COO--1269-15
CONF-670641--1
SM-94/21

Gamma-Radiation Detection of Water Content in Two-Dimensional Evaporation Prevention Experiments

by

Don Kirkham, Professor; D. E. Rolston, Graduate Assistant;

and D. D. Fritton, Graduate Associate

Agronomy Department

Iowa State University

Ames, Iowa

United States of America

REVISED ABSTRACT

A cesium-137 gamma scintillation detector system (gamma apparatus) was used to measure water contents in a two-dimensional soil model. The gamma apparatus was built into a lifting apparatus which accomodates both vertical and horizontal 150 cm long soil columns and 150 x 35 cm two-dimensional soil models. The lifting apparatus was constructed by using a vertical rectangular frame with internal dimensions of 80 cm width and 70 cm height. Lead cubes, 25 cm on a side, containing a 251 mCi cesium-137 source and a NaI scintillation detector are offset to one side of the vertical rectangular frame to scan a vertical cylindrical column. The faces of the lead cubes are 24 cm apart and attached to the rectangular frame so that the gamma beam is midway between the base and top. There are no attachment parts that cross the 24 cm gap between the lead cubes, and this leaves a 24 cm wide by 70 cm high space which will allow a two-dimensional model or horizontal

DISCLAIMER

column to be moved horizontally through this space. Vertical movement of the gamma apparatus and horizontal movement of the model then allow two-dimensional scanning of a model. To demonstrate the ability of this design for a gamma apparatus to scan two dimensions, a 92 cm long, 30 cm tall, and 10.15 $\pm$ 0.05 cm wide model with three equal 30 cm long compartments was used to evaluate potential water conservation. A vertical sand mulch, 2 cm thick, was placed on each side of each compartment, a 3 cm thick sand layer was placed on the bottom, and soil was packed in the rest of the model. The surface treatments were: bare soil, 1 cm soil over 1 cm of sand mulch, and 1 cm of sand mulch. Water contents in two dimensions were determined for 2 cm simulated rainfall applications for the three treatments. When a subsurface sand mulch was used, the mulch acted as a barrier to infiltration. Therefore, the surface sand mulch conserved more water than did the subsurface sand mulch, but both the surface and the subsurface sand mulches conserved water as compared with no sand mulch layers.

In addition, soil columns, 6.9 cm in diameter and 33 cm tall, were used to study the effectiveness of various thicknesses of surface sand mulches in preventing evaporation. Thickness of sand mulches did not influence greatly the amount of water conserved if the sand layer was 1 cm or more thick.

Gamma-Radiation Detection of Water Content in Two-Dimensional Evaporation Prevention Experiments*

by

Don Kirkham, Professor; D. E. Rolston, Graduate Assistant;

and D. D. Fritton, Graduate Associate

Agronomy Department

Iowa State University

Ames, Iowa

United States of America

1. INTRODUCTION

Laboratory investigations of the soil water content along the length of soil columns have been greatly facilitated by the use of gamma-radiation attenuation. Gamma-radiation attenuation provides a rapid, nondestructive means of measuring soil bulk density and soil water content.

If a collimated beam of gamma rays is allowed to penetrate a material, the number of rays passing through depends upon the density and thickness of the material. Gurr and Marshall [1] and Gurr [2] measured the soil density and water content, for steady-state conditions, of an unconsolidated porous material in the laboratory with a ^{137}Cs source of gamma radiation. Ferguson and Gardner [3] used a similar technique for extremely slow transient water flow in uniformly packed soil columns. Using additional equipment and a source of greater intensity, Rawlins [4] obtained more frequent measurements

*Journal Paper No. J-5651 of the Iowa Agricultural and Home Economics Experiment Station, Ames, Iowa. Project 998. Paper No. COO-1269-15 supported by contract No. AT(11-1)-1269 of the U.S. Atomic Energy Comm. Supported by Dept. of Int., Office of Water Resources Res. P. L. 88-379.

from the same soil studied by Ferguson and Gardner. Davidson et al. [5] refined the technique further by a method of making rapid and frequent measurement of rapidly changing water contents in laboratory soil columns. Gurr [6] described a method for calculating water contents of undisturbed field samples of unknown initial conditions from gamma-ray data. The use of gamma radiation has become a fairly widespread method for nondestructive determinations of soil bulk density and water content.

The attenuation of monoenergetic gamma radiation is described by

$$I = I_o \exp(-\mu\rho x) \qquad (1)$$

where I_o is the radiation intensity with no interference, μ the mass-absorption coefficient (cm^2/g) of the absorber for the quantum energy of the radiation, ρ the density of the material (g/cm^3), and x the thickness of the sample (cm). The necessity that the radiation be monoenergetic can be met by the use of instrumentation having energy discriminators.

This paper will discuss the application of gamma radiation for determination of soil bulk density and soil moisture distribution in two-dimensional soil models. Soil models were used to study the influence of surface sand mulches on evaporation prevention and infiltration.

Wiegand and Taylor [7] reviewed literature on soil mulches. They present a graph summarizing several studies of evaporation rate versus mulch thickness. They conclude that a mulch must be greater than 0.3 to 0.6 cm thick to reduce evaporation rates. The necessary thickness increases with increase in coarseness of the underlying soil. They state that, for a mulch to be effective, it must make vapor diffusion the rate-limiting process in evaporation. Tselishcheve [8] presents data for various mulch thicknesses of dry soil and an equation which describes evaporation as a function of the thickness of the mulch layer, evaporation from a wet soil surface, and soil properties. Kolp et al. [9] showed that tallow alcohol added to the top 1 cm of soil decreased evaporation by allowing the surface 1 cm of soil to dry more rapidly than a bare soil surface. This allowed vapor diffusion to become the rate-limiting factor in the evaporation more rapidly for the tallow alcohol treated soil than for the bare soil. The effect was even greater in a sand. Kolp et al. also determined the moisture contents after a 1 cm application of water for two durations of evaporation. After 33% of the added water had been evaporated from each treatment (3.5 hours with bare soil and 20 hours with a 2.5 cm tallow alcohol surface-treated soil), the water had penetrated deeper in the tallow alcohol-treated soil than in the bare soil.

In the present paper, our purpose is to compare the influence of infiltration and evaporation under three conditions: bare soil, surface mulch, and subsurface mulch. These three treatments were studied in a two-dimensional model. In addition, the influence of mulch thicknesses on evaporation were studied in columns under evaporating conditions only. These columns were initially saturated and allowed to evaporate

for 18 days. Soil water contents at various depths were obtained by using gamma attenuation in both experiments.

