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GROUND WATER RECHARGE AS AFFECTED BY SURFACE VEGETATION AND MANAGEMENT

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ABSTRACT

GROUND WATER RECHARGE AS AFFECTED BY
SURFACE VEGETATION AND MANAGEMENT

Ground water resources on the high plains of Colorado are being mined for irrigation at a rate surpassing natural recharge of the aquifer. Detailed information on recharge rates, as well as possible methods for increasing recharge, is essential to sound agricultural planning. Various surface soil treatments were investigated in field experiments to determine their effect on ground water recharge. Plots were established in 1967 on initially very dry soil of semi-arid native range land. The water table is about 100 feet below the surface. Water content profiles were measured periodically to determine the downward movement of water resulting from the surface treatments. Changes in the total water content of the profile were used to evaluate soil water accumulation and possible ground water recharge. A 2.5 cm coarse sand and gravel mulch, with vegetation controlled by herbicides, accumulated 50% of the annual precipitation during a two-year period. The sand and gravel mulch with native grass vegetation showed only seasonal fluctuations in the upper 120 cm of the profile with no net accumulation of water. Fallow treatments (chemical and mechanical) did not show significant accumulation until heavy October 1969 snows.

Matric potential profiles for various locations on fine textured soils in the high plains area showed high tension values to considerable depths except where conservation practices or irrigation had been used.

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KEYWORDS: Ground water / Recharge / Evaporation / Mulches / Surface Management / Soil Water Flow / Vegetation Control.

INTRODUCTION

Recent large scale irrigation development on the high plains of Colorado has spurred considerable interest in ground water recharge rates. Ground water resources are being depleted and natural recharge rates are small. Individual farmers and ground water management districts are concerned with continuing ground water supplies.

Ground water recharge on the high plains of eastern Colorado comes from precipitation that occurs within the region. No water is received from outside the region as underground or surface flow (Reddell, 1967). The recharge must come by percolation of water through the soil profile. This percolation could occur in areas of runoff collection or from direct infiltration and percolation through the soil.

The Ogallala formation is the principal aquifer of the high plains. Its depth below the surface ranges from zero to more than 100 feet and it is overlain by various materials (Reddell, 1967). The two most extensive of these are the dune sands and the Peorian loess materials. Dune sands overlie the Ogallala formation over an important area of the Colorado high plains. Relatively larger recharge rates have been attributed to this area. Irrigation development in the dune sand area is somewhat limited because of the low water holding capacity of the soil and the unfavorable topography. The silt to silt loam loess deposits vary in thickness from zero to more than 100 feet. They cover a significant portion of the high plains and are quite important in the development of irrigated agriculture.

The quantity of water moving through the soil profile in a given time depends on many factors including amount and intensity of rainfall, soil characteristics, topography and evapotranspiration losses. Both micro and macro topography influence water movement into the soil. Steeply sloping lands may lose considerable water to runoff during intense showers. Rough surfaces may reduce runoff. The evaporative and transpirative losses will influence net water movement through the soil and a reduction in either loss may significantly increase soil water recharge rates.

Several investigators have reported natural ground water recharge rates on the high plains as averaging about 0.8 inch per year (Boettcher, 1966; Cardwell and Jenkins, 1963; McGovern, H. E., 1964; Weist, 1964). These values were calculated on a large scale basis and give little insight into surface conditions that affect recharge rates. Reddell (1967) computed recharge rates for 36 square mile grids on the high plains. These grids are rather large areas and give only rough indications of how surface conditions contribute to ground water recharge.

The ground water recharge rates of eastern Colorado are not sufficient to meet current demands and the water resources are presently being mined. Detailed information on natural recharge rates and supplies of water as well as any possible method of increasing supplies of available water is essential to sound planning of the use of the ground water resources of eastern Colorado.

OBJECTIVES

This project had the following objectives:

1. To determine the contribution to ground water of range and cultivated lands under a semi-arid climate. Plant species and micro relief and texture of the soil will be evaluated as factors modifying this contribution, and water requirements of crops will also be obtained.

2. To evaluate changes in the contribution to ground water caused by surface treatments such as:

   a. Contour ridging

   b. Pitting

   c. Herbicide treatments to reduce transpiration

   d. Herbicide treatments to eliminate transpiration

   e. Altering the surface texture of soil

   f. Snow fences and other snow trapping systems

   g. Chemicals to increase infiltration and retard evaporation

PROCEDURES

Field Plots

Field trials with controlled surface conditions were established in August 1967, near Burlington, Colorado in order to determine possible ground water recharge resulting from various dry land management techniques and a gravel mulch. The water movement into the soil and through the profile was determined periodically by measuring the water content of the soil as a function of depth below the surface. The experimental plots were established at a site 2.5 miles south of Burlington, Colorado. The area is legally described as being located in the southeast corner of section 14, T-9-S, R-44-W. The surrounding area is semi-arid native range land which is characterized by gently rolling hills of the high plains. The predominant geology is the Peorian loess deposit overlying the Ogallala formation. The native grasses are buffalo and blue grama which are characteristic of the 15- to 16-inch average annual precipitation zone of the Colorado high plains. The experimental site is mapped as a Fort Collins loam soil with little or no apparent erosion. The soil is developed on a thin alluvial deposit which overlies sand and gravel of the Ogallala formation. The surface has a 1 to 2 percent slope from the southeast toward the northwest.

The experimental plots are located in a valley of the intermittent Little Beaver Creek which runs along the west and north sides of the site. The creek did not run water during the course of this experiment and should not have affected the results.

The site was native range, similar to the surrounding area, and had never been intensively managed or irrigated. Thus, the initial soil water conditions should have been very nearly uniform over the entire site varying only with minor textural and topographic variations. The water table is approximately 100 feet below the surface and should not have influenced the soil water content near the surface.

The site was divided into twelve individual plots, each 100 feet long and 80 feet wide. Twenty-foot alleys separate each east-west row of plots as shown in Figure 1. There was no separation along the east or west side of the plots. The site was surrounded by a 20-foot alley and a barbed wire fence to keep livestock out of the plots. Plot Number 3 (Figure 1) was cut off on the corner to allow room for the fence and alley between the plot and the Little Beaver Creek.

Six surface management treatments were assigned to the plots in a randomized block design. Plots 1 through 6 and 7 through 12 in Figure 1 are randomized replicates of the experiment. The treatments are described below.

The purpose of the experiment was to measure infiltration and water movement through the soil profile with natural precipitation as the only

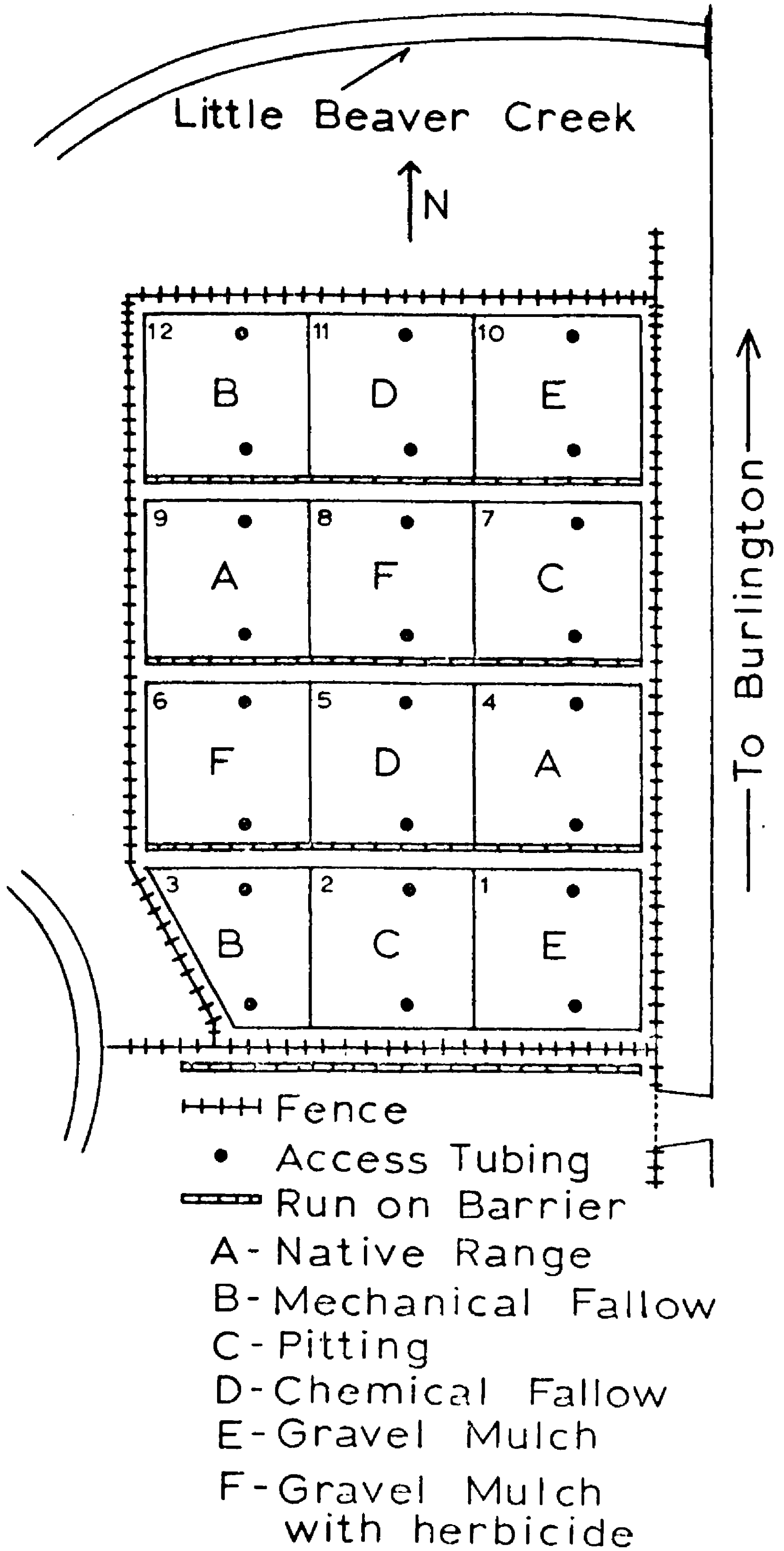

Figure 1. Location and layout of surface management plots.

source of water. For this reason normal runoff from the plots was not prevented but was directed away from the area to prevent surface flow to another plot. The various surface treatments, of course, had different runoff potentials.

