HYDROLOGIC PROPERTIES OF SEVERAL UPLAND FOREST HUMUS TYPES IN THE LAKE STATES REGION

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ABSTRACT

HYDROLOGIC PROPERTIES OF SEVERAL UPLAND
FOREST HUMUS TYPES IN THE LAKE
STATES REGION

by Wade Lowry Nutter

Forest humus has an important role in the evaporation and uptake of water in the forest soil profile. To better define this role for different humus types within a geographical region ten sites in Michigan were sampled that included a variety of soil and forest conditions and the three generally recognized morphological humus varients of mull, duff-mull, and mor.

Undisturbed cores of the humus-soil complex, 16.5-cm diameter and 25.4-cm deep, were excavated from the profile keeping the humus-mineral soil interface intact. Rates of evaporation in controlled environment chambers were determined by weight loss and water redistribution within the humus-soil profile during evaporation or infiltration was determined by the attenuation of a transmitted gamma radiation beam in 2.5-cm increments of depth. During two separate experiments each humus-soil core was subjected to a free water potential evaporation of 0.76 and 0.43 cm/day.

The humus classification used in this study is a system proposed for the Lake States Region based on the degree of biological activity and organic matter incorporated in the mineral soil. Based on the results of this study, the humus types were separated by their hydrologic properties into four groups, each independent of inter-site mineral soil variation. Listed by humus type they are 1) mulls without an F horizon, 2) mulls with an F horizon, 3) mors, including pseudo duff-mulls, and 4) duff-mulls. A continuous falling rate of evaporation was observed during a 50-day period with the humus horizons acting as a mulch to reduce the rate of evaporation to a rate lower than the maximum water transmitting properties of the humus-soil complex. The complexes of mull and duff-mull humus types held more water at 40-mb tension and the total evaporative loss was greater than in the mors. However, the mors lost by evaporation a greater fraction of the total initial water content than either the mulls or duff-mulls.

Water was observed to flow against the humus-soil water content gradient during evaporation in response to an assumed matric suction gradient. At 50 days the loss from the 4- to 5-cm thick organic horizons of mors and duff-mulls was similar to that lost from the first 5-cm of mineral soil. In the mulls the loss from the surface 5-cm was approximately twice that of the 5- to 10-cm depth. The F horizon ceased to lose water between 16 and 30 days but the H horizon continued to lose water at a decreasing rate for the entire period of evaporation. When the F horizon was removed the initial evaporation rate increased. Total loss at 53 days remained the same for mulls and duff-mulls. In contrast, there was little change in the rate of loss from mors.

During a simulated rainfall water advanced quickly through the soil as a wetting front maintaining the non-uniform shape of the initial water content profile except in the surface layer and at the end of the wetting front. The advance of the wetting front was similar in the mors and duff-mulls and also more rapid than in the mulls. During the simulated rainfall the F and H horizons resisted wetting and water moved rapidly through them into the underlying soil.

HYDROLOGIC PROPERTIES OF SEVERAL UPLAND FOREST HUMUS TYPES IN THE LAKE STATES REGION

By

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CHAPTER I

INTRODUCTION

A prominent part of the forest soil environment is the forest humus consisting of partially or completely decomposed organic detritus either overlying or intimately mixed with the mineral soil. It is a part of the forest which always changes, yet remains somewhat constant with time. Humus is continually supplied with new organic detritus throughout the year, the greatest input occurring at the beginning of the dormant season. Each addition is shortly transformed by chemical and biological decomposition to become a part of the uniform and distinct layers which show little change from year to year in an undisturbed state.

Forest ecologists and soil scientists have long recognized the importance of forest humus and the underlying mineral soil in the development of forest succession and soil horizons. Forest hydrologists have been concerned with the development of these horizons and their influence on the hydrologic properties of forest soils and the hydrologic cycle within a forest.

Humus serves a well recognized function of interest to both the forest manager and forest hydrologist; first, it protects the mineral soil surface from the impact of raindrops and the resulting erosion and reduction in infiltration capacity, and second, it stores and transmits water. However, humus is responsive to changes in the forest environment, whether this be catastrophic such as fire or less so in the form of livestock grazing or logging. A change in the hydrologic properties would be expected after such disturbances with reduced infiltration rates, greater surface runoff and erosion, and increased evaporation from the mineral soil.

Approximately one-half of Michigan is forested and in view of the projected needs of domestic and industrial water supply, forests will play an important role in the future water budget of the state. It has been estimated that approximately two-thirds of the precipitation that falls on Michigan each year is returned to the atmosphere via evaporation and transpiration. The manipulation of the vegetation through forest management practices and the resulting changes in humus (as well as other environmental factors) may well affect not only evaporation and transpiration but the water resources of the state as well. Because humus is an important part of the forest affecting the hydrologic cycle it is important to have quantitative information on the hydrologic properties of humus to guide the forest manager in his multiple-use objectives.

To understand the disposition of precipitation beneath the forest canopy, the effects of humus on evaporation, moisture retention, detention, and transmission into the mineral soil must be fully evaluated. Just how much change in the physical properties of the humus-soil complex can be tolerated before the increase in evaporation or the decrease in infiltration capacity become detrimental to the objectives of watershed management is not fully known. What is known is explored in detail by Trimble and Lull (1956) in an excellent review of the hydrologic influence of humus and its application in the northeastern United States. They stress that to date quantitative interpretation is lagging behind qualitative recognition.

Foresters and soil scientists have devised classification systems of forest humus based on the arrangement and physical properties of the humus horizons and mineral horizons with an admixture of organic matter. Although the quantity of literature on composition, classification and structure of humus is imposing, the information on hydrologic properties for differing humus types within any one region is lacking. No attempt has been reported in the literature on classification that includes both hydrologic and morphologic properties although these are closely linked. Hydrologic properties of humus horizons and mineral soil horizons dominated by organic matter are understandably governed by the physical properties of the organic matter, their principal component (Trimble and Lull, 1956).

The objective of this study is to determine differences in hydrologic properties of several upland forest humus types common to the Lake States Region and to relate these properties to evaporation loss and water content distribution in the humus and soil during evaporation, and to water content distribution during infiltration. A basis for including hydrologic properties in a humus classification system proposed by White (1965) for the Lake States Region is also presented.

This study was conducted in the laboratory under controlled conditions and provides information necessary for guiding later field investigations. Because this is one of the few studies involving different humus types within the same region and investigational methods are new they may have application in other regions.

CHAPTER II

STUDY OBJECTIVES

This study represents one of the first attempts to evaluate the hydrologic properties and characteristics, particularly as related to evaporation, of common humus types found within a specific region. Instrumentation was developed for the non-destructive measurement of volumetric water content such that hydrologic properties of forest humus could be studied in relation to the underlying mineral soil, an important factor that has limited studies on undisturbed samples. Most past studies were conducted under conditions where the mineral soil-humus interface was disturbed and the humus studied apart from the underlying soil. Because liquid water in unsaturated soil will not move across an air-water interface but must move as a thin, continuous film from particle to particle it is important to keep intact all humus and mineral soil horizons so continuity between the horizons is not disrupted. A field sampling procedure was developed whereby a core of the humus-soil complex could be removed from the soil profile keeping all horizons intact.

The primary objectives of this study were:

1. Determine feasibility of combining hydrologic properties with other physical properties of humus

used in a classification system proposed by White (1965) for the Lake State Region.

2. Determine the effects of humus type on rate of evaporation and total evaporation from the humus-soil complex.
3. Study the redistribution of water that occurs during evaporation in the humus and soil horizons.
4. Study the effects of F horizon removal on evaporation.
5. Study the distribution of water with time in the humus and soil horizons during a simulated rainfall.

CHAPTER III

LITERATURE REVIEW

Humus classification

The classification of forest humus has traditionally been one of confusion because of the complexity and regional variability caused by the interactions of climate, topography, species arrangement and succession, soil parent material, faunal activity, and of particular importance, the past disturbance history.

The basic classification guide in general use today is that of Hoover and Lunt (1952), however it is most suited to the classification of humus types on the glaciated soils of the northeastern United States. A simplified key with particular application to watershed management but retaining the basics of the Hoover and Lunt key is that of Trimble and Lull (1956). These classification systems are based on the arrangement and physical properties of the three distinct humus layers as recognized by Hoover and Lunt (1952). They are:

F - Fermentation layer consisting of partially decomposed organic matter with origin of the material still recognizable.

H - Humus layer consisting of well-decomposed, generally black, amorphous organic matter where the origin of the material is no longer recognizable.

A_1- Surface mineral horizon typified by the accumulation of humified organic matter mixed with mineral soil.

An additional organic layer, the L or litter layer, is sometimes present in the humus profile as freshly fallen leaf litter but due to its transitory nature is not considered in the classification system of Hoover and Lunt (1952). Trimble and Lull (1956) suggest that litter may have important effects on hydrologic properties during certain times of the year and therefore should be considered in hydrologic studies when present in the profile.

Forest humus is broadly classified as either mor or mull, based on the degree of incorporation of organic matter in the mineral soil. A mor humus type is one in which there is an abrupt change from the H layer to the underlying mineral soil; no organic matter is present in the mineral soil (A_2 horizon). In a mull humus the H layer is absent and there is an A_1 horizon with a strong admixture of organic matter. An intermediate humus type, with features of both mor and mull, has been termed a duff-mull (Hoover and Lunt, 1952). Each type includes several subtypes according to thickness, structure, and amount of organic matter.

The Hoover and Lunt key is based on morphologic features and its application has proven contradictory in the Lake States Region as well as other regions of the United States (White, 1965). These contradictions are due in part to the state of forest humus terminology which Wilde (1966) represents as confused and chaotic and suggests a new system of terminology placing emphasis on readily determinable morphologic features of forest humus and their position relative to the mineral soil.

As expressed by White (1965) the fundamental problem in using a humus key in any region is the recognition and interpretation of decomposition processes and the nature and degree of biological activity which is taking place in the organic matter and upper mineral horizons with incorporated organic matter. Wilde (1958) contends that a morphological classification should be supplemented by the determination of chemical and microbiological properties.

White's (1965) proposed classification refines that of Hoover and Lunt (1952) to be applicable within the Lake States Region. It is based primarily on the degree of biological incorporation within the mineral soil as distinguished from incorporation as illuvial colloidal organic matter. The distinguishing characteristics of the three common humus types as outlined by White (1965) are as follows:

Mor - presence of an F and well-defined H layer at an abrupt boundary with the surface mineral horizon which may contain infiltrated organic matter but shows no evidence of incorporation by faunal activity.

Duff-mull - shows some evidence of faunal activity; both an F and H layer are present as well as a biologically incorporated mineral-organic A_1 horizon as distinguished from illuvial colloidal staining.

Mull - indicates strong evidence of incorporation of organic matter in the mineral horizon by biological activity with no H layer present; a thin F layer may be present.

The definition of the mull type humus corresponds to that of Hoover and Lunt (1952). A transition humus type common in the Lake States Region is also described by White (1965). Termed a mor in transition to a duff-mull, it shows some biological incorporation of organic matter in the mineral horizons but is not as well developed as a true duff-mull. A pseudo duff-mull, so called because of an apparent high organic matter content in the mineral horizons, is actually a mor because the organic matter is not biologically incorporated but rather stained by illuvial colloidal organic matter. These two variants, mor in transition and pseudo-duff mull, are usually associated with a recent change in forest type as a result of drastic disturbance, i.e., fire or logging.

Considerable variation exists in the literature on hydrologic studies in the use of the terms litter, forest floor, and humus. Rarely is an actual description of the organic layers presented and the reader is confused as to the actual humus type and what organic and mineral horizons are present. This study will incorporate the terminology used by Trimble and Lull (1956): litter indicates current annual deposits only; humus designates the presence of an F and H horizon in mors or an F and A_1 horizon in mulls; and forest floor indicates the inclusion of all organic horizons (and A_1 in mulls) not excluding litter when present.

Hydrologic properties of humus

As summarized by Metz (1958), the hydrologic importance of forest humus has long been recognized:

> Litter (forest humus) does function effectively in reducing raindrop impact and subsequent erosion, in slowing overland flow and allowing more time for infiltration of water, in maintaining surface soil in condition for rapid infiltration of water, and in reducing erosion by holding the soil in place.

To this may be added the ability of humus to store water and to affect evaporation (Trimble and Lull, 1956).

Humus has a high absorptive capacity for water but its chief function in controlling surface runoff is building and/or maintaining a macrostructure of the mineral soil capable of high percolation rates (Lowdermilk, 1930). Similarly, Trimble and Lull (1956) stress that humus also promotes faunal activity which tends to increase aggregation and porosity. Being highly porous, humus promotes rapid downward movement of water to the mineral soil and at the same time protects the soil from the destructive forces of raindrop impact.

Perhaps more importantly, humus forms an obstruction and resistance to overland flow and thus holds water for infiltration to take place over a longer period of time (Trimble and Lull, 1956).

Disturbances such as fire or logging can effectively reduce infiltration rates by exposing the mineral soil surface. On infiltration plots in upland hardwood stands of the Ozarks, Arend (1941) reported an average forest floor infiltration rate of 2.12 inches per hour as compared to 1.32 inches per hour for similar sites that had been annually burned for the previous 5 to 6 years. Mechanical removal of the L and F layers resulted in an 18 per cent reduction in the infiltration rate as compared to a 38 per cent reduction on burned plots. Arend (1941) explains the marked decrease due to burning to be the result of physical changes in the surface horizon in addition to a probable reduction in microbiological activity.

Trimble, Hale, and Potter (1951) compared percolation rates through small cores of individual humus and soil horizons collected in northeastern hardwood forests. They reported percolation rates of mors to be roughly twice that of mulls. Except in one instance there was no significant difference in percolation rates between subtypes within mor or mull classifications included in the study.

In a lysimeter study in California, Rowe (1955) determined the effects of ponderosa pine forest floor depth on infiltration. The lysimeters were filled with soil and then covered with forest floor material collected in natural stands. Increases in forest floor depth from 1/4 to 1-1/4-inch had little effect on reducing surface runoff and increasing percolation rates through the soil. Thus, a 1/4-inch forest floor depth was sufficient to break raindrop impact and maintain soil structure for high percolation rates.

A hydrologic property of forest humus that has received wide attention in the literature is its water storage capacity. Trimble and Lull (1956) contend that an increase in water storage capacity has several effects, most importantly that of flood control where an increased retention provides more storage for large storms and an increased detention storage slows movement of water to the stream channels. They stress that any factors affecting humus type and depth will directly affect the water storage capacities.

Another factor that has received some attention is the rate of water loss from storage after a storm. Information of this type, apart from hydrologic significance, could be useful in determining fire danger ratings (Blow, 1955). Helvey (1963), in a study conducted in the mountains of southwestern North Carolina, reported evaporation from the humus to be virtually ended 12 days after the last storm. The amount of water remaining in the organic layers was determined by covering a plot with a reflector to inhibit evaporation and by assuming that after 24 hours all downward movement had ceased and water held in the humus was available for evaporation.

Blow (1955), in a similar study in hardwood forests of eastern Tennessee, reported relatively stable water contents of the forest floor (mor humus) 14 to 16 days after the last storm with field capacity reached in approximately 2 days. Rowe (1955) used samples of ponderosa pine forest floor placed in pans separated from mineral soil and determined rates of evaporation assuming the difference between precipitation and free drainage to be the water available for evaporation.

In these three studies, and others of similar nature, the authors have assumed that when field capacity is reached after short periods of free drainage all further downward movement ceases. The water detained in the humus is assumed available for evaporation. Using the procedures described above, Helvey (1960) determined that 3 per cent of the total annual precipitation was lost through evaporation from the forest floor. Blow (1955) reported 2 per cent, and Rowe (1955) 3 to over 5 per cent from forest floors ranging from 1.0- to 3.6-inches in depth.

The presence of a forest floor, although a source of water loss as discussed, can also reduce losses in evaporation from the mineral soil. According to Kittredge (1948), evaporation from soil underlying a forest floor is 10 to 80 per cent less than that from a bare soil. Rowe (1955) observes that although evaporation from the forest floor can reach important amounts, this loss is more than compensated for by the reduction in evaporation loss from the underlying mineral soil.

A mulch, as defined by Hanks and Woodruff (1958), is a medium which transports water only in the vapor phase. Although humus may not be considered a mulch in the agricultural sense, it may serve the same function. One difficulty in comparing humus to a mulch arises in specifying the depths of humus as compared to mulch; mor humus depth cannot be compared to mull humus depth because of the mineral soil incorporated in the mull (Trimble and Lull, 1956). However, if forest humus dries quickly and its moisture content remains constant after approximately 12 to 16 days (Helvey, 1963; Blow, 1955), then it may act as a diffusion barrier and be a mulch as defined by Hanks and Woodruff (1958).

Hide (1954) presents an excellent review of investigations prior to 1954 concerned with evaporation from soil. He lists two important variables which influence the rate of soil water evaporation: 1) the vapor pressure difference between the layer from which water is evaporating (zone of evaporation) and the turbulent atmosphere, and 2) the resistance to vapor flow of the intervening layer. As long as the soil surface remains moist the principal resistance to vapor movement is caused by the thin layer of non-turbulent air adjacent to the surface. As soon as the soil surface becomes dry the resistance to vapor movement within the soil rapidly increases as the vapor moves through a thickening layer of dry soil.

The moisture flux from a soil by evaporation can be either steady-state or nonsteady-state under constant evaporative conditions. Steady-state evaporation generally occurs when the water table is near the surface. Lemon (1956), reviewing the work of the Russian investigator Kolasew, recognizes three stages of nonsteady-state evaporation. The first is a stage of rapid and steady loss dependent upon net effects of water transmission properties of the soil and atmospheric evaporative potential as determined by wind speed, temperature, relative humidity, and radiant energy. This initial stage ends when a dry diffusion barrier develops at the soil surface. For a saturated soil the evaporation rate during the first stage will equal the potential evaporation from a free water surface. The second stage is one of continual decline in the rate of loss as the water content is depleted. The atmospheric conditions are no longer important and the evaporation rate depends solely on the water content distribution and the water transmitting properties of the soil (W. R. Gardner and Hillel, 1962). The third and final stage occurs at low water contents and is one of extremely slow water movement, most likely vapor diffusion.

The effects of a mulch in reducing initial evaporative loss from a bare soil were reported by Russel (1939). He concluded that protection of the wet soil surface by a straw mulch from direct solar radiation was more important than the obstruction the mulch provided against vapor diffusion. Mulches 3/4-inch thick were almost as effective in reducing evaporation as depths up to 6 inches. Studying the effects of wind on rates of evaporation from laboratory soil columns, Hanks and Woodruff (1958) reported that 1/4-inch thicknesses of soil, gravel, or straw mulches placed on wet soil were as effective as 1-1/2-inch thicknesses in reducing evaporation. Evaporation increased with an increase in wind speed which indicated there was an increase in turbulent mixing of air within the mulch itself. Thus, vapor transfer from the soil through the mulch was not a true diffusion process. The greatest effect of the internal turbulent mixing was noted in the more porous gravel and straw mulches.

Studying the effects of a stubble residue on evaporation, Army, Wiese, and Hanks (1961) found a reduction only during the first stage of drying. This was attributed in part to a reduction in soil heating from radiant energy. Another reason was the increase in thickness of the relatively non-turbulent air layer above the soil, resulting in decreased vapor transport from the soil surface. After the soil surface dried, the effect of a mulch became less important and evaporation was controlled by the water transmitting properties of the soil.

Benoit and Kirkham (1963) in a laboratory study found the rate of evaporation to increase with increased air movement and radiation for soil cores covered with 2 inches of either a soil dust, gravel or ground corn cob mulch. Although the samples were near saturation and the mulches were added so there would not be a capillary break at the soil surface, a constant rate of drying was observed that was far lower than the evaporative potential. Although the experiment continued for 70 days a falling rate period of drying was not observed. Flow through the dry surface was by vapor transfer at a rate dependent upon the porosity of the layer. The water content distribution decreased uniformly with depth during evaporation from both mulched and unmulched soil columns.

CHAPTER IV

DESCRIPTION OF SAMPLING SITES

Of the ten sites chosen for sampling in this study, seven were included in White's (1965) investigations to develop a forest humus classification key for the Lake States Region. Each humus type was classified by White after field examination and laboratory determinations of organic matter (loss on ignition), total nitrogen, and pH.