2. EXPERIMENTAL EQUIPMENT AND CALCULATION PROCEDURE

The soil density and moisture measuring equipment (gamma apparatus) consists of a low-energy gamma source, a detecting and analyzing system, and a lifting mechanism for the source and detector section. The lifting mechanism and the source and detector section are shown in Figure 1. The source of gamma radiation consists of a 251 mCi ^{137}Cs capsule. Although ^{137}Cs does not emit a strictly monoenergetic gamma ray, the greater part of the radiation has an energy of 0.66 Mev. The half-life of ^{137}Cs is 27 years. The ^{137}Cs capsule is placed in the center of a lead cube, 25 cm on a side, as depicted in Figure 1. This lead cube reduces the external radiation to a safe level (less than 0.1 mrad per hr). A 5 mm diameter hole 12.5 cm long located in the center of this cube collimates the radiation. A second lead cube of the same dimensions and containing a scintillation detector is located opposite the source cube. The detector cube also has a 5 mm diameter hole 12.5 cm long located at its center to collimate the radiation reaching a scintillation crystal in the center of the detector cube. The collimated holes were lined up by the use of X-ray film. The crystal is a thallium-activated NaI crystal 2.5 cm in diameter and 2.5 cm thick. The voltage for the detector photomultiplier is supplied from power supplies incorporated in an analyzer/scaler (Nuclear-Chicago, Model 8727). Pulses from the detector are amplified by a linear amplifier. The base line and window width on the pulse height analyzer is manually adjustable and, for this study, was set to accept all gamma radiation above 0.50 Mev. By setting the analyzer to accept all radiation above 0.50, the entire ^{137}Cs energy peak is being accepted, and the problem of a base line shift at high count rates is essentially eliminated. The pulse pair resolution of the analyzer is 1.5 μ sec. Pulses from the analyzer drive the scaler. The analyzer/scaler is equipped with an automatic digital printing lister.

The source and detector cubes are attached 24 cm apart to a vertical rectangular frame (support frame Fig. 1) with internal dimensions of 80 cm width and 70 cm height. The cubes are offset to one side of the rectangular frame to facilitate the placing of vertical soil columns within the gamma beam. There are no attachment parts that cross the 24 cm gap between the lead cubes, and this leaves a 24 cm wide by 70 cm high space which allows a two-dimensional model or horizontal column to be moved horizontally through this space. A removable slide is placed horizontally within the rectangular frame to support models and columns and to allow their horizontal movement. The vertical rectangular frame supporting the lead cubes moves vertically up and down on 275 cm long and 3.8 cm diameter stainless steel rods connected to the floor and ceiling of the laboratory. The rectangular frame is raised and lowered on the rods by a cable hooked to a motor driven winch. Vertical movement of the gamma apparatus and horizontal movement of the model then allow two-dimensional scanning of a model.

density of the soil in the models is

$$\rho_{ds} = \frac{-\ln(I_{ds}/I_{pl})}{(\mu x)_{ds}} \qquad (7)$$

The intensity through the moist soil is

$$I_{ms} = I^{*} \exp\left[(\mu\rho x)^{*}_{Pb} - (\mu\rho x)_{pl} - (\mu\rho x)_{ds} - (\mu\rho\theta d)_{w}\right] \qquad (8)$$

where I_{ms} is the intensity through moist soil, μ_w is the absorption coefficient of the water, ρ_w is the density of water, θ is the volumetric water content, and d is the thickness of the soil. Therefore, x_{ds} is the same as d. Dividing Equation (8) by (6) and simplifying, the volumetric water content of the soil model is

$$\theta = \frac{-\ln(I_{ms}/I_{ds})}{(\mu\rho d)_{w}} \qquad (9)$$

If I_{pl} of Equation (5) is above the capacity of the instrumentation, as is true for our model, then including a lead disc with the empty model in the gamma beam is necessary to decrease the count rate sufficiently. Another term for the lead disc is then added to the exponential parts of Equations (5), (6), (7), and (8). Detailed equations need not be presented here.

3. PROCEDURE

3.1 Vertical Soil Column Evaporation Experiment With Mulches

Five Plexiglas columns, 6.9 cm inside diameter, 33 cm tall, and wall thickness 3 mm, were packed with a soil mixture (soil mix) containing 2 parts Edina silt loam, A1 horizon, and 1 part Clayton white silica sand, 0.25 - 1.00 mm particle size. Five surface treatments were used: bare soil mix, 1 cm Clayton sand mulch (1 cm mulch), 2 cm Clayton sand mulch (2 cm mulch), 4 cm Clayton sand mulch (4 cm mulch), and 1 cm Clayton sand below 1 cm of soil mix (subsurface mulch). The depth of soil mix, plus surface layers, was 33 cm for all columns. After packing, the columns were wetted with water from the bottom with a small head until they were near saturation. Initial water added varied from 522 to 544 g.

The five soil columns and a column containing open water were then placed 13 cm from the center of a round table rotating at 1.5 rev/min and maintained level by four adjustable wheels. The columns were surrounded by a drum-like framework covered with aluminum foil to keep

To find the bulk density and moisture profiles of the models from gamma-ray attenuation, values for the mass-absorption coefficients (μ) of lead, Plexiglas, water, soil, and sand had to be determined. The mass-absorption coefficients for these materials were determined by essentially the same methods as those of Davidson et al. [5] (determining quantities in equation 1 except μ, which is solved for). The mass-absorption coefficients were found to be 0.1036 cm^2/g for lead, 0.0806 cm^2/g for Plexiglas, 0.0802 cm^2/g for water, 0.0689 cm^2/g for soil, and 0.0525 cm^2/g for sand.

The values of the mass-absorption coefficients in combination with gamma-ray intensity allow for the determination of soil bulk density and volumetric moisture content. The empty models are placed in the gamma apparatus and counted. The attenuation of the radiation by the Plexiglas models is described by

$$I_{pl} = I_o \exp\ (-\mu\rho x)_{pl} \qquad (2)$$

where I_{pl} is the intensity through the empty Plexiglas model, I_o is the intensity through air, μ_{pl}, ρ_{pl}, and x_{pl} are the absorption coefficient, density, and thickness, respectively, of Plexiglas. The intensity I_o is beyond the capacity of the instrumentation; thus, an indirect method of obtaining I_o must be used. A standard lead disc is placed in the gamma beam, and the transmitted gamma rays counted. The intensity through the standard lead disc is then related by

$$I^* = I_o \exp\ (-\mu\rho x)^*_{Pb} \qquad (3)$$

where I^* is the intensity through a standard lead disc and μ_{Pb}, ρ_{Pb}, and x_{Pb}, are the absorption coefficient, density, and thickness, respectively, of lead. Therefore,

$$I_o = I^* \exp\ (\mu\rho x)^*_{Pb} \qquad (4)$$

Equation (4) is then substituted into (2) to obtain

$$I_{pl} = I^* \exp\ [(\mu\rho x)^*_{Pb} - (\mu\rho x)_{pl}\ ] \qquad (5)$$

for the intensity through the empty model. The intensity I^* is used also in the attenuation equations for the bulk density and moisture content.