The six surface management treatments investigated in this experiment may be described as follows:

A. Native Range

The native range left undisturbed. No further management or grazing.

B. Mechanical Fallow

The plot worked with a rotovator to a depth of 4-6 inches which completely destroyed the sod.

C. Pitting

The plots worked as in treatment B. The loose soil then pitted to eliminate runoff. The pits were about 6 inches deep, 36 inches apart, and 10 feet long. The pitting was redesigned in June 1969, because the original equipment was no longer available. Furrows were made in diagonal criss-cross fashion about 5 feet apart and 5 feet long.

D. Chemical Fallow

Plant growth controlled with herbicides without disturbing the soil surface.

E. Gravel Mulch

A layer of coarse sand and gravel, with average thickness about one inch, spread over the native range without disturbing the surface.

F. Gravel Mulch with Herbicide

The plots treated with herbicides, as in treatment D, before the gravel mulch, as in treatment E, was applied.

The plots required occasional maintenance after they were established. A listing of major maintenance operations is given in Table 1. Weed control on the mechanical fallow and pitted treatments was accomplished with a small

Table 1. Chronology of maintenance of experimental plots.

Date	Comments
8/21/67	Treatments established
6/4/68	Chem. fallow and gravel mulch with herbicide plots retreated, Dalapon and 2-4-D treated areas as original, atrazine areas spot treated
6/25/68	Mech. fallow and pitted plots disced, pitted plots repitted as originally
9/5/68	Pitted plots sprayed with 2-4-D; north ½ of chem. fallow and gravel mulch with herbicide plots treated with atrazine
9/16/68	Mech. fallow plots disced
3/23/69	Rain recorder installed at the site
6/10/69	Pitted and mech. fallow plots disced, pitted plots repitted with one-way disc
6/26/69	Large weeds pulled by hand from pitted and mech. fallow plots
7/29/69	Weeds pulled by hand from pitted and mech. fallow plots; chem. fallow and gravel mulch with herbicide plots paraquat treated
9/10/69	Chem. fallow and gravel mulch with herbicide plots treated with paraquat
5/25/70	Pitted plots and mech. fallow plots disced, pitted plots repitted. Large weeds pulled by hand from plots
6/25/70	Paraquat treatment applied to gravel mulch with herbicide and chemical fallow plots
8/26/70	Chemical fallow and gravel mulch with herbicide treated with paraquat
6/5/71	Mech. fallow and pitted plots disced; pitted plots repitted
7/25/71	Hand weed control used on all plots, paraquat applied to chemical fallow and gravel mulch with herbicide.
9/10/71	Paraquat used on chemical fallow and gravel mulch with herbicide.

one-way disc. The chemical fallow and gravel mulch plus herbicide plots were split and given two different herbicide treatments. The north 1/2 of each plot was treated with Atrazine at the rate of 22 pounds per acre. The south 1/2 of each plot was treated with Dalapon and 2-4-D. Dalapon was applied at the rate of 2.7 pounds per acre in combination with 2-4-D at the rate of 2.7 pounds per acre. Both treatments were applied as sprays.

Effective vegetation control with herbicides was difficult. The Dalapon and 2-4-D treatment was re-applied in the early summer of 1968. This was still ineffective control and the Atrazine treatment was applied to the areas originally treated with Dalapon in the fall of 1968. The areas originally treated with Atrazine were spot sprayed again with Atrazine in the early summer of 1968. In the spring of 1969, a contact herbicide, which was less dependent on soil moisture and rainfall conditions, was used to control vegetation. Paraquat at the rate of 0.1 pounds per 100 gallons of water was applied directly to plants of both previous herbicide treatments. This practice was repeated throughout the summer and was very effective in keeping growth to a minimum.

There was some variation in the thickness of the gravel mulch due to the uneven sod surface, but the average thickness was about one inch. The gravel contained 50 percent particles less than 1.0 mm in diameter and 17 percent larger than 2.0 mm. The native grasses subsequently grew through the gravel. No additional management of these plots was needed.

Soil Water Content Measurements

The neutron scatter method was used to determine water content of the soil as a function of depth below the surface. Ten-foot lengths of galvanized electrical conduit, with an inside diameter of 1.59 inches, were installed for neutron probe access. Three-inch diameter holes 9.5 feet deep were augered at two locations in each plot. The conduit was placed in the hole and soil was tamped around it. Six inches of access tubing extended above the soil surface and was covered with a metal container to prevent rainfall and rodents from entering the tubes. The position of each access tube is shown in Figure 1.

Four longer access tubes were installed near the original tubes in the gravel mulch with herbicide (Treatment F) plots on May 1, 1969. They were installed in a similar manner except that two 10-foot sections of conduit were coupled together before placing them in the hole. They were placed as deep as the auger could remove the soil materials from the profile. This depth varied from 15 to 18 feet below the surface. The tubes were cut off 6 inches above the soil surface.

Neutron readings were taken by lowering a probe to the desired depth and recording two 1-minute counts at each location. Duplicate measurements were taken to reduce the error of determination to less than 0.5 percent water by volume.

Van Bavel (1958) recommends 6-inch depth intervals for sufficient overlap in readings to give accurate details of the water content profile. However, 1-foot intervals were used in this experiment without seriously limiting the significance of the results. Readings were taken starting 1 foot below the surface. The 1-foot depth reading neglected the water content near the soil surface, but should not have been influenced by the soil-air interface. Neutron readings were taken immediately after the access tubes were installed and periodically thereafter.

The calibration used to convert the neutron readings to water contents had been determined for field experiments on a Fort Collins soil. This calibration was assumed to be essentially the same for the soil of this experiment. The standard count ratio (counts in soil/standard count) was used in converting readings to water contents. Standard counts were obtained in the shield at each access tube before the readings in the soil were taken. Shield counts did not vary to any great extent so the average of all shield counts was used as the standard count.

Two different neutron probes and scalers were used. The majority of the data was obtained with a Nuclear-Chicago P-19 probe and model 2800 portable scaler. Later measurements were made with a Troxler S-6A probe and model 600 portable scaler. A calibration check was obtained for the two probes from readings taken with both probes on the same date. It was found that the corresponding water contents were not in agreement. The Troxler probe readings were therefore converted to an equivalent Nuclear-Chicago reading and the original calibration was used throughout the study so that consistency was assured. The Troxler probe readings were converted to the Nuclear-Chicago calibration in the following manner. By assuming that both probes had measured the same water content, a linear regression equation was obtained relating the Troxler readings to an equivalent Nuclear-Chicago reading. This equivalent reading was then used to convert the readings to water contents. This conversion to an equivalent Nuclear-Chicago reading appears to work very well at water contents above 10 percent by volume. However, it may introduce small amounts of error at lower water contents. The regression equation is:

$$(\text{count ratio})_{\text{Nuclear-Chicago}} = \frac{(\text{count ratio})_{\text{Troxler}} - .068}{.647}$$

where

$$(\text{count ratio}) = \frac{\text{counts in soil/min.}}{\text{standard count/min.}} .$$

The regression coefficient is 0.88.

The percent water data were later converted to quantities of water by multiplying by the depth increment taken uniformly as 12 inches. This assumes the water content as determined is representative of a volume of soil extending 6 inches above and below the point of determination. In a nearly uniform water content profile this does not introduce significant error; however, in regions of steep water content gradients, some degree of error would be introduced.

Soil Properties

Soil samples were taken in August 1967 from the 5 to 6, 10 to 11, and 15 to 16-foot depths near each access tube. Similar samples were also obtained in June 1968 from the 5 to 6 and 10 to 11-foot depths. Samples were taken with a probe after augering to the desired depth. The probe was designed to obtain undisturbed cores, in aluminum cylinders, which could be transported to the lab. Gravimetric water content, bulk density, particle-size analysis, and water retention characteristics were determined on these samples.

Bulk density was determined by drying three 100-cm^3 subsamples of the 1968 cores at 105° C.

Particle-size distribution was determined, on a subsample of the August 1967 samples, using the hydrometer procedure described by Day (1965). Calgon was used as a dispersing agent and no attempt was made to remove organic matter, lime, or soluble salts. The calgon dispersed suspensions were stirred with an electric mixer for 5 minutes, and then transferred to a 1000-ml cylinder. The hydrometer readings for clay content were taken after the suspension reached a stable temperature. The suspension was then poured through a 300-mesh (47-micron opening) sieve and the particles retained on the sieve were determined gravimetrically.

Water retention characteristics were determined by first saturating a 15- to 20-gram subsample of the soils and desaturating with positive (greater than atmospheric) air pressure above a porous ceramic plate. The saturated samples were placed on a wetted porous ceramic plate in a pressure chamber where the desired differential air pressure was applied across the plate. The differential air pressure applied was equal in magnitude to the matric potential desired for the soil samples. The samples were removed after 48 hours and the gravimetric water content was determined by drying at 105° C. Water contents (on a dry weight basis) were determined at 1, 5, and 15-bars matric potential. Because these values should be influenced only slightly by structural changes, air dried and sieved (less than 2 mm size) soils were used.

