Soil Water Evaporation as Affected by the Placement of a Coarse Layer: a Laboratory Soil Column Study

MOHAMED ASSEED[1]

INTRODUCTION

In arid and semi-arid regions, important amounts of water are lost from the soil by evaporation, and reduction of this loss would be of great value in providing adequate moisture for crop production. Evaporation is an endothermic reaction which requires heat. One of the most important atmospheric factors that influences water evaporation in arid regions is the availablility of heat energy from the sun during most of the year, where the sun is rarely absent. Evaporation can be controlled if energy transfer from sun to water is regulated by management. For example mulch on the soil surface acts as an insulating material which isolates the surface of the soil from direct reach by solar energy. Also the effect of surface mulch is to change the albedo of the soil surface, which will result in a higher rate of reflection of the coming radiation and a lower absorption rate.

Water movement through the soil plays an important role in evaporation. In considering methods for the reduction of evaporation it is important to determine whether one is dealing with the constant rate period where such external factors as atmospheric factors are limiting, or the falling rate period when the water transmitting properties of soil are limiting.

Attempts to limit evaporation by surface mulch have been studied by Greb et al. (5). Bond and Willis (2,3) have studied the effect of different rates of surface residue on the reduction of evaporation from wetted columns of fine sandy loam soil. Fritton et al. (4), traced chloride movement to allocate the zone of evaporation during water loss from the soil. They found that the evaporation zone lies between the zero and 5 cm depth below soil surface. Limited quantitative information is available relating soil water evaporation to thickness of coarse sand used as mulch on the soil surface. Also data on the effect of inserting a course layer just below the soil surface to impede capillary movement of water to the soil surface or to the location where it is subjected to evaporation, is not available.

[1] *Mohamed Asseed. Soil and Water Department, Faculty of Agriculture, University of Libya, Tripoli, Libyan Arab Republic.*

The objectives of this study were:

1. To determine the effect of coarse sand layers of different thicknesses placed at the soil surface, on the loss of water by evaporation from initially wetted columns of Libyan sandy loam soil, subjected to uniform daily evaporation potential.

2. To study the effect of the placement of a coarse sand layer of different thicknesses 4 cm below the soil surface to impede the capillary movement of water upward, and examine the effect of that on water evaporation from initially wetted columns of Libyan sandy loam soil subjected to uniform daily evaporation potential.

MATERIALS AND METHODS

Soil from the surface horizon of the valley soil of the Faculty of Agriculture Experimental Farm in the Sidi El Mesri area was collected. The soil is sandy loam in texture and it contains about 9 % Ca CO_3 (1). The soil was spread and allowed to dry in the air. After air drying, the soil was sieved through a 2 mm sieve and mixed for homogeneity. For soil columns, glass tubes of diameter = 6 cm and length = 40 cm were used, and each glass tube was fitted from the bottom with a rubber stopper with a drain hole drilled inside the rubber stopper. Columns were hand packed using screened marks at 5 cm intervals of column length. Equal masses of soil were then packed at each 5 cm section, the amount depending on the bulk density desired. Each individual section was taped with large rubber stoppers fastened to the end of a large rod. The packing bulk density of 1.45 gm/cm^3 was used in this study, and this value was used because this is the average value of bulk density in the valley soils used in this study (1). Fourteen soil columns were used in this experiment. Six of the soil columns were packed with soil to a distance 2 cm from the top end of the soil column. After packing a layer of coarse sand (sand has a particle size between 0.5 and 1 mm diameter) was placed on the top of the soil. Three different thickness of sand layer were used; they were 1, 0.5, and 0.25 cm, respectively. Two replications were used for each treatment, and the treatment here was the thickness of sand layer placed on the soil surface.

Another six columns were packed with soil to a distance = 5 cm from the top, then sand layers of thicknessess 1, 0.5, 0.25 cm were placed, and above this sand layer packing of soil was continued to complete filling of the columns with soil. In other words the sand layer was placed 4 cm below the soil surface in the soil columns. Two replications were used for each treatment and the treatment here was the thickness of the sand layer placed 4 cm below soil surface. Two soil columns were used as a check in which no sand layer was place on or below the soil surface, and this was designated as bare soil. Soil columns were then wetted from the bottom with distilled de-aerated water with a head approximately 1 meter referred to the cylinder bottom, until the soil surface was visually wet. Each column was covered with aluminium foil around the side. Each soil column was then mounted on a stand and subjected to radiant energy for evaporation. Infra red reflector lamps of 250 watts were placed at a given distance above the top of the soil columns to supply an evaporation potential = 1.5 cm/day. To measure the evaporation potential applied in this study, one column was kept filled with water, and placed with the distance between the water surface in the water column and the lamp, the same as the distance