Nine sites included in this study on hydrologic properties are in the Spodosol (Podzol) soil region of the upper (northern) and northern part of the lower (southern) peninsulas of Michigan. All nine sites have a history of severe disturbance within the last 50 to 70 years. The remaining site (sample M) was selected in a relatively undisturbed forest in Michigan's southern part of the lower (southern) peninsula on a soil of the Alfisol (Gray-Brown Podzolic) group. The samples were collected in September 1966 before current year leaves began to fall.

Soil and humus type, location and description of each site are presented in Table 1.

At the end of the study humus and mineral A horizon thicknesses were measured on four cores from each sampling

Table 1. Humus, soil and site descriptions; and location and site history for the ten sampling sites in Michigan.

Humus Type	Site	Soil Type[1]	Forest Type	Avg. DBH[2]
				inches
Mull	A	Munising Sandy Loam	N. Hwd.	15+
Mor	B	Kalkaska Sand	N. Hwd.	5.0-8.9
Mor	C	Blue Lake Sand	N. Hwd.	5.0-8.9
Pseudo Duff-Mull (Mor)	D	Rubicon Sand	Jack pine	5.0-8.9
Mull	E	Munising Sandy Loam	N. Hwd.	15+
Duff-Mull	F	Deerton Sand	Sugar maple	5.0-8.9
Duff-Mull	G	Graycalm Sand	Aspen, Oak	9.0
Mull	H	Blue Lake Sand	N. Hwd.	7.5
Mull	K	Mancelona Sand	Sugar maple, Elm	9.4
Mull	M	Hillsdale Sandy Loam	N. Hwd.	8.0

[1]All soils are well drained.

[2]Tree diameter at 4.5 feet above ground level.

Crown Cover	Michigan Location and County	Stand History
per cent		
>70	Sec. 35 T46W, R23W Marquette	Selective cutting of pines and hwds. 1850-1900
40-70	Sec. 31 T46N, R20W Alger	Clear cut. 1900
>70	Sec. 18 T46N, R20W Alger	Clear cut. 1900
40-70	Sec. 32 T47N, R20W Alger	Clear cut and burned. 1850-1900
>70	SW 1/4, Sec. 35 T46N, R23W Marquette	Selective cutting of pines and hwds. 1850-1900
>70	NE 1/4, Sec. 15 T46N, R23W Marquette	Clear cut. 1900
>70	NE 1/4, Sec. 16 T21N, R12W Wexford	Clear cut and burned, present stand established 1918.
>70	NE 1/4, Sec. 15 T21N, R12W Wexford	Clear cut. 1900
>70	NE 1/4, Sec. 31 T22N, R12W Wexford	Clear cut. 1900
>70	SE 1/4, Sec. 30 T4N, R1W Ingham	Relatively undisturbed since 1850.

site. Samples from site M were destroyed when the steel core was removed and horizon measurements were not possible. Each horizon contained in the 25.4-cm deep cores was measured at four equidistant points around the core's circumference. In many cases where there was a wide transition zone between F and H and between H and A horizons the actual point of measurement is arbitrary. Average horizon thicknesses for each core are presented in Table 2.

After horizon thicknesses were measured each humus-soil core was photographed. A photograph of a 25-cm core from each site, except site M, is presented in Figures 1 through 5. Figure 1a, core B-2, is an example of a particularly well-developed root mor with thick F and H horizons and an abrupt boundary between the H and A_2 horizons. This sample is quite different from the other site B samples and is presented in this study as an example of water loss from thick organic horizons.

The amount of organic matter in the mineral horizon, whether it be illuvial or biologically incorporated, is an important factor in the humus classification system proposed by White (1965)(see page 9). As previously discussed, organic matter content is also an important factor in determining hydrologic properties of the humus-soil complex. With this in mind, organic matter contents of each horizon, expressed as per cent loss on ignition,[1] were determined

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[1]Samples were ground to pass through a 20-mesh seive. Organic matter was ignited from a 10- to 20-gram sample at 700°C for 5 hours. Per cent loss on ignition is a weight loss determination.

Table 2. Average humus and mineral soil horizon thicknesses for each core from the nine northern-lower and upper peninsula sites in Michigan.

Humus Type	Site-Core Designation	F	H	A_{11}	A_{12}	A_{21}	A_{22}
				centimeters			
Mull	A-2	T[1]		12.4	R[2]		
	A-3	T		10.0	R		
	A-4	T		10.2	R		
	A-5	T		8.8	R		
	Avg.	T		10.3			
Mor	B-2	3.9	5.8			0.8	R
	B-3	1.8	1.4			4.4	R
	B-4	2.5	3.4			2.2	R
	B-5	1.5	2.4			5.5	R
	Avg.	2.1	3.3			3.2	
Mor	C-2	3.2	2.0			0.8	9.6
	C-3	1.6	1.1			3.1	8.6
	C-4	1.9	1.3			1.5	10.7
	C-5	2.7	0.7			5.5	R
	Avg.	2.4	1.3			2.7	>9.6
Pseudo Duff-Mull (Mor)	D-2	1.4	1.0			4.6	R
	D-3	1.5	2.4			6.8	R
	D-4	1.3	1.7			6.7	8.6
	D-5	1.5	4.0			3.0	8.0
	Avg.	1.4	2.3			5.3	>8.3
Mull	E-2	0.9		2.5	7.6		
	E-3	1.5		1.3	3.3		
	E-4	0.5		5.1	6.2		
	E-5	1.3		4.2	9.0		
	Avg.	1.0		3.3	6.6		

Table 2 (Continued)

Humus Type	Site Core Designation	F	H	A_{11}	A_{12}	A_{21}	A_{22}
		Horizon					
		centimeters					
Duff-Mull	F-2	2.1	2.7	5.7	11.1		
	F-3	3.0	2.2	6.6	6.2		
	F-4	3.1	1.2	3.4	5.3		
	F-5	2.9	3.2	2.7	9.0		
	Avg.	2.8	2.3	3.9	7.9		
Duff-Mull	G-2	1.0	3.0	4.2	7.0		
	G-3	2.1		3.3	5.8		
	G-4	0.8		5.7	7.9		
	G-5	1.1	2.2	3.8	5.6		
	Avg.	1.3	1.3	4.3	6.6		
Mull	H-2	0.4		5.9	5.4		
	H-3	1.0		4.8	9.7		
	H-4	1.6		5.5	6.6		
	H-5	0.3		6.1	12.3		
	Avg.	0.8		5.6	8.5		
Mull	K-2	0.5		10.8	7.8		
	K-3	0.8		7.7	6.6		
	K-4	0.7		8.0	8.3		
	K-5	0.6		10.4	6.0		
	Avg.	0.7		9.2	7.2		

[1]Trace

[2]This horizon extends below the sample depth (25.4-cm)

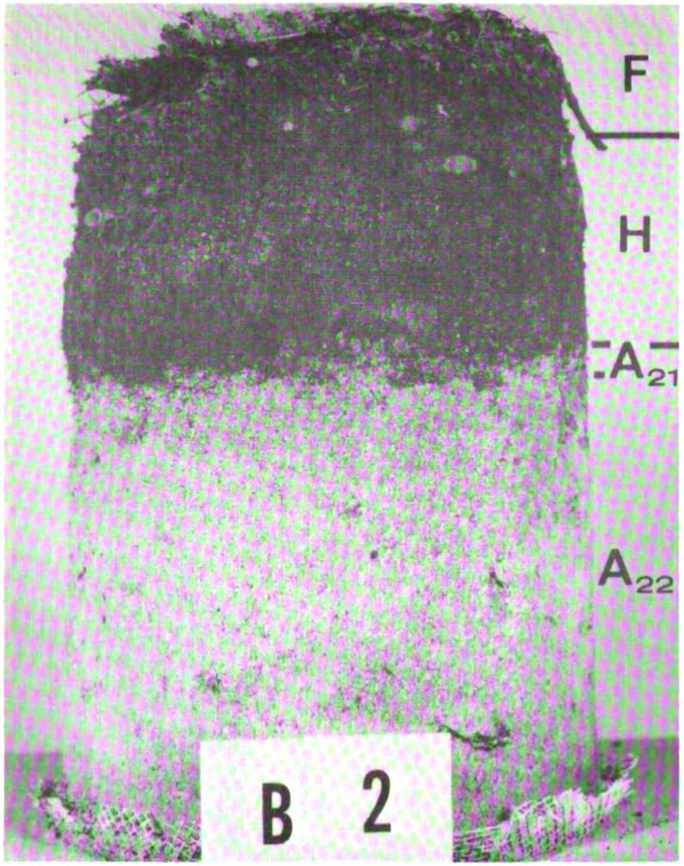

FIGURE 1a. Well-developed root mor humus developed on Kalkaska sand under a mature northern hardwood forest, site B, Alger County, Michigan

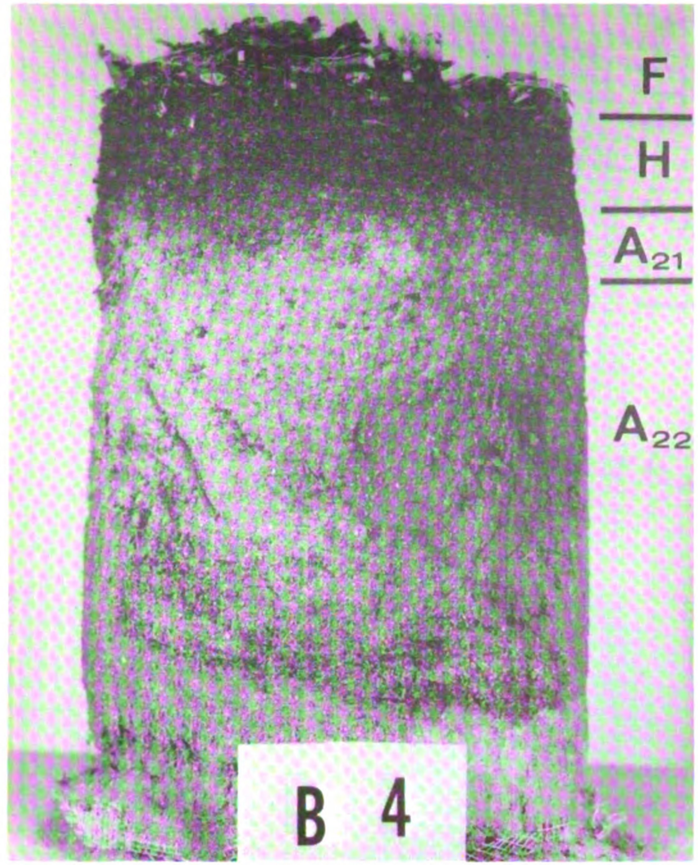

FIGURE 1b. Mor humus developed on Kalkaska sand under a mature northern hardwood forest, site B, Alger County, Michigan.

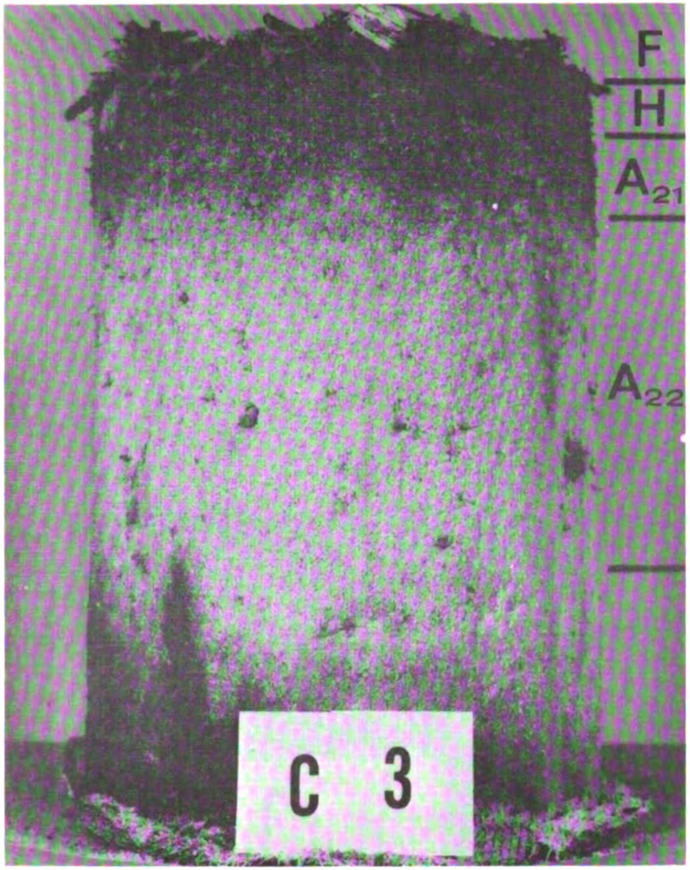

FIGURE 2a. Mor humus developed on Blue Lake sand under a second growth northern hardwood forest, site C, Alger County, Michigan.

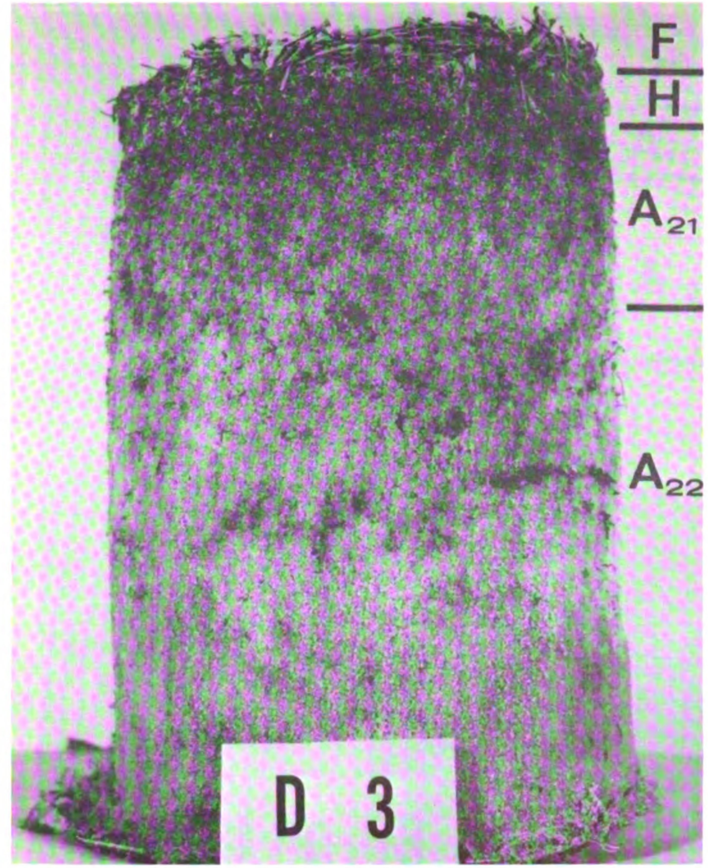

FIGURE 2b. Pseudo duff-mull (mor) humus developed on Rubicon sand under a jack pine forest, site D, Alger County, Michigan.

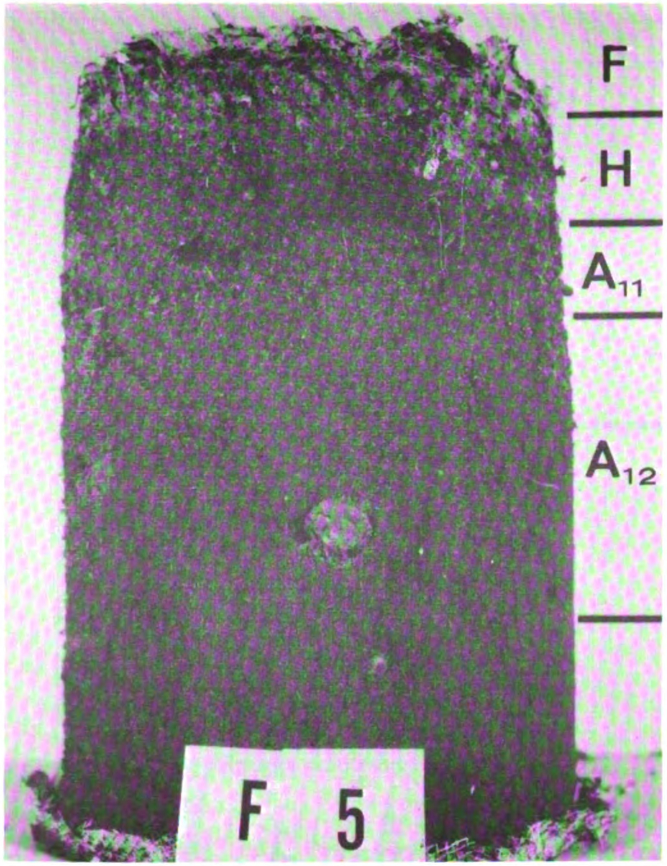

FIGURE 3a. Duff-mull humus developed on Deerton sand under a second growth sugar maple forest, site F, Marquette County, Michigan.

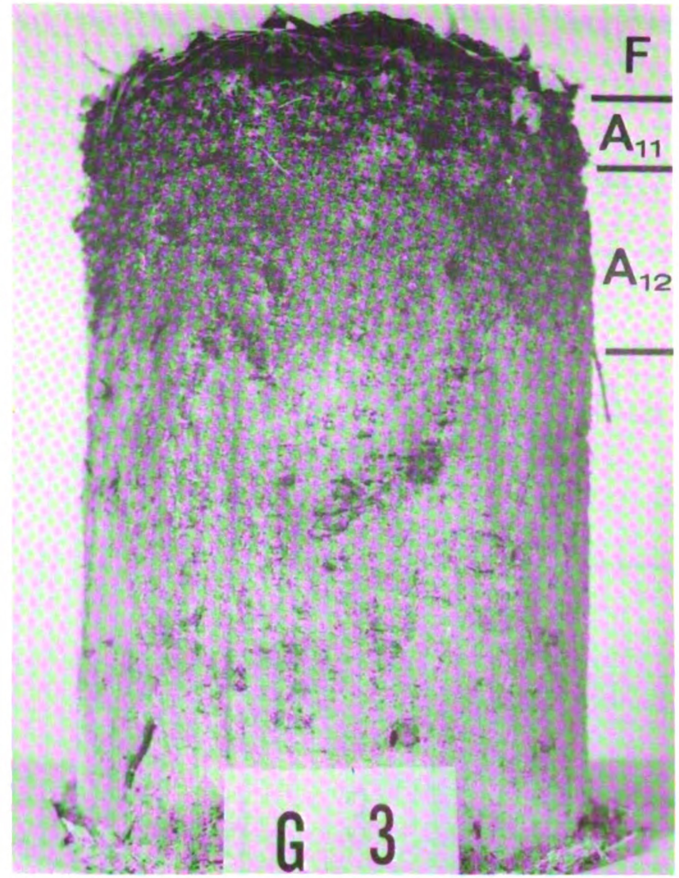

FIGURE 3b. Duff-mull humus developed on Graycalm sand under a second growth aspen and oak forest, site G, Wexford County, Michigan.

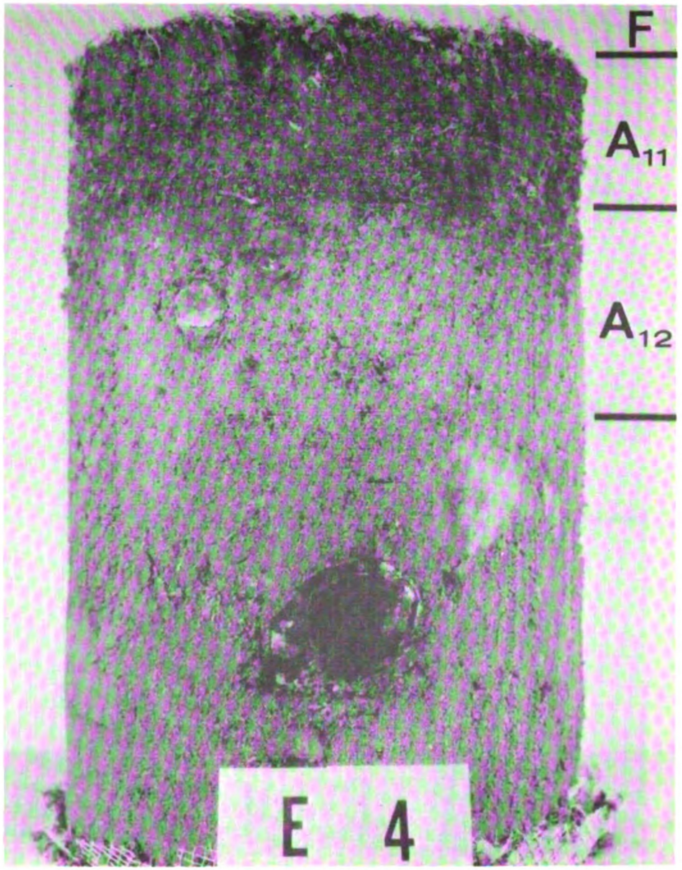

FIGURE 4a. Mull humus developed on Munising sandy loam under an old growth northern hardwood forest, site E, Marquette County, Michigan. Note the hollow root cavity in the lower mineral soil horizon, only the epidermis and part of the cortex remains.