The water content pressure relationship is influenced by pore-size distribution and the larger pores can be changed by structural changes in unconsolidated soil material. Thus disturbing soil samples will have a definite effect on the water retention characteristics of the soil in the wet range. This structural porosity effect is primarily important below 1-bar matric potential. For this reason only a limited number of water contents were determined for matric potential below 1 bar and these were made on 1-inch deep undisturbed cores from the June 1968 samples.

An attempt was made to determine several points on a single undisturbed sample by measuring the water outflow with an increase in applied air pressure. A single sample was saturated and placed on a small saturated porous ceramic plate. A positive pressure (greater than atmospheric) was applied above the ceramic plate. The sample was allowed to come to equilibrium (approximately 24 hours). The air pressure was then increased and the volume of water removed from the sample through the ceramic plate was measured. The outflow volume was determined by readings on a buret connected to the lower side of the ceramic plate with Tygon tubing. The pressure was increased in increments and each time the outflow volume was recorded. After the final pressure equilibrium the sample was removed and the water content determined gravimetrically by drying at 105° C. The outflow volumes were added to the final water content to obtain values at the other pressures. These values should be regarded as rough approximations since the procedure appeared to be subject to large experimental errors. These errors could be due to shrinkage as the air pressure was increased and to evaporative losses of water which were not determined.

Precipitation records are available from the city records of Burlington, Colorado approximately 3 miles from the experimental site. These figures are only very rough estimates of the precipitation on the plots because the pattern of rainfall is variable. For this reason, a 30-day recording rain gauge was installed at the plot site in March 1969. The amounts of rainfall prior to March 1969 are from the Burlington records and those subsequent to that time from the recorder at the plot site. However, the recorder is not very accurate for snow and some estimates of the water from snowfall have been obtained from the city records.

Soil Water Profiles of the Surrounding Area

In addition to the information obtained from the field plots near Burlington, numerous locations in the surrounding area were sampled and analyzed to obtain water content profiles. Approximately 45 locations in Yuma County and 35 locations in Kit Carson County were sampled. This information was gathered to confirm and extend to a larger area the information about ground water recharge obtained from the field trials. Locations for sampling were selected to be representative of several natural conditions on the high plains. These surface variations included: rangeland with variations in slope; pitted rangeland, dry-farmed areas; terraces; playa lakes; and irrigated farm land. The profiles were sampled at 2- to 3-foot intervals to depths of 10 to 28 feet below the surface. Water content of the samples was determined by drying at 105° C. Water retention characteristics between 1 and 15-bar tension were determined in the same manner described earlier. The desorption curve was used, in conjunction with the water content values, to determine matric potential profiles for these sites.

Hydraulic Conductivity-Water Content Data

At the time of preparation of the proposal for this project, it was believed that at depths below the root zone and well above the water table a hydraulic gradient acting in a downward direction of about unity would exist -- at least in many profiles. If such were the case, knowledge of the hydraulic conductivity would give the flux density of water to the water table. Thus, it was considered imperative to develop a method to measure the hydraulic conductivity at the water content existent in situ below the root zone. A routine sensitive method was required. Preliminary work[1/] indicated that a method utilizing undisturbed cores, a centrifuge and a recording analytical balance would provide satisfactory hydraulic conductivity data. When a partly saturated core sample of porous material is rotated in a centrifuge at a constant angular velocity, the water is moved away from the inner end toward the outer end of the core. The resulting non-uniform water distribution will give rise to a capillary pressure gradient in the core. Water will move until the centrifugal force and the capillary pressure gradient force balance each other. If the centrifuge can be stopped instantaneously the only force tending to move the water is the capillary pressure gradient. The movement of water in response to the capillary pressure gradient may then be detected by placing one end of the core on a fixed fulcrum and the other end on a recording balance. A diagram of the arrangement of the sample on the recording balance is shown in Figure 2.

Measurements were made on undisturbed cylindrical soil core samples 5 cm long and 5 cm in diameter. Tests of the method were also performed using porous ceramic cylinders of the same dimensions. The soil cores were obtained with a pickup-mounted, power driven sampling machine. A sampling probe with a cutting head, and a lining of aluminum rings was pushed into the soil. The soil cores in the aluminum rings were then transported to the laboratory and trimmed. Aluminum end plates with knife edges attached (See Figure 3) were sealed to the ends of the sample with screws, rubber gaskets, and rubber cement. The samples were centrifuged at a constant

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1/ The concept of using a centrifuge to measure hydraulic conductivity was devised by Dr. W. D. Kemper.

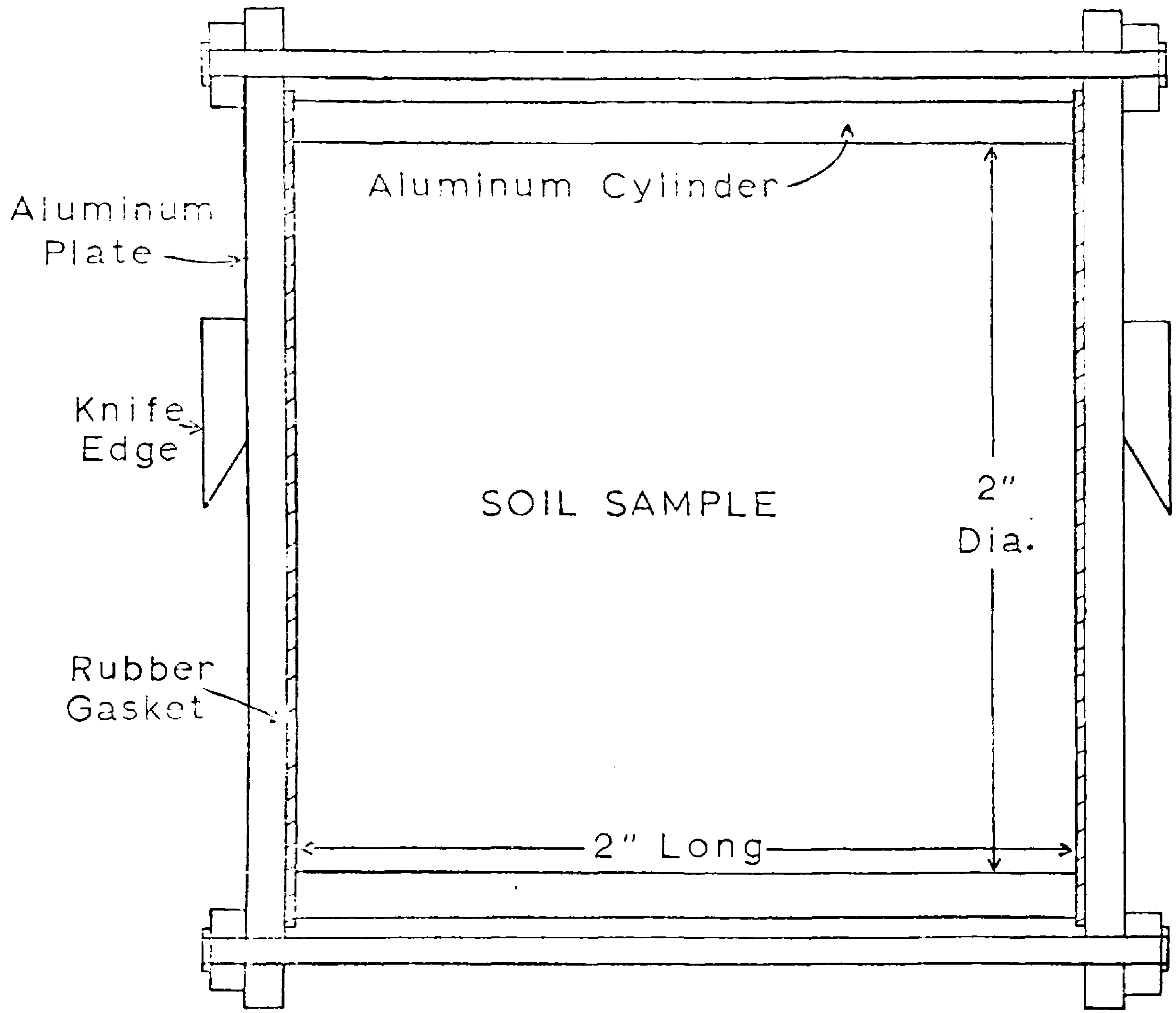

Figure 2. Sample holder for undisturbed cores for measurement of hydraulic conductivity.

