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EVAPORATION RESPONSE OF POST-WETTING TILLAGE IN RELATION TO SOIL TYPE AND EVAPORATIVITY

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Abstract

Among the effects of other forms of tillage, the effect of post-wetting shallow tillage on evaporation from bare soil has been a subject of investigation by soil physicists. Loosening by tillage accelerates the formation of a dry layer, which acts as barrier to further loss of water by evaporation by lowering the locus of phase change and retarding the upward liquid flow by changing ... D(θ) relations. Evaporation response to tillage has been observed to depend upon soil type, evaporativity, time and type of tillage.

Past research on the subject has largely been empirical, although some efforts have been made to model water loss through tilled layer, simulated by surfactant treated soil mulch with the assumption that the tilled layer dries out instantaneously. This is far from realistic as the development of dry layer is dynamic and non-uniform and depends upon factors mentioned above. For any realistic modelling of evaporation losses from tilled soil it would be necessary to have quantitative estimates of changes in bulk density, roughness index, and soil area in contact with atmosphere; and the effect of these changes on albedo, thermal and hydraulic conductivities of soil, transfer coefficient of vapour and potential evaporation. In addition information on the downward movement of the locale of evaporation as influenced by soil, evaporativity and tillage variables would also be required. Till successful models become available, empirical studies to generate the needed coefficients and to further the understanding of the process should be continued.

Evaporation response of post-wetting tillage in relation to soil type and evaporativity

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Tillage refers to "manipulation of soil from surface downward to some depth with the objectives of controlling weeds, preparing seed beds, to place seed within the soil and to mix an additive to the soil"(Linden, 1982). Time and type of tillage determine its effect on soil properties, soil water balance and crop growth. Opening up of soil by tillage before wetting by rain or irrigation affects rate of water entry into the soil and water redistribution within the profile. Similarly, deep tillage to break compact layers in the root zone or to mix up an impervious layer with more pervious soil may also alter the infiltration and moisture retention characteristics of soil and also affect soil water balance through evapotranspiration effects caused by changes in depth and pattern of rooting. Similarly, shallow tillage after wetting is intended to control evaporation losses from soil, which is the subject matter of this paper. The available literature shows that this effect of tillage is greatly influenced by the time and quality of tillage, the soil type and the prevailing atmospheric evaporativity.

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Mechanism Of Tillage Effect On Evaporation

Loosening of surface soil by tillage alters the soil-atmosphere boundary and hydral and thermal properties of soil. The latter, in turn, affect the water and heat fluxes responsible for evaporation. Starting with initially wet soil, time-trends in evaporative flux from tilled soil, normalised against those from the untilled soil, are schematimized in Fig.1. Immediately after tillage, evaporation from the tilled soil increases (Linden, 1980) as compared to that from untilled soil because loosening

i) increases roughness of soil surface, which reduces albedo and increases potential evaporation by concentrating the heat in surface layers (Fig.2),

ii) increases surface area of soil exposed to atmosphere (Fig.3),

iii) changes moisture retention capacity of soil.

Initial rise in the rate of drying thus caused by tillage dries out the top few centimeters of the tilled soil more rapidly and more intensively (Fig.4). This dry layer acts as a barrier to both the liquid flow within the soil and vapour flow from soil to atmosphere and reduces further evaporation losses compared to those from the untilled soil; as the latter dries out more gradually and permits liquid flow to surface for a longer period. In the tilled soil, liquid flow from interior of the soil to the surface gets restricted owing to breaking down of capillaries by tillage; but the lower portion of the tilled layer may permit upward capillary flow to some distance above the interface depending upon the

fineness of clods and water content of the tilled layer and the type of soil. Gill (1978) verified the presence of the phenomenon of liquid water flow to seeds placed in a simulated tilled layer lying over untilled soil. When a layer of water proof soil was placed some distance below the seed within the tilled layer the water flow to seed was reduced. This evidently showed that in the absence of a water proof layer the liquid water moved to the seed through the loose soil. This would indicate that in the tilled soil, phase change from liquid to water does not occur at the interface of tilled and untilled soil but at various locii within the tilled layer. Nevertheless the formation of dry layer has the following effects.

i) it lowers temperature at the interface of tilled and untilled layers and thus reduces vapour pressure because the latter is strongly related with temperature (Fig.5).

ii) it pushes the locus of conversion of liquid water to vapour to some distance (variable) below surface.

iii) the soil layer above the plane of phase change resists the flow of vapour from soil to atmosphere.

iv) the loose layer conducts liquid water at a much lower rate than the undisturbed soil below.