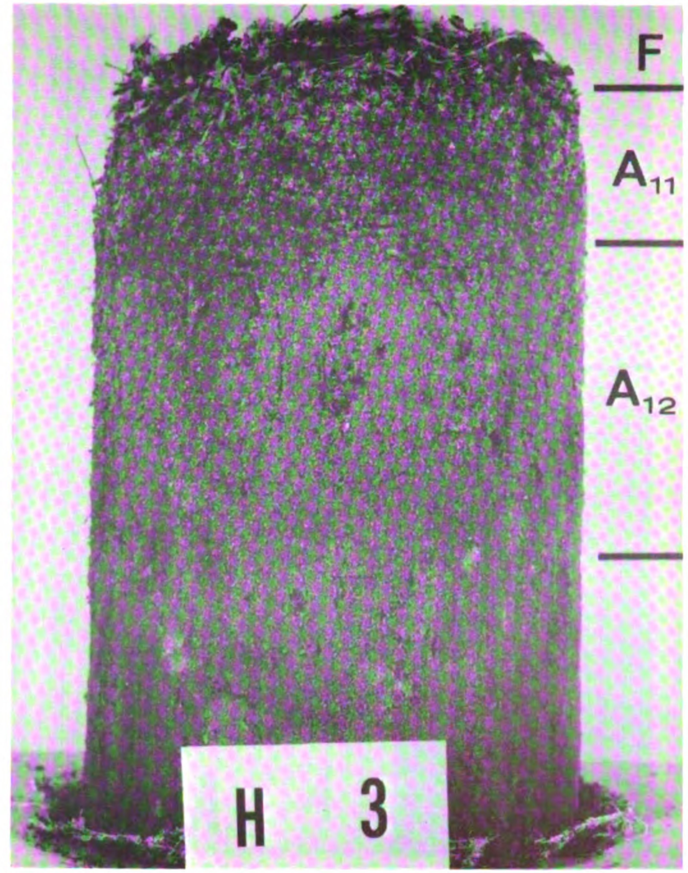

FIGURE 4b. Mull humus developed on Blue Lake sand under a second growth northern hardwood forest, site H, Wexford County, Michigan.

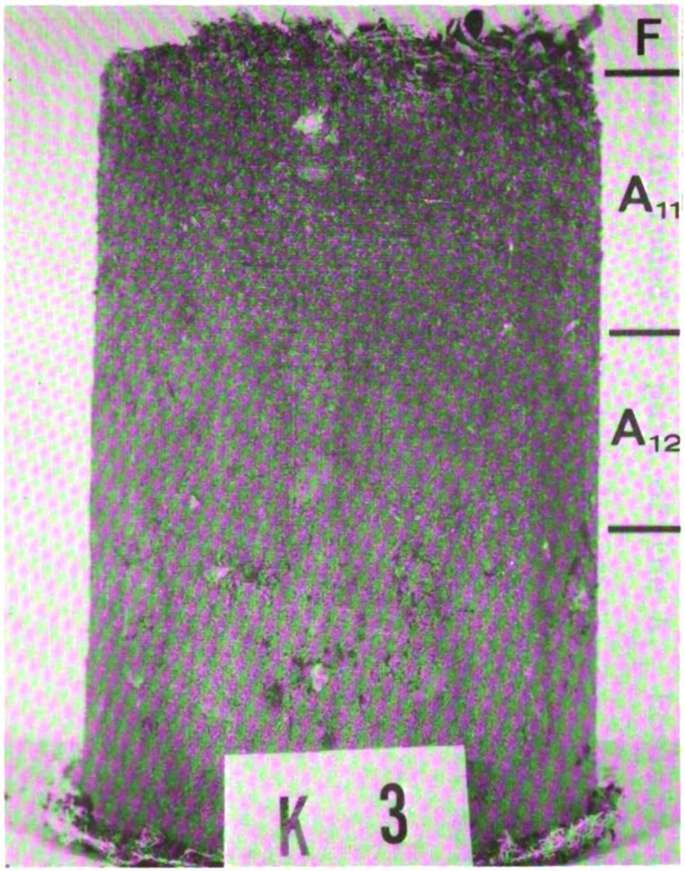

FIGURE 5a. Mull humus developed on Mancelona sand under a second growth sugar maple and elm forest, site K, Wexford County, Michigan.

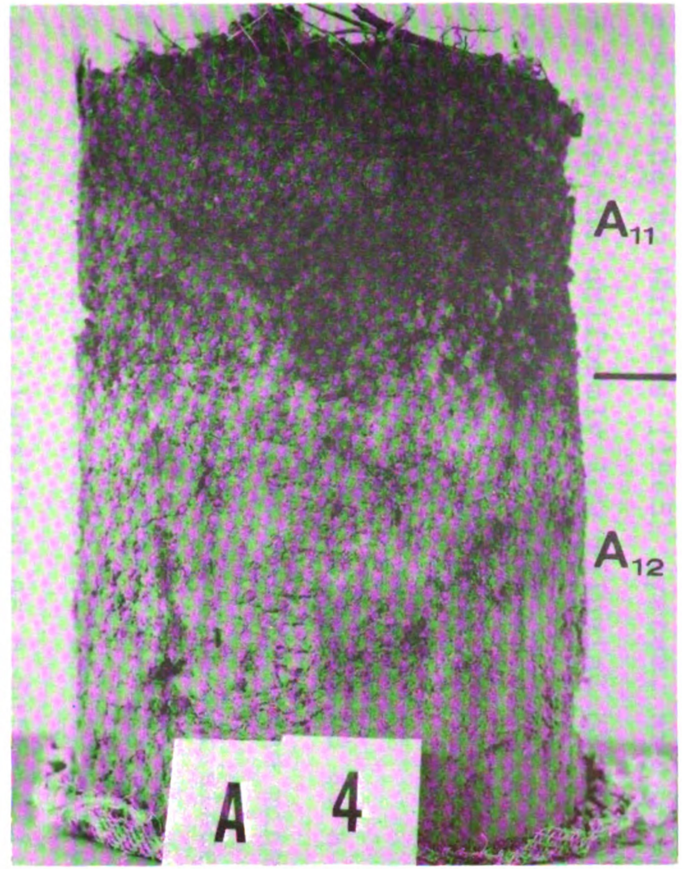

FIGURE 5b. Mull humus developed on Munising sandy loam under an old growth northern hardwood forest, site A, Marquette County, Michigan.

for one randomly selected sample from each site. These data, used to verify field and laboratory classifications according to White's (1965) system, are presented in Table 3. Note the uniformly low illuvial organic matter contents of the mor mineral horizons as compared with the greater amount of biologically incorporated organic matter in the mull mineral horizons.

Site D (Figure 2b), classified as a pseudo duff-mull because of organic staining in the mineral horizons, should be properly classified as a mor since the organic matter content of the mineral horizons is low (Table 3) and no biological incorporation is visibly evident in the horizons. Site G was classified as a duff-mull, however the H horizon in two of the cores was broken up and mixed with mineral matter. Because the H horizon was not continuous it was included as part of the A_{11} horizon (Table 2). One of these cores, G-3 (Figure 3b), was selected for organic matter determination and the intermixing of pieces of H horizon is reflected in the high organic matter content of the A_{11} horizon (Table 3).

Table 3. Per cent organic matter in each horizon of a randomly selected humus-soil core from each sampling site.

Humus Type	Site-Core	Per cent Organic Matter[1]					
		Horizon					
		F	H	A_{11}	A_{12}	A_{21}	A_{22}
Mor	B-2	67.3	38.0			2.9	0.6
Mor	B-4	79.2	29.6			4.7	1.7
Mor	C-5	77.6	36.8			4.9	0.7
Pseudo Duff-Mull (Mor)	D-3	63.4	36.0			4.6	0.7
Duff-Mull	F-3	78.3	25.3	7.0	3.8		
Duff-Mull	G-3	79.4		25.7[2]	9.2		
Mull	E-2	56.2		9.6	3.3		
Mull	H-3	78.6		15.8	2.4		
Mull	K-5	71.7		16.8	6.1		
Mull	A-4			16.1	0.7		
Mull	M-3			7.4	3.2		

[1]Per cent loss on ignition

[2]See text for explanation

CHAPTER V

METHODS OF INVESTIGATION

Sampling procedure

To obtain an undisturbed sample of the humus and mineral soil a sampler was designed to cut a core 16.51-cm (6.5-inch) inside diameter by 25.4-cm (10-inch) deep. The sampler is similar to the conventional Uhland soil sampler but cuts a core twice the diameter and three times as deep. This type of sampler permits removal of a soil core that is cut with a leading edge designed to minimize compaction and disturbance. A large diameter reduces the effects of water transmission at the soil-core wall boundary by increasing the ratio of core surface area to circumference. The larger sample also serves to reduce the variability common in humus.

The core was constructed from 22-gauge (0.79 mm) galvanized steel with a soldered overlap seam on the inside. Boiler tubing with a 0.32-cm (0.125-inch) wall and 16.83-cm (6.625-inch) inside diameter formed the sampler. A beveled cutting edge was extended 2.54-cm (1.0-inch) below the core to facilitate cutting a smooth face on the bottom of the core (Figure 6).

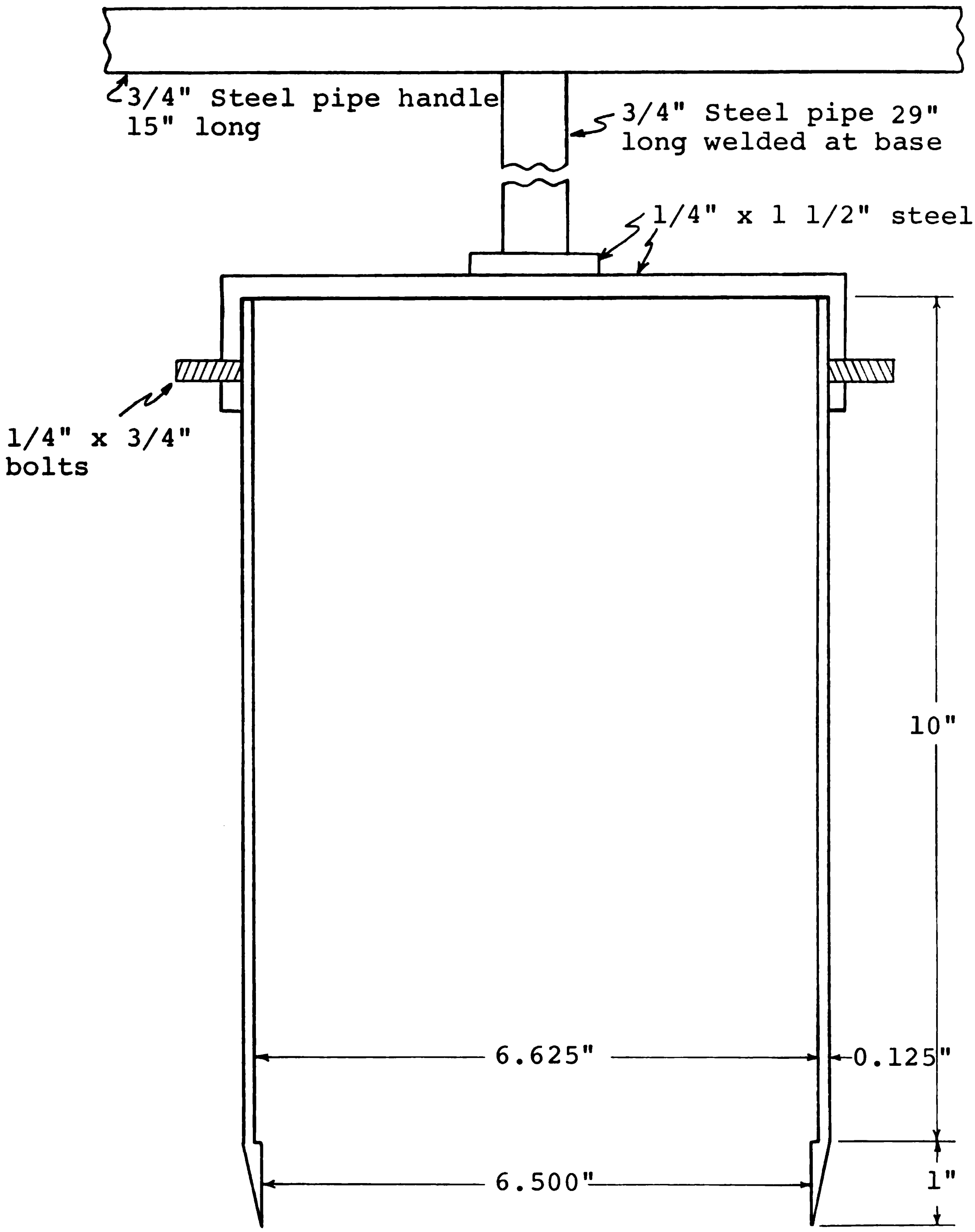

Figure 6. Cross-section of the humus-soil sampler and handle assembly.

Upon positioning the sampler with core in place on the sampling site the F and H horizons were cut with a sharp long-bladed knife using the sampler's cutting edge as a guide. The sampling assembly was then pushed into the soil paying particular attention to keep it vertical. After digging the sampler out a square piece of plywood was placed on top to hold the surface humus layer in place and the entire sampler was carefully turned upside down. The sampler was slipped from the core and the bottom face of the soil dressed with a large knife and then covered with several layers of cheesecloth and a 1/8-inch wire mesh screen. The screen was held in place by a perforated steel band tightened by a 1/4-inch bolt. The component parts of the sampler and core are shown in Figure 7.

The field sampling site was first selected to correspond when possible to the exact location sampled by White (1965). A one-half chain square grid was laid out on a uniform site chosen to eliminate extremes in microtopography. Samples were taken at each corner and in the middle of the grid. A sixth sample was taken at random for a photographic record. If a sampling point happened to fall on a non-uniform spot (mound, depression, etc.) or too near a tree the grid corner was extended to the nearest uniform point. If unusual stoniness, rocks, or large roots were encountered the grid corner was extended until this did not occur. Generally seven to eight points at each site were sampled before five cores were obtained for investigation.

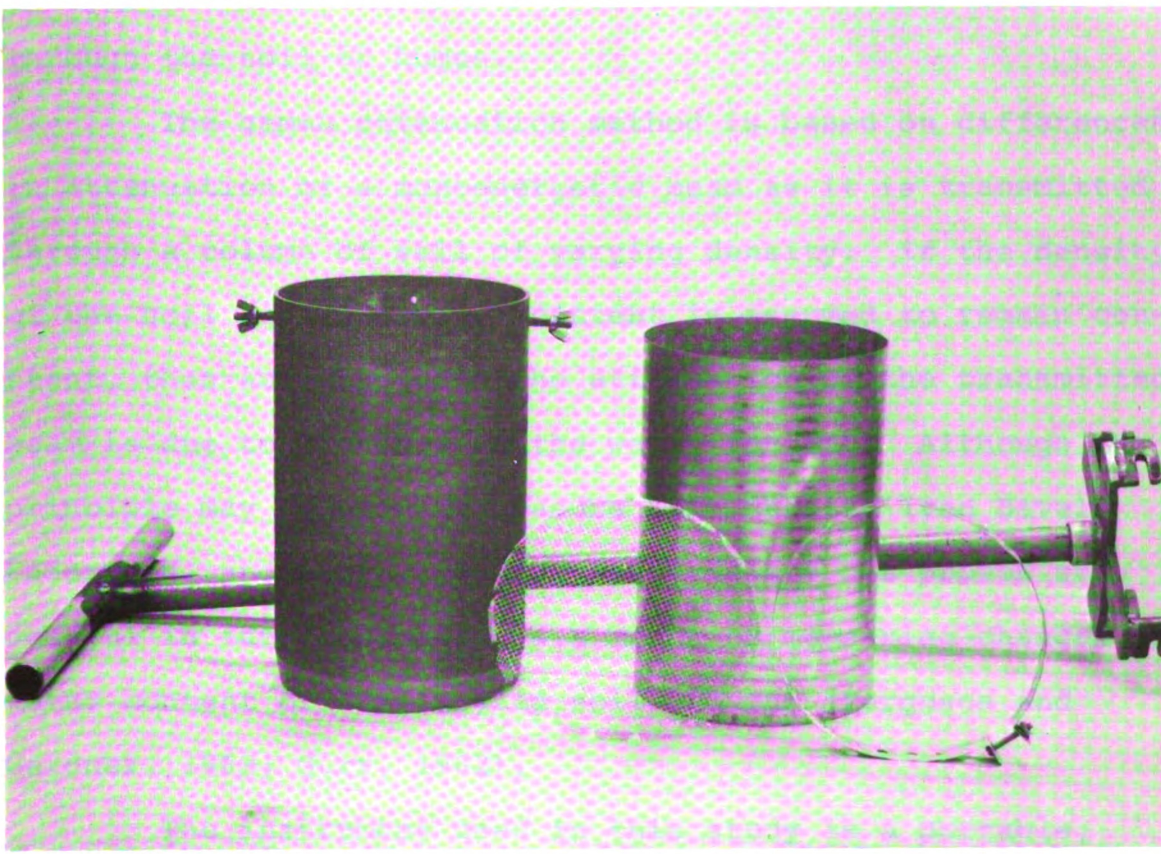

FIGURE 7. Humus-soil sampler, handle, core, 1/8-inch wire mesh bottom and perforated steel band.

Instrumentation and theory of water content measurement

To determine changes in water content with depth in the humus-soil core it is necessary to use a non-destructive, high resolution technique of measurement. This can be accomplished by using the principle of attenuation of electromagnetic gamma radiation as it is transmitted through the soil or humus.

The gamma attenuation method is based on differences in attenuation of a monoenergetic beam as it is transmitted through a column of soil of varying density. If the density of the soil less its water content is assumed to remain constant, then any change in the attenuation of the transmitted beam is due to a change in the water content. Although the principle may be used to measure bulk density (van Bavel, Underwood, and Ragar, 1957), the technique has proven successful in the laboratory as a means of measuring changes in water content of unsaturated soil columns (Ferguson and Gardner, 1962; Gurr, 1962).

The instrument used in this study is a portable, self-contained unit manufactured by Troxler Electronic Laboratories, Raleigh, North Carolina and specified as the SC-10 Two-Probe Density Gauge. It employs a scintillation detector to detect the intensity of an attenuated gamma beam transmitted through soil from a 5 mc. Cesium 137 radioactive source.

The scintillation detector consists of a 1.5-inch diameter by 0.5-inch thick NaI(Tl) detection crystal directly coupled to a photomultiplier tube. The detector probe and source are designed to fit in standard aluminum tubing of 1.9-inch and 0.75-inch I.D. respectively. High resolution is possible when amplified electronic pulses from the detector probe are fed into a single channel pulse height analyzer for electronic discrimination of low energy scattered or partially attenuated photons. A standard Troxler Model 200-B scaler counts all non-discriminated pulses from the pulse height analyzer. Both instruments are internally powered by rechargeable nickel-cadmium batteries.

Cesium 137, with a half life of 27 years, emits low energy photons with a peak energy of 0.661 Mev (million electron volts) and is preferred over high energy sources because water is a poor absorber of high energy gamma rays (W. H. Gardner, 1965). The manner in which photons of the incident energy are attenuated when transmitted through matter is exponential as expressed by the following law:

$$I = I_0 \exp\left[-(\mu \rho X)\right] \qquad (1)$$

where I_0 is the incident intensity of the source in counts per minute (CPM), I the transmitted intensity through a sample of thickness X (cm), ρ the density (g/cm^3) of the absorbing material, and μ the mass attenuation coefficient (cm^2/g), a function of both the radiation energy and the absorbing material.