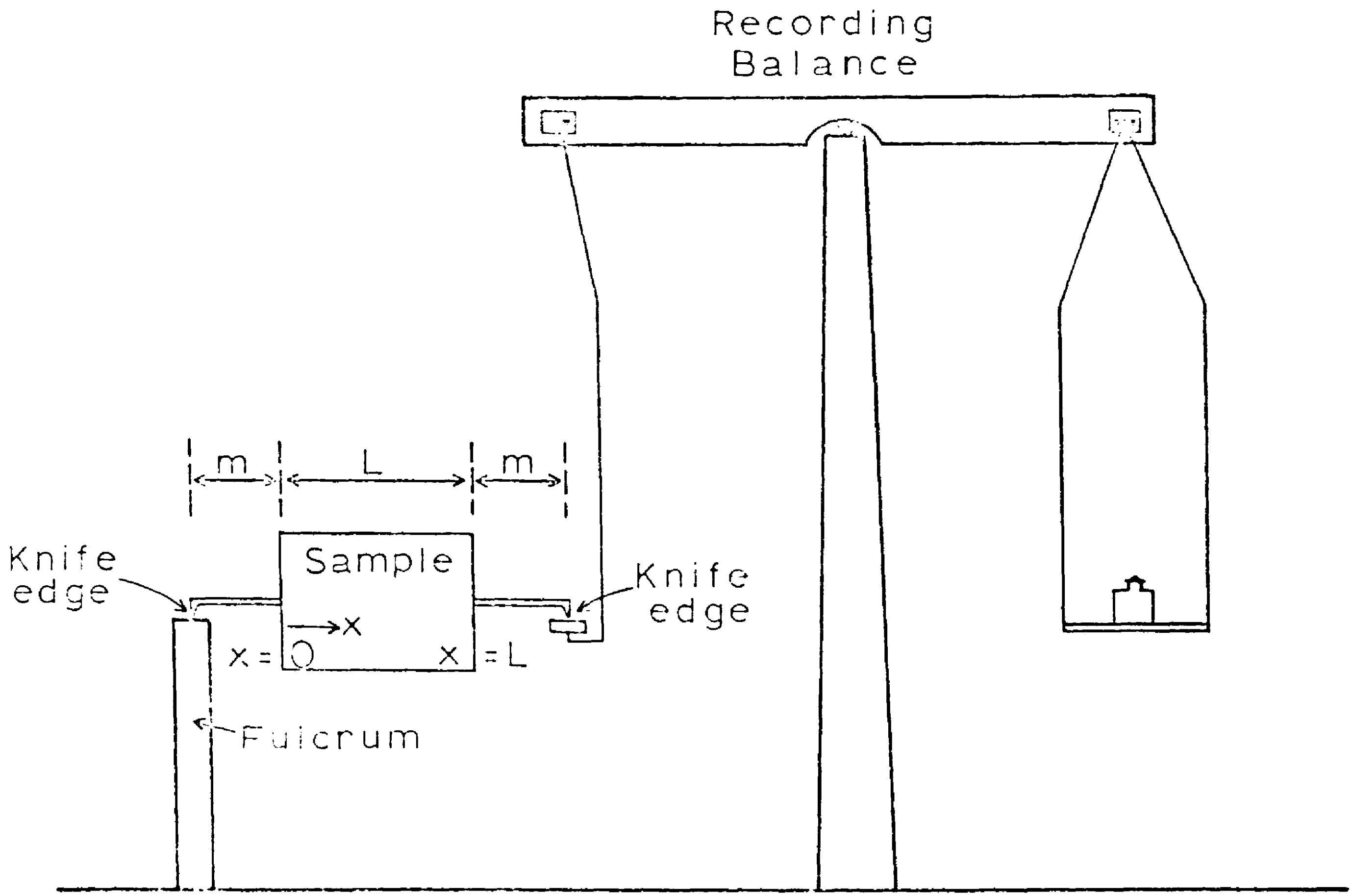

Figure 3. Diagram of the arrangement of the sample on the recording balance for measurement of hydraulic conductivity.

rotational speed for at least 24 hours. At the end of the centrifuging period, the samples were quickly removed and placed on the fulcrum and pan of the recording balance (See Fig. 2). A recording of the mass M displayed on the balance versus time was obtained for a period of 10 to 15 minutes.

The hydraulic conductivity at a given water content is the ratio of the water flux to the hydraulic gradient. Two theories were developed to relate the time rate of change of mass, as observed on the balance, to the hydraulic conductivity.

Theory I

The following assumptions were made:

1. The flow of water in the core is one-dimensional, i.e., gravitational effects are neglected.

2. The capillary pressure P_c, or the pressure head h of the soil water is a single valued function of the volumetric water content θ. Hysteresis is neglected.

3. Variations in θ induced by centrifuging are small and within this range the conductivity K is constant.

4. Within the above range of θ the relation between P_c and θ is linear.

5. At the moment the centrifuge is stopped (t = o) the water distribution in the core is a linear function of position of the form

$$\theta\ (x, 0) = \overline{\theta} + (x - \frac{L}{2})\ B(o) \qquad [1]$$

where $\overline{\theta}$ is the average water content of the core, L is the length of the core, and B(o) is the slope of the above relation at t = o.

6. At $t > o$, the water distribution in the core remains linear with x:

$$\theta (x, t) = \bar{\theta} + (x - \frac{L}{2}) (B(t)) \qquad [2]$$

where B(t) is the time dependent slope of the time relating θ to x at $t > o$.

With this assumption, an equation was derived relating the hydraulic conductivity to the time rate of change of mass displayed on the recording balance:

$$K(\bar{\theta}) = \frac{3(L + 2m)}{2\pi r^2 \rho L n} \left. \frac{dM}{dt} \right|_{t = o} \qquad [3]$$

where $K(\bar{\theta})$ is the hydraulic conductivity at the average water content $\bar{\theta}$ of the core, ρ is the density of water, L is the length of the core, $\left. \frac{dM}{dt} \right|_{t = o}$ is the time rate of change of mass at time zero, and n is given by:

$$n = \frac{4 \pi^2 N^2 (R - L/2)}{g} \qquad [4]$$

in which N is the number of revolutions of the centrifuge per unit time, and g is the acceleration of gravity. In equations [3] and [4], R, and M have the significance shown in Figure 2.

Theory II

In this analysis assumptions 1, 2, 3, and 4 of Theory I are used. Assumptions 5 and 6 concerning the slope of the water content profile in the core are <u>not</u> used. Using assumptions 1, 2, 3, and 4, it can be shown that the water content in the core should satisfy the partial differential equation.

$$\frac{\partial \theta}{\partial t} = \frac{K}{c} \frac{\partial^2 \theta}{\partial x^2} \qquad [5]$$

in which c is the water capacity, $d\theta/dh$. The ratio K/c is the soil water diffusivity D. A solution of equation [5] subject to the boundary conditions of no flow across the ends allows one to obtain an equation for θ (x, t). An equation was then derived relating the mass shown on the balance as a function of time to the average water content of the core $\bar{\theta}$, the soil water diffusivity, the various geometric factors of the arrangement on the balance, and the speed of the centrifuge. The result was

$$M(t) = C_1 \bar{\theta} + C_2 N^2 C \exp(-C_3 Dt) \qquad [6]$$

in which C_1 and C_2 are collections of constants (sample radius, sample length, density of water, etc.), C is the water capacity, and C_3 is π^2/L^2. For the numerical values of R, L, m, r and ρ used in the measurements, equation [6] may be written:

$$M(t) = 50.6 \bar{\theta} + 29.4 N^2 C \exp(-0.4 Dt) \qquad [7]$$

with M in grams, t in secs, C in cm^{-1}, and D in cm^2/sec.

The values of C and D can be determined from the recording as follows: From an arbitrary point on the curve of M versus t, the mass changes over two successive time intervals of the same length are determined. Denoting the mass changes as ΔM_1 for the time interval Δt_1, and ΔM_2 for the succeeding time interval $\Delta t_2 = \Delta t_1$, the following equation can be derived from equation [7]:

$$\frac{\Delta M_1}{\Delta M_2} = \exp(-0.4 D \Delta t) \qquad [8]$$

The soil water diffusivity D can then easily be computed. The value found for D can then be substituted in equation [7] to calculate C. Finally K is found as the product of D and C.

In Situ Measurement of Soil Water Potential

A limited number of thermocouple psychrometers were installed at depths of 10 to 20 feet on a native range site south of Burlington, Colorado. The psychrometers were mounted on the end of a $1\frac{1}{2}$ inch diameter thin wall steel conduit (neutron access tube). The access hole was made with a Giddings hydraulic core sampling machine and the access tube with the psychrometer unit was pushed into the hole. At the time of installation the ceramic shell of the psychrometers was wetted with water. After approximately 4 weeks readings were begun.

RESULTS AND DISCUSSION

Soil Properties

The bulk density data are shown in Table 2. The values are fairly uniform and average about 1.5 gms/cm^3. Plots 3, 6, 11, and 12 appear to have soils with a somewhat lower bulk density. These plots have a deeper dark-colored fine textured layer than the rest of the site.

Particle size distribution data are also shown in Table 2. The non-uniformity of the soils in the experimental site is displayed by the variability in the percents less than 2 microns and greater than 47 microns. Plots 3, 6, 11, and 12 have a deeper layer of fine textured soil as indicated by the percent clay of the 5 to 6-foot depth. However, the majority of the samples are sandy loam.

The water retention data of the soils in the plots are given in Table 3. The data from the single samples at a series of increasing applied air pressure may be identified as those samples where $\frac{1}{2}$ bar percentages are given. In general, the water retention data again point out the non-uniform nature of the soils of the experimental site. Some of the samples in plots 3, 6, 11, and 12 have higher water contents at given matric potentials which indicate finer textured soils.

Table 2. Bulk density and particle size distribution of soils.

		BULK DENSITY (grams/cm^3)											
Depth (feet)	*	Plot Number 1	2	3	4	5	6	7	8	9	10	11	12
5-6	N	1.4	1.5	1.2	1.6	1.6	1.4	1.5	1.6	1.5	1.4	1.1	1.3
	S	1.6	1.5	1.3	1.4	1.6	1.3	1.6	1.6	1.6	1.6	1.5	1.5
10-11	N	1.4	1.5	1.3	1.5	1.5	1.5	1.5	1.6	1.6	1.5	1.2	1.5
	S	1.5	1.4	1.5	1.5	1.4	1.2	1.4	1.5	1.6	1.6	1.4	1.4
		PARTICLE SIZE DISTRIBUTION											
		Percent less than 2-micron effective diameter (clay fraction)											
5-6	N	10	14	23	11	7	10	8	12	10	19	8	13
	S	15	18	25	18	10	23	10	11	8	8	19	10
10-11	N	10	15	15	7	8	9	10	8	13	6	8	8
	S	6	15	15	10	10	10	13	10	10	6	9	9
15-16	N				9	10	9	7		10	6	8	8
	S	11			9	10	10	9	11				8
		Percent greater than 47-micron diameter (sand & gravel fractions)											
5-6	N	58	63	28	67	76	68	75	72	64	25	84	34
	S	54	51	32	44	77	31	60	79	79	70	33	73
10-11	N	75	69	59	77	73	63	64	72	79	84	88	76
	S	85	66	45	63	70	62	66	74	74	85	82	77
15-16	N				74	70	76	72	60		81	88	78
	S	76			71	75	69	59		84			84

* N - near north access tube, S - near south access tube

Table 3. Water retention characteristics of soil.