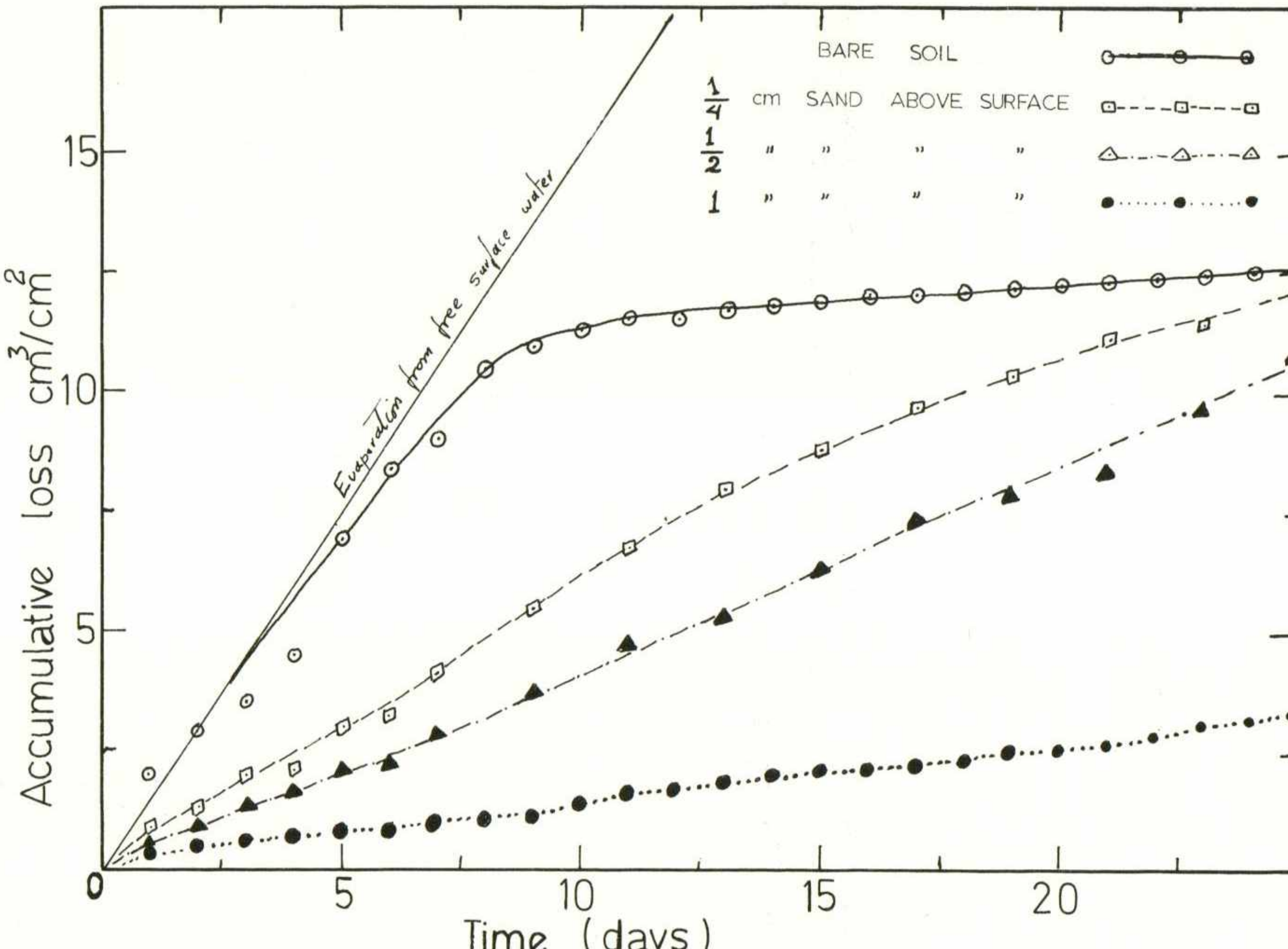

Fig. 1. Cumulative soil water evaporation with time as affected by placement of coarse sand layer on soil surface.

between the soil surface in soil columns and lamps. The evaporation potential was measured in terms of how much water evaporated from the free surface water every 24 hours. The experiment was conducted in a room where the temperature was 22 ± 2°C.

To determine evaporation losses from soil columns, they were weighed daily for the first 2 weeks and at shorter intervals thereafter. These readings were used to obtain cumulative evaporation from day to day. Water was added to the cylinder containing only water to replace that evaporated during the previous day. At the end of the experiment soil columns were sectioned to determine moisture distribution in the soil columns.

RESULTS AND DISCUSSION

Figure 1 shows the accumulative evaporation plotted as a function of time for different treatments of coarse sand layers of different thicknesses, placed on soil surface. The treatments are 0, 0.25, 0.5 and 1 cm sand layers placed on soil surface.

The straight line in the figure shows the evaporation from the free surface of water. By definition, evaporation potential has the value of the slope of the linear relationship between cumulative evaporation and time for a free water surface, and this is represented on the figures by the straight line which has a slope = 1.5 cm/day, which is the evaporation potential used in this study. The curve for bare soil (zero thickness of coarse sand layer on soil surface) shows three stages of evaporation. The first stage is a constant rate of evaporation, the second is a declining rate of evaporation, while the third stage is a constant, slow rate of evaporation. In the first stage of evaporation from the bare soil the evaporation rate approaches the evaporation potential used in this study which was 1.5 cm/day. This means that evaporation per unit time from a saturated soil initially will be the same as the evaporation per unit time from a free water surface, as was found by Lemon (6) and Fritton et al. (4). In this first stage the limiting factor is the availability of heat needed for evaporation. When the surface dries at the second and third stages of evaporation, the limiting factor for evaporation is the rate at which water could be conducted upward at a gradient of matric suction low enough to keep the surface of soil moist, so the maximum rate of evaporation which takes place at the constant third stage rate is controlled by the rate at which water is conducted through the soil to the surface. This final rate in our experiment using this sandy lawn soil is = 0.10 cm/day. This gives some indication of the rate at which water is conducted through this kind of soil. In the curve where we have a 0.25 cm of coarse sand layer on the soil surface the evaporation rate initially decreased but at the first stage rate of evaporation is prolonged. At the end of 25 days the total loss of water was close to the total loss of water from the soil with a zero thickness of sand layer in the soil surface (bare soil). The curve for 0.5 cm sand layer reduced the evaporation initially but prolonged the initial steady stage of evaporation and at the end of 25 days the amount lost from this treatment compared to the loss from bare soil is equal = 10.75/12.5, a reduction of just 14 % of the accumulative loss from bare soil. Now if we look to the curve where we have a sand layer = 1 cm above the soil surface, we find that the reduction in both daily loss, and accumulative loss at the end of 25 days was very high. The application of this 1 cm sand layer to the soil surface resulted in a reduction of $(1 - 3.25/12.5)\ 100 = 74\ \%$ compared to the evaporation loss