The intensity through the dry soil is related by

$$I_{ds} = I^* \exp\ [(\mu\rho x)^*_{Pb} - (\mu\rho x)_{pl} - (\mu\rho x)_{ds}] \qquad (6)$$

where I_{ds} is the intensity through dry soil and μ_{ds}, ρ_{ds}, and x_{ds} are the absorption coefficient, bulk density, and thickness, respectively, of dry soil. By dividing Equation (6) by (5) and simplifying, the bulk

infrared light from entering the columns at any point other than the column surface. A single 250 watt infrared reflector heat lamp was centered 29 cm above the top of the columns. The column containing water was used to characterize the evaporation potential. This column was kept full by adding water as it was evaporated. All six columns were weighed at daily intervals during the first few days and at 2 or 3 day intervals later in the experiment. At the end of 18.5 days, the columns were placed in the gamma apparatus and scanned. The count rates were used to calculate the volumetric moisture content at depth intervals of 1 cm. The driest layer occurred in the 1 cm of soil above the subsurface mulch and was used as the zero moisture content. In calculating moisture contents from the scanning, it was assumed that the thickness and density of plastic and the bulk density of the soils were uniform.

3.2 Two-Dimensional Model Experiment

A two-dimensional model constructed with 1 cm thick Plexiglas, containing three identical compartments, 30 cm long, 30 cm tall, and 10.15 $\pm$ 0.05 cm wide, was used in this experiment. Since the model was to be used for infiltration, air escape holes were drilled along each side, 2 cm from the bottom of the model. Before packing, the model was scanned by the gamma apparatus. The bottom 3 cm of each compartment was filled with Clayton sand. A vertical sand mulch, 2 cm thick, was placed on each side of the compartments, with soil mix packed in the rest of the model. The surface treatments were: bare soil, subsurface mulch, and 1 cm surface mulch. All final surfaces were at the same height. The compartments packed with soil were scanned by the gamma apparatus, and bulk densities calculated.

A 2 cm application of water was then applied to each compartment. The model was allowed to equilibrate for 4 hours and then scanned by the gamma apparatus, and moisture contents were calculated. (A measured air-dry moisture content correction of 3.22% was made for all bulk density and moisture measurements with the two-dimensional model.) The model was then placed 1 meter below a bank, 120 cm long, of five 300 watt reflector spot lamps, equally spaced on a line, for 24 hr. The bank of lamps provided an evaporation potential of 1.43 cm/24 hr as measured from the open water column. Moisture contents were again determined at 42 points in each compartment.

A second application of a 2 cm depth of water was added to the same model after the 24-hr evaporation period. The model was allowed to set 10 hr before moisture contents were determined. The model was then placed under the heat lamps for 24 hr. The evaporation potential was 1.30 cm/24 hr for this second 24 hr evaporation. At the end of this period, moisture content was determined again.

A third 2 cm application of water was added to the model at the end of the second evaporation period. The model was allowed to set 4 hr before moisture contents were taken. Then, the model was placed under the heat lamps for 83 hr. The total evaporation potential during this period was 4.77 cm. A final moisture content was taken at 42 points in each compartment.

4. RESULTS

4.1 Soil Column Experiments

Figure 2 shows water loss from three (1 cm mulch, 4 cm mulch, and bare soil) of the five treatments in the experiment involving soil columns. The average evaporating potential measured by an open-water surface with an area of 44.2 cm^2 was 1.68 cm/24 hr or 74.1 g/24 hr. The 2 cm mulch and the subsurface mulch curves lie on or between curves shown. After 1377 g of open-water loss, the 1 cm mulch column lost 168 g compared with 314 g for bare soil and 130 g for the 4 cm mulch. The 2 cm mulch column lost 128 g and the subsurface mulch column lost 135 g.

Figure 3 shows moisture content with depth for two (bare soil and 1 cm mulch) of the five treatments used in the column experiment. Data for the other three treatments are not shown because the other mulch treatment curves of moisture content with depth are not significantly different from the curve for 1 cm mulch.

The temperature after 1 day of evaporation of the columns was measured on the outside surface near the base of the columns with a mercury-in-glass thermometer and was 27.1°C. Surface temperatures measured by an aluminum foil-covered mercury-in-glass thermometer were 33.2°C.

4.2 Two-dimensional Model Experiment

Figures 4 (bare soil), 5 (subsurface mulch), and 6 (1 cm mulch) show the volumetric water content for 42 points measured. The values shown are final moisture contents after three 2 cm applications of water for a total of 6 cm and after three evaporation periods with potential evaporation of 1.43 cm, 1.30 cm, and 4.77 cm, for a total of 7.50 cm. The initial soil was at an air-dry moisture content of 3.22%. Lines of equal water content are shown for 20.0%, 25.0%, and 30.0% moisture by volume. Associated with each figure are the average moisture contents of the surface 1 cm for the three wettings. These moisture contents were obtained by averaging the middle four moisture contents for the surface row of measurements.

For Figure 4, these values are 33.4% for the first wetting, 25.7% for the second, and 29.1% for the third. The point in Figure 4 at $x = 3$ and $y = 1$ is -10%, an absurd value. We suspect the soil surface settled so that the measurement of intensity for moist soil was partly through air instead of soil.

In Figure 5 the average moisture contents of the surface 1 cm for the three wettings are 41.6% for the first wetting, 34.7% for the second, and 33.5% for the third. The point in Figure 5 $x = 13$ and $y = 1$, -9.8%, is absurd for the same reason given for the point $x = 3$ and $y = 1$ in Figure 4. The point $x = 3$ and $y = 1$ in Figure 5 is 42.2% another absurd value because the soil was visibly dry. We believe this resulted when

the gamma beam was partially going through air when the dry soil intensity was established. This also occurred at x = 27 and y = 1 (54.5%) in Figure 6. These absurd points bring out the problems in lining the gamma beam initially and the change that occurs when the soil settles.