For any mixture of elements the mass attenuation coefficient is the sum of the individual mass attenuation coefficients for each element on a weight fraction basis. All the elements of a dry soil, except hydrogen, have nearly equivalent mass attenuation coefficients. For example, the average theoretical mass attenuation coefficient of oven-dry soil for nine representative U.S. soils was determined by Reginato and van Bavel (1964) to be 0.0775 cm^2/g at 0.662 Mev. In contrast, the mass attenuation coefficient for hydrogen at the same energy is 0.1538 cm^2/g. Hydrogen constitutes a very small weight fraction of dry soil and the density can be determined from a graphical solution of equation (1) by using either two standard absorbers of different density such as aluminum and magnesium or one standard absorber of varying thickness.

Because the mass attenuation coefficient is both additive and independent, equation (1) can be written for a moist soil as

$$I = I_0 \exp [-\mu_s \rho_s + \mu_w \rho_w) X] \tag{2}$$

where $\mu_s \rho_s$ and $\mu_w \rho_w$ are the mass attenuation coefficients and densities of soil and water. The value ρ_w may be expressed as the volume fraction of water or the water content θ (g/cm^3).

A direct method derived from equation (2) for determination of the water content θ in soil columns, attributed to W. H. Gardner (1965), is

$$I_m = I_0 \exp [-(\mu_s \rho_s + \mu_w \rho_w) X - 2\mu_c \rho_c X_c] \tag{3}$$

and

$$I_d = I_0 \exp [-\mu_s\rho_s X - 2\mu_c\rho_c X_c] \tag{4}$$

where I_m and I_d are the incident intensities through moist and dry soil and $\mu_c\rho_c$ and X_c are the mass attenuation coefficient, density, and thickness of the container. Division of equation (3) by (4), transposing and substituting θ for ρ_w yields

$$\theta = \frac{\ln(I_m/I_d)}{\mu_w X} \tag{5}$$

If only the peak energy of 0.661 Mev is used, i.e., collimation and electronic discrimination eliminate all scattered and secondary radiation, the established theoretical value of μ_w can be used for a solution of equation (5). Perfect collimation and electronic discrimination are rarely attained but satisfactory results are possible when a range of energy about the peak is used including some scattered and secondary radiation. In this case equation (5) must be solved using a mass attenuation coefficient empirically derived for each range of energy and each instrument and geometry of design (W. H. Gardner, 1965). For example, Gurr (1962) successfully determined water contents in soil columns by counting the transmitted energies between 0.50 and 0.66 Mev and using an empirically derived μ_w.

The apparatus constructed to facilitate humus-soil water content measurements is shown in Figure 8. The

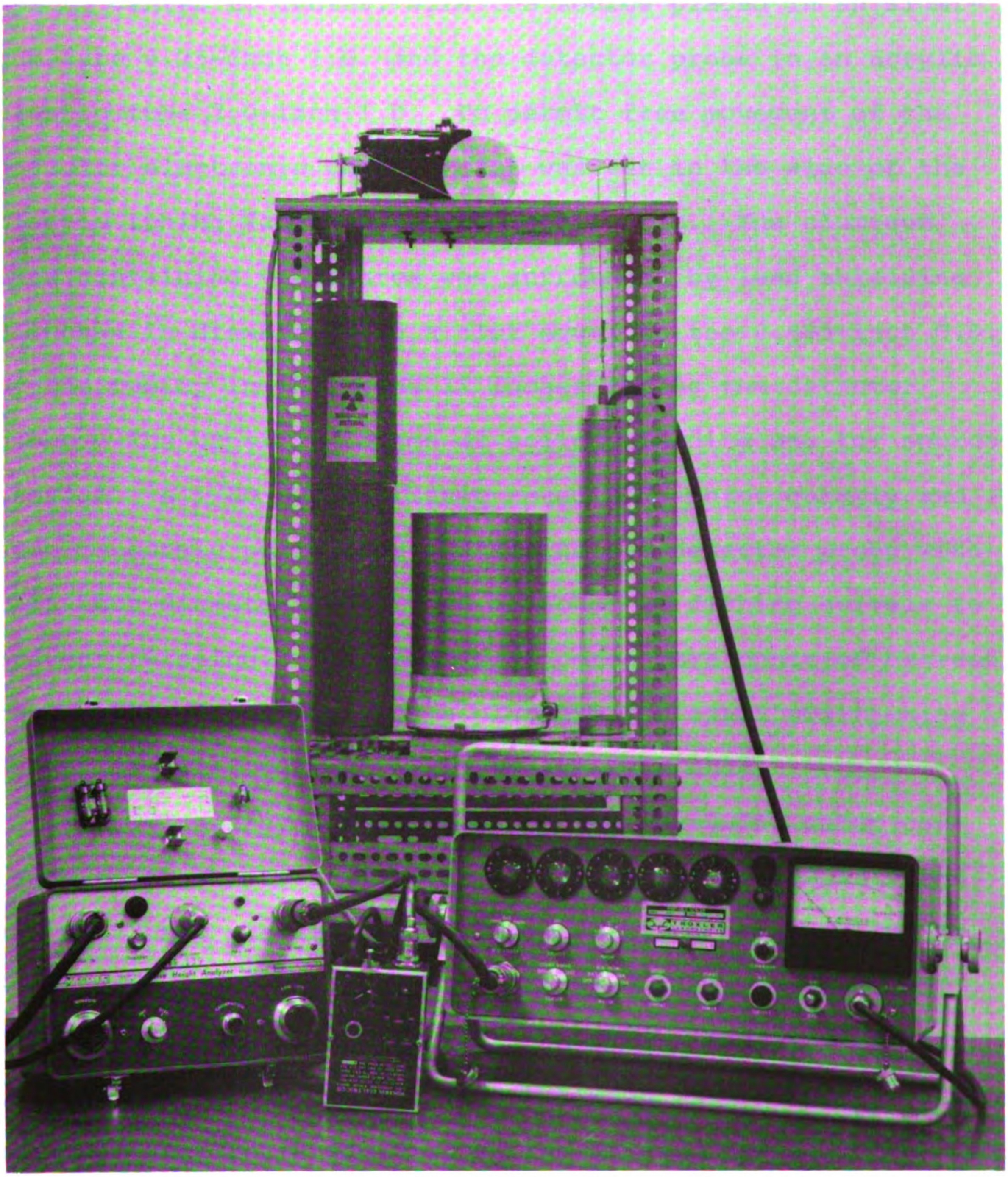

FIGURE 8. Gamma attenuation instrumentation and jig to hold cores and guide the source and detector for water content measurements. The scaler with ratemeter and high voltage power supply is the instrument on the right and the pulse height analyzer is on the left. Between the two is the variable speed control for the motor used to move the detector probe and source.

detector probe and Cs^{137} source were 12 inches (30.5 cm) apart, center to center, with the source placed in an aluminum tube 0.75-inch I.D. and the detector probe in an acrylic plastic tube 2.0-inch I.D. To permit free movement of the detector electronic cable a slot was cut in the side of the plastic tubing facing away from the source. The aluminum tube containing the source was surrounded by lead shielding 3 inches in diameter with a slot equal to the 0.875-inch O.D. of the tubing in the lower 12 inches facing the detector probe. The upper 10 inches of solid shielding was for source storage. A 1/50 H.P. variable speed D.C. motor quickly and simultaneously positioned the source and detector probe with 1/16-inch diameter nylon cord attached to fishing swivels to prevent twisting. The humus-soil cores were centered between the source and detector on a platform for exact positioning each time water content measurements were made.

Two energy levels were used in measuring water contents of the humus-soil cores. Only energies between 0.550 and 0.575 Mev resulted in a linear relation between $-\ln (I/I_0)$ and density ρ or thickness X. The second energy level of 0.661 - 0.691 Mev resulted in a non-linear relation similar to that reported by Thames (1965). When Thames improved the beam collimation in addition to the already present electronic discrimination a linear relation was obtained. However, Reginato and van Bavel (1964) obtained a linear relation without using collimation, depending on electronic discrimination alone. The reason for the non-linearity observed in the current study is not clear. It is possible that a combination of instrumentation, geometry of design, and lack of collimation were responsible. The lack of collimation may not be as critical when the slightly lower energies, 0.550 - 0.575 Mev, are counted and a linear relation exists.

Careful checks were made of known water contents in a quartz sand by gamma attenuation at each of the above energy levels. Results were comparable, indicating that the non-linearity did not seriously affect the accuracy of water content measurements. Calibration procedures were identical for both energy levels used and the discussion to follow will be concerned with calibration results from the 0.550 - 0.575 Mev energy level.

Theoretically, the volume of soil measured by a transmitted beam will be a solid angle from the point source subtended by the scintillation crystal. Using similar instrumentation without collimation and depending on electronic discrimination only, van Bavel (1959) showed that a vertical resolution approximately equal to the thickness of the crystal (0.5-inch) is possible. The resolution of the instrumentation used in this study was checked by passing an aluminum plate 0.79-cm thick through the beam at a point equidistant from source and detector. For energies between 0.550 and 0.575 Mev the vertical resolution was approximately 0.6 inches (1.5-cm).

Calibration was required to find the value of μ_w in equation (5) to solve for water content θ. A tray was constructed inside a standard, empty soil-humus core that would hold 36 aluminum plates, each 0.397 cm thick, normal to the transmitted gamma beam. The tray would hold either aluminum plates, water, or combinations of both.

To determine μ_w it is necessary to solve the following equation

$$I/I_c = \exp\ [-(\mu_{al}\rho_{al}X_{al} + \mu_w\rho_w X_w] \qquad (6)$$

where I_c is the intensity of the transmitted beam through the empty standard core. Count rates of the transmitted beam I were determined for various thicknesses of aluminum and aluminum-water combinations. For the aluminum-water combination an equal thickness of water was added for each aluminum plate removed. These data are shown in Figure 9 in a plot of $-\ln(I/I_c)$ as a function of aluminum thickness X_{al}. The slopes, $\mu_{al}\rho_{al} - \mu_w\rho_w$ and $\mu_{al}\rho_{al}$, were used to solve equation (6) for μ_w.

Calculation of each set of slopes in Figure 9 for solution of equation (6) results in a mass attenuation coefficient for water of 0.0623 cm^2/g as compared with the theoretical mass attenuation coefficient of water at 0.662 Mev of 0.0862 cm^2/g. Thus, the value of μ_w calculated is valid only for this instrumentation, geometry of design, and range of energy counted.

According to W. H. Gardner (1965) the precision of gamma attenuation in water content measurements varies with the thickness and density of the soil core, the mass attenuation characteristics of the soil, and the magnitude of

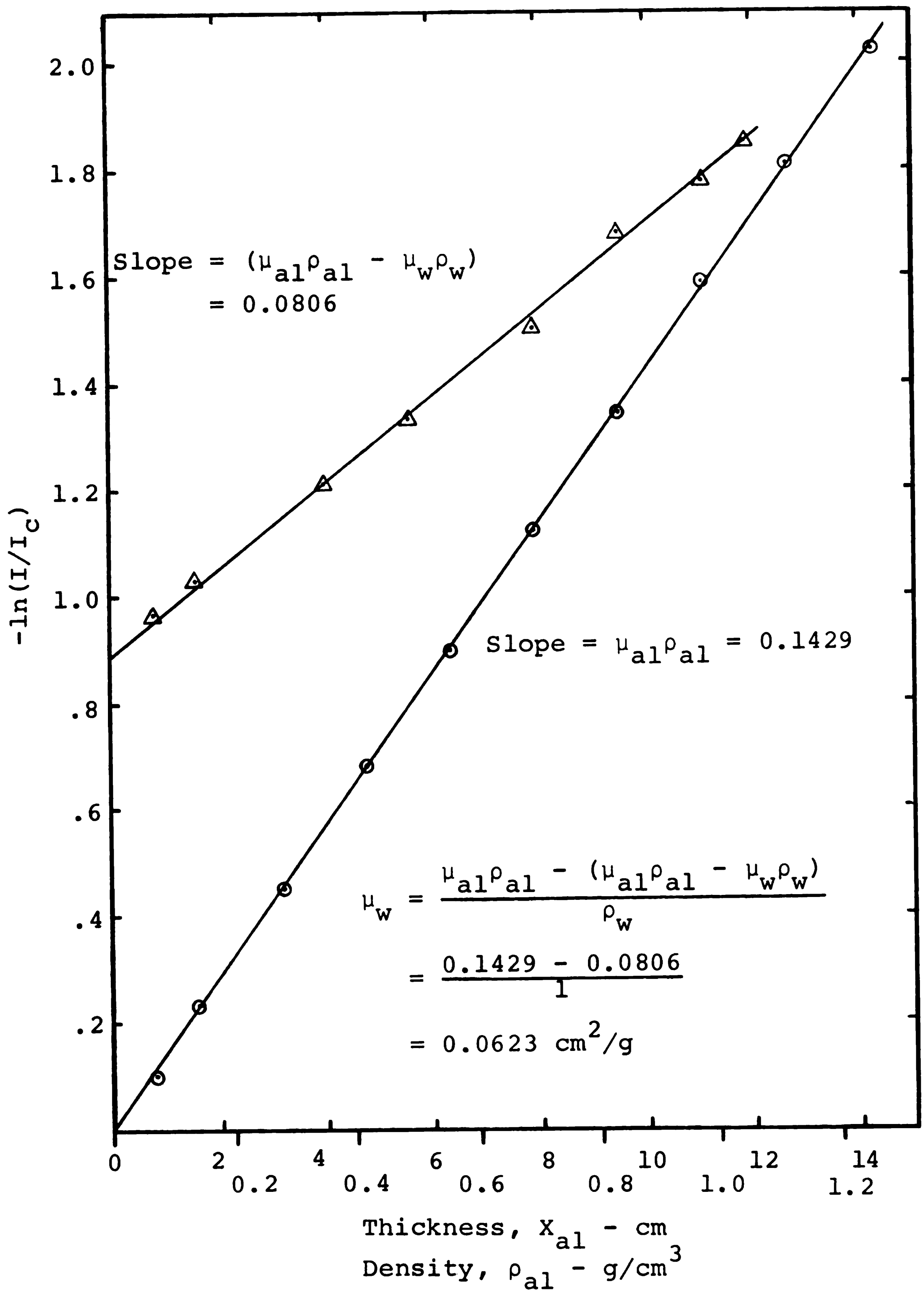

Figure 9. Calculation of μ_w by determining the slopes of count ratio (I/I_c) as a function of aluminum thickness X_{al}.

the counts I_m and I_d in equation (5). The standard deviation in water content, as derived by Gardner, is given by the equation

$$\sigma_\theta = \left(\mu_w \times \sqrt{I_m}\right)^{-1} \tag{7}$$

when I_d is counted over a period 3- to 4-times longer than I_m. For the range of I_m between 20,000 and 85,000 CPM experienced in this study the average precision in water content θ is 0.010 g/cm^3 (i.e., 1.0 per cent water content by volume) at the 95 per cent confidence level.

Accuracy was determined by comparing calculated values of θ from equation (5) with actual values of θ in a known sample. Medium quartz sand was packed to a dry density of 1.433 g/cm^3 in a standard core to a depth of 3 inches. The water content was changed by adding a known quantity of water with an atomizer to the quartz spread out on a plastic sheet, thoroughly mixing, and repacking in the core to the required volume. For θ between 0.085 and 0.410 g/cm^3, the latter being saturation, the values of θ determined by gamma attenuation were an average 7.7 per cent lower than the actual values of θ. At a water content of 0.200 g/cm^3 this represents an accuracy of 0.015 g/cm^3.

Similar counts through a standard absorber were not possible at the beginning of each period of instrument operation because the detector photomultiplier tube voltage supply could not be finely adjusted. Thus, all values of I_m and I_d were adjusted to correct for the difference in standard count rates. Five minute standard counts every 20 to 30 minutes during instrument operation were used to correct for any drift that occurred. The standard counts, I_{al}, were taken through a standard absorber of an empty core with aluminum plates normal to the beam. A second standard, an empty core, was used to check the ratio I_{al}/I_c. Frequently differential drift would occur and the ratio would change making μ_w invalid. If this change was significant measurements were terminated and the instrument readjusted to give the proper ratio.

At the end of the study each core was oven dried at 105°C for one week after the temperature had been slowly elevated over several days. Very little shrinkage was observed since most of the soils were sand with only slight amounts of fine textured material. The humus horizons, already slowly dried by evaporation, did not exhibit excessive shrinkage except in a few isolated cases. What shrinkage did occur was observed to be laterally away from the sides of the core and not longitudinal. Lateral shrinkage will not significantly change the count rate because the quantity of solid material within the zone of measurement between the core walls remains the same.

After drying, I_d was counted for 3 minutes at each depth and water contents were computed by equation (5). All computations were done on the Michigan State University CDC 3600 computer. With knowledge of I_d and I_c, the data in Figure 9 of $-\ln(I/I_c)$ and X_{al} can be utilized to determine density of mineral soil assuming $\mu_{al} = \mu_s$ as demonstrated by Reginato and van Bavel (1964). The assumption that μ_s is valid for humus and mineral soil with large amounts of incorporated organic matter is questionable due to the increased quantity of hydrogen in organic matter. This assumption is valid for organic matter contents in mineral soil less than 5 per cent (inferred from data presented by Reginato and van Bavel, 1964) and would probably hold for organic matter contents as great as 10 per cent. Assuming the validity of μ_s for humus will result in an underestimation of the humus density. To account for the increased hydrogen content in humus a mass attenuation coefficient should be determined for several ranges of organic matter content encountered. This is a time consuming procedure and beyond the scope of this study. Raginato and van Bavel (1964) describe a technique to determine the actual mass attenuation coefficient for soils which could be adapted for humus.

A least squares equation fit to the data of $-\ln(I/I_c)$ and ρ_{al} was used to determine the dry density (g/cm^3) of mineral soil and to estimate that of humus. The average density of each aluminum plate used in calibration was 2.677 g/cm^3. For 36 aluminum plates between the source and detector 30.5-cm apart the effective density was 1.255 g/cm^3. A scale of density is shown in Figure 9 along the X-axis to correspond with thickness of aluminum.

Determination of rates of evaporation and water content distribution

Evaporation experiments were conducted in a Sherer-Gillett (Marshall, Michigan) Model CEL-512-37 environment chamber equipped with a Dryomatic (Alexandria, Virginia) Model 150 dehumidifier. Temperature and humidity within the chamber were controlled by a pair of wet- and dry-bulb temperature sensors. Evaporation loss from the humus-soil cores was determined by weighing each core at approximately 2 to 3 day intervals. Water content distribution was determined by gamma attenuation at 2 to 3 week intervals during evaporation loss.

Two separate experiments with different potential evaporation conditions were conducted in the same environment chamber, each over 7 weeks in duration. During each experiment the temperature was maintained at 24 ± 0.6°C, the radiation level was 6.04×10^{-4} cal/cm^2/min, and the air circulation in the chamber remained constant. Relative humidity in the first experiment was 40 ± 2 per cent and in the second was 70 ± 2 per cent. This resulted in an average potential evaporation, expressed in depth of water evaporated from a free water surface in several standard cores, of 0.76 and 0.43 cm/day respectively. The radiant energy was supplied by a bank of incandsecent bulbs to simulate the near infra-red light quality normally found beneath a forest canopy.

Forty samples (four of the five from each sampling site) were prepared for each experiment in an identical manner. The samples were wetted from the bottom in tubs by raising the depth of water one inch each day for 10 days, then remaining at saturation for five additional days. After saturation the cores were placed on tension tables at 40-mb (one millibar equals approximately one cm water) tension on the bottom of the core, a total 65-mb tension at the top. Fine quartz sand of 70-120 mesh covered the paper on the tension table assuring contact with the soil through the 1/8-inch wire mesh on the bottom of each core. Equilibrium, as established by weighing, occurred in all cores within 3 days. Plastic bags covered the tops to prevent evaporation during all phases of preparation. After removal from the tension table a plastic cover and lid from a one gallon bulk ice cream container formed a base. A tight seal was made around the base with masking tape.