Plot* No.		Depth (feet)	Water content (% dry weight basis)						
			Matric potential (bars)					Field moisture	
			1/3	1/2	1	5	15	8/67	6/68
1	N	5-6			8.9	6.1	5.2	3.7	4.5
	S		7.9		7.4	4.7	4.3	4.6	3.3
	N	10-11	14.5	12.9	8.6	6.0	5.4		4.4
	S				7.9	5.8	5.1	2.5	3.6
2	N	5-6			10.7	7.2	5.8	2.9	5.3
	S				11.1		6.3	2.4	4.6
	N	10-11			9.6	6.8	5.7	4.3	4.5
	S							3.9	3.8
3	N	5-6	30.8	27.5	24.0	15.1	12.5	7.3	10.2
	S				19.4	12.2	9.9	8.6	9.2
	N	10-11			14.3			5.7	9.3
	S				15.8	10.3	8.8	4.1	6.3
4	N	5-6			8.2	6.2	5.2	4.8	3.4
	S				9.9	7.1	6.1	4.2	4.6
	N	10-11	14.4	11.7	7.3	5.3	4.7	2.9	3.7
	S				8.5	6.2	5.3	3.6	3.7
5	N	5-6	7.1		6.4	4.4	4.3	2.6	2.8
	S		6.9		6.0	4.6	3.9	1.8	2.5
	N	10-11	9.1	8.4	7.6	5.3	4.8	3.6	4.7
	S				7.9	5.2	4.9	5.6	5.8
	N	15-16				5.0	4.3	3.8	
6	N	5-6			12.9	8.7	7.0	5.1	6.3
	S				26.4			7.9	7.9
	N	10-11	10.7		9.9	6.4	5.3	3.2	4.4
	S				9.8		5.4	2.2	11.1
	N	15-16				5.2	4.9	4.3	
	S					6.4	5.6	3.0	
7	N	5-6	9.3	8.1	6.1	4.7	3.6	2.2	4.4
	S		9.1	7.6	7.9	5.7	4.8	2.5	3.2
	N	10-11	5.7		5.8	4.4	3.2	4.3	4.6
	S				6.9	5.1	4.0	2.8	5.3
	N	15-16				5.3	4.2	4.1	
	S					7.2	5.2	3.7	

Table 3. (cont.)

Plot* No.		Depth (feet)	Water content (% dry weight basis)						
			Matric potential (bars)					Field moisture	
			1/3	1/2	1	5	15	8/67	6/68
8	N	5-6	5.6		6.5	5.0	4.3	2.0	2.7
	S		8.3	7.7	6.2	4.5	3.9	4.2	3.4
	N	10-11			6.4	4.7	3.6	1.9	3.6
	S				5.9	4.4	3.3	3.8	3.3
	N	15-16				5.3	4.0	3.9	
9	N	5-6	10.0		11.2	8.1	6.1	2.8	2.9
	S		12.7	9.3	8.9	7.0	5.7	2.8	3.6
	N	10-11	14.0	11.5	8.8	6.5	5.8	2.5	2.8
	S		9.3		6.9	5.4	4.1	3.0	3.2
	S	15-16				3.9	2.9	3.7	
10	N	5-6			9.7	7.2	6.0	2.0	4.2
	S				8.6	6.3	5.4	3.1	3.1
	N	10-11	10.3		7.4	4.8	4.2	2.2	2.4
	S		6.4		5.2	4.1	3.3	4.7	2.8
	N	15-16				4.2	3.4	2.5	
11	N	5-6	30.3		25.5	19.3	14.6	10.3	12.8
	S				17.6	11.8	9.6	3.1	5.1
	N	10-11			18.2	12.3	10.3	2.9	8.3
	S		11.8		9.2	6.7	5.5	3.1	4.2
	N	15-16				4.5	3.0	1.7	
	S					4.0	3.1	2.1	
12	N	5-6			13.1			7.4	10.8
	S		20.0	16.9	16.0	11.6	9.3	4.4	7.2
	N	10-11	13.8			8.9	7.8	2.8	5.3
	S				9.9	7.3	6.4	2.8	5.2
	N	15-16				5.2	3.6	3.0	
	S					3.4	2.4	2.8	

Water Content Profiles

The water content profiles showed conditions indicating negligible water movement past the root zone. The results will be discussed only as the accumulation of water in the surface soil (Table 4).

Water content profiles were determined 16 times with the neutron probe between August 1967 and April 1972. The first determinations, taken just after the access tubes were installed, were not considered satisfactory probably because the soil around the access tube had been disturbed and conditions were not at equilibrium.

The first reliable profile water data were collected on June 5, 1968. These values are the starting point from which changes are determined and water movement evaluated. It should be noted that these readings (June 1968) do not represent the pretreatment water content profiles. They reflect 9 months of treatment effects. However, if these treatment effects are continuous, later water content profiles should also reflect treatment differences.

Typical water content profiles for each treatment as measured on June 5, 1968, March 21, 1969, and June 10, 1970 are shown in Figure 4. These profiles show that below 6 feet only the profiles of the gravel mulch with herbicide treatment have changed significantly from the June 1968 values. This observation was consistent for all four replicates on each of the observation dates. The significant change for the gravel mulch with herbicide treatment has been a progressive wetting of the profile to deeper depth.

The original objective of this experiment was to evaluate ground water recharge by observing water movement through a soil. However, the water content profiles showed very dry soils where water movement would be expected

Table 4. Net change in total soil water content since June 5, 1968.

Treatment	Plot No.	Location*	Net Change (inches) 1968 8/19	1968 9/17	1969 1/3	1969 3/21	1969 5/1	1969 6/10	1969 6/27	1969 9/10	1970 1/3	1970 3/23	1970 6/10	1970 9/21	1971 6/3	1972 4/20
Gravel	1	N	-1.6	-2.6	-1.9	1.6	1.6	.6	-1.0	-1.4	1.5	2.1	1.1	-2.8	1.7	-2.6
Mulch		S	-.9	-1.7	-.3	-.6	.1	.2	-.7	-.8	1.0	1.3	.2	-2.4	.5	-2.7
	10	N	-2.1	-2.8	-2.9	.5	.1	-1.4	-1.7	-.6	.4	2.0	1.2	-3.0	6.6	.2
		S	-2.9	-3.4	-3.1	.1	-.2	-.3	-.7	-2.6	.8	1.1	.7	-3.4	3.2	-2.5
Pitted	2	N	.5	.4	.2	.3	.7	1.3	1.2	1.8	3.3	3.6	4.4	4.9	7.0	4.7
		S	.6	.3	0.0	.2	.8	2.4	2.0	1.5	3.7	4.8	8.1	5.4	8.2	4.8
	7	N	.5	.2	.1	.5	.3	.7	.5	1.6	1.4	1.7	1.7	2.1	3.4	.3
		S	.4	-.1	-.1	-.6	-.1	.7	.6	1.3	2.6	2.7	2.9	4.4	4.5	1.4
Mech.	3	N	1.7	1.3	1.0	1.6	1.7	1.4	1.3	2.3	3.1	2.8	3.1	3.0	4.9	1.7
Fallow		S	3.4	2.0	1.2	2.0	2.4	.6	.6	1.1	3.4	2.5	1.3	.9	4.0	1.2
	12	N	2.5	.3	.4	.8	.9	.5	.6	-.1	3.6	4.1	3.4	2.1	5.2	1.3
		S	1.0	.2	-.1	.1	.4	-.1	0.0	.1	2.4	2.6	3.0	1.8	4.1	1.4
Range	4	N	-.4	-.7	-.8	-.5	-.2	-.3	-.4	.1	1.0	1.5	-.1	-1.6	.4	-1.9
		S	-.3	-.4	-.7	-.5	-.4	-.4	-.6	-.4	1.7	.7	.7	-1.5	1.0	-1.5
	9	N	-.2	-.8	-.7	.1	0.0	-.3	-.4	-.2	1.8	1.8	.7	-.8	.7	-.8
		S	.1	-.7	-.7	-.2	0.0	.2	-.3	0.0	1.8	2.2	1.0	-.5	.2	-.8
Chem.	5	N	-.7	-1.3	-1.6	-1.3	-1.5	-.4	-.4	-.3	1.2	1.0	3.2	1.3	2.9	1.6
Fallow		S	.3	-.1	-.1	.2	.1	.7	.6	1.0	2.2	2.3	2.6	2.8	4.1	2.3
	11	N	.7	-.7	-.9	-.4	-.2	.7	.7	.9	2.5	3.4	3.6	4.2	6.3	4.8
		S	1.0	0.0	-.3	-.2	.1	.8	.6	.3	1.6	2.0	2.1	2.3	4.7	3.7
Gravel	6	N	2.8	1.9	1.6	3.6	4.0	7.0	6.6	9.2	10.1	10.3	13.3	14.9	18.8	13.3
Mulch		S	4.2	3.9	3.5	4.0	4.7	8.2	8.3	10.8	11.1	11.8	13.5	17.5	21.4	17.0
&	8	N	2.0	.5	.4	1.3	1.4	3.7	3.2	4.4	5.8	5.3	6.0	8.9	12.2	9.0
Herb.		S	3.2	2.5	2.8	3.0	3.0	6.4	6.5	8.5	8.7	8.7	10.9	13.3	16.0	10.5

* N - north access tube, S - south access tube.