Variation in soil bulk density for the three compartments will have some influence on the moisture contents. The average bulk density of 30 points for Figure 4 is 1.34 g/cm^3, for Figure 5 is 1.32 g/cm^3, and for Figure 6 is 1.29 g/cm^3. The extreme values for the entire experiment were 1.21 and 1.39 g/cm^3.

5. DISCUSSION

5.1 Vertical Soil Columns

In the column experiment, the columns were initially wetted to a water content near saturation. When evaporation started, the 1 cm mulch was almost immediately effective in reducing evaporation (Figure 2) because the sand dried quickly and the underlying layers were composed of a fine-textured material. The 4 cm mulch lost a greater amount of water during the initial stages because the 4 cm sand layer was initially wet and could easily conduct water vertically for a small distance. After 800 g (18.1 cm) of evaporation potential, the 4 cm mulch became more effective than the 1 cm mulch. The 2 cm mulch and the 1 cm subsurface mulch curves were identical and intermediate to the curves shown for 1 cm mulch and 4 cm mulch. Evidently, 2 cm of dry material, whether soil or sand, offers very nearly the same resistance to vapor flow.

All mulch treatments saved water when compared with the bare soil after 31.2 cm (1377 g) of evaporating potential. The water saving is large [(314-168)/314] (100) = 46% to [(314-128)/314] (100) = 59% (see Section 4). This large water saving is partly due to the high moisture content with which we started the experiment since the water was initially trapped below the mulches.

Figure 3 shows the distribution of the saved water at the end of the experiment when 1377 g (31.2 cm) of open water had evaporated. The surface 4 cm layer of the bare soil is dried to a low moisture content. Below 6 cm, the moisture content is approximately constant at 30%. In comparison, the 1 cm mulch has allowed the surface 4 cm layer to dry considerably, but not to the extent that drying has occurred under bare surface. Also, a much greater amount of water has been stored below 6 cm by the mulch treatment. The subsurface mulch (results not shown in Fig. 3) also showed a high amount, about the same as the 1 cm mulch, of stored water in the lower depth. This storage was possible because the soil was initially near saturation. In a field situation, the soil would be saturated only after infiltration had occurred. Since a subsurface mulch is known to inhibit infiltration, we included vertical mulches to help infiltration in the two-dimensional model experiment.

5.2 Two-dimensional Soil Models

The two-dimensional model was used to investigate the influence of bare soil, a 1 cm surface mulch, and a 1 cm subsurface mulch when vertical sand mulching was included. The vertical sand mulching at the sides of the model should at least partly overcome the infiltration problems involved with the subsurface mulch which inhibits infiltration. The vertical sand mulch did improve infiltration for all three treatments since the soil mix transmitted water much more slowly than did the vertical mulch sand.

Results in Section 4.2 show that the 1 cm layer of soil above the subsurface mulch in the model retained a greater amount of water than the top 1 cm of the bare-soil treatment. For the first 2 cm addition of water, the subsurface mulch caused 41.6% water content to be held compared with 33.4% for the bare soil; for the second 2 cm addition the subsurface mulch caused 34.7% water content to be held, compared with 25.7% for the bare soil; and for the third addition of 2 cm the subsurface mulch caused 33.5% water content to be held, compared with 29.1% for the bare soil. This comparison shows that the 1 cm surface layer of soil above a subsurface mulch retains 4.4% to 9% more moisture than a homogeneous soil. Then, when evaporation occurs, the water held above the subsurface mulch is lost before the subsurface mulch becomes effective in reducing water loss. This effect does not occur in the surface mulch.

Figures 4, 5, and 6 have shown the end result of infiltration of relatively small amounts of water followed by relatively high intensity evaporation for the three treatments. The overall average moisture content for these three figures is of interest. This moisture content can be found by averaging the six values for a moisture measurement depth shown on a figure and by weighting this average for the thickness of the layer of soil it characterizes. Using this method we found that the average water content for Figure 4 was 21.2%; for Figure 5, 23.3%; and for Figure 6, 25.0%. The average water content can be converted to a volume of water by multiplying the values by the total volume of soil. The volume of soil is (26 cm length) (25 cm height) (10 cm width) = 6500 cm^3. Thus, 21.2% is 1378 cm^3 water, 23.3% is 1514 cm^3, and 25.0% is 1625 cm^3. The initial water present in the soil was 3.2% or 208 cm^3, and the added water was (3) (600 cm^3), equaling a total of 2008 cm^3. Then 2008 cm^3 - 1378 cm^3 = 630 cm^3 was evaporated from the bare soil; 494 cm^3, from the subsurface mulch treatment; and 383 cm^3, from the surface mulch treatment. Thus, the subsurface mulch treatment saved 630 cm^3 - 494 cm^3 = 136 cm^3 or (136/630) (100) = 21.6% of the water evaporated from the bare soil treatment; and the surface mulch treatment saved 630 cm^3 - 383 cm^3 = 247 cm^3 or(247/630) (100) = 39.2% of the water evaporated from the bare soil treatment.

The lines in Figures 4, 5, and 6 connect points of equal water content. In Figure 4, the line for 20% water content lies deeper than in Figures 5 and 6. This shows that the bare-soil treatment caused more drying at the lower depths than the other treatments. For example, the deepest point of the 20% line in Figure 4, is 15 cm below the

surface; and for Figures 5 and 6, 12 cm below the surface. The 25% line in Figure 4 is 19 cm below the surface and is about 2 cm below the 25% line in Figure 5 at 17 cm depth and about 4 cm lower than the 25% line in Figure 6 at 15 cm depth. The 30% line in Figure 6 is much higher than in Figures 4 and 5. All the lines curve upward when they lie near the edges where vertical coarse sand mulches had an effect. The vertical mulches increased infiltration, which caused the wetting fronts in the model compartments to advance from the sides and bottom as well as from the top. This type of phenomenon can be described quantitatively rather than qualitatively by using the gamma-ray attenuation procedure.

5.3 Comparison of Soil Column and Two-dimensional Model Results

There are two differences between the experiment with soil columns and the experiment with the two-dimensional model. The differences are initial moisture contents, and wetting and drying procedure.