With time the surface layer of the untilled soil also dries out and the locus of phase change moves deeper into soil with time even in the absence of tillage. The dry layer that develops at the surface of undisturbed soil is less porous than that created by loosening. Hence, when the drying front moves deeper into untilled soil, the less porous dry surface layer permits less vapour flow compared with an equal depth of the more porous layer of the tilled soil (Acharya & Prihar, 1969). Hence, the trend of evaporation losses from tilled and untilled soil reverses.

Factors Affecting Tillage Response To Evaporation

As shown in the preceding section, tillage affects evaporation by hastening the formation of a dry layer at the surface. Evidently, the properties and thickness and the rapidity of development of this layer vis-a-vis the rate of development and properties of a dry layer in the surface of untilled soil would determine the magnitude and time course of evaporation rates from the tilled soil relative to that from the untilled. Hence the evaporation response of tillage is likely to be affected by soil type, evaporativity and the depth and fineness of tillage. The time of tillage after wetting is also crucial in this regard. Independent and interactive effects of these factors observed in controlled laboratory experiments are described hereunder.

Soil type and evaporativity. Climatic environment and soil type exhibit a strong interaction with regard to the effect of tillage on evaporation reduction. As is well known the hydraulic conductivity decreases sharply with decrease in soil water content in the coarse textured soils and gradually in the fine textured (Fig.6). Consequently, the liquid flow to the surface during drying is sustained for a longer period in the fine compared with the coarse textured soil. Likewise under milder climate, where the drying process is slow, liquid flow to the surface continues for longer periods than under intense climate where the water content of the surface layer decreases rapidly.

In fact, various combinations of soil and climate may yield a range of longivity of liquid flow to surface between the two limits represented by fine textured soil under low evaporavitity on the one hand and coarse soil under high evaporativity on the other. As long as the liquid flow to surface continues tillage may help lower the locus of evaporation to some distance below the surface and retard the upward liquid flow to the surface.

The reduction of evaporation with tillage was observed to be greater under high than under low evaporativity (Fig.7). However, under high evaporativity, the cumulative reduction started decreasing earlier than under lower evaporativity because when a dry layer developed at the surface of the untilled soil also the evaporation rates from the latter fell below those from the tilled soil. But on fine textured soil, under low evaporativity, the cumulative reduction in evaporation continued to increase for longer periods as the formation of a dry surface layer in the untilled soil took longer under lower E_o. Where the soil is coarse and evaporativity is high, a rapid decrease in surface water content is accompanied by a sharp decrease in hydraulic conductivity and a dry layer is formed rapidly whether the soil is stirred or not. Under such conditions, tillage may ~~only~~ hasten the formation of a dry layer only slightly and, hence, offers little benefit for moisture conservation. In fact, in coarse soils such as loamy sand tillage was observed to increase evaporation loss under high evaporativity (Fig.7). However, where evaporativity was low, the liquid flow even in slightly coarse textured soils continued for sometime and the hastening of formation of dry layer through tillage did help in reducing evaporation losses to some extent (Fig.7).

Time and type of tillage. Hanks et al.(1965) demonstrated that changes in diffusivity in the wet range had a large influence on cumulative evaporation. Since K(Θ) and D(Θ) functions of fine textured soils differ a great deal from those of coarse textured, it is to be expected that the soil type and the wetness at which the D (Θ) change is caused by tillage will determine the course of evaporation. Qualitative evidence of this effect is available in the literature inasmuch as the effect of time of tillage after wetting on evaporation has been studied on different soils.