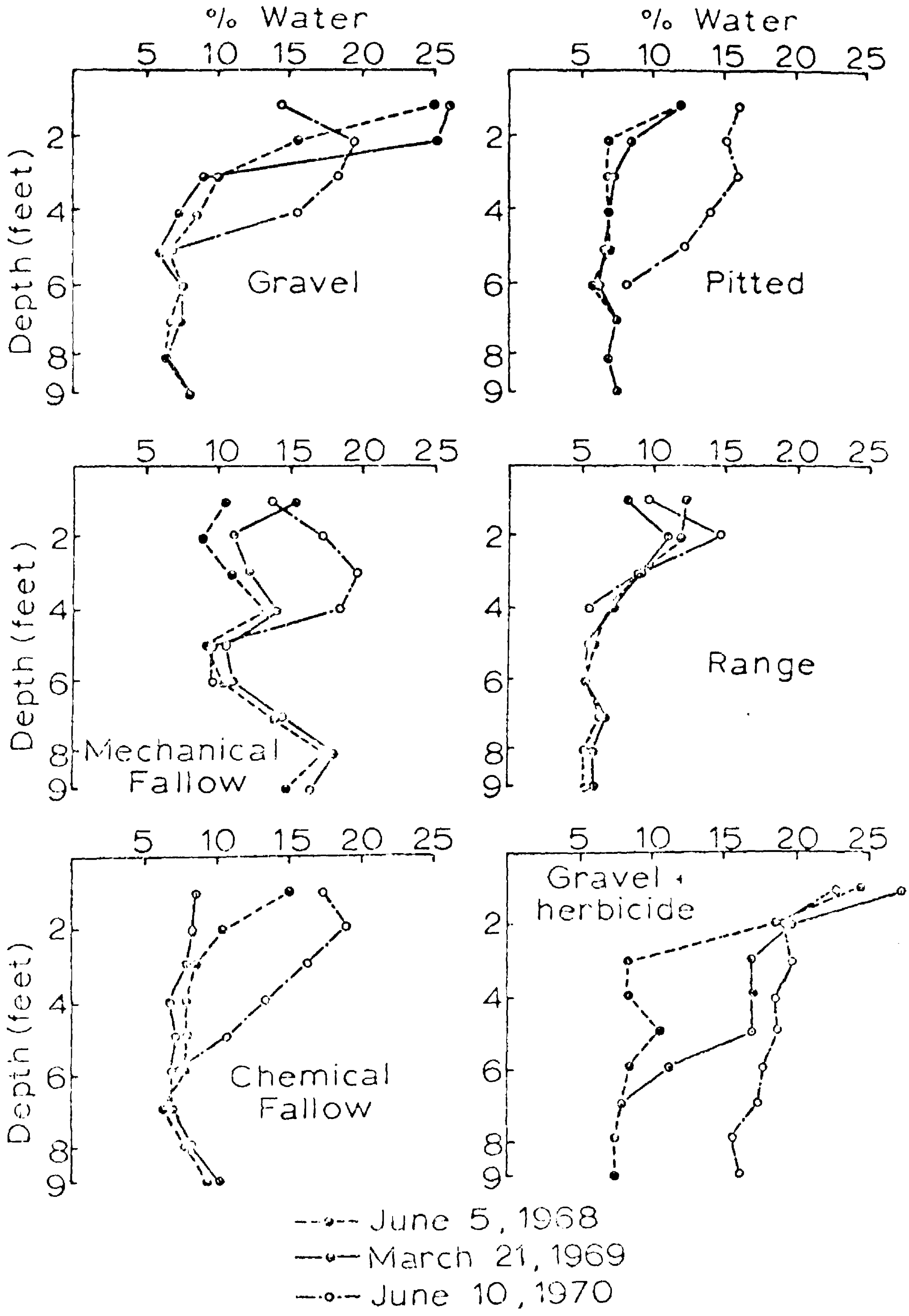

Figure 4. Representative soil water content profiles.

to be small. Water movement past the 6-foot depth in all but the gravel mulch with herbicide treatment must be negligible since no change in water content has been observed below this point. Under the gravel mulch with herbicide treatment the soil was wetted to a greater depth (about 9-10 feet by June 1970, and approximately 15 feet by June 1972). Water movement in the profile where no change in water content is observed would be expected to be small for several reasons. First, at the water contents found in the lower profile, the hydraulic conductivity and water movement would be expected to be very small. The uniform water content profiles would also indicate that vapor pressure gradients would be small and therefore water movement in the vapor phase would be small.

In order to confirm the idea that water movement at the 6-foot depth could be neglected, the gravimetric field water contents determined on the June 1968 samples were compared with water retention characteristics of these soils. These comparisons may be seen in Table 3. At each location and depth the soils had a lower water content than that determined for the 15-bar percentage. This indicates that the soils are at least as dry as permanent wilting, and that water movement, even over short distances to a plant root, is very slow.

The preceeding observations allowed us to neglect the water movement past the 6-foot depth in the profile and to present the data as changes in the total water content of the profile. This change is a measure of the infiltration and conservation of water.

Total Water Content of the Soil

In the preceeding section the reasons why the data could be presented as changes in the total water content of the profile were discussed. It should be recognized, however, that the term "groundwater recharge" no longer applies. The flux past some depth and subsequently into or out of an aquifer at about 100 feet below the surface during this experiment was considered negligible. More correct terminology would be soil water accumulation or loss as affected by the surface treatments.

The total water stored in a profile to a given depth was computed from the water contents of the various depth increments. The total quantity of water is expressed as a volume of water per unit surface area or as a depth. The infiltration and conservation of soil water can be evaluated by observing changes in total water content of the profile. The changes in the total water content of the profile were calculated by subtracting the volume of water in the profile on June 5, 1968 from the volume of water on all subsequent dates. The net change in inches since June 1968 are presented for each location in Table 4. These data show some variability, however, the trends for each treatment are reasonably consistent.

The total water content and changes were calculated using the sum of the nine 12-inch intervals measured at each access tube. However, after March 21, 1969 the water contents below 5 feet were not determined at those locations where changes were not taking place and the averages of six previous readings at each depth and location were used to compute the total water content of the 9-foot profile.

The average net change in total water content for each treatment is shown in Figure 5. The gravel mulch and herbicide treatment accumulated significant quantities of water in the upper profile while the other treatments have shown only seasonal fluctuations and little net accumulation of water.

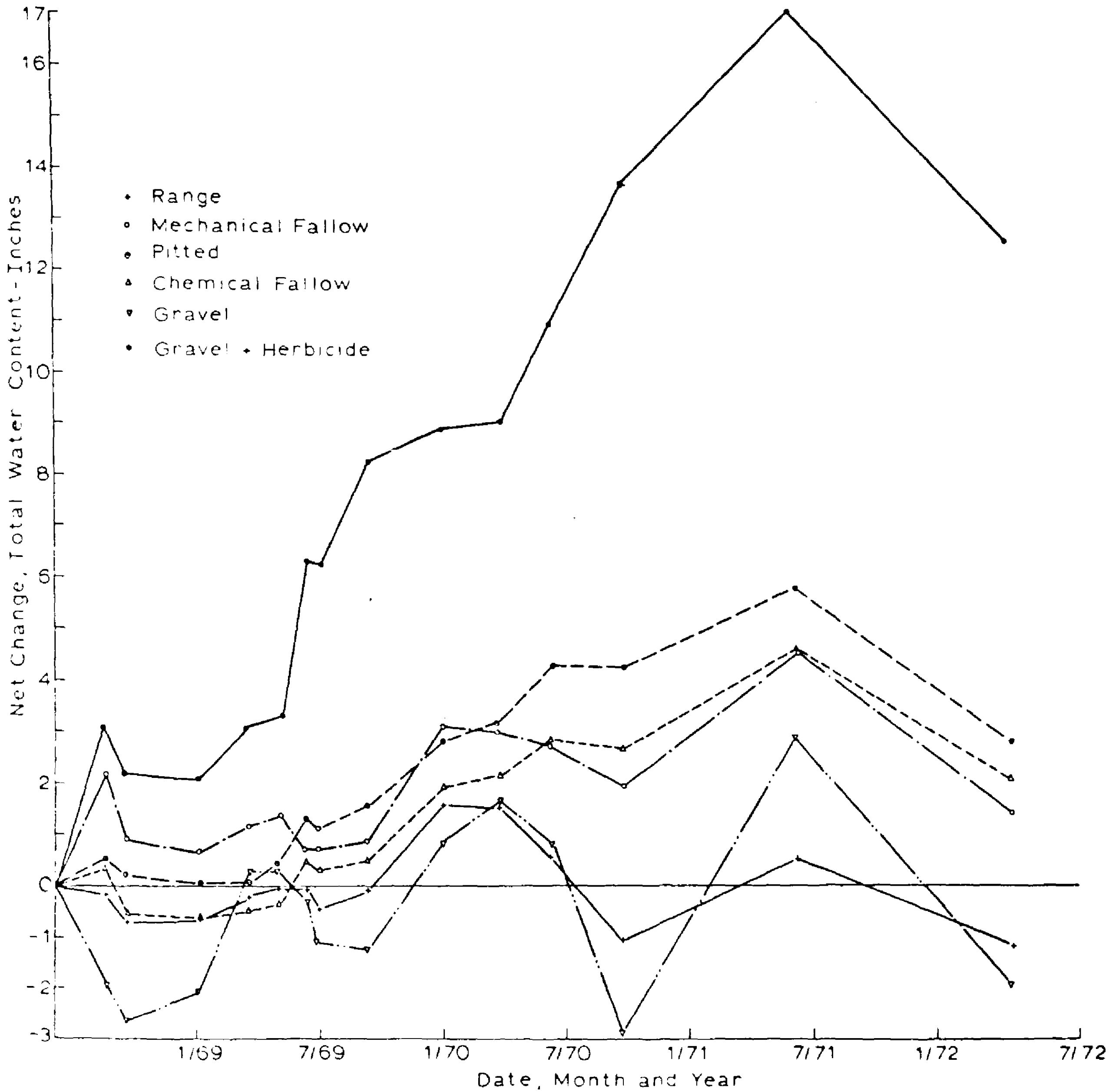

Figure 5. Average net change in total water content of the soil profiles for each treatment.