The cores were arranged in four blocks, one core from each sampling site in each block, equally spaced over a 53- by 100-inch steel mesh plant bed in the chamber. The blocks, and cores within the blocks, were randomly arranged for each experiment.

Water loss by evaporation was determined by periodic weighing on a top loading automatic balance with an accuracy of ±1 g. This evaporation loss E, expressed as depth of water in centimeters, is calculated for any time period from the relation

$$E = \frac{dS}{Adt} \tag{8}$$

where dS/dt is the water loss S in grams from the humus-soil core during a specified time interval t in hours, and A is the cross-sectional area in cm^2. Cumulative evaporation for a time interval $t_2 - t_1$ is defined as

$$\int_{t_1}^{t_2} E dt = \Delta S/A. \qquad (9)$$

Cumulative fractional evaporation is also determined and is simply cumulative evaporation at any time divided by the total initial water content at 40-mb tension.

Water content distribution within each core was determined at eight depths by gamma attenuation before evaporation began (t = 0) and at approximately 2, 4 and 7 weeks thereafter for each experiment. Water content measurements were made at the center of one-inch increments of depth, except at the surface, because the physical dimensions of the scintillation crystal and resolution precluded smaller increments. The source and crystal were centered at depths from the surface of 0.75, 1.5, 2.5, 3.5, 4.5, 5.5, 6.5, and 7.5 inches corresponding to 1.9, 3.8, 6.4, 8.9, 11.4, 14.0, 16.5, and 19.0 cm. Each core, when removed from the chamber during water content measurements, was covered with a plastic bag to prevent evaporation. Total time out of the chamber for each core was generally less than 30 minutes.

A third evaporation experiment was conducted on the remaining fifth core from each sampling site to observe the effects on evaporation by removal of the F humus layer. The cores were prepared in the same manner as in the first two experiments and evaporated in the chamber at the same constant conditions and 40 per cent relative humidity. At the end of eight weeks the cores were saturated and drained as previously described, the F humus layer removed, and the cores placed in the chamber under the same conditions for the same period. To simulate the conditions in the chamber as applied during the first two evaporation experiments, the 10 cores in the humus removal experiment were arranged in a single block with 30 empty cores filling the remaining blocks. Evaporation rates were determined by weight loss as in the earlier experiments. Water content distributions were not measured.

Biological activity in the humus and soil horizons no doubt continued during the evaporation experiments. Earthworm activity in the mulls was most evident in the form of new casts deposited on the surface. Other visible evidence of change in humus structure due to biological activity was not noted. When the samples were not in use, the biological activity was arrested by storage at 4°C. Due to relatively low evaporative potentials the humus and soil horizons dried slowly. Lateral shrinkage, restricted to the surface of the F layer, was observed in a few cases. All visible changes, when they did occur, were noted throughout the study.

Infiltration and redistribution of water

To study the water transmitting properties of the humus horizons, simulated rainfall was applied to one core from each site selected from the group previously used in the evaporation experiments with F horizon intact. Changes in water content during and after application were measured by gamma attenuation.

To apply water uniformly and at a constant rate a rainfall simulator was constructed similar to one described by Adams, Kirkham, and Nielsen (1957). The simulator (Figure 10) consisted of an acrylic plastic reservoir, 16.25-cm I.D., in which raindrop applicators were supported 5-cm above the humus-soil surface. The raindrop applicators were 0.635-cm O.D., 0.152-cm (0.060-inch) diameter bore, 2.54-cm long glass capillary tubes with 0.129-cm (0.051-inch) diameter Chromel-A wire 2.8-cm long supported in each. One-hundred fourteen such applicators were arranged 1.3-cm apart in six concentric circles and affixed in two round plastic plates 2.6-cm apart.

A pressure head regulator as described by Adams, et al. (1957) was used to maintain a constant head in the reservoir of 0.6 cm producing a simulated rainfall of 3.0 cm/hr (1.18 inch/hr).

The cores selected for the infiltration study were saturated and drained on the tension table following the same procedure outlined for the previous experiments.

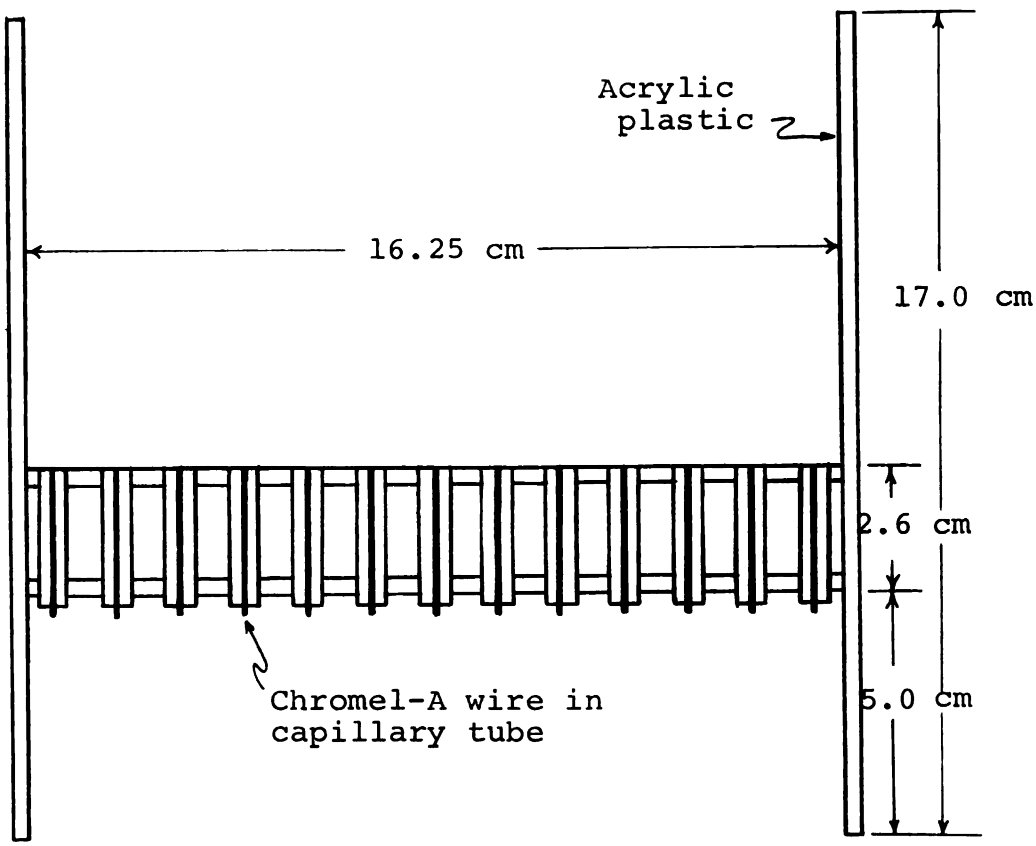

Figure 10. Cross-section of the rainfall simulator.
See text for explanation.

Because of the coarse texture of most soils used in this study the rate of water movement is rapid at high water contents and water applied to the surface will move too quickly to follow with the type of gamma attenuation instrumentation used. To avoid this problem the cores were subjected to a high evaporative potential to decrease water contents before applying simulated rainfall.

Generally 1.5- or 2-cm of water was applied in approximately 30- or 40-minutes depending on the texture of the soil. The core bottom was open to the atmosphere so air could move freely ahead of the wetting front. Immediately before applying simulated rainfall the initial water contents were determined by gamma attenuation at the same eight depths used in the previous experiments. Measurements following the wetting front continued during and after application at approximately one-minute intervals until redistribution was slow, at which time they were spaced over longer intervals until the wetting front reached the core bottom.

CHAPTER VI

RESULTS AND DISCUSSION

The variation in rate of evaporation and cumulative fractional evaporation among replicates or samples from each site was slight and these results can be presented as an average for each site. However, due to differences in depth and physical arrangement of horizons in relation to the point of water content measurement, water content-depth profiles in each sample from a particular site varied considerably preventing the determination of an average water content-profile for each site. For the purpose of illustration and discussion an average sample was chosen to represent each site. These selected samples will be termed representative but must not be considered to fully represent all conditions at each site. Cumulative fractional evaporation and water content profiles as functions of time and potential evaporation are presented in Figures 11 through 21 for each representative core. Organic and mineral horizon depths are indicated in relation to total core depth on the water content profiles.

A complete tabulation of cumulative evaporation expressed as depth of water in centimeters, cumulative

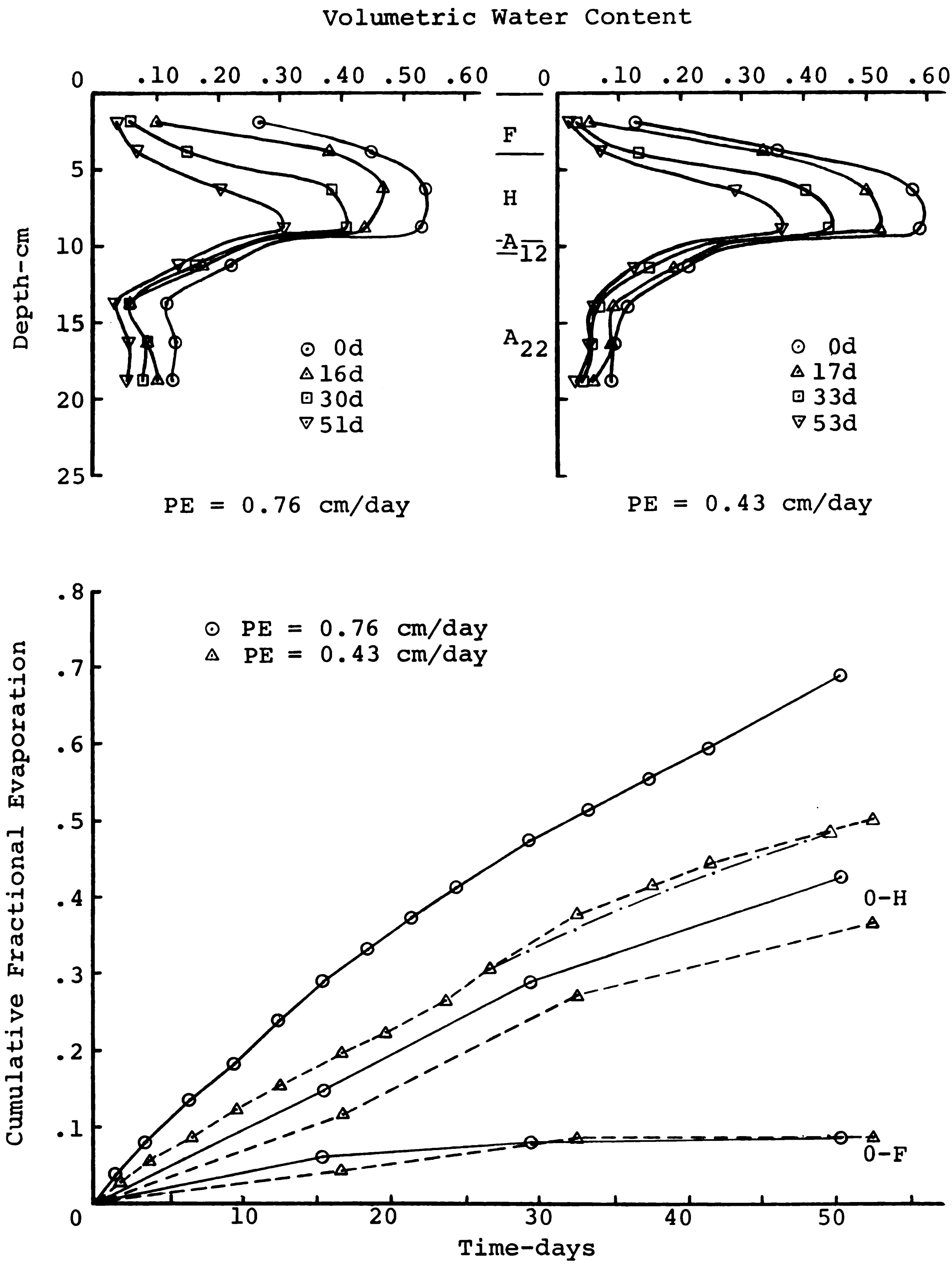

Figure 11. Cumulative fractional evaporation and water content profiles at each potential evaporation for core B-2, MOR HUMUS TYPE.

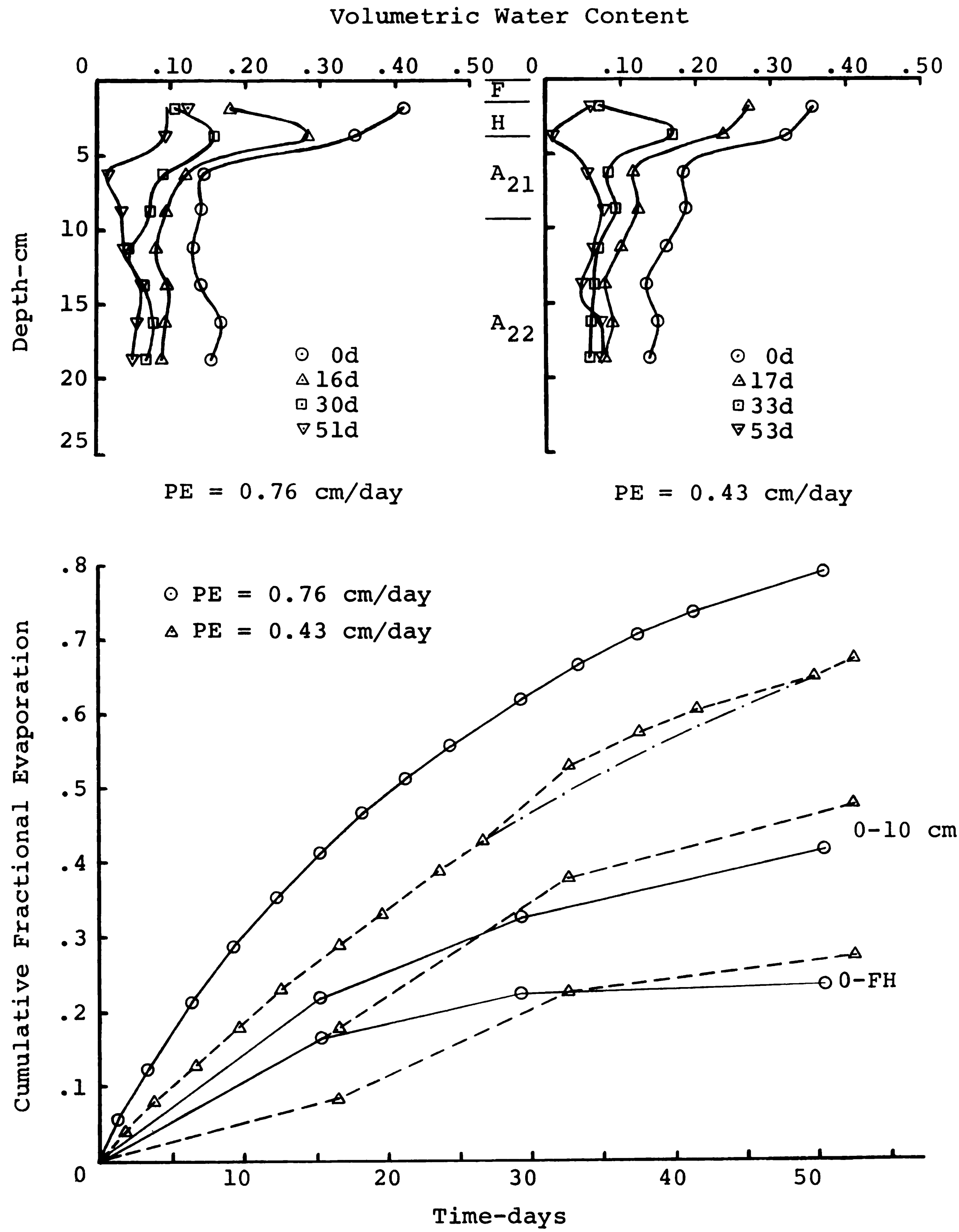

Figure 12. Cumulative fractional evaporation and water content profiles at each potential evaporation for core B-5, MOR HUMUS TYPE.

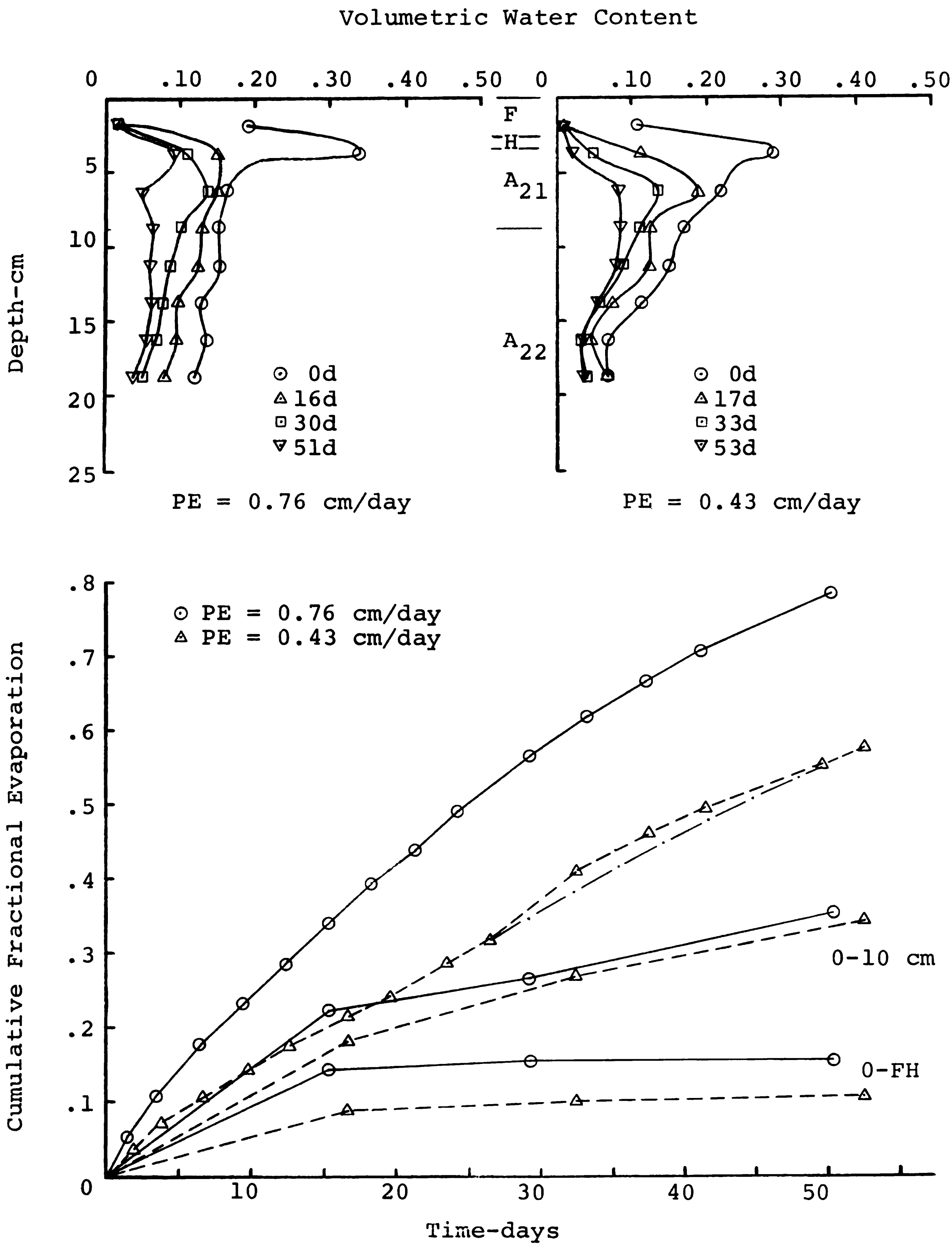

Figure 13. Cumulative fractional evaporation and water content profiles at each potential evaporation for core C-5, MOR HUMUS TYPE.