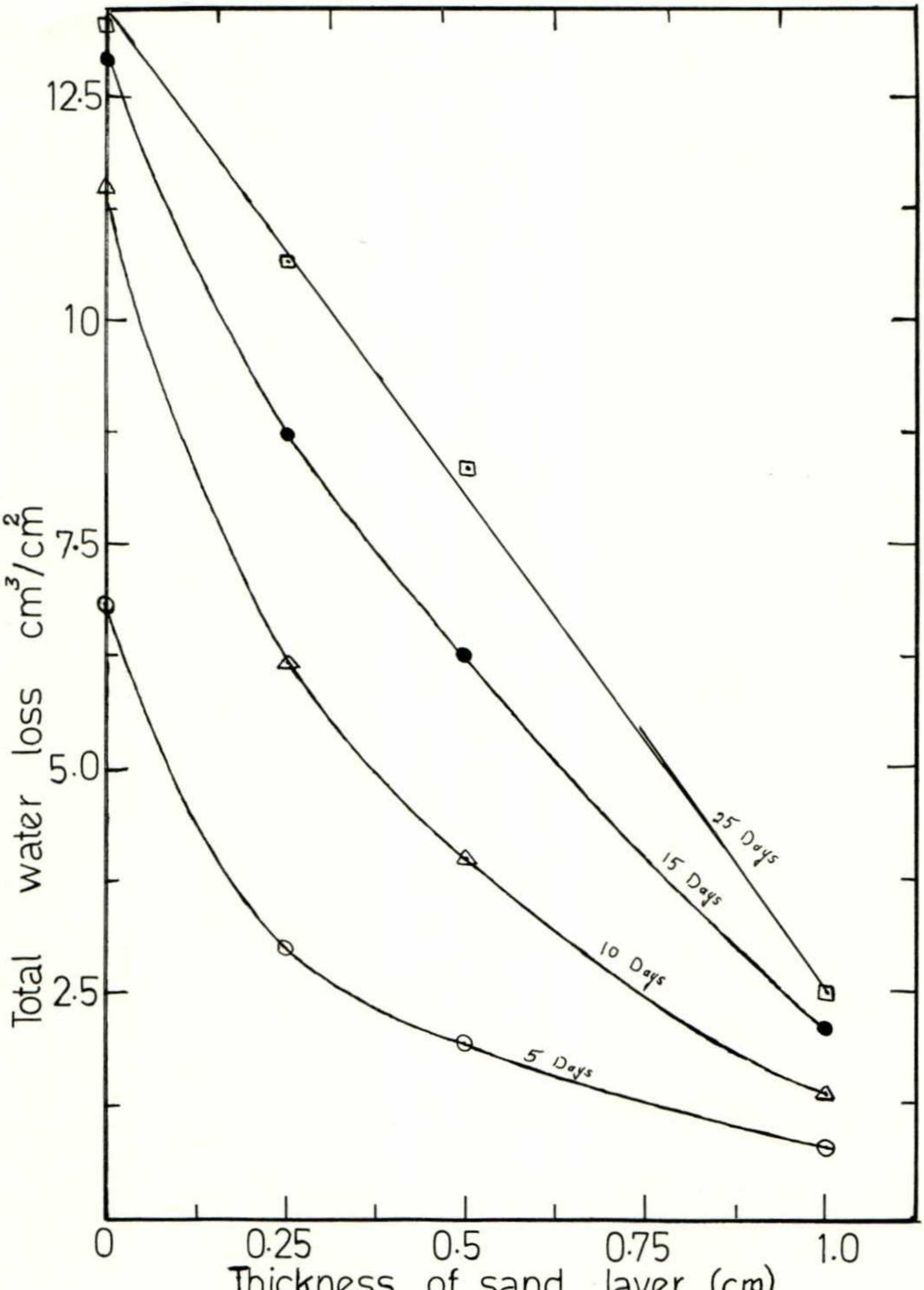

Fig. 2. Cumulative soil water evaporation as influenced by surface application of coarse sand layer of different thicknesses for different periods of drying an initially wetted soil.