On sandy loam and fine sandy loamy soils (Fig.8) earliest tillage caused maximum reduction in evaporation (Willis and Bond, 1971, Gill et al.1977). Gill et al.(1977) further observed that the benefit of tillage for evaporation reduction showed an interaction between time of tillage and tilth of the disturbed layer. For tillage after 5 days, coarse tilth was more effective while with delayed tillage at 11 days after wetting finer tilth was more effective in reducing evaporation (Fig.8). They also reported that in a silty clay loam intermediate time of tillage was most effective (Table 1). It appears that when fine soil is tilled in a wet condition capillarity is re-established, especially if evaporativity is high.

Thus, for a given time of tillage, the characteristics of

tilled layer such as porosity, clod size distribution and depth of tillage influence the extent and time-course of evaporation losses. Porosity has a direct relation with evaporation loss (Hanks, 1958) as reduction of porosity increases diffusion resistance to vapour flow by making the flow path more tortuous. On this basis compaction of the dry tilled layer is advocated to lower evaporation losses. But another effect of reduced porosity is to increase the thermal conductivity of the tilled layer (Papendick et al.,1973) which would tend to increase evaporation. On the other end of the scale a decrease in thermal conductivity with increase in porosity, would enhance the vapour exchange by increasing turbulent flow of air (Hanks and Woodruff, 1958 and Acharya and Prihar, 1969) and, thus, mass transfer of vapour (Holmes et al.,1960). Therefore, to achieve maximum evaporation reduction, we must look for that threshold of porosity of the tilled layer which reduces thermal conductivity without much increase in turbulent flow of air.

Since porosity of the tilled layer is a function of clod size distribution; researchers have attempted to define optimum clod size ranges for maximum evaporation reduction. Some such values on clod size available in the literature are summarised in Table 2. It is seen that where clod size exceeded 10 cm in dia, pore dimensions became sufficiently large to accommodate eddies which enhanced the rate of vapour flow by mass transfer. When clods were finer than 0.5 mm dia, they apparently allowed greater liquid-water transmission. Clods of 3-6 mm dia were reported to be optimal by Scooter and Raats (1969) as these allowed minimal transport of water in liquid and vapour phases combined. In fact, the optimal clod size would depend upon the properties of soil and wind gustiness.

Depth of tillage. Hanks (1958), Acharya and Prihar (1969) and Hillel et al.(1975) reported that evaporation loss was inversely related to the thickness of surfactant treated soil mulch. When the depth was less than a certain threshold value evaporation was limited by external conditions rather than by mulch. Gardner and Fireman (1958) reported a threshold thickness of 3 mm for dry sand mulch. Deeper tillage reduced evaporation by providing a stronger barrier to vapour diffusion (Willis & Bond, 1971; Gill and Prihar, 1983). Actually, the tilled layer starts drying from top and the drying front moves downward into soil untill the dry layer is sufficiently thick to reduce the loss rate such that it is balanced by unsaturated upward flow dictated by the soil and climatic conditions (Papendick et al.,1973). While computing the thickness of dry layer (TDL), that permits the same vapour loss as the tillage-induced soil mulch at a given point of time, Jalota (1984) observed that TDL increased with time after tillage under low (4.6 $\pm$ 1.1 mm day^{-1}) evaporativity in silt loam, sandy loam and loamy sand soils. But under high evaporativity (15.1 $\pm$ 2.06 mm day^{-1}) it attained the maximum value of 1.2 cm and 1.1 cm after 28, and 23 days in sandy loam and loamy sand soils, respectively.

Drying Pattern Of Profile

In addition to cumulative evaporation the effects of soil

type, E_o and tillage variables are also reflected in the depth-distribution of water in the soil profile (Gill et al.1977; Gill, 1978 and Jalota, 1984). In the untilled soil, moisture profile was continuous with depth and water content gradient increased with coarseness of soil and evaporativity to compensate respectively for the decreased hydraulic conductivity and for meeting the evaporative flux dictated by the prevailing conditions. Above the interface the tilled soil dried quicker than the corresponding depth of the untilled soil because of the reasons already mentioned. But below the interface soil in the tilled columns dried slower than corresponding depth of untilled columns (Fig.4) because of the interface resistance to water flow (Hillel and Hadas, 1972). A relatively steeper moisture gradient develops at the interface of tilled and untilled layer, suggesting a break in capillarity (Benoit and Kirkham, 1963). The steepness of gradient at the interface depends upon the soil type, evaporativity, and clod size of tilled layer. Gradient becomes steeper with increase in evaporativity, fineness of soil texture and clod size of the tilled layer (Jalota, 1984).