The soil in the columns was initially nearly saturated, while the soil in the two-dimensional model was initially air-dry. Thus, in the soil columns, we are concerned only with evaporation. Since mulches cause early surface drying, the surface treatments in the column experiment are only working as a vapor diffusion resistance. In the two-dimensional model, the surface treatments are acting as a resistance to three processes: upward capillary movement, vapor diffusion, and infiltration. Consider the top 2 cm of soil mix and or sand in the three compartments of the model. During infiltration, the 1 cm surface mulch and the 1 cm of soil below it offer less resistance than the top 2 cm of the bare-soil treatment. The top 2 cm of the bare-soil treatment offer less resistance to infiltration than do the top 2 cm of surface if there is 1 cm of sand below 1 cm of soil. This means that the subsurface mulch should be less effective when infiltration and evaporation are involved than when evaporation alone is involved, when compared to a surface mulch. This is true as seen from the water saved in both cases. In the column experiment (see Results, Section 4.1) the 1 cm surface mulch saved

$$[\,(314-168)/314\,]\ (100) = 46.5\%$$

and the 1 cm subsurface mulch saved

$$[\,(314-135)/314\,]\ (100) = 57.0\%$$

These values, 46.5% and 57.0%, for the columns may be compared with corresponding values, 39.2% and 21.6%, for the model as found in Section 5.2. From the four percentages, 46.5, 57.0, 39.2, and 21.6, we see that the surface mulch was 46.5 - 39.2 = 7.3% less effective under the conditions of the two-dimensional model, while the subsurface mulch was 57.0 - 21.6 = 35.4% less effective.

6. CONCLUSIONS

1. A gamma apparatus was used to measure soil bulk density and water content in two-dimensional models as well as in vertical columns, and results were compared for different types of mulching.

2. When the soil columns were initially saturated and when one of the treatments (1 cm sand, 2 cm sand, 4 cm sand, or 1 cm sand below 1 cm of soil) was used, there was a saving of water of 46-59% for an 18-day evaporation period, compared with the situation for bare soil.

3. Water content in the 1 cm of soil above the subsurface mulch after a 2 cm irrigation ranged from 4-9% higher than for a bare soil.

4. The use of a 1 cm surface mulch in a situation involving both infiltration and evaporation resulted in a saving of 39.2% of the water evaporated from a bare soil. The use of a 1 cm subsurface mulch in a situation involving both infiltration and evaporation resulted in a saving of 21.6% of the water evaporated from a bare soil.

5. A 1 cm subsurface mulch lost 35.4% of its effectiveness when a situation involving infiltration and evaporation was compared with a situation involving only evaporation.

6. The use of two-dimensional models may be used to study further the influence of vertical and horizontal mulches on evaporation and infiltration, to evaluate moisture content above a water table in drainage systems, water contents around the roots of plants growing in a model, and possible lateral movement of water because of different evaporation potentials, such as due to shading, at the soil surface.

References

[1] Gurr, C. G. and Marshall, T. J., Trans. Intern. Congr. Soil Sci., 7th, Madison, Wisconsin 1 (1960) 306.

[2] Gurr, C. G., Soil Sci. 94 (1962) 224.

[3] Ferguson, A. H. and Gardner, W. H., Soil Sci. Soc. Am. Proc. 26 (1962) 11.

[4] Rawlins, S. L. and Gardner, W. H., Soil Sci. Soc. Amer. Proc. 27 (1963) 507.

[5] Davidson, J. M., Biggar, J. W. and Nielsen, D. R., Jour. of Geophy. Res. 68 (1963) 4777.

[6] Gurr, C. G., Aust. J. Soil Res. 2 (1964) 29.

[7] Wiegand, C. L. and Taylor, S. A., Utah State Univ. Agric. Expt. Sta. Spec. Rept. 15 (1961) 7.

[8] Tselisheheva, L. K., Soviet Soil Sci. (1965) 257.

[9] Kolp, D. G., Krause, F. P., and Lange, W., Water Resources Res. 2 (1966) 213.

Figure Captions

Fig. 1. Gamma-ray attenuation soil moisture detection apparatus

Fig. 2. Cumulative soil water loss from mulched and bare soil columns

Fig. 3. Soil column moisture distribution after 31.2 cm of open water column loss

Fig. 4. Bare soil model moisture distribution. Slashed areas are coarse sand. Lines of equal moisture content are shown for 20, 25, and 30%.