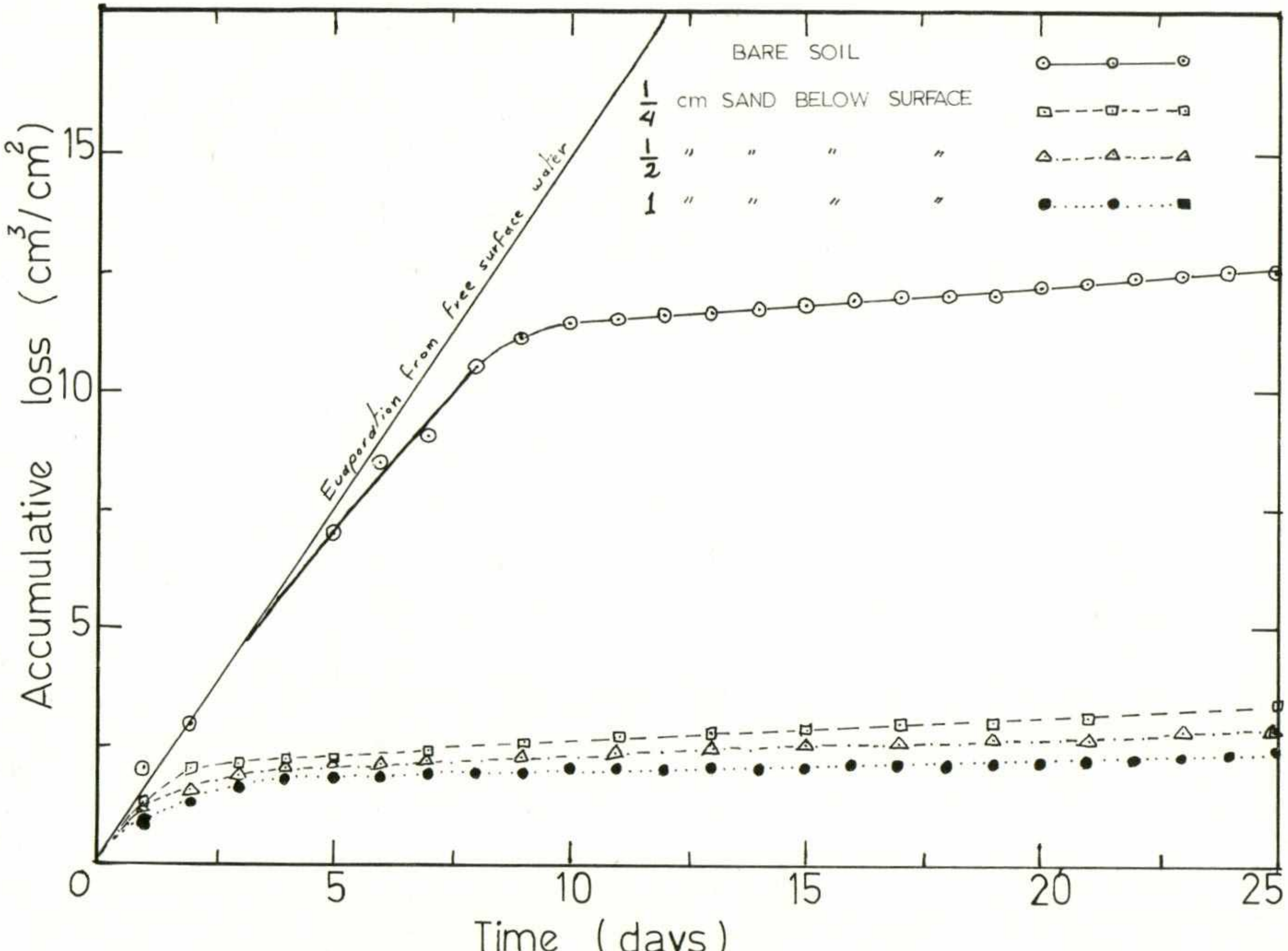

Fig. 3. Cumulative soil water evaporation with time as affected by placement of coarse sand layer 4 cm below soil surface.

from bare soil. This generally indicates that the application of a 1 cm sand layer to the soil surface was highly effective in decreasing the accumulative loss from the soil surface, and there is a big jump in reduction of evaporation loss when we increase the surface of coarse sand from 0.5 to 1 cm.

Figure 2 shows the relationship between the total loss and the thickness of the coarse sand layer placed on the soil surface. The curve after 5 days shows that the application of the first 0.25 cm of sand in the soil surface reduced the evaporation loss at a high rate compared to the bare soil, then the successive increase in thickness of the sand layer resulted in a smaller total water loss. The curve for the total loss after 25 days shows a close linear relationship between the total water loss and the thickness of the sand layer placed on the soil surface. This indicates the importance of both time and rate of application of the coarse sand layer in the soil surface. We can conclude that initially, as a greater thickness of coarse sand is added to the soil surface there is comparatively less change in cumulative evaporation i.e. as the thickness of the sand layer increases, the reduction in cumulative evaporation per unit thickness of sand layer decreases. Conversely later in time (curve for 25 days), as more sand is added, there is a comparatively greater change in cumulative evaporation. These considerations suggest that during the period of peak soil water storage, just the application of a small thickness of sand layer on the soil surface will result in the greatest evaporation reduction.

Figure 3 shows the relations between accumulative evaporation and time when sand layers of different thicknesses were placed 4 cm. below the soil surface. The thicknesses of the sand layers were 0, 0.25, 0.5 and 1 cm respectively. The reason this layer of sand was placed 4 cm below soil surface was to achieve capillary discontinuity, and so to impede capillary movement of water in the upward direction in the soil column. The reason that 4 cm below the soil surface was decided, on is that the vaporization zone depth as reported by Fritton et al. (4) was between a 0 and 5 cm depth. The graph shows that placement of this layer of coarse sand was highly effective in evaporation loss reduction. For a soil with zero thickness of sand layer placed 4 cm below soil surface, the accumulative evaporation after 25 days was about 12.5 cm, while the accumulative loss for the same period from soil columns where a sand layer was placed 4 cm below soil surface, ranged only from 2.5–3.5 cm for different thicknesses of sand layer. This indicates that there was on the average a reduction in evaporation loss compared to control $= (1 - 3/12.5)\ 100 = 76\,\%$.