Summary And Further Outlook

As is obvious from the foregoing discussions research on the effects of the factors affecting evaporation response to tillage has so far been largely empirical. Some efforts have been made to model evaporation fluxes through tilled layers simulated by surfactant treated soil. Assuming instant drying of tilled mass of soil, vapour fluxes were computed taking interface of tilled and untilled soil as the locus of phase change and involving evaporativity as such (Acharya & Prihar, 1969; Ludagoveskly, 1962); as vapour pressure at the surface (Hanks, 1958; Hanks & Woodruff, 1958); as heat on the soil surface available for evaporation (Hillel et al, 1975) or as equivalent water content of the atmosphere (Hammel et al, 1981). Evidently, these assumptions are far from realistic as the drying of tilled layer is dynamic and non-uniform; and depends upon the interaction of water transmission characteristics of the soil, properties of the tilled layer and evaporating agents viz. wind and/or radiation. Also the roughness of surface caused by tillage alters heat flux and surface area of soil in direct contact with atmosphere. Moreover, evaporation region is a diffused (multilocci) downward moving zone rather than a distinct plane. Therefore, for any realistic modelling of evaporation losses from tilled soil it would be necessary to have quantitative (may be semi-empirical) estimates of changes in bulk density, roughness index and area of soil in contact with atmosphere; and the effect of these changes on albedo, thermal and hydraulic conductivities of soil, transfer coefficient of vapour and potential evaporation. In addition, information on the downward movement of the locale of evaporation as influenced by soil, evaporativity and tillage variables would be required. Our increasing capabilities to predict soil temperature wave in tilled and untilled soils

and wind penetration as affected by clod size are likely to facilitate our effort on modelling evaporation response to tillage. In the meantime, empirical studies need to be continued which would help further understanding of the process, provide the needed coefficients for modelling and a data base for validation of predictive models as they become available.

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Table 1. Evaporation reduction(mm) in 20 days after tillage in silty clay loam in relation to time of tillage and tilth

Time of tillage	Days after wetting	Clod size		
		Coarse (45-50) mm	Fine (7-13 mm)	Very fine (2-7 mm)
First	5	9.3	7.3	3.2
Second	11	9.4	23.2	17.7
Third	18	-5.9	5.2	9.7
Fourth	42	-11.6	-0.9	4.1

Table 2. Clod sizes permitting least evaporation reported by different authors

Authors	Clod diameter (mm)
Ramachrlu (1957)	0.76
Hillel and Hadas (1972)	0.50
Hillel and Berliner (1974)	2.0 -5.0
Holmes et al. (1960)	2.5
Scooter and Raats (1964)	3.0 -6.0
Wadham (1944)	∠ 10 mm