Changes in the total water content of the profile for the gravel with herbicide treatment after June 10, 1969 were computed using data from the longer access tubes. This became necessary because some water had moved past the 9-foot depth of the shorter access tubes.

The gravel mulch with herbicide treatment accumulated approximately 50 percent of the total precipitation during this experiment. This is primarily due to the reduction of evaporation through the gravel mulch (4). The gravel mulch also reduced evaporation on the plots where the grass was allowed to grow. This resulted in increased available water and a marked increase in plant growth.

Between January and March 1969, there was a large increase in soil water storage under the non-herbicide gravel treatment (See Figure 5, Treatment E, gravel). This increase was greater than the recorded precipitation and can probably be attributed to the snow-trapping ability of the vegetative growth on this treatment.

The large decrease in soil water for the gravel treatment between June and September 1968 was due to the effect of the treatment before that time. The gravel treatments were applied in the fall of 1967 and accumulated water during the winter and early spring by reducing evaporation. In the spring of 1968 the available soil water caused luxuriant grass growth and rapid removal of water by transpiration.

The fallowed treatments (mechanical fallow, B; chemical fallow, D; pitted, C) show seasonal fluctuations in the total soil water content with a slight trend toward net accumulation of water. However, this trend is only statistically significant after a heavy October 1969 snow. The chemical fallow treatment appears to be less efficient than the mechanical fallowed surfaces. This could in part be due to runoff. The soil surface under chemical fallow is relatively smooth and more compact and runoff may be expected to begin sooner than from the mechanical fallowed soils where a rough surface is maintained. The mechanical fallowed surfaces may also form a dry or dust mulch sooner than the chemical fallow and thereby are more effective in reducing evaporation.

The large increase in soil water between September 1969 and January 1970 for all treatments is due to heavy October snows. These snows were not typical of the area in that very little blowing and drifting occurred. The snow melted slowly and infiltrated with little loss to evaporation.

Some of the data of Table 4 were analyzed statistically and the analysis of variance for two dates is given in Table 5. The difference between the gravel mulch with herbicide treatment and all the other treatments accounts for all the statistically significant treatment effects on June 10, 1969. The fallowed treatments (mechanical, chemical, and pitted) show significant water accumulation on June 10, 1970. Components of variance were computed for duplicate determinations (two access tubes in one plot) for each plot and measurement date. It was found that the variance was dependent on the time involved. Therefore the experiment could not involve time as a factor and treatment effects could be separated only for each date. Furthermore, the initial data contains some treatment effects which statistically biases the data and makes mean comparisons difficult.

The only significant treatment effect until October 1969 is the accumulation of water under the gravel mulch with herbicide treatment. The differences between the other treatments are not statistically significant because of large variations in the total water content. Furthermore, none

Table 5. Analysis of variance for change in total water content of the profile from June 1968 to June 1969 and June 1970.

Source	d.	f.	Sum of squares	Mean square	F
June 1968 to June 1969					
Total	23		139.8622		
Treatment	5		122.4928	24.4985	42.517**
gravel & herb. vs. all other treatments		1	116.2694	116.2694	201.786**
Remainder		4	6.2234	1.5558	2.700
Block	1		4.0180	4.0180	6.973*
Block X Treatment	5		6.4369	1.2873	2.234
Error	12		6.9145	0.5762	
June 1968 to June 1970					
Total	23		353.1611		
Treatment	5		288.7987	57.7597	30.133**
gravel & herb. vs. all other treatments		1	259.4722	259.4722	135.367**
All fallow vs. native range		1	21.856	21.856	11.402**
Remainder		3	7.4705	2.4901	1.299
Block	1		8.3662	8.3662	4.364
Block X Treatment	5		32.9947	6.5989	3.442*
Error	12		23.0015	1.9168	

* Significant at 5% level.
** Significant at 1% level.

of the other treatments shows a significant accumulation of water, which is indicative of the relatively low efficiency of fallow treatments to conserve water. After October 1969 the fallow treatments also show significant water accumulation.

Erosion and Mulch Quality

The quality of the gravel mulch has not deteriorated significantly during this experiment. No visible deposition of fine soil particles that would reduce the efficiency of the mulch has been detected. However, in the spring of 1970 large cracks developed in the surface soil which allowed the gravel to mix with the soil. This affected only a small fraction of the total area and is not believed to have seriously reduced the quality of the mulch. This mixing action, however, could become progressively more important.

The gravel mulches have shown few signs of erosion. Only near the end of the third year did the bare mulch begin to show signs of wind erosion. This erosion was very minor and had not deteriorated the quality of the mulch. The chemical fallow treatment showed definite signs of wind and water erosion. This is evidenced by erosion around the remaining clumps of dead sod. The mechanical fallow and pitted treatments showed no signs of erosion.

Water Content Profiles of the Surrounding Area

Matric potential profiles, expressed as tension in bars, for 21 locations are shown in Table 6. The tensions shown as greater than 15 bars were drier than the 15-bar percentage and tensions shown as less than 1 bar were wetter than the 1-bar percentage. Locations 1, 2, and 3 are playa lakes where runoff water collects occasionally. Locations 1 and 2 are from the same playa lake approximately 10 feet apart. All three locations had

Table 6. Soil water tension profiles of several locations in Kit Carson County, Colorado 1968 (tension in bars)

	Location* and Surface Description					
	4-9-44		33-8-43		27-6-42	
	1	2	3	4	5	6
Depth (ft.)	Playa Lake	Playa Lake	Playa Lake	Terrace Channel	Between Terraces	Range
0-1				>15	>15	>15
1-2				"	"	"
2-3				3.8	"	"
3-4				2.5	"	"
4-5	2.8	2.8	15	2.1	13	"
5-6				2.3	8	15
6-7				2.2	9.5	10
7-8				2.0	10.5	>15
8-9						
9-10		8	<1	2.2	15	"
10-11						
11-12				2.6	8	12
12-13						
13-14				4.4	3.7	>15
14-15	<1	1	1			
15-16					5	"
16-17						
17-18				>15	8	"
18-19						
19-20	<1	1.2	<1	>15	9	15
20-21				>15		
21-22				>15	9.8	>15
22-23					11.5	"
23-24						
24-25						

Table 6. (cont.)

	Location* and Surface Description								
			31-7-42			16-7-43		15-9-43	13-9-43
	7	8	9	10	11	12	13	14	15
Depth (ft.)	Fallow		Range	Irrigated		Range		Range	Land Bank
0-1					1.2	>15	>15		
1-2		8	>15	2.3	1.1	"	"	>15	
2-3	>15			3	1.3				>15
3-4	"	>15	"	7	<1	"	"		
4-5									
5-6	"	>15	"						
6-7	"						"		
7-8	"	"	"	4.6	"	"			"
8-9					"				
9-10	"		"	2.6	"		"		
10-11		"			"	"			"
11-12	10		"	2.8	"			"	
12-13					"	"	"		
13-14	10	"		2.3	"			"	"
14-15			"		"	"			
15-16	>15	"		2.0	"			"	"
16-17			"		"	"	"		
17-18	12		"	1.8	"		"	"	"
18-19			"		>15	"			
19-20	15	"	"	1.7	"			"	"
20-21						"			
21-22	>15	"		1.8	"			"	"
22-23					"	"			
23-24		"		1.7				"	"
24-25									

Table 6. (cont.)

	Location* and Surface Description					
	19-10-42	35-10-43	5-11-42	31-10-43	27-7-42	26-9-42
	16	17	18	19	20	21
Depth (ft.)	Dry Farm	Irrigated 1963	Dry Farm	Range	Dry Farm	Range
0-1						
1-2	>15	>15		>15	>15	>15
2-3			>15			
3-4						
4-5						
5-6						
6-7		"			15	"
7-8	"	3.5	15	"		
8-9					>15	
9-10		2.2	>15			"
10-11	"				"	
11-12			"	"		"
12-13		3.0		15		
13-14	"					
14-15		1.2			"	
15-16	"				"	"
16-17		1.2				
17-18	"				"	"
18-19		1.4				
19-20	"				"	"
20-21						
21-22		3.1			"	
22-23						
23-24		>15			"	
24-25		15				

* Section - Township - Range

about 5 feet of sediment overlying the loess material. They show low tension values below the root zone where some deep percolation of water could be anticipated.

Locations 4, 5, and 6 are in the same section and point out the difference between a runoff collection area and adjacent non-terraced range. The terrace channel (location 4) and a location between two adjacent channels (location 5) show low tension profiles below the root zone. These profiles then become much drier and could indicate a wetting front about 17 feet below the surface of the channel. The site was terraced 3 years prior to sampling. Sampling on adjacent non-terraced range (location 6) showed high tensions throughout the 23-foot profile indicating that precipitation had continuously been used by evapotranspiration.