As shown in the graph the thickness of the layer of sand place 4 cm below soil surface was not important, since with 0.25 cm layer the reduction was close to that obtained when a 1 cm layer was applied. It is interesting to notice in Figure 3 that the initial evaporation in the three cases where we have a sand layer placed in the soil, was equal to the evaporation loss from bare soil and the evaporation from free water; this is because the 4 cm of soil above the sand layer behaved as bare unprotected soil in the initial stage of evaporation. This amount of water evaporated from this portion of soil resulted in increasing the total loss from these soil columns.

Figures 4 and 5 show the comparison between the evaporation loss when the sand layer was placed on the soil surface and when the sand layer was placed 4 cm. below the soil surface. It is clear that the placement of a layer of sand below the soil surface resulted in a higher reduction in evaporation loss, compared to the placement of the sand layer on the soil surface. For example a placement of 0.25 cm sand layer 4 cm below the soil surface compared to above surface, resulted in a reduction of approximately $(1 - 3/10)$ $100 = 70\,\%$ after 25 days. This can be explained on the basis that the coarse sand layer

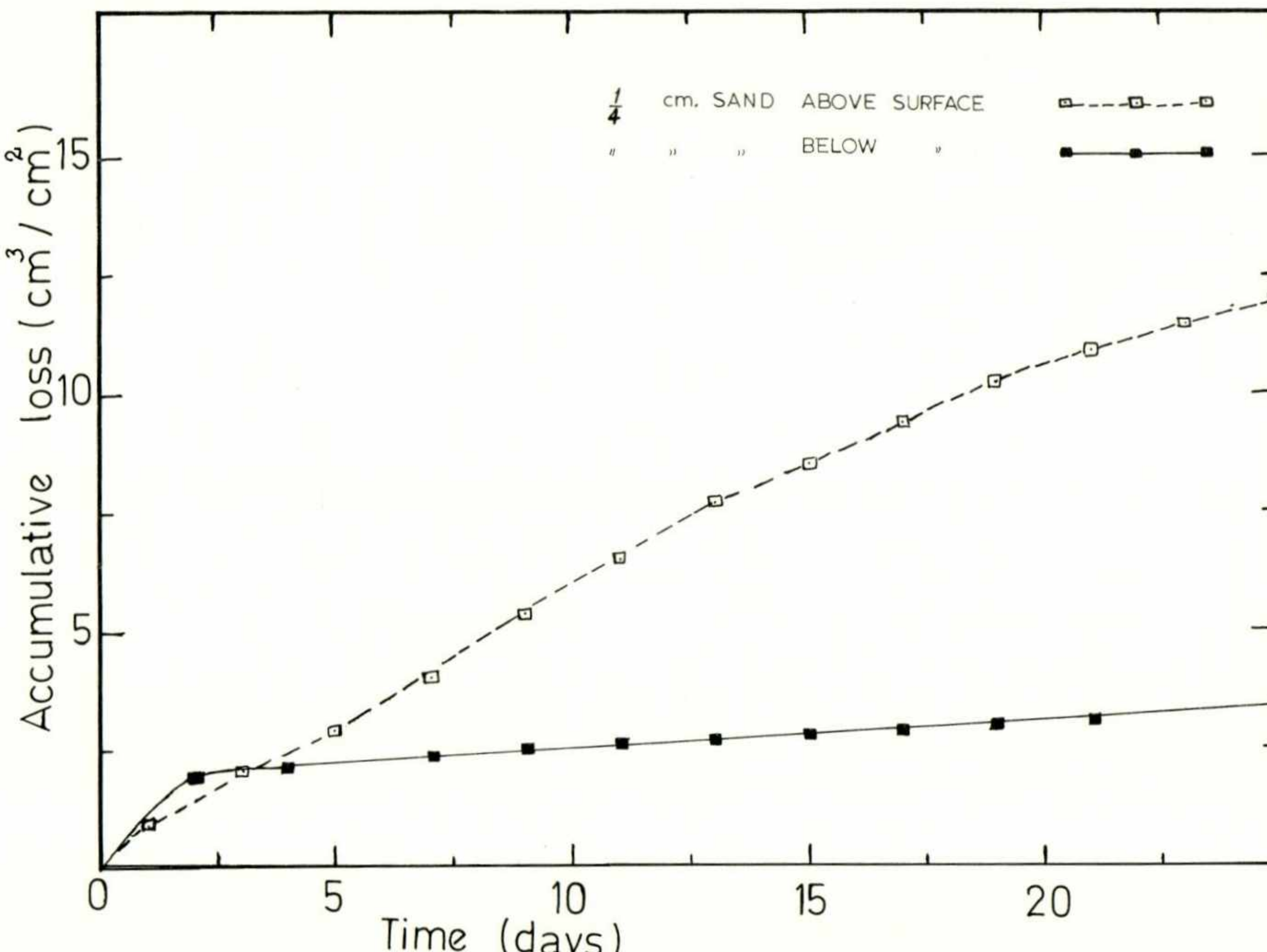

Fig. 4. Comparison between soil water evaporation as affected by placement of 0.25 cm coarse sand layer on soil surface or 4 cm below soil surface.