Fig. 5. Same as Fig. 4 except for a 1 cm subsurface sand mulch

Fig. 6. Same as Fig. 4 except for a 1 cm surface sand mulch

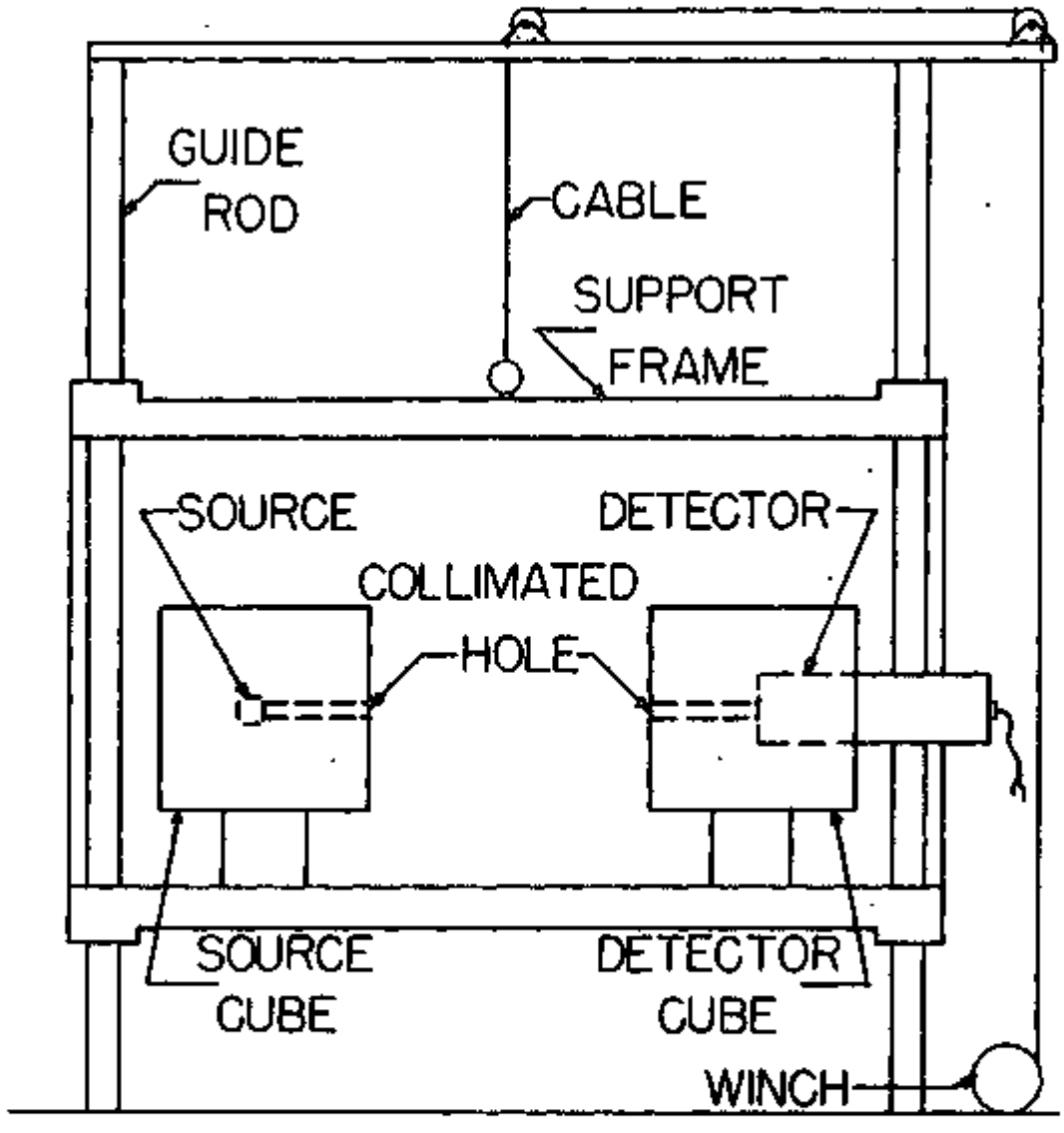

FIG. 1. GAMMA-RAY ATTENUATION SOIL MOISTURE DETECTION APPARATUS

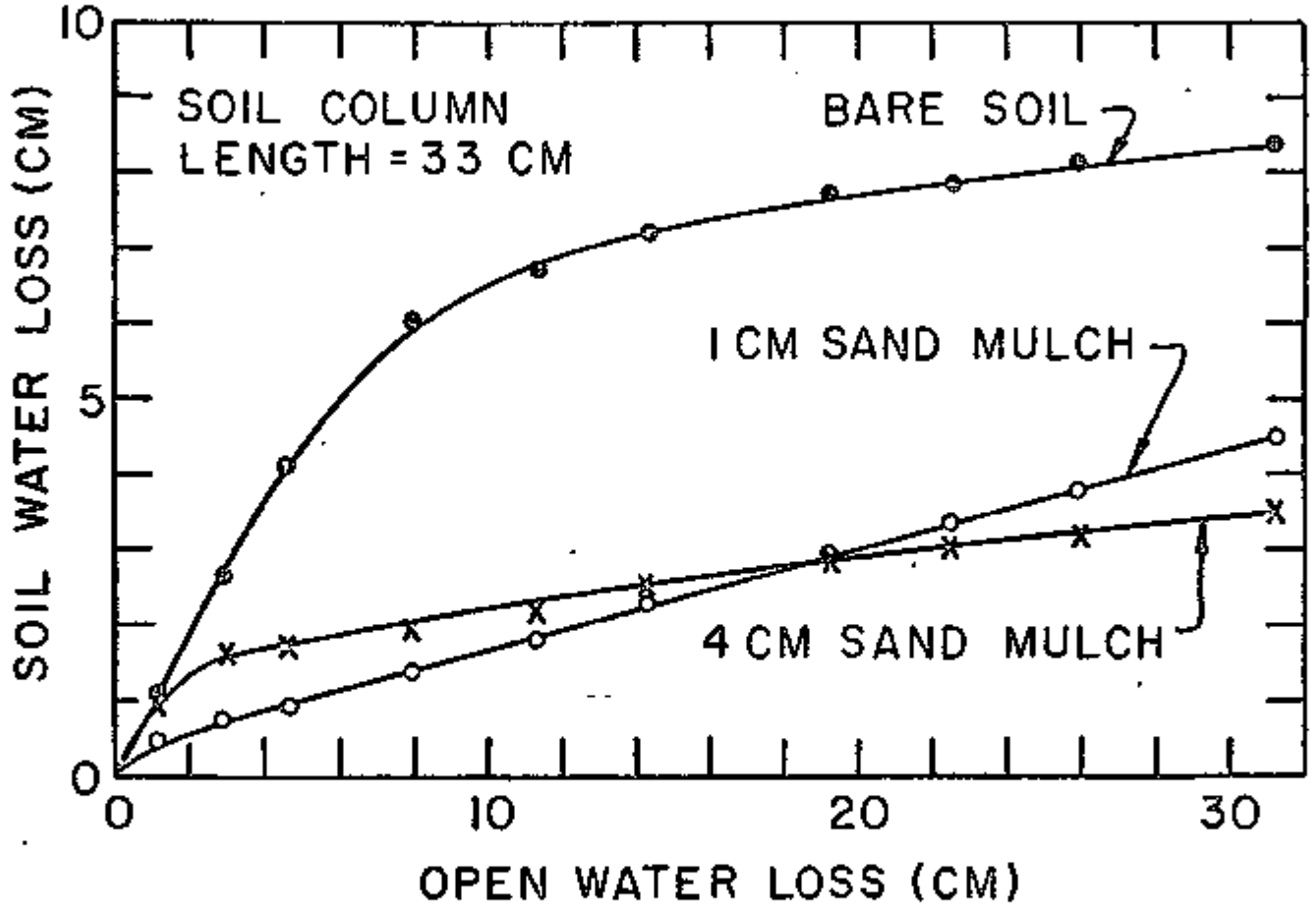

FIG. 2. CUMULATIVE SOIL WATER LOSS FROM MULCHED AND BARE SOIL COLUMNS