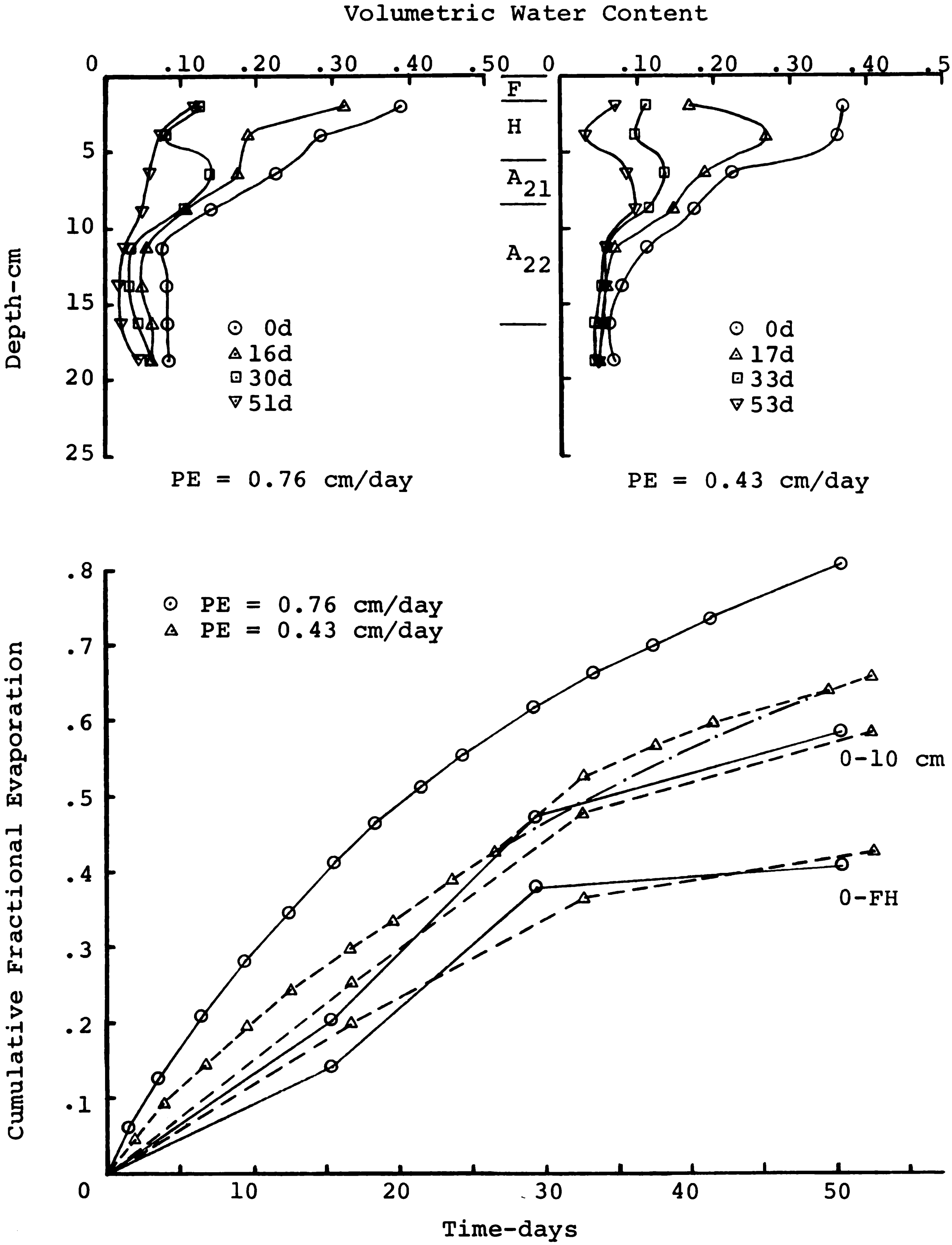

Figure 14. Cumulative fractional evaporation and water content profiles at each potential evaporation for core D-5, PSEUDO DUFF-MULL (MOR) HUMUS TYPE.

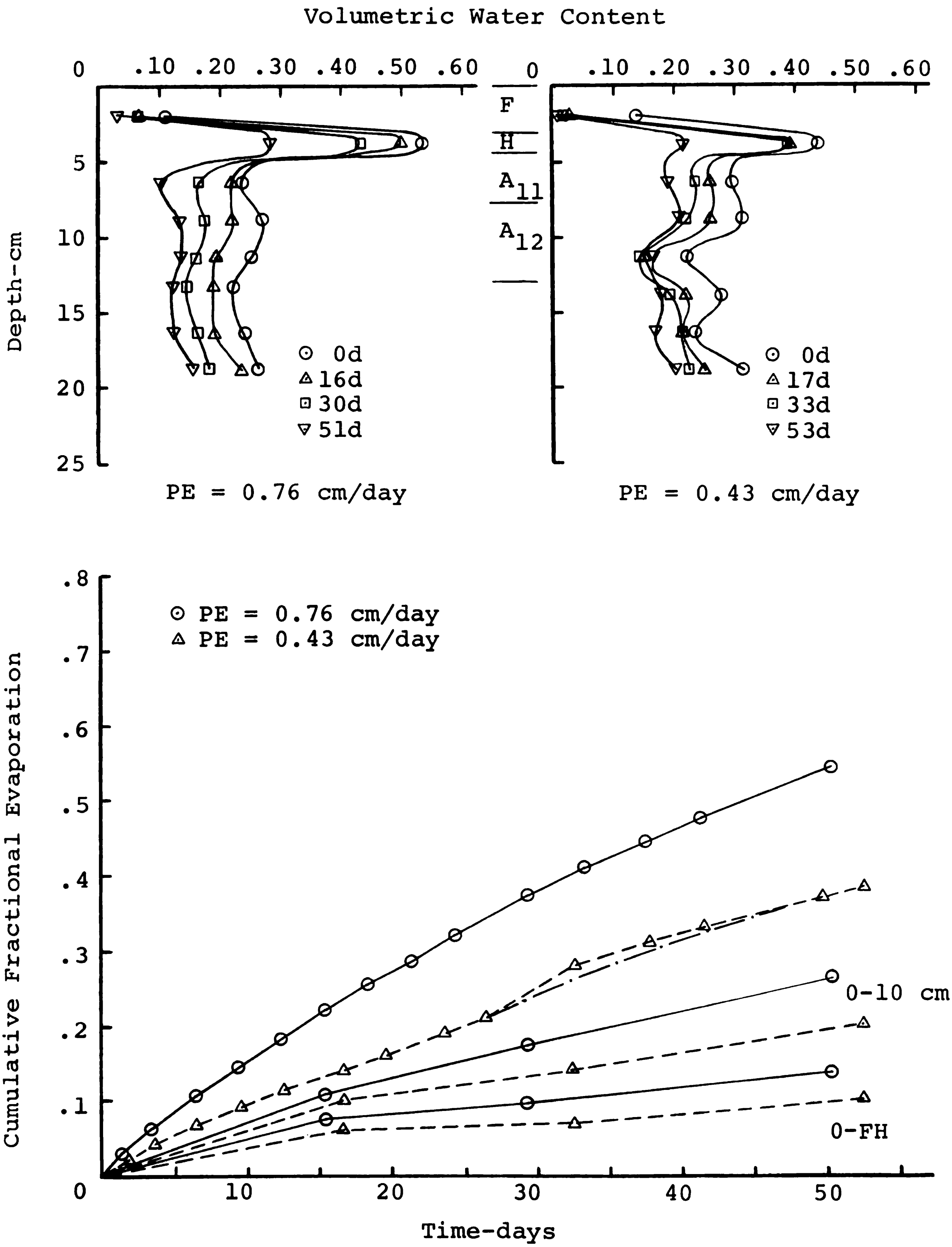

Figure 15. Cumulative fractional evaporation and water content profiles at each potential evaporation for core F-4, DUFF-MULL HUMUS TYPE.

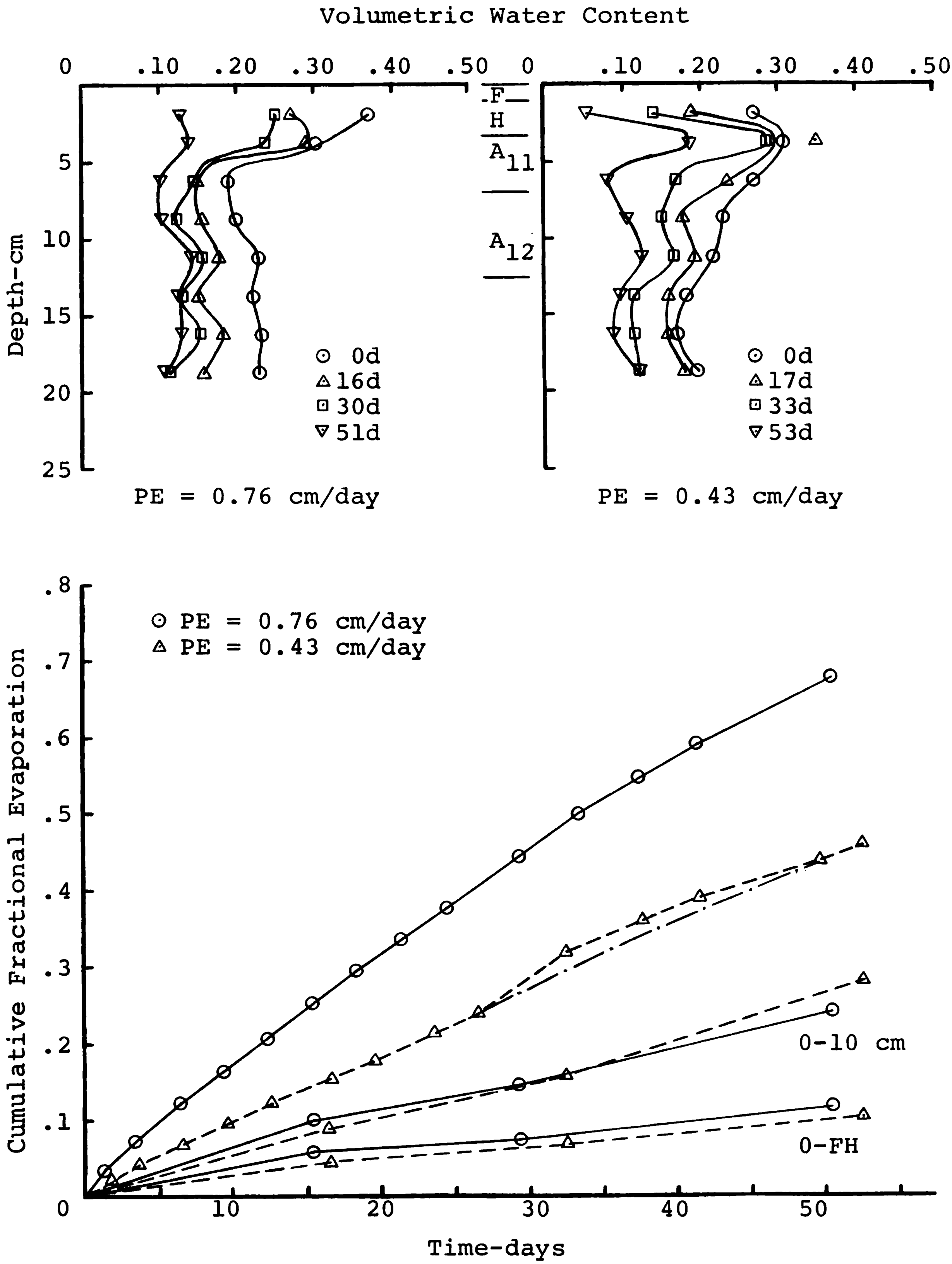

Figure 16. Cumulative fractional evaporation and water content profiles at each potential evaporation for core G-5, DUFF-MULL HUMUS TYPE.

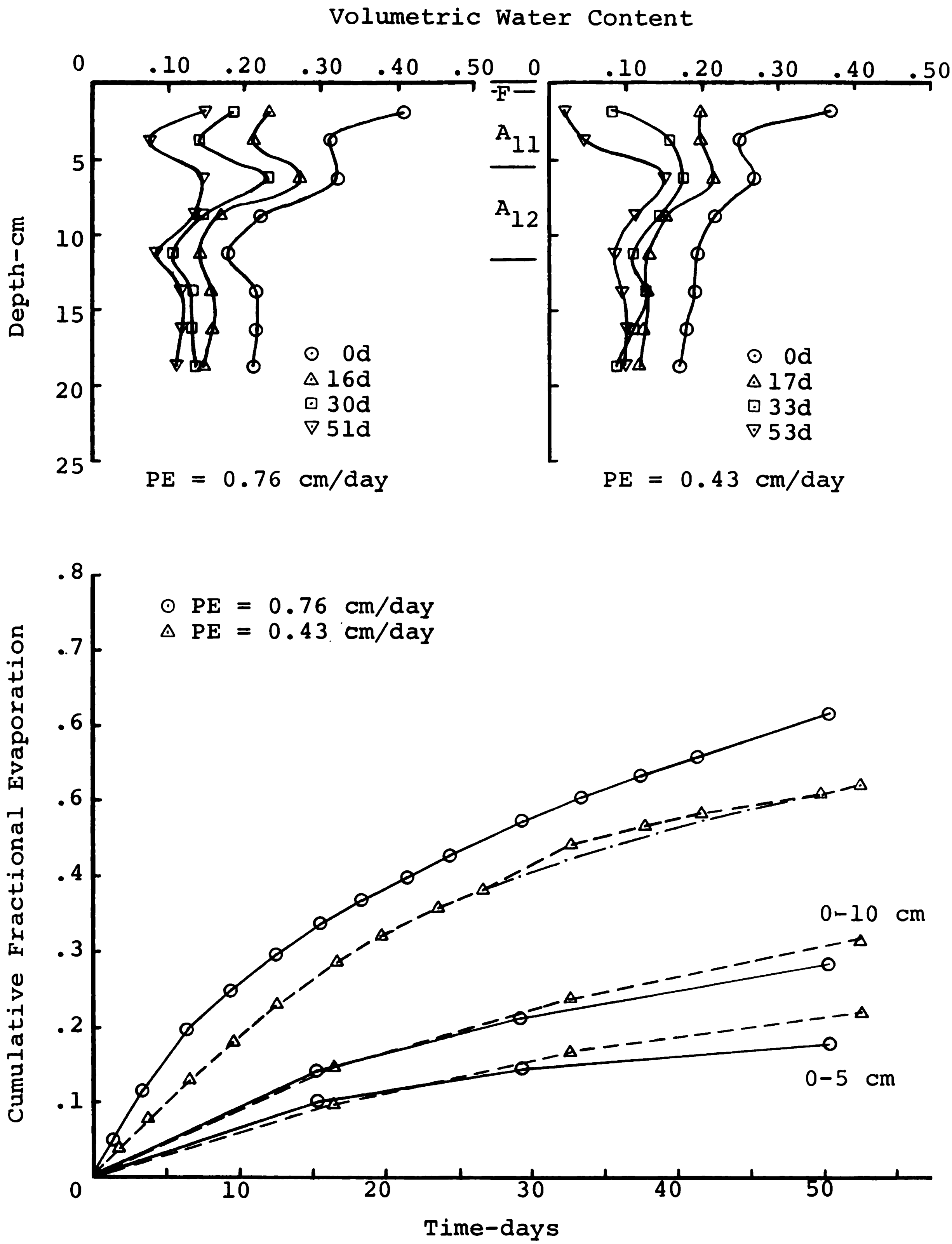

Figure 17. Cumulative fractional evaporation and water content profiles at each potential evaporation for core E-4, MULL WITH F HORIZON HUMUS TYPE.

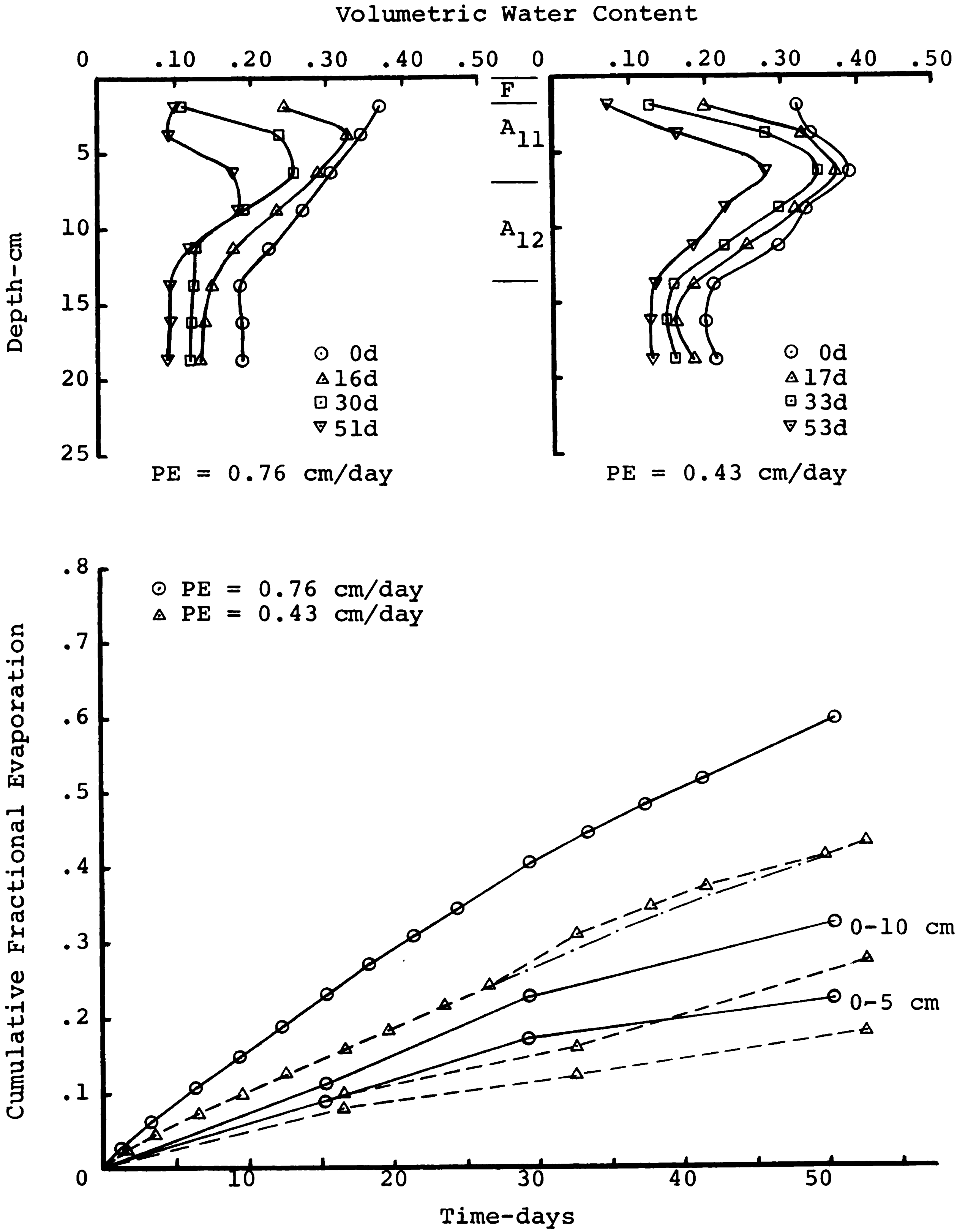

Figure 18. Cumulative fractional evaporation and water content profiles at each potential evaporation for core H-4, MULL WITH F HORIZON HUMUS TYPE.