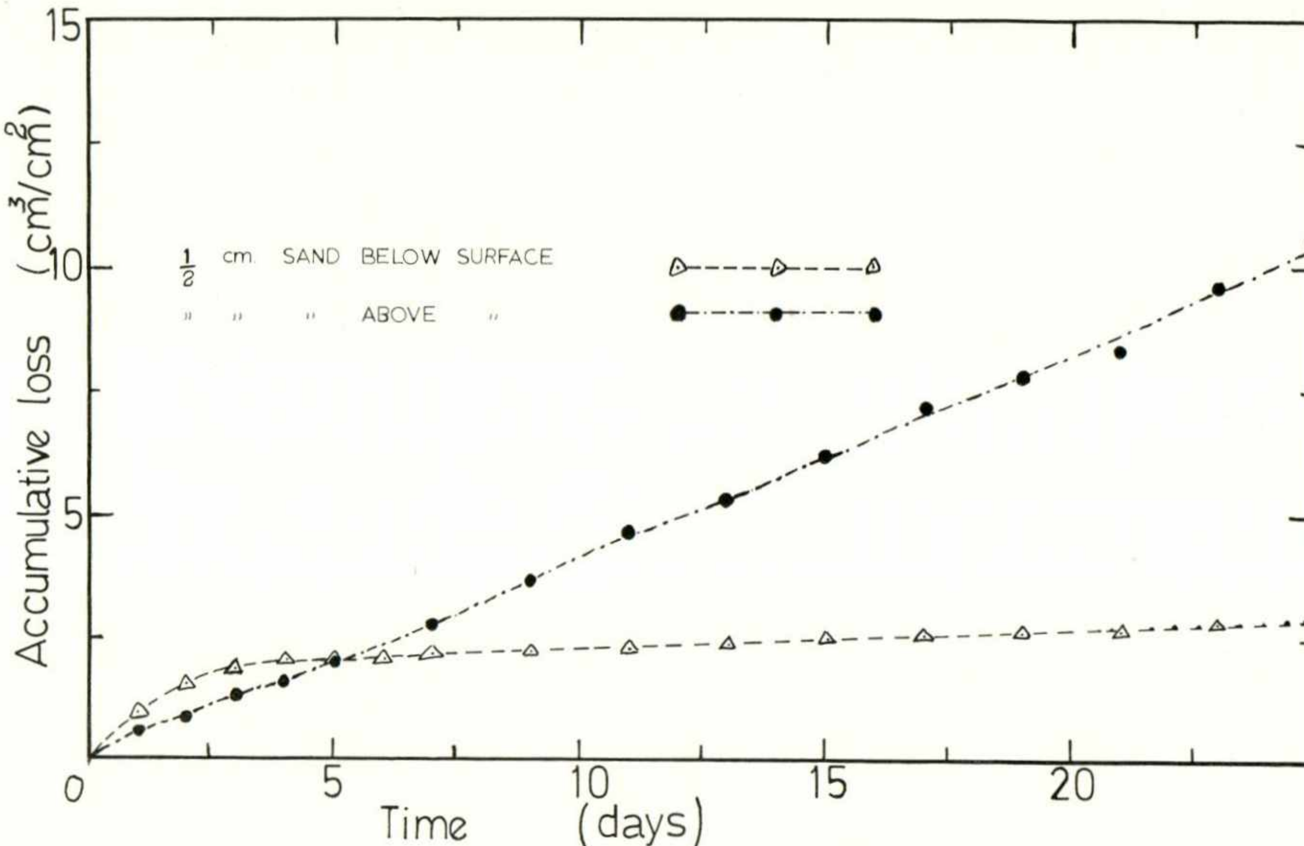

Fig. 5. Comparison between soil water evaporation as affected by placement of 0.25 cm coarse sand layer on soil surface or 4 cm below soil surface.

on the soil surface reduces capillary movement to the surface of the sand layer and also acts as an insulator, which shades the soil surface, but still the water for evaporation is available in the vaporization zone where it is converted to vapour without rising to the sand surface to be evaporated; once it is evaporated the water vapour diffuses through the sand layer to the atmosphere. But the placement of this sand layer 4 cm below soil surface will result in capillarity discontinuity and movement of waters to the vaporization zone will be stopped or very much slowed down, so water is conserved inside the soil and protected from being subjected to evaporation in the vaporization zone.

The comparison between the treatment when we have a 1 cm sand layer above and below the soil surface is not included, but a look at both figures 1 and 3 shows that the accumulative loss difference between the two cases after 25 days is not large. But the slope of the curve at 25 days when we have a 1 cm sand layer on the soil surface is higher than the slope of the curve when we have 1 cm sand layer 4 cm below the soil, and this means that the loss rate is still going on at a higher rate when there is a 1 cm sand layer on the soil surface than the loss rate when a 1 cm sand layer is placed 4 cm below the soil surface.

Figure 6 shows the distribution of moisture content in the soil column versus depth at the end of the evaporation period when there was a coarse sand layer of different thicknesses on the soil surface. The solid straight line which represents a uniform mositure content of 46% on a volume basis represents the initial moisture content in the soil column before it was subjected to evaporation. For the curve of water content versus depth for bare soil, there is a surface dryness up to a depth equal approximately to 6 cm where the curve has points of relatively rapid curvature change. After this dry surface the moisture content is uniform with depth and it is about 10% by volume. In the curve for a sand layer of 0.5 cm on the soil surface the moisture content changed from an initial uniform distribution of 46% to a distribution of about 12% on the average, and the curve indicates that the loss was from the whole soil column. When 1 cm of sand was placed on the soil surface most of the water loss was from the surface layer but the subsoil remained at a high moisture content, and it can be seen from the curve that the bottom end of the column contains as high a mositure content as the initial moisture content before subjecting the column to evaporation.