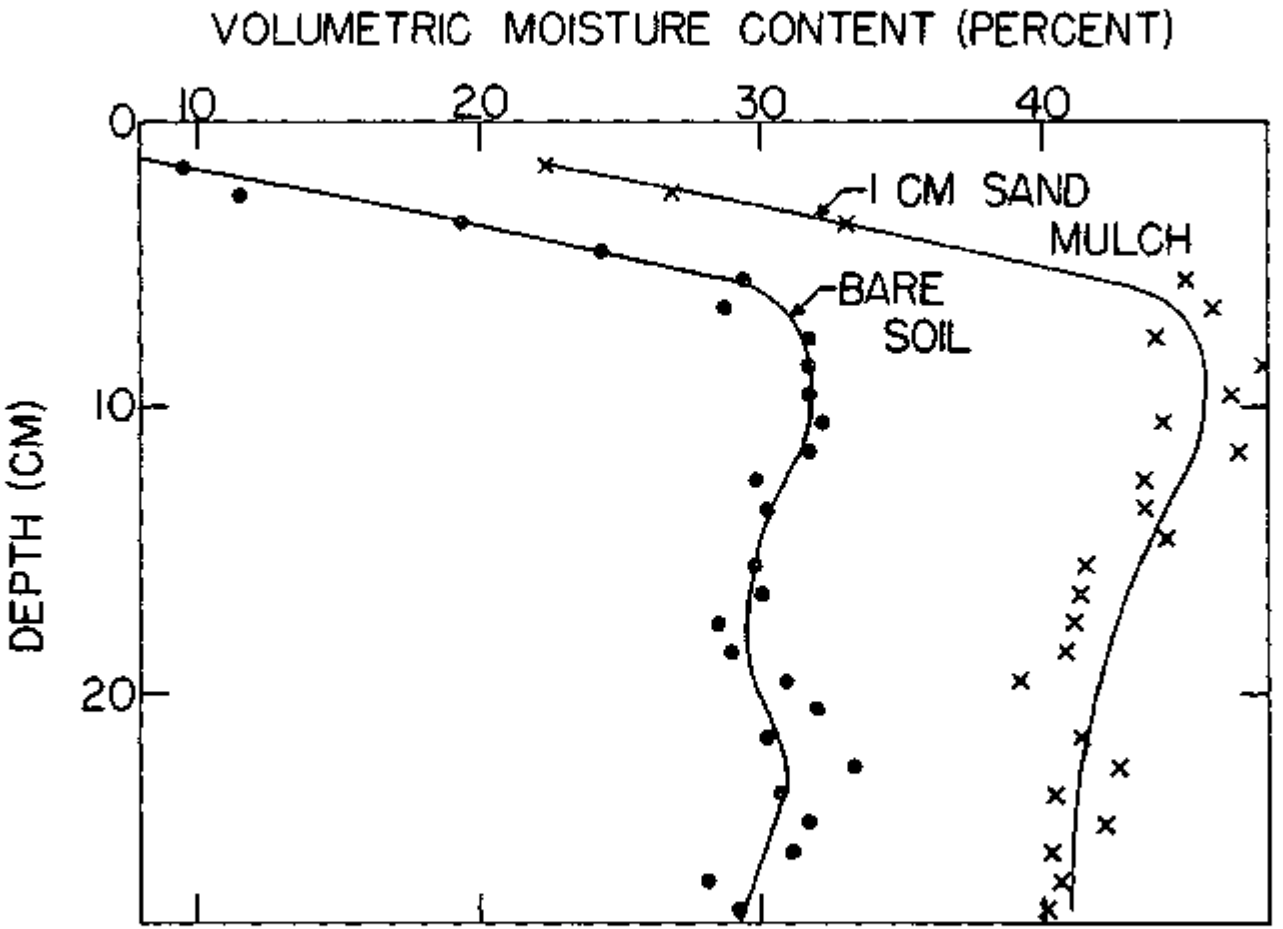

FIG. 3 SOIL COLUMN MOISTURE DISTRIBUTION AFTER 31.2 CM OF OPEN WATER COLUMN LOSS

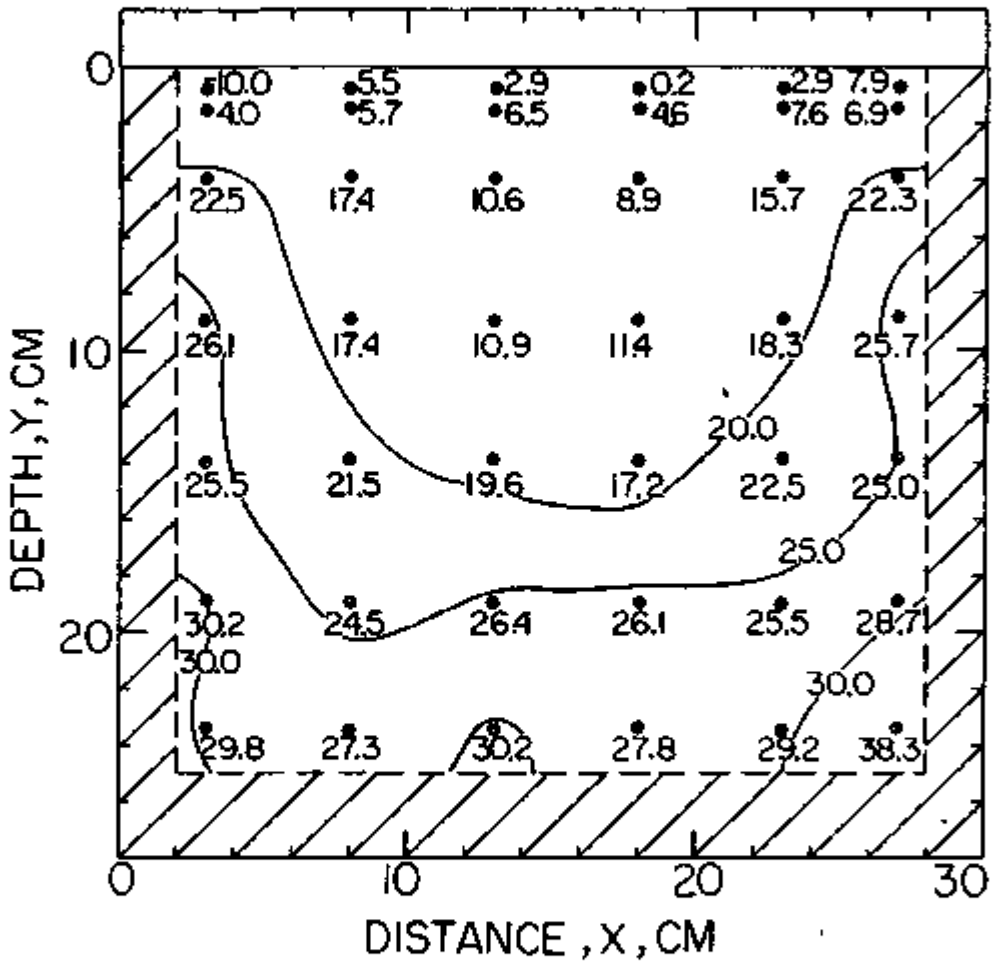

FIG. 4. BARE SOIL MODEL MOISTURE DISTRIBUTION. SLASHED AREAS ARE COARSE SAND. LINES OF EQUAL MOISTURE CONTENT ARE SHOWN FOR 20, 25, AND 30%