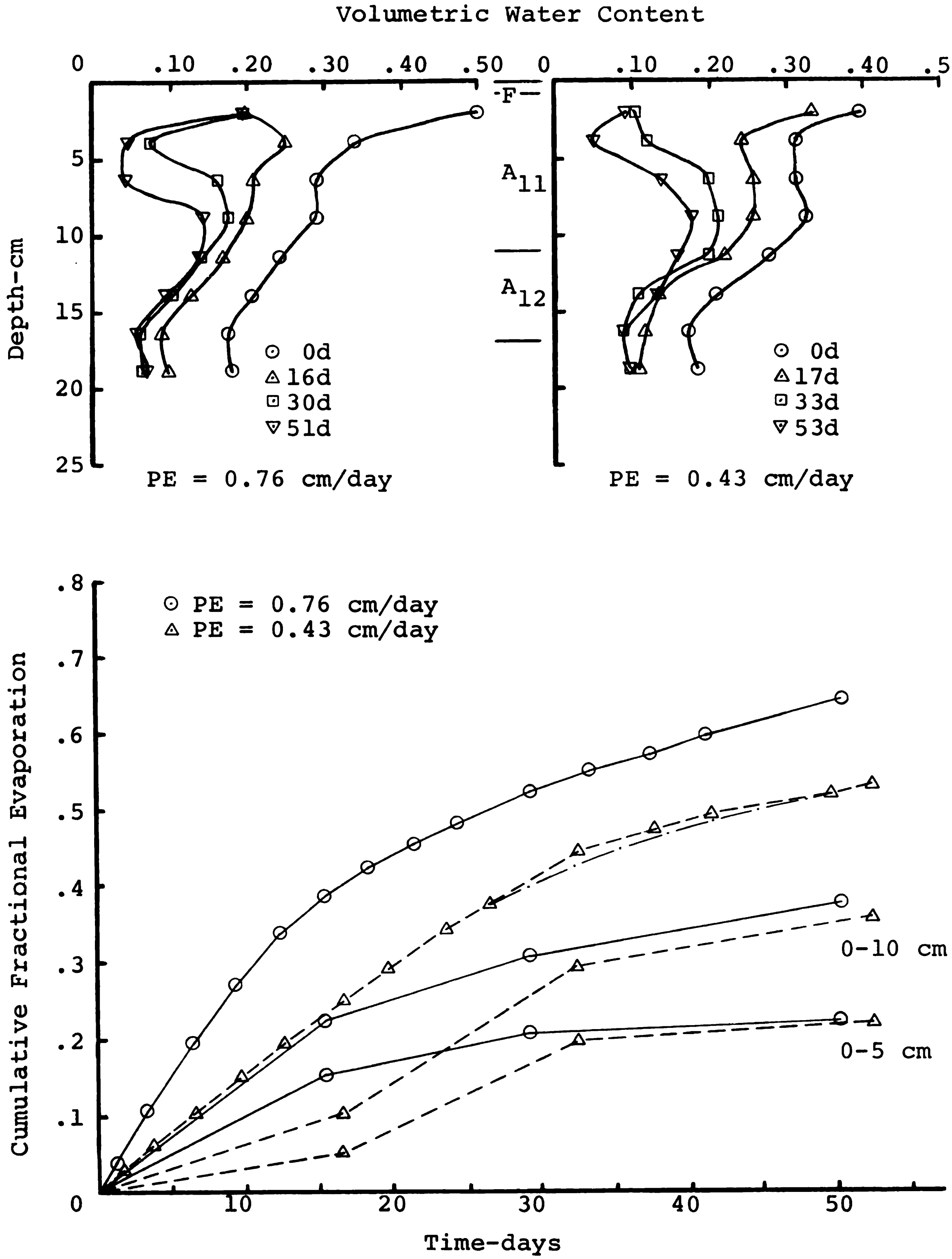

Figure 19. Cumulative fractional evaporation and water content profiles at each potential evaporation for core K-5, MULL WITH F HORIZON HUMUS TYPE.

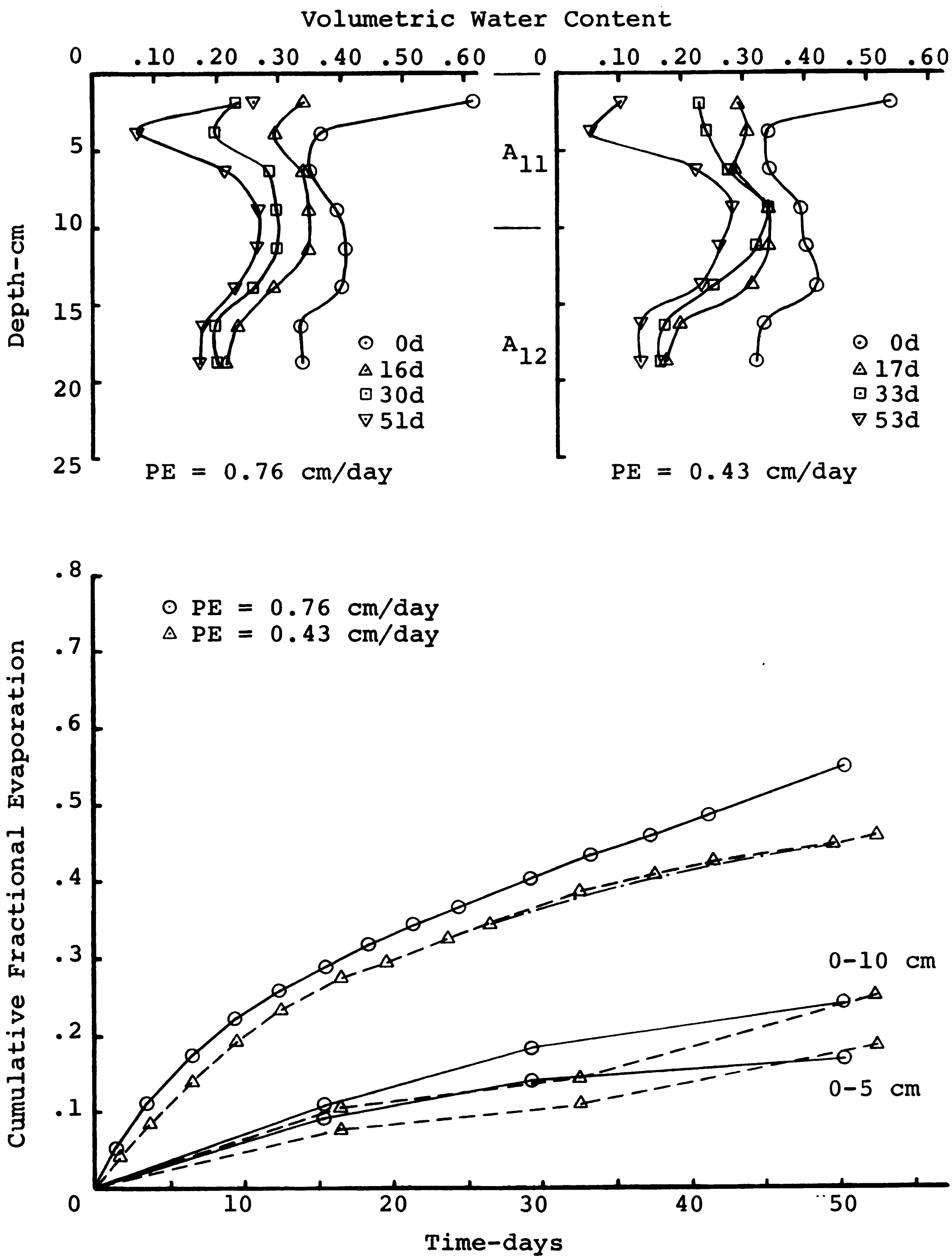

Figure 20. Cumulative fractional evaporation and water content profiles at each potential evaporation for core A-4, MULL HUMUS TYPE.

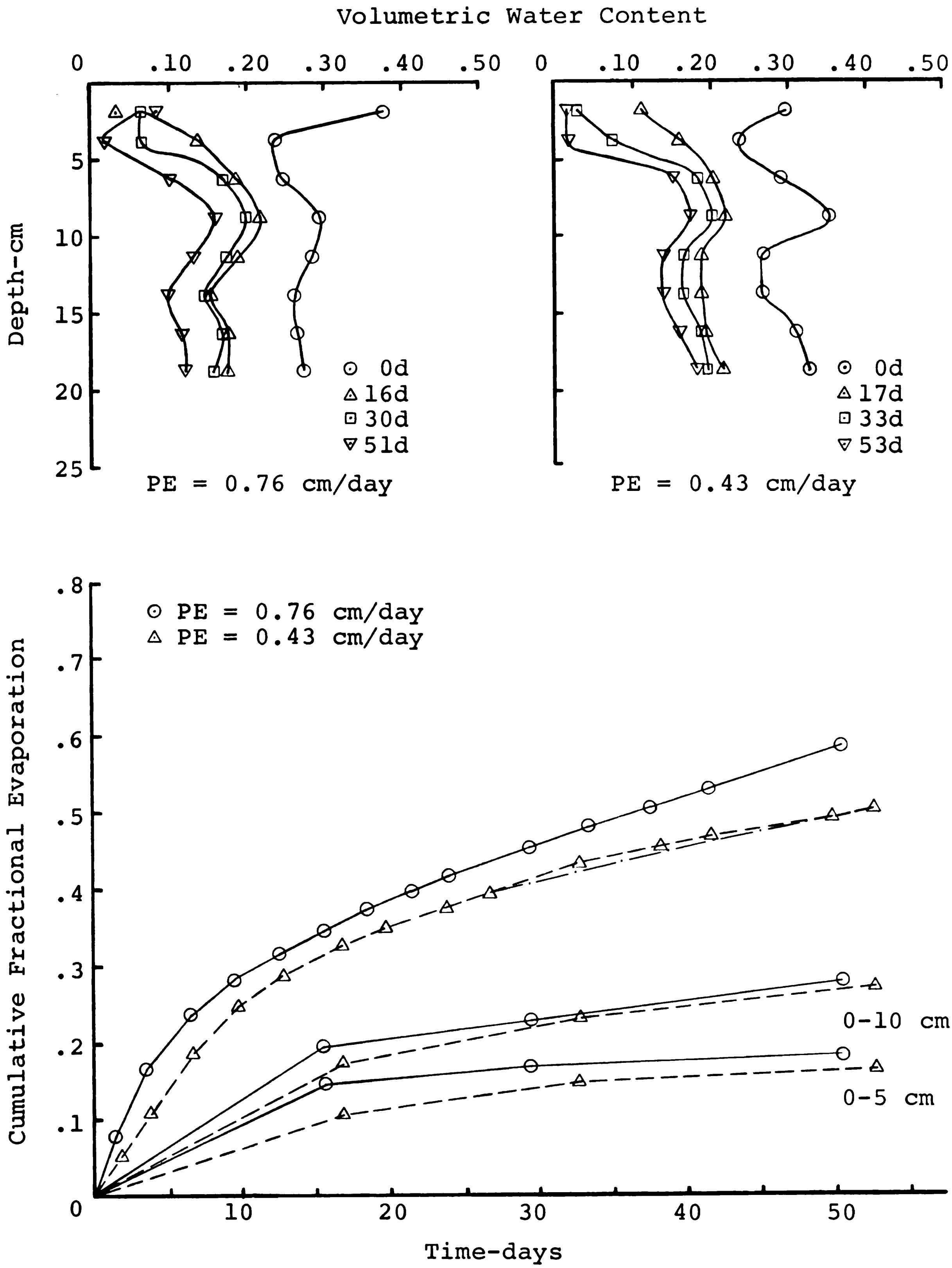

Figure 21. Cumulative fractional evaporation and water content profiles at each potential evaporation for core M-4, MULL HUMUS TYPE.

fractional evaporation for each core, and averages for each site as a function of time and potential evaporation are presented in Appendix I. Volumetric water contents as a function of depth and time and bulk density as a function of depth, both determined by gamma attenuation, are presented in Appendix II for each core.

Cumulative evaporation

For every sample included in this study the cumulative fractional loss at any time t > 0 at the high potential evaporation (0.76 cm/day) was greater than that at the low potential evaporation (0.43 cm/day). The classical initial stage of constant rate evaporation equal to the potential evaporation is not evident in these data and probably lasted only several hours. It is observed in several samples, most notably K-5 (Figure 19) that a constant rate period extended for several days but at approximately 0.2 cm/day the evaporation is far below the potential evaporation of 0.76 cm/day.

For the mull humus types (Figures 17 through 21) the rate of fractional evaporation generally decreases more rapidly after 30 days at the low potential evaporation than at the high potential evaporation. To a lesser extent this is generally true for the mor and duff-mull types (Figures 11 through 16). This is a departure from the type of curves associated with the drying of bare soil. W. R. Gardner and Hillel (1962), studying the evaporation from bare soils at various potential evaporations, indicate that at sufficiently long periods of time the cumulative evaporation will be the same regardless of the potential evaporation. This same result might be expected for the humus-soil cores at very long times, perhaps two- to three-times longer than the approximate 50 days which these results represent.

Although there was a considerable difference between humus types in the total water retained at 40-mb tension and the fractional evaporation, the difference in depth of water lost by evaporation between the two potential evaporations was small and showed little variation with humus type. This data is tabulated in Table 4 for the representative cores and in Table 5 as an average for all cores from each sample site. The difference in loss between the two potential evaporations for the averaged data in Table 5 ranged from 0.6- to 1.2-cm, averaging approximately 0.9-cm. Except for sample B-2 (the well-developed root mor) and the duff-mulls, the difference in loss due to potential evaporation was approximately the same for both mulls and mors. However, this difference for all humus types represents less than 0.02 g/cm^3 water content.

The data of Table 4 and 5 indicates that the total depth of water retained at 40-mb tension is less for the mors (except B-2) than the mulls and duff-mulls. This reflects the improvement of soil structure associated with mulls and duff-mulls due to increased faunal activity and

Table 4. Initial water content, total evaporation, total fractional evaporation, and differences due to change in potential evaporation for each representative core.

Humus Type	Site-Core	PE = 0.76 cm/day			PE = 0.43 cm/day			Difference	
		Initial	Total Evap.	Total Frac. Evap.	Initial	Total Evap.	Total Frac. Evap.	Total Evap.	Total Frac. Evap.
		cm	cm		cm	cm		cm	cm
Mor	B-2	6.4	4.4	.690	5.9	3.0	.502	1.4	.188
Mor	B-5	4.7	3.7	.789	4.2	2.8	.671	0.9	.118
Mor	C-5	3.8	3.0	.782	3.6	2.1	.578	0.9	.204
Pseudo Duff-Mull (Mor)	D-5	3.3	2.7	.807	3.2	2.1	.660	0.6	.147
Duff-Mull	F-4	6.7	3.6	.546	6.8	2.6	.386	1.0	.160
Duff-Mull	G-5	6.3	4.2	.676	5.8	2.7	.459	1.5	.217
Mull w/F	E-4	6.4	3.9	.614	6.2	3.2	.520	0.7	.094
Mull w/F	H-4	6.0	3.6	.596	5.9	2.5	.433	1.1	.163
Mull w/F	K-5	6.5	4.2	.646	6.3	3.4	.533	0.8	.113
Mull	A-4	10.0	5.5	.549	9.8	4.5	.459	1.0	.090
Mull	M-4	7.6	4.5	.587	7.8	3.9	.504	0.6	.083

Table 5. Average initial water content, total evaporation, total fractional evaporation, and differences due to change in potential evaporation for each site.

Humus Type	Site. Core	PE = 0.76 cm/day			PE = 0.43 cm/day			Difference	
		Initial	Total Evap.	Total Frac. Evap.	Initial	Total Evap.	Total Frac. Evap.	Total Evap.	Total Frac. Evap.
		cm	cm		cm	cm		cm	cm
Mor	B[1]	4.4	3.3	.753	4.3	2.7	.617	0.6	.136
Mor	C[2]	4.2	3.3	.773	3.9	2.3	.581	1.0	.192
Pseudo Duff-Mull (Mor)	D	3.0	2.7	.878	2.9	2.0	.715	0.7	.163
Duff-Mull	F	6.9	3.8	.543	6.8	2.6	.385	1.2	.158
Duff-Mull	G	6.4	4.0	.625	6.3	3.0	.487	1.0	.138
Mull w/F	E	7.1	4.4	.620	7.0	3.5	.503	0.9	.117
Mull w/F	H	5.7	3.9	.681	5.5	3.1	.552	0.8	.129
Mull w/F	K	5.8	3.9	.675	5.6	3.2	.564	0.7	.111
Mull	A	9.4	5.1	.540	9.3	4.2	.451	0.9	.089
Mull	M	7.4	4.6	.617	7.5	4.0	.530	0.6	.087

[1] Average does not include B-2.

[2] Average does not include C-4.

incorporation of organic matter. The organic matter not only improves aggregation, particularly in sands by cemetation (Baver, 1956), but also absorbs and retains water. A good example of this is mor sample C and mull sample H (Tables 4 and 5), both developed on Blue Lake sand. The depth of organic matter is greater for the mor than the mull but probably due to improved structure and incorporated organic matter the mull retains about 1.5-cm more water than the mor at 40-mb tension. In the case of sample B-2, the well-developed root mor, the thickness and water holding capacity of the H horizon contributed to this sample's capacity to retain more water (Table 4).

The data in Tables 4 and 5 also indicate that mors, including the root mor B-2, lose a greater fraction of the total water in the core than either duff-mulls or mulls. However, the water remaining in the mulls and duff-mulls at the end of both the experiments (51 and 53 days) was greater than that in the mors. Any mulching effect due to thicker organic matter accumulations in the mors is not apparent from this phase of the study.

In summary, the mors retain less water after saturation and lose a greater fraction of this water by evaporation than do either mulls or duff-mulls. The total loss, in terms of actual depth of water evaporated, is generally greater at both potential evaporations for mulls and duff-mulls.

During the low potential evaporation experiment a temporary failure of the humidity controls in the environment chamber at 30 days caused the relative humidity to drop from 70 to 30 per cent, increasing the potential evaporation. This situation continued for two days. As shown in Figures 11 through 21 the rate of evaporation increased for all samples and decreased thereafter until the normal rate was reached at approximately 45-48 days. This has several implications. If the evaporation is a true falling rate drying process as defined for a bare soil only the water transmitting properties of the soil control the rate of evaporation and not the atmospheric conditions. Thus, the criteria of the falling rate stage of drying for bare soils appears to fail for these humus-soil complexes. The rate of evaporation for the mulls without an F horizon, samples A and M (Figures 20 and 21) changed only slightly and much less than the other samples due to the increased potential evaporation. This is to be expected since these two mulls most closely represent a bare soil.

The total loss at 53 days appears to be the same whether the change in potential evaporation had occurred or not. W. R. Gardner and Hillel (1962) report similar results for bare soil when covered to prevent evaporation. After the cover was removed the evaporation rate increased until the total corresponded with that of a sample not covered. At any time thereafter the total loss and evaporation rate were the same for both samples. Gardner and Hillel (1962), also report that the addition of a small quantity of water to the soil results in an increased evaporation rate until the quantity added is lost and then the evaporation rate returns to the rate associated with that time had water not been added. The total loss is increased by the amount of water added. Although the work of Gardner and Hillel (1962) does not cover the same situation experienced in the humus-soil cores where an increased evaporation rate occurred due to an increased potential evaporation, it appears that similar mechanisms of water movement and evaporation within the soil are involved.

Water content-depth profiles

Several observations are common to all the water content-depth profiles as a function of time and potential evaporation as shown in Figures 11 through 21. The considerable heterogeneity of the humus-soil cores is reflected in the variation in initial water contents ($t = 0$) between and within horizons. Also noted is the uniform change in water content with depth during a specified time interval, particularly at the lower depths and regardless of the differences in initial water content with depth. In most cases the loss below 10-cm depth was decreasing uniformly as a function of time.

Another observation is that the apparent water loss is the same for both potential evaporations, not only in the horizons above 10-cm but also below this depth. This is due in part to the small differences in evaporation loss at the two potential evaporations. A difference of 1.0-cm in total evaporation is only 0.04 g/cm^3 water content. When this difference in loss is distributed over the time intervals of water content measurement and depth of the core it is generally less at any point than the precision and accuracy of the gamma attenuation instrumentation.

Surface water contents were lower during the low potential evaporation than during the high potential evaporation experiment. It is noted that the initial water content was less in almost every case at the low potential evaporation and this trend continued during the period of evaporation. This demonstrates the resistance to wetting or hydrophobic nature of dry organic matter. Although the cores were saturated in the same manner before each experiment, the organic matter was probably drier after the high potential evaporation experiment than it was when collected in the field and initially saturated.

Water content measurements permitted an analysis of the relative water loss from the surface layers of the cores. This is accomplished by integrating between water content curves for the desired time interval and depth. The integration procedure was accurately and quickly completed by cutting the areas to be integrated from graphs and weighing. This method permitted more flexibility than numerical methods since profiles could be drawn freely between points of water content measurement to adjust for soil heterogeneity.

The results of the above analysis for the representative cores at both potential evaporations are shown in Figures 11 through 21 as part of the cumulative fractional evaporation with time curves. These curves show the average rate of evaporation and cumulative fractional evaporation at the time of water content measurement for the combined F and H horizons (0-FH in the Figures) and total upper 10-cm layer (0-10 cm in the Figures) for the mors and duff-mulls, and the 0- to 5-cm and total upper 10-cm layer for the mulls.