Figure 7 shows the relation between moisture content and depth in the columns at the end of the evaporation period, for soil columns where a coarse sand layer was placed 4 cm below the soil surface. The moisture distribution with depth is uniform below this sand layer, which indicates that the moisture did not move from beneath the sand layer due to the capillarity discontinuity. This indicates how effective the placement of this coarse sand layer was in impeding capillary movement upward in soil columns when they were subjected to evaporation. The layer of thickness equals 4 cm of soil above the coarse sand layer dried in the same pattern as bare soil while the soil just below the sand layer was close to the initial moisture content.

SUMMARY

Wetted soil columns, which were packed with sandy loam soil, were subjected to a uniform daily evaporation potential. These soil columns were treated with the placement of coarse sand layers of different thicknesses, placed on the soil surface or 4 cm below the

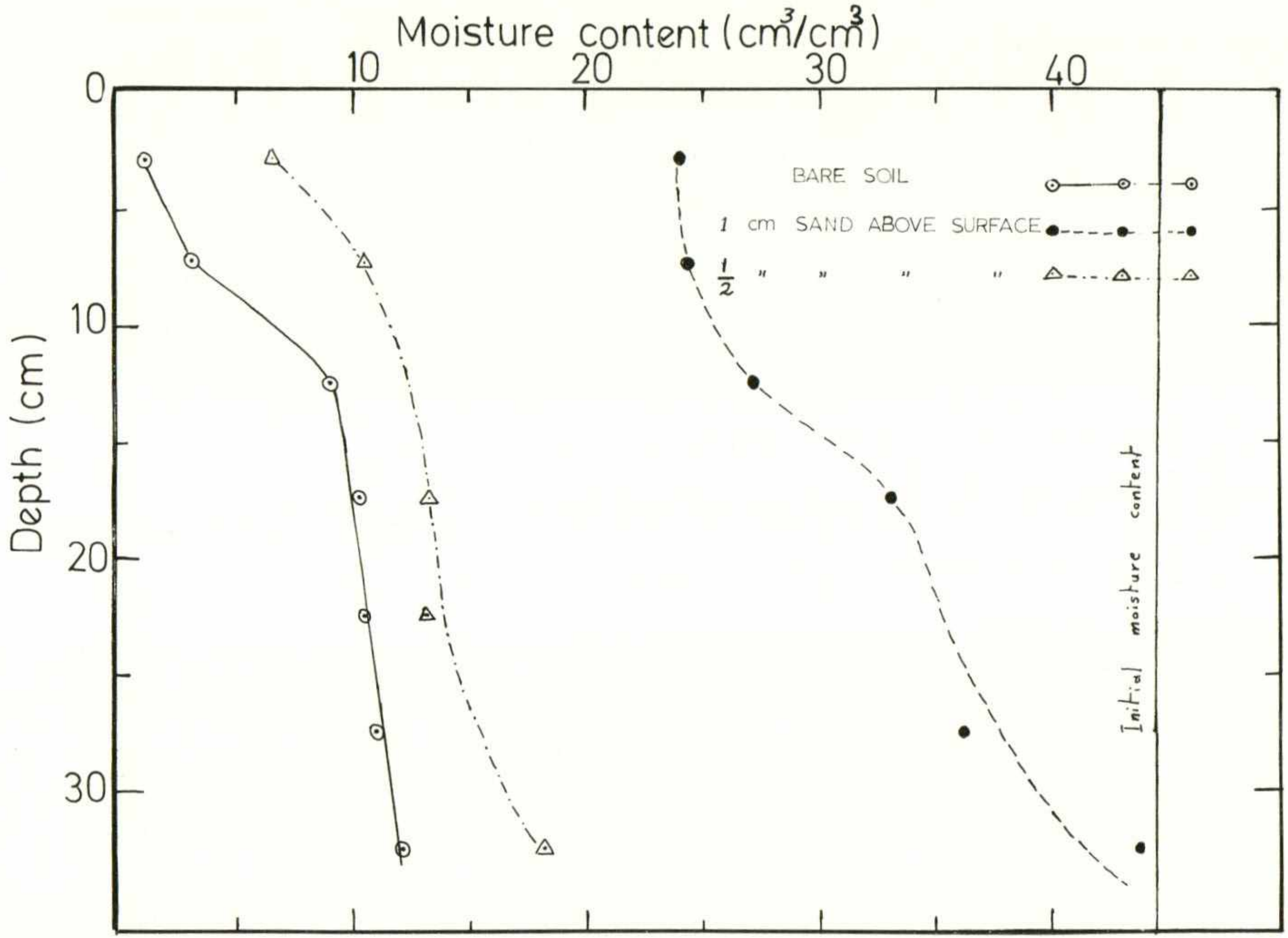

Fig. 6. Water distribution with depth in soil columns at the end of 25 days of evaporation with different thicknesses of coarse layer placed on soil surface.