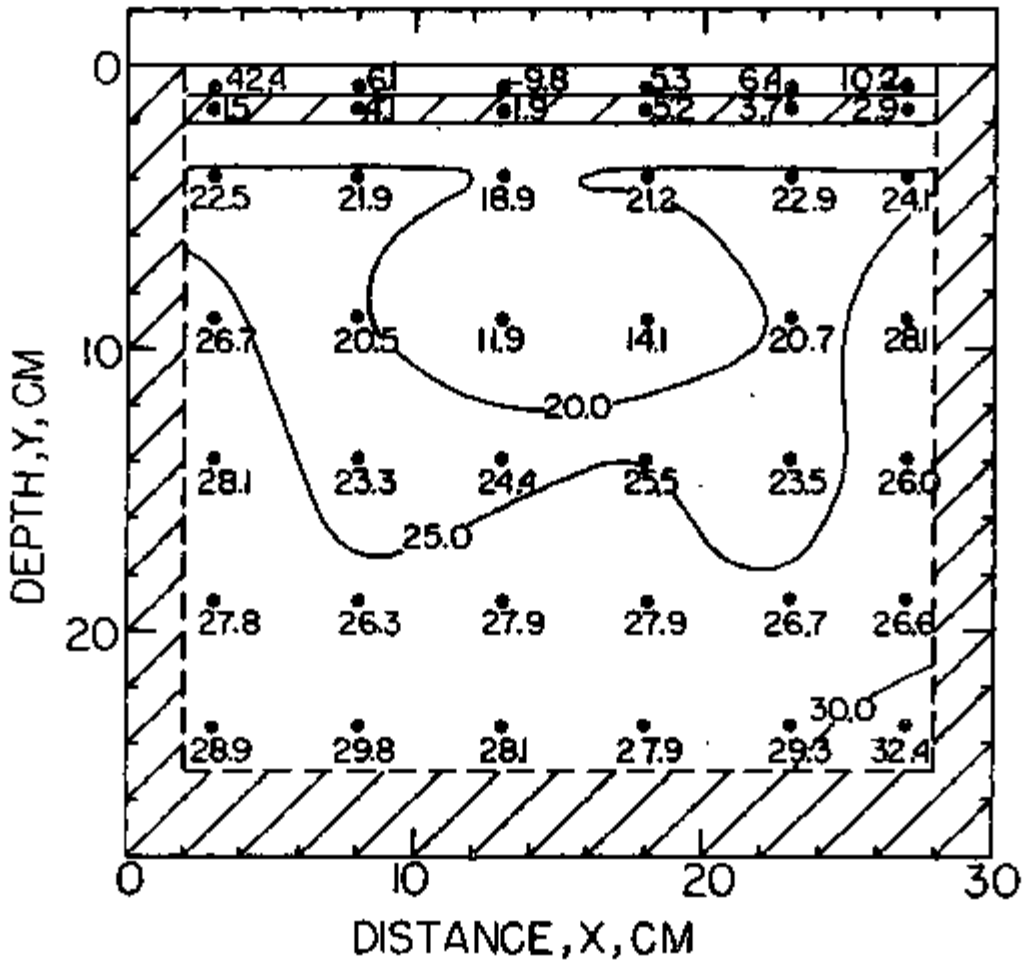

FIG. 5. SAME AS FIG. 4 EXCEPT FOR A 1 CM SUBSURFACE SAND MULCH

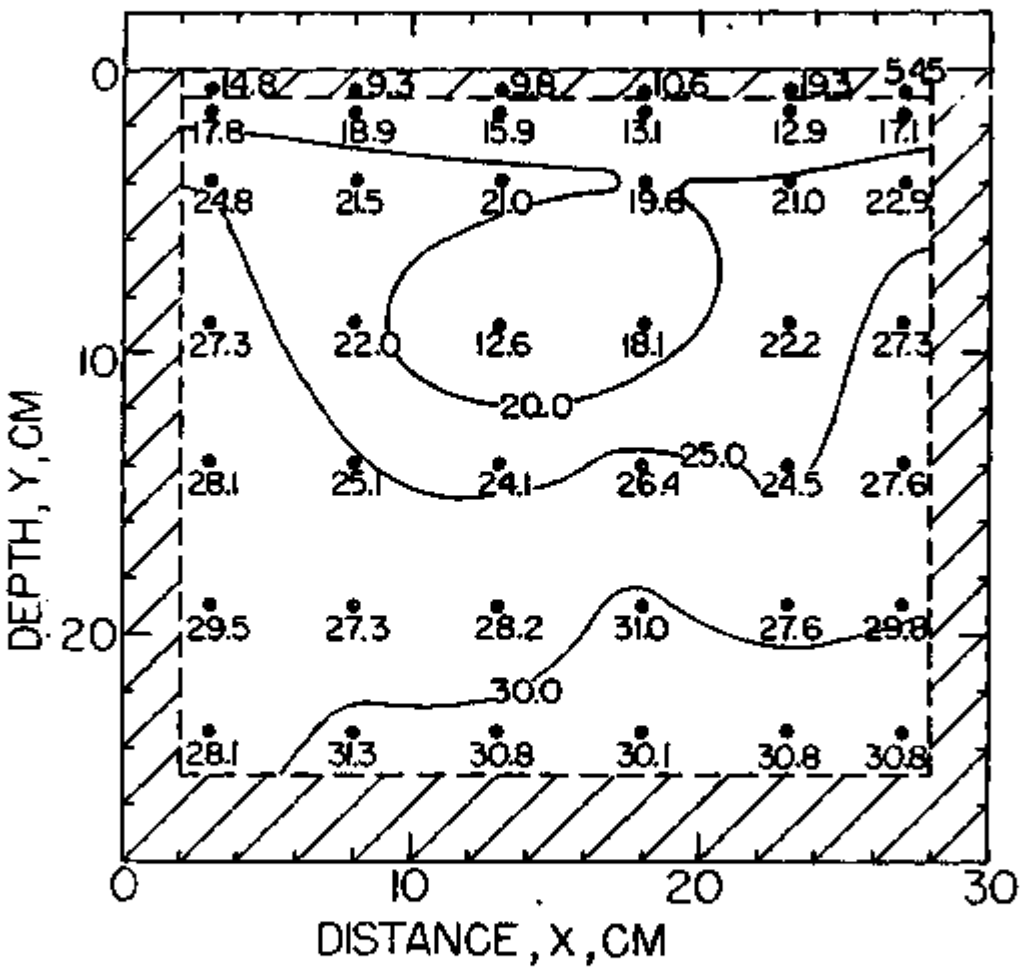

FIG. 6. SAME AS FIG. 4 EXCEPT FOR A 1 CM SURFACE SAND MULCH