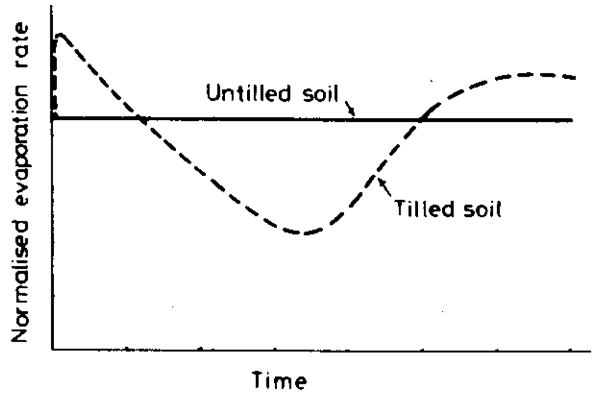

FIG1. EVAPORATION RATE FROM TILLED SOIL RELATIVE TO THAT FROM UNTILLED – A SCHEMATIC REPRESENTATION

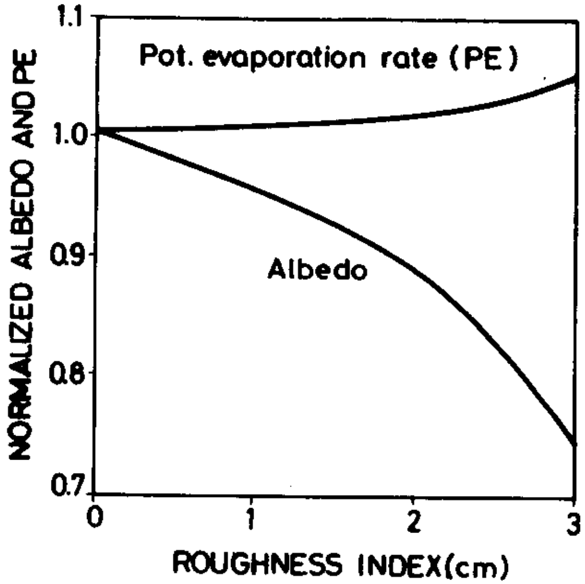

FIG. 2 ROUGHNESS EFFECTS ON ALBEDO AND POTENTIAL EVAPORATION (AFTER LINDEN, 1982)

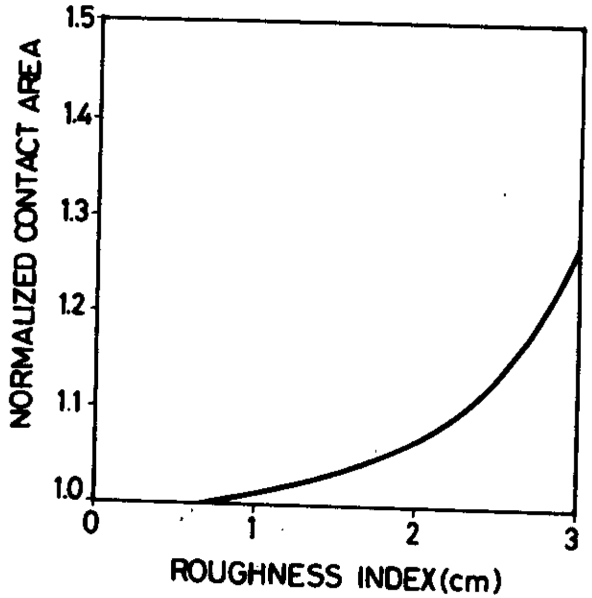

FIG. 3 SOIL - ATMOSPHERE CONTACT AREA PER UNIT HORIZONTAL AREA AS A FUNCTION OF ROUGHNESS INDEX (AFTER LINDEN, 1982)