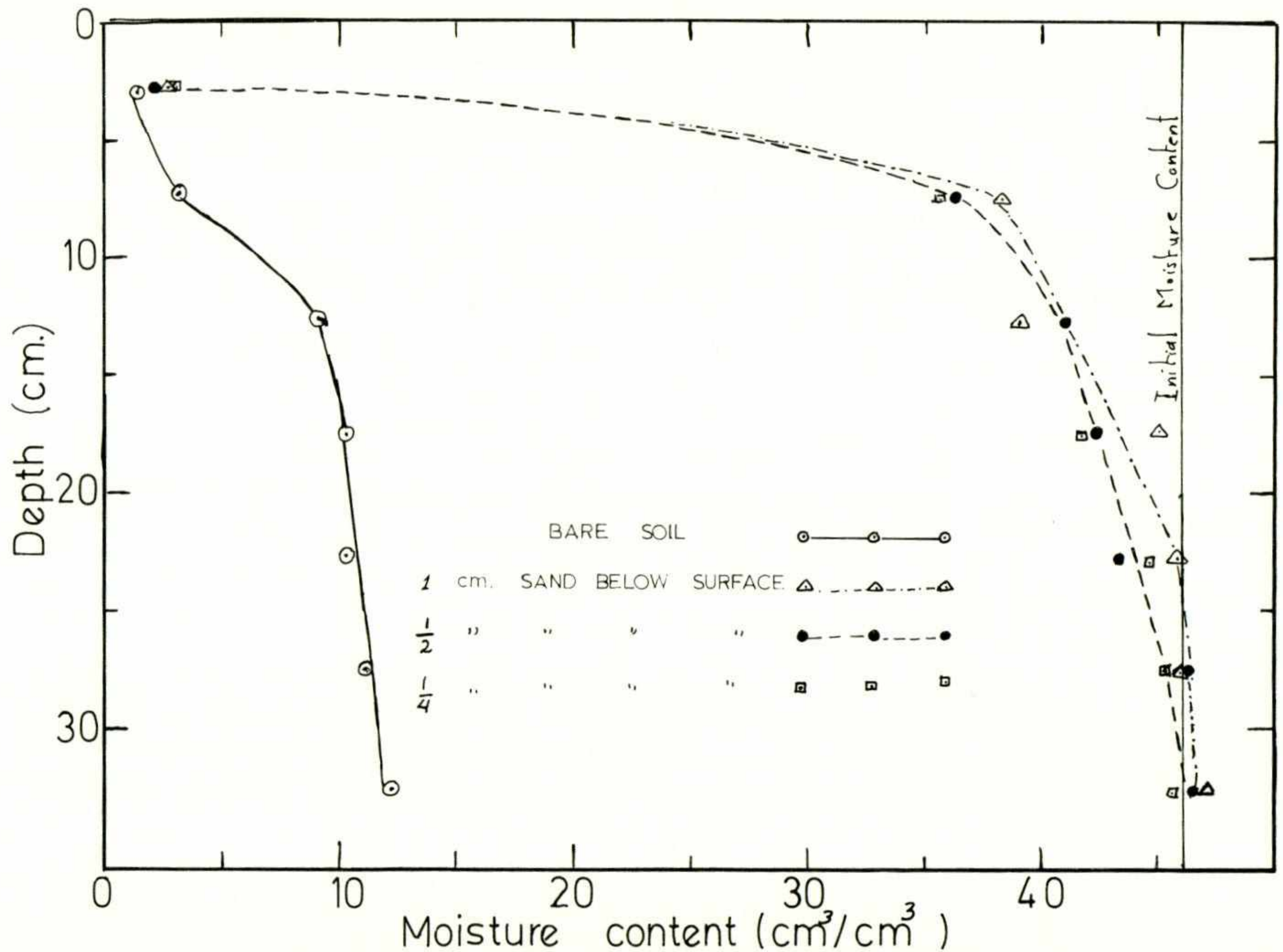

Fig. 7. Water distribution with depth in soil columns at the end of 25 days of evaporation with different thicknesses of coarse sand layer placed 4 cm below soil surface.

soil surface. Evaporation with time, water redistribution after evaporation, and thickness of the dry surface layer were measured.

It was found that evaporation is characterized by three stages, the initial constant high rate, the declining rate, and the final constant slow rate. In the first stage the evaporation rate approaches the evaporation potential, which indicates that when the soil is moist directly after irrigation, evaporation will approach openpan evaporation. The final constant slow rate for the soil studied was approximately equal to 0.1 cm/day, which gives an indication about the transmitting properites of this soil.

When a layer of coarse sand was placed on the soil surface, the first stage rate was decreased but its duration was prolonged, depending on the thickness of the coarse sand layer placed on the soil surface. The appreciable reduction in evaporation loss at the end of an evaporation period = 25 days occurred when this coarse sand layer = 1 cm. The data indicates the importance of both time and rate of application of a coarse sand layer on soil surface in evaporation reduction. When a coarse sand layer of a different thickness was placed 4 cm, below soil surface, capillary discontinuity was achieved, and evaporation loss was greatly reduced. This reduction was about 76 % compared to the evaporation loss from bare soil. The difference in thickness of this coarse sand layer which was placed 4 cm below surface, did not result in much difference in evaporation loss reduction.

The thickness of the dry surface layer was about 6 cm, and this is the vaporization zone.

Moisture distribution after evaporation indicates that when a coarse sand layer was placed 4 cm below the soil surface, the moisture content of the soil just below this coarse sand layer did not change much from the initial moisture content. This ensures the impedence of capillary movement in the upward direction due to the presence of this coarse sand layer below the soil surface.

ACKNOWLEDGEMENT

The Author wishes to express his thanks to Mr. Abusbeha for his co-operation during this research.

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