It is quite apparent from Figures 11 through 21 that the total fractional evaporation for the upper 10-cm depth is quite similar for both potential evaporations in each representative core and what differences do exist represent little water. For instance, the total loss in the upper 10-cm of core B-5 is 1.9-cm water at the high potential evaporation and 2.0-cm at the low potential evaporation, a difference of only 0.1-cm (Table 6). Because of the small differences in evaporation loss at both potential evaporations, the difference in quantity of water lost in the upper 10-cm may represent only 0.01 to 0.03 g/cm^3 water content which is within the approximate precision and accuracy of the gamma attenuation instrumentation used. Thus, to show any real differences in loss of water within various layers due to a change in potential evaporation the differences must be greater than those

Table 6. Total fractional evaporation and total evaporation from the surface 10-cm at both potential evaporations for each representative core.

Humus Type	Site-Core	PE = 0.76 cm/day Fractional Evap. 0-FH[1]	FH-10	0-10	Total Evap. 0-10	PE = 0.43 cm/day Fractional Evap. 0-FH	FH-10	0-10	Total Evap. 0-10
					cm				cm
Mor	B-5	.235	.181	.416	1.9	.272	.206	.478	2.0
Mor	C-5	.154	.200	.354	1.4	.107	.236	.343	1.2
Pseudo Duff-Mull (Mor)	D-5	.407	.176	.583	1.9	.427	.158	.585	1.9
Duff-Mull	F-4	.139	.124	.263	1.8	.103	.101	.204	1.4
Duff-Mull	G-5	.117	.122	.239	1.5	.102	.179	.281	1.6
		0-5[2]	5-10	0-10	0-10	0-5	5-10	0-10	0-10
Mull w/F	E-4	.177	.106	.283	1.8	.219	.094	.313	1.9
Mull w/F	H-4	.226	.099	.325	2.0	.181	.097	.278	1.6
Mull w/F	K-5	.225	.153	.378	2.4	.226	.134	.360	2.3
Mull	A-4	.170	.069	.239	2.4	.187	.065	.252	2.5
Mull	M-4	.185	.095	.280	2.1	.168	.105	.273	2.1

[1] 0-FH; surface to bottom of combined FH horizon.
FH-10; bottom of combined FH horizon to 10-cm depth.
0-10; surface to 10-cm depth, sum of 0-FH and FH-10 layers.

[2] 0- 5; surface to 5-cm depth.
5-10; 5- to 10-cm depth.
0-10; surface to 10-cm depth, sum of 0-5 and 5-10 depths.

experienced. This does not detract from the usefulness of the data in determining relative rates of loss or relative loss from layers within the cores.

The cumulative fractional evaporation for 16 days at the high potential evaporation is greater than that at the low potential evaporation for all representative cores (except D-5, Figure 14) and the differences in most cases should be considered real. This indicates that at the higher potential evaporation the initial rate of loss within the surface layers is greater than that at the lower potential evaporation. The total cumulative fractional evaporation for mulls from the 0- to 5-cm depth is generally about twice that of the 5- to 10-cm depth (Table 6). The loss in the mors from the combined F and H horizons is about equal to that from the mineral soil surface to the 10-cm depth. In the well-developed root mor, core B-2, the major loss occurred in the H horizon with only small losses in the underlying 5.3-cm of mineral soil to a total depth of 15-cm (Table 7).

The data in Table 6 indicate that generally the total loss of water from the upper 10-cm in each humus type, in terms of depth of water evaporated, is independent of the initial total water content. Although the mors generally have a greater cumulative fractional evaporation in the upper 10-cm, the total loss in terms of depth of water is similar to that lost in the mulls and duff-mulls.

Table 7. Total fractional evaporation and total evaporation from the surface 15-cm at both potential evaporations for root mor humus type, core B-2.

PE = 0.76 cm/day					PE = 0.43 cm/day				
Fractional Evaporation				Total Evap.	Fractional Evaporation				Total Evap.
0-F[1]	F-H	H-15	0-15	0-15	0-F	F-H	H-15	0-15	0-15
				cm					cm
.086	.341	.079	.506	3.2	.101	.279	.082	.462	2.7

[1]0- F; F horizon.
F- H; H horizon.
H-15; bottom of H horizon to 15-cm depth.
0-15; surface to 15-cm depth.

It is interesting to note in core B-2 (Figure 11), the well-developed root mor, that sometime between 16 and 30 days evaporation from the F horizon ceased for both potential evaporations. This no doubt occurred in the other samples with an F horizon but was not observed because the surface water content measurement was either below the F horizon or the volume measured included part of another horizon. The evaporation rate from the H horizon in core B-2 closely resembles that of the entire core since most of the evaporation loss was from the H.

Discussion of unsaturated flow mechanisms as related to evaporation

Factors effecting the rate and total evaporation from a humus-soil core can be separated into two groups; intrinsic and extrinsic. Intrinsic factors are those within the humus-soil core and extrinsic factors are those outside and controlled externally.

The extrinsic factors are temperature, relative humidity or vapor pressure, air turbulence, and radiant energy supplied to the core surface. During each experiment the above extrinsic factors were held constant with the exception of relative humidity which was varied between experiments.

The intrinsic factors primarily control the transmission of water to the soil surface. Among these factors may be listed the heterogeneity of the humus-soil complex, temperature and vapor pressure gradients due to evaporative cooling, initial water content and water content gradient, matric suction gradient, conductivity, diffusivity and specific water capacity variations between non-homogeneous horizons, and column length. Another intrinsic factor possibly affecting transmission of water in the humus horizons is the property of most organic matter to shrink and change internal structure with changes in water content.

Assuming that Darcy's law is valid for the flow of water in unsaturated soil, the nonsteady-state flow in one direction is generally expressed

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(K\frac{\partial \phi}{\partial z}\right) \qquad (10)$$

where θ is the volumetric water content, t is time, z is distance, ϕ is the total potential and K is the capillary conductivity expressed in length per unit time when ϕ is expressed in units of head. In an isothermal flow system the potential is primarily due to matric or capillary suction and gravity. The value of K has considerable range and is a function of the matric suction or water content with its maximum value at saturation.

For a homogeneous isothermal flow system where a single valued relationship exists between the water content and matric suction the potential can be eliminated from equation (10) by defining the variable diffusivity as

$$D(\theta) = K(\theta)\frac{d\phi}{d\theta} = K(\theta)/C(\theta) \qquad (11)$$

where the diffusivity $D(\theta)$, expressed as length squared per unit time, is a function of the water content and $C(\theta)$ is the specific water capacity, or $d\theta/d\phi$. When gravity is neglected, $C(\theta)$ is the slope of the matric suction-water content curve, $d\theta/dP$. A single valued relationship between the water content and matric suction exists only for a homogeneous column and when water contents are obtained under the same conditions, i.e., during adsorption or desorption. Neglecting gravity and using the relationship of conductivity to diffusivity, the flow equation (10) expressed as a diffusion type equation is

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left(D(\theta)\frac{\partial \theta}{\partial z}\right) \qquad (12)$$

In summary, according to the above theory the isothermal flow of water in unsaturated soil is due primarily to the driving force of the matric suction gradient when the gravitational head is small. The water content gradient can be substituted for the matric suction gradient only when the matric suction-water content relationship is single valued, or in other words, when the soil is homogeneous throughout its depth and is in a complete desorption or adsorption cycle.

The above theory is presented for an isothermal flow system. However, cooling during evaporation results in a temperature gradient and may cause a net transfer of soil water from warmer to cooler regions (Cary, 1966). Flow due to temperature gradients may be in both vapor and liquid phases with the vapor flow primarily as molecular diffusion. As the water content decreases the relative importance of thermally induced flow increases; liquid flow decreases and vapor flow increases. A change in the temperature gradient will have a greater effect on vapor flux because of the exponential relation of vapor pressure with temperature.

Although evaporation from soil is not an isothermal process, it has been shown that the diffusion flow equation (12) adequately describes the major components of flow during evaporation (Philip, 1957; W. R. Gardner, 1959). This is necessarily true when the soils are initially wet or near saturation. At low water contents the thermal gradients are more important and must be considered.

When a homogeneous soil has both uniform initial water content and diffusivity with depth the flux is also uniform with depth at low evaporation rates (W. R. Gardner and Hillel, 1962). Short column lengths and/or high initial water contents will also result in uniform drying with depth (Covey, 1963).

Jensen and Klute (1967) demonstrated in small soil columns that during evaporation water will flow against the water content gradient as vapor in response to a thermal gradient. Under isothermal conditions water flowed as a liquid against the water content gradient in response to the matric suction gradient. In either case the water content decreased with depth in a more or less uniform manner.

During evaporation from a heterogeneous field soil Hallaire (1958) reports that the water contents of successive soil layers to a depth of 60-cm, although not at the same initial water content, decreased uniformly with depth in response to a suction gradient and not the water content gradient. In fact, flow was generally against the moisture gradient. The matric suction varied with depth in a continuous and regular manner except in the surface layers where greater evaporation loss occurred. This indicates that below the surface layers the water flux is proportional to the matric suction gradient.

When evaporation begins from an initially wet or near saturated soil, water flows in response to the suction gradient in both the liquid and vapor phases (Hanks, H. R. Gardner, and Fairbourn, 1967). The vapor flow is restricted to the surface layer. As the soil dries the magnitude of thermal induced flow increases but the major flux is still in response to the suction gradient.

The depth or zone of evaporation has been estimated in a number of ways. H. R. Gardner and Hanks (1966) used heat flux plates and determined that the zone of evaporation moved into the soil from the surface at a continuously decreasing rate and the zone in which evaporation took place was about 1-cm thick. This was also confirmed by Fritton, Kirkham, and Shaw (1967) by observing the depth of dry crust development and salt accumulation. The higher the potential evaporation the deeper the zone of evaporation moved into the soil. Above the zone of evaporation the transfer of water is in the vapor phase, below the zone the transfer is primarily liquid if the soil is sufficiently wet.

From this brief outline of water flow in unsaturated soil during evaporation, some concepts of flow in the humus-soil cores can be developed. Because the initial and final water contents of the samples used in this study were generally high we can conclude from the earlier discussion that thermal gradients were probably slight and only a small percentage of the net flux was thermally induced. Also, any thermal gradients that did develop were probably quickly altered by heat transfer into the soil through the uninsulated core walls because external conditions around the cores were constant. Thus, the following discussion will center on theoretical matric suction gradients as developed during evaporation and their relation to observed results. The discussion will apply to the results from both potential evaporations since only small differences in loss occurred.

From the water content profiles in Figures 11 through 21 it is evident that for all humus types the initial water content in the surface organic or mineral horizons with high organic matter content is greater than that at deeper depths. Since the matric suction was slightly greater at the surface after equilibrium was reached on the tension table, the moisture release characteristics (water content as a function of matric suction) differ from layer to layer reflecting heterogeneity in physical properties and density. Although the matric suction gradient is uniform and continuous with depth (except at the surface) and not affected greatly by heterogeneity, the amount of water loss at each depth is determined by the moisture release characteristics of the soil as controlled by physical properties.

As an example of the forces involved in unsaturated flow within the humus-soil cores the results from a mull will be discussed. For purposes of illustration it will be assumed that the initial matric suction at the surface is equal to that at the bottom when actually there was a slight difference of 25-mb. The initial matric suction P_0 as a function of depth is shown in Figure 22.

Hypothetical moisture release curves for desorption are presented in Figure 23 for a soil with an upper layer h with incorporated organic matter and a deeper mineral layer s. Coarse to medium textured soils, containing a quantity of large pores, as in the deeper mineral layer, have characteristic moisture release curves where the greatest amount of water is lost at relatively low suctions. On the other hand, due to highly absorptive organic matter mixed with mineral soil and improved structure the upper layer retains more water at low suctions and loses water less rapidly with an increase in suction. Thus, the initial water contents of the humus layer θ_{ho} and the mineral soil

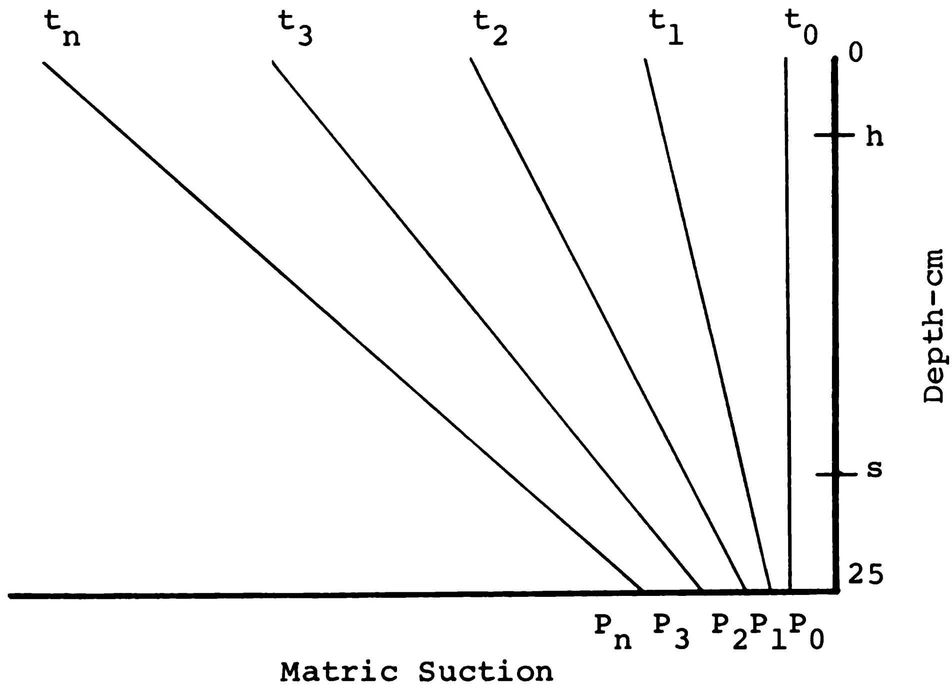

Figure 22. Hypothetical matric suction gradients developed during evaporation as a function of core depth and time.

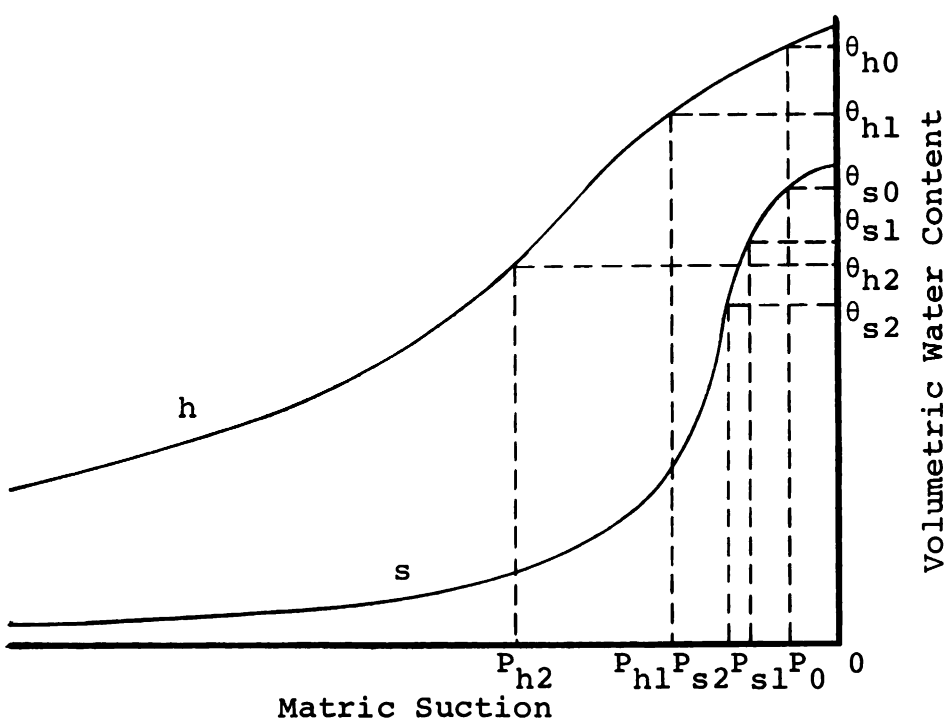

Figure 23. Hypothetical moisture release curves for a humus horizon, h and mineral soil horizon, s.

layer θ_{so} are shown to differ due to the ability of the media to retain water as a function of the matric suction.

As evaporation loss from the humus-soil core continues the matric suction gradient becomes steeper as demonstrated by Hallaire (1958). The change in gradient dP/dX is represented in Figure 22 at times $t_1, t_2, \ldots, t_n$. The matric suction increases in a continuous manner regardless of the heterogeneity except at the surface where a larger gradient exists due to development of a dry layer as evaporation progresses. This surface gradient is not shown in Figure 22.

Translating the information of matric suction as a function of depth to the moisture release curves in Figure 23 readily explains the water content profiles observed during evaporation. As the matric suction increases more rapidly in the upper humus layer it loses more water than does the lower mineral layer. Thus at time t_1, $(\theta_{h1} - \theta_{ho}) > (\theta_{s1} - \theta_{so})$, and at a later time t_2, $(\theta_{h2} - \theta_{h1}) > (\theta_{s2} - \theta_{s1})$. This situation continues for any time interval considered during the period of observation. Depending on the moisture release characteristics, these differences in water loss as shown may decrease with time. It may be concluded that the evaporative loss at any time from a heterogeneous soil is a function of the matric suction gradient and its interaction with the moisture release characteristics as they vary with depth.

The same principles advanced above will also apply to the other humus types. In the mors, instead of a gradual change in physical characteristics with depth there is a sharp discontinuity at the H-A_2 interface. A series of moisture release curves may be constructed for the organic and mineral horizons leading to results similar to those observed.

The actual zone of evaporation in the humus-soil cores is difficult to determine from the water content profiles because of the masking effect of heterogeneity. Differences due to varying the potential evaporation are also masked by heterogeneity and by the small differences in actual water loss as previously discussed. At both potential evaporations the mulls without an F horizon (Figures 20 and 21) generally exhibit a continuous loss of water at the 2- to 3-cm depth indicating that the zone of evaporation was above or within this depth. This depth is similar to that reported by Fritton, et al. (1967) for bare soils under a similar potential evaporation. The zone of evaporation in humus types with an F horizon is most certainly below the F horizon and probably within the H horizon when present since it is still losing water at the end of the experiment. The F horizon may exhibit a continual loss of water over a long period of time due to a slower release to evaporation of the absorbed water in twigs and other woody material. The primary zone of evaporation, the zone where most of the soil water is evaporated, would move into a lower horizon with more continuous smaller pores after the initial water is lost from the F horizon. The F horizon was visually observed to be dry after a few days in most humus types verifying that additional loss was absorbed water.

Comparison of humus types by rates of evaporation and diffusivities

A comparison of the average cumulative fractional evaporation curves for each site indicates that some similarities exist in the general curve shape or change in rate of evaporation with time. Based on these and previously discussed hydrologic properties the humus types can be separated into four groups, each representing a distinct humus condition. The cumulative fractional evaporation curves in Figures 11 through 21, although representative and not an average for each site, nevertheless indicate the general shapes. Differences in shape are more distinct for the average curves of each site.

The four basic hydrologic groups, as represented by general humus types, and characteristics of each are:

1. Mulls without F horizon - includes cores A and M (Figures 20 and 21); initial high evaporation rate rapidly changes at approximately seven days to a continuous, gradual falling rate.
2. Mulls with an F horizon - includes cores E, H and K (Figures 17, 18 and 19); initial evaporation

rate is somewhat constant for 12 to 20 days, and thereafter decreases at a gradual falling rate.

3. Mors and pseudo duff-mulls - includes cores B, C and D (Figures 11, 12, 13 and 14); evaporation rate is uniformly decreasing for the entire period of evaporation.
4. Duff-mulls - includes cores F and G (Figures 15 and 16); evaporation rate also decreases uniformly with time as with mors but rate of decrease is less.

Average diffusivities as a function of the total water content at any time were determined by adapting a procedure presented by W. R. Gardner and Hillel (1962) using a solution of the unsaturated flow equation (12) as outlined by W. R. Gardner (1962). The rate of evaporation is shown to be

$$E = -dW/dt = D(\theta)W\pi^2/4L^2 \qquad (13)$$

where E is the evaporation rate, θ is the average water