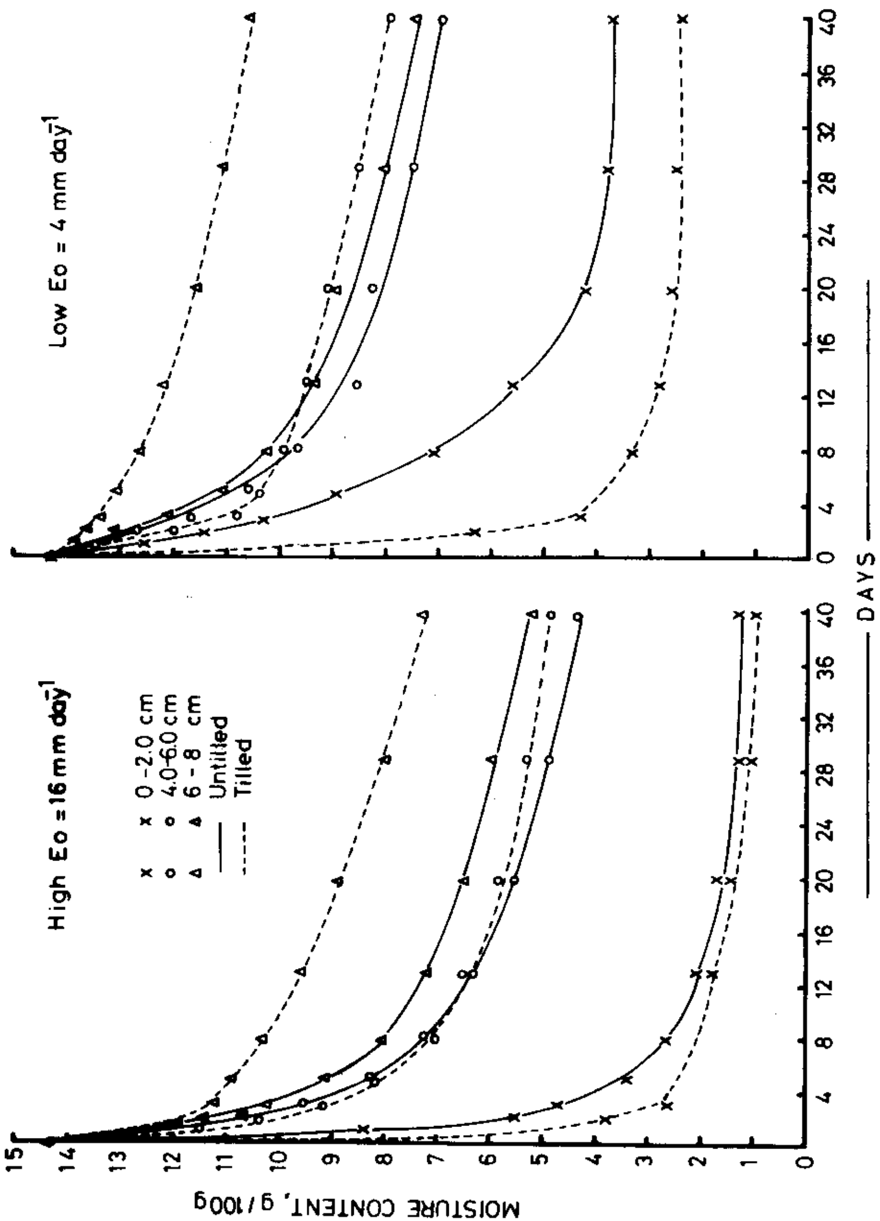

FIG.4 TIME COURSE OF DRYING OF DIFFERENT LAYERS IN TILLED (6cm deep) AND UNTILLED SOIL UNDER LOW AND HIGH EVAPORATIVITY

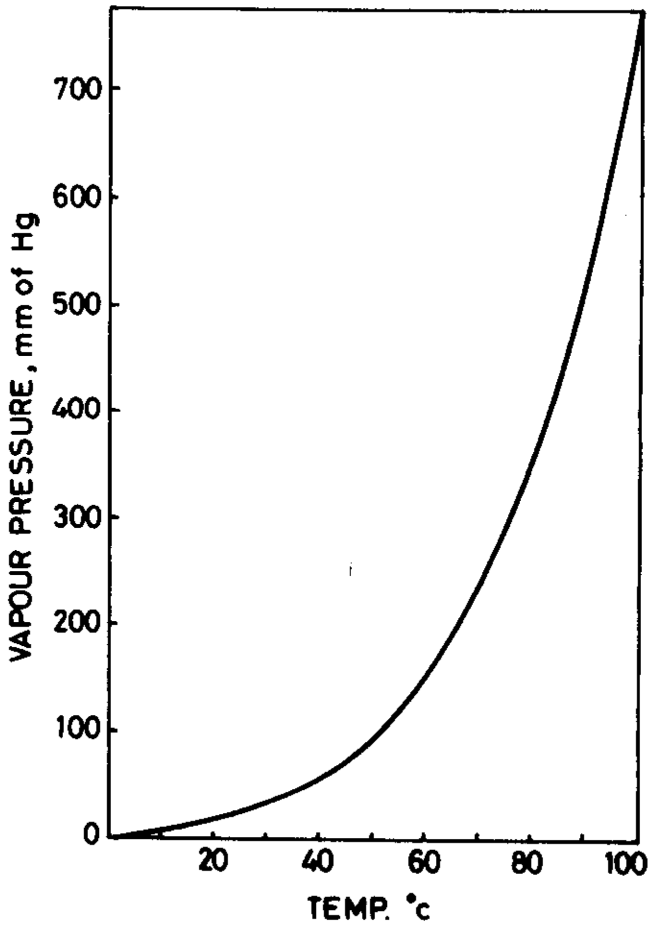

FIG.5 TEMPERATURE V/S SATURATION VAPOUR PRESSURE OF WATER

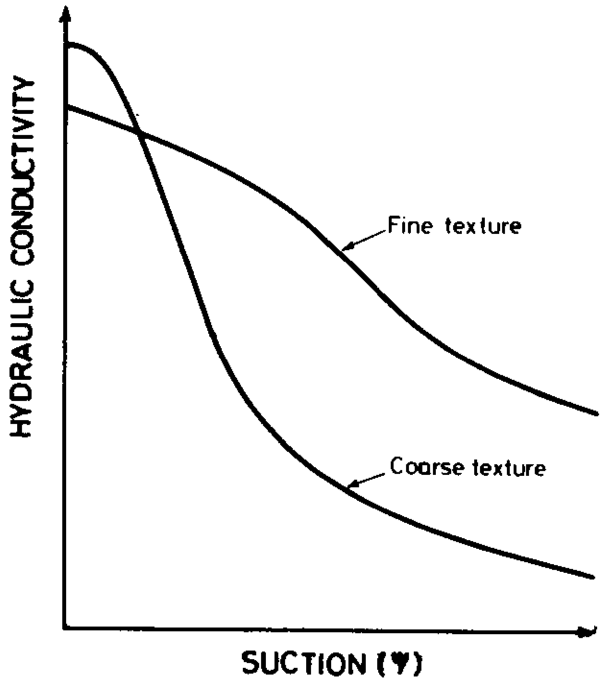

FIG.6 EFFECT OF SOIL ON K (Ψ) RELATION - SCHEMATIC DIAGRAM.