Locations 7 through 11 represent three management systems in the same section. Fallowed land, which had been fallowed 1 year, (locations 7 and 8) and range (location 9) show high tension profiles while an irrigated area (location 10) and a field irrigated one time 6 days prior to sampling (location 11) have low tension profiles. Location 11, irrigated just once with no growing crop had a sharp wetting front 18 feet below the surface. Locations 12 and 13 are range land in the same section. They both have high tension profiles. Location 12 was steeply sloping land while 13 was nearly flat. Location 17 was sampled in a dry farmed field that had been irrigated in 1963. The profile shows relatively low tensions to the 23-foot depth. The remaining range and dry farmed locations have high tension profiles again indicating that normal precipitation in the area is removed by evapotranspiration and that natural ground water recharge through these soils is negligible.

Dry profiles similar to the experimental plots were found under surrounding range and dry-farmed areas of the high plains of Colorado. All the locations were on silt or silt loam soils (Peorian loess). This indicates that conditions for water movement through the profile would be similar and would be expected to yield extremely small quantities of water to ground water recharge. These dry conditions were not observed, however, when the sampling location had received a concentrated supply of water. Areas such as terrace channels, playa lakes, and irrigated fields had wetter profiles where some water movement into and through the profile could be anticipated.

Measurements of Soil Water Potential with Thermocouple Psychrometers

Table 7 shows some representative results of these measurements. The potentials observed are of the same magnitude found on similar soils in the sampling survey.

Table 7. Soil water potentials obtained from thermocouple psychrometer readings.

Location: Native range, loess derived soil, Sec. 16, TWP 10S-44W, 8 miles south and 2½ miles west of Burlington, Colorado.

TCP No.	Depth	Date:	Potential - Bars 7/20/71	12/15/71	5/20/72
1	20 ft.		23.0	23.5	20.5
3	20 ft.		23.5	22.0	20.5
4	20 ft.		18.0	17.5	16.0
6	10 ft.		16.0	11.5	13.0
7	10 ft.		14.0	8.5	7.0

Evaluation of the Hydraulic Conductivity Measurements

Some difficulty was encountered in the measurements of hydraulic conductivity of soil cores by the centrifuge procedure as described above. Results were erratic and it was suspected that some or all of the assumptions made in developing the theory were not valid. Porous ceramic cores were obtained and used as test samples in a more careful investigation of the method. The rigid matrix of the ceramic cores permitted resaturation and drying with minimal change in the hydraulic properties so that the conductivity could be determined on the same core over a range of values of average water content.

Table 8 shows some representative conductivity data obtained on a porous ceramic core at four average water contents, a range of values of centrifuge speed and using the data analysis procedures according to Theories I and II. If the assumptions made in the theories are valid, the conductivity value obtained should be independent of the centrifuge speed, N. Such is not the case, and furthermore there does not seem to be a systematic trend.

As a result of a detailed study of results of the kind illustrated in Table 8, the following comments can be made:

1. At a given value of $\bar{\theta}$, rather large differences in K are computed from successive runs, even when N was kept the same for successive runs.
2. In the case of Method I, difficulty was experienced in obtaining $dM/dt \Big|^{t = o}$.
3. In the Method II analysis it was observed that the curves of M vs t are not truly exponential as predicted by equation [6]. Hence the computed value of K will depend on the particular section of the M(t) curve chosen for analysis.

Table 8. Conductivity data obtained by the centrifuge method on a porous ceramic core.

(I) Refers to data obtained by Method I.
(II) Refers to data obtained by Method II.
$\bar{\theta}$ Average water content of the core

	$\bar{\theta}$ = 0.100			$\bar{\theta}$ = 0.093			$\bar{\theta}$ = 0.076			$\bar{\theta}$ = 0.056	
N	K(I)	K(II)	N	K(I)	K(II)	N	K(I)	K(II)	N	K(I)	K(II)
rpm	cm/yr	cm/yr	rpm	cm/yr	cm/yr	rpm	cm/yr	cm/yr	rpm	cm/yr	cm/yr
180	282	96	200	165	62	280	9	9	370	2	2
190	169	89	180	81	54	380	19	14	430	4	2
260	192	116	240	105	38	380	15	11	430	4	2
260	146	115	260	65	33	480	26	18	500	3	3
320	137		310	96	45				500	3	2
320	135	-							570	4	4
260	202	89							480	3	3
260	148	91							420	4	3
190	155	99							370	4	4
190	150	95							380	4	4
Ave.	171	99		102	46		17	13		3.5	3

The results with soil cores were more erratic than those from ceramic cores. It was discovered that a very slight tapping of the core when it was being transferred to the balance, had a great effect on the results. It is possible that centrifuging modifies the structure of the soil cores and that the mass change observed is in part the "rebound" of the soil structure.

In view of these difficulties the centrifuge technique, at the present time at least, cannot be considered to give reliable conductivity data. Further study of the method may be warranted, but the errors imposed by unstable soil structure, and hysteresis seem to be difficult to overcome.

CONCLUSIONS AND RECOMMENDATIONS

A coarse sand and gravel mulch, overlying a finer-textured soil, reduced evaporation and conserved water in the soil profile. Under the conditions of this experiment (semi-arid climate, initially dry soils, and a deep water table) the water remained in a fallowed surface soil or was totally consumed by native grass vegetation and did not affect ground water recharge. The treatment will not contribute to ground water recharge until after the soil profile is wetted to a "field capacity" which may require 10 or more years and several feet of water. With these conditions the cycling of gravel-mulch-conserved-water into a deep aquifer to be pumped for irrigation seems unfeasible. An additional limitation is the high cost of the gravel mulch treatment. There are, however, conditions where a gravel mulch could be very useful in increasing the amount of ground water recharge from normal precipitation. In areas where some recharge is naturally occurring the profile will be wet and any decrease in surface evaporation should result in increased flow to the ground water. The cost of developing a gravel mulch would be greatly reduced where gravel can be separated from a gravelly soil or when gravel from a nearby excavation is available.

The results of this experiment confirm the observation of others that evaporation losses account for the majority of the precipitation on the high plains. Preventing transpiration losses as evidenced by the fallow treatments (mechanical, pitted, and chemical) may not result in significant conservation of water. Therefore, to significantly change ground water recharge both evaporation and transpiration losses must be reduced. A gravel mulch is one possibility for reducing evaporation losses. A marked increase in plant growth was obtained by use of a gravel mulch, thus the possibilities for range improvement or crop production utilizing a gravel mulch needs further research.

Some of the 15 to 16 inches of precipitation on the dry-farmed and range lands of the High Plains fine textured soils is lost to runoff. This occurs under high intensity rainstorms. In these cases runoff collection may be important in ground water recharge. Soils under playa lakes are at "field capacity" and these areas probably are contributing to ground water recharge. The limiting factor in these areas is the very fine sediment layer that develops at the surface and greatly restricts water infiltration. Terrace channels, in addition to controlling soil erosion, evidently collect enough water to wet the soil below the root zone and contribute to ground water recharge. They depend on runoff collection to affect the depth of wetting of the soil. All these areas of runoff collection, if a sediment layer does not restrict water infiltration, could be contributing significant quantities of water to ground water recharge.

The average recharge value of 0.8 inch per year reported by various sources does not apply to the range and dry-farmed areas on fine textured soils. If the estimates of 0.8 inch per year are accurate much larger recharge rates must come from much smaller areas. Some of the areas that could be contributing to ground water recharge are stream beds, playa lakes, terrace channels, and irrigated lands. However, these small areas would have to have tremendous quantities of recharge to give a 0.8 inch per year average when divided by the total contributing surface area. Reddell (1967) points out differences in recharge rates on the high plains and gives an overall average value for Kit Carson County (primarily a Peorian loess area) of 0.4 inch per year. This recharge does not come through the deep fine-textured loess soils. Reddell (1967) also contributes larger recharge rates to the sandhills area. This has been confirmed by observing low tension profiles to a depth of 10 to 20 feet in the sandhills. This area, however, needs further investigation to evaluate ground water recharge rates. The results of this experiment demonstrate the need for refined research on sources of ground water recharge on the high plains of Colorado. The estimates of 0.8 inch per year may be too high. However, it should be pointed out that this is a very small fraction of the total precipitation and is an insignificant quantity of water per acre in comparison with the water requirement of irrigated crops. Recharge of 0.8 inch per year is only important because of the large area involved.

The results of this research leads to some areas of needed further research: 1. Refined research on sources and rates of ground water recharge; 2. Intensified research on the efficient use of a limited natural supply of water for crop production; 3. The economic aspects of establishing and maintaining a gravel mulch in a specific location; 4. The gravel mulch results in favorable plant growth conditions and weed control techniques need further research; 5. The water quality reaching an aquifer if the water percolating through a soil profile would be drastically changed; 6. Techniques of best utilizing the water conserved by the gravel mulch.

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A Note on Project Personnel

This project was initiated in 1967 under the leadership of Dr. W. D. Kemper. About a year thereafter he left the CSU campus and the project continued under the direction of Dr. R. E. Danielson. In February 1970, Dr. A. Klute assumed direction of the project. Mr. Philip Hamaker, a graduate assistant who was supported by the project, began his Ph.D. studies under Dr. Kemper and worked on the measurement of hydraulic conductivity by the centrifuge method. When it became apparent that this work was not leading to a satisfactory Ph.D. thesis, he began and completed research on another topic which was not directly related to the project. The title of Mr. Hamaker's thesis is "Upward Flow from Shallow Water Tables."