned. The negative osmotic movement in the liquid phase is undoubtedly a factor causing a reduction in solution movement to the evaporative front when salt concentrations range from 0.1 to 1.0 N in the salt gradient formed near such fronts. An acceleration of solution movement to the front by the salt gradient will occur only when the salt concentration becomes greater than 1 N. These tendencies may have been factors in the observed (Todd, 1970) reduction of evaporation by Na salts and increased by Ca salts in the soil profile. Ca salts accumulated to the higher concentrations near the evaporative surface necessary to induce positive osmosis. Na salts were generally at lower concentrations where negative osmosis (away from the evaporation front) would be expected. Another factor favoring the positive osmosis by the Ca salts is the large hydrated radius of the Ca ions, which allows the porous media to more effectively restrict the motion of the Ca ion and consequently increase its osmotic efficiency.

D. To evaluate the influence of structure and texture, and their interactions with salt content, on the rate at which the dry surface crust forms and evaporation is reduced.

Expansion of earlier work by A. T. Corey and others indicated that gravel and sand mulches and coarse textured surface layers of all kinds reduced evaporation. This is particularly true when finer materials lie below the coarse materials and almost immediately extract water from the coarse textured soil, leaving the coarse layer as a highly non-conductive barrier to evaporative loss. These results are summarized largely by Corey and Kemper (1968) and give the basic reasons why successful agriculture can be practiced under coarse textured mulches in areas such as the Canary Islands and some coastal regions of Spain under average annual rainfalls of less than 10 inches. The findings of this study helped initiate the studies on effects of coarse textured mulches on corn and tomato growth which were supported by the U. S. Dept. of Agriculture, SWCRD, and Colorado State University and carried out by M. L. Fairbourn.

Bresler and Hanks (1969) developed a computerized numarical method which allows the prediction of the distribution of salt in a soil after wetting and drying cycles. This information was deemed valuable as a first step in computing potential osmotic movement. Concurrent studies on osmotic efficiency resulted in the conclusion that the salt gradients predicted under reasonably moist conditions would have practically negligible influence on the movement of water through soils at depths more than an inch below the evaporative surfaces.

Bresler, Kemper and Hanks (1969) found that NaCl added to the surface before applying a given amount of water reduced the subsequent evaporation. One mechanism involved was the slower entry of water into the soil occasioned by the Na treated surface. They showed that soils wetted more slowly, wet more deeply (because of hysteresis and other factors which they discuss in detail). They then went on to show that soils wet more deeply had slower rates of evaporation. A computer program was developed on the basis of information gathered in the experimental studies which predicts the effect of different rates of wetting and different soil characteristics (water retention characteristics based on soil structure and texture) on subsequent evaporation. A note of caution should be expressed here in that some means of holding the water on the soil long enough for infiltration to take place must accompany such NaCl treatment if net increases of stored water are to be achieved. If the infiltration time becomes extremely large, under field conditions the additional evaporation from surfaces wet for a longer period of time may exceed the subsequent evaporation reduction.

However, the information on rate of evaporation as affected by rate of wetting should have considerable application in the development of irrigation systems and equipment for most efficient use of water.

The resistance to water flow during evaporation was determined as a function of depth in the soil by Bresler and Kemper (1970). They found that the structure of the soil affected the resistance occurring at any depth, but particularly within the top few centimeters. Specifically they found that dense "crust" forming the top few mm of soil will often retain all its water in its small pores and thus has a higher unsaturated conductivity than the structure soil with large pores lying below the crust. During the early stages of evaporation from soils with these dense saturated crusts, the crust often transports water away from the loose soil below it faster than the loose soil at greater depths can move water upward. The result is a dry layer forming below the crust, cutting off the water supply to the crust which then dries. The evaporation rate of these crusted soils decreases much more abruptly than from the noncrusted soils where the evaporation rate decreases more gradually. The net effect is generally for the crusted soils (soils with a dense surface layer) to develop a dry surface layer more quickly and lose less water by evaporation. These thin, dense evaporation reducing crusts form to a greater extent under rainfall or sprinkler irrigation than under flood irrigation.

The ability to wet soils more slowly, coupled with this crust formation factor involved in sprinkler irrigation, tends to reduce evaporation from sprinkler irrigated soils compared to flooded soils following irrigation. This water saving must be balanced against the greater evaporation loss during the irrigation with sprinklers to determine the most efficient system. Sprinkler irrigation during evening or early night hours when humidity is high may reduce some of the negative factors associated with sprinkler irrigation and allow it to be more efficient than flooding.

Additional studies are still needed to determine effects of the various salts on the rate at which the dry surface crust forms. The data obtained by Todd (1970) show that the drying of the surface layer can be accelerated or decelerated depending on the type of salt (Na or Ca, respectively) used. These considerations, plus the knowledge of how structure interacts with salt and evaporation, should be used to design a more extensive and sophisticated set of experiments to gain quantitative answers and fulfillment of this objective. Such studies should be greatly facilitated by the methodology developed and by the hydrodynamic dispersion coefficients in unsaturated systems which were measured in the process of this study (Todd and Kemper, 1970).

III. Estimate of Extent to Which Objectives Were Achieved:

A. 80%.

B. 70%.

C. 30%.

D. 50%.

IV. Significant Findings:

A. Osmotic flow at solution concentrations less than 1 N is mainly an electro osmotic process.

B. Osmotic flow is not generally appreciable compared to hydraulically induced flow under the gradients commonly encountered below the top few inches of soil.

C. Coarse textured surface soils and sand and gravel mulches greatly decrease evaporation as compared to soils with fine textured surface layers.

D. A computerized numerical method was developed which allows the prediction of distribution of salt in the soil after wetting and drying cycles.

E. Depth of wetting was found to be a major factor controlling evaporation rates, with slow rates of wetting causing greater depths of wetting when a given amount of water is applied.

F. Soil structure involving a thin dense crust at the surface overlying looser soil will cause more rapid surface drying than when the soil is more uniform.

G. A method was devised for obtaining hydrodynamic dispersion coefficients in unsaturated soils which seems to have several advantages over past methods. The coefficients obtained should help predict the salt distributions in future studies.

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