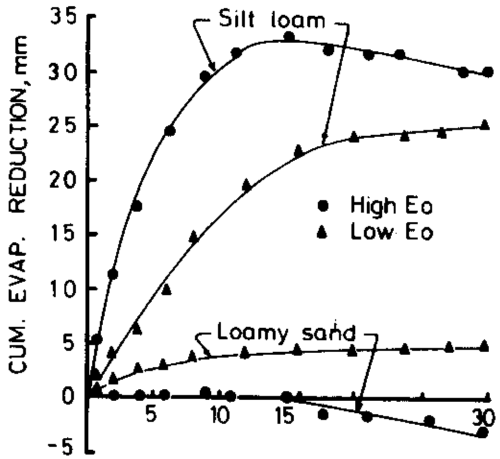

FIG.7 EVAPORATION REDUCTION BY TILLAGE AS A FUNCTION OF TIME IN SILT LOAM AND LOAMY SAND SOIL UNDER LOW (4.6 mm day^{-1}) AND HIGH (15.1 mm day^{-1}) EVAPORATIVITIES

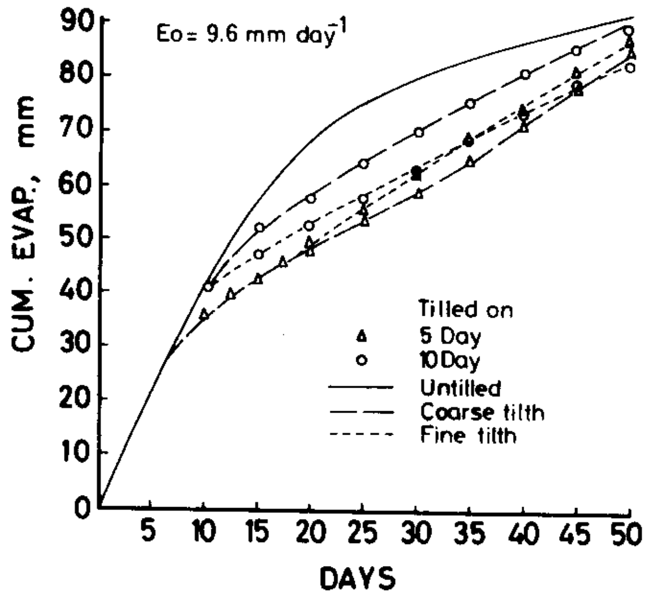

FIG.8 CUMULATIVE EVAPORATION AS AFFECTED BY TIME OF 5 cm DEEP TILLAGE AND CLOD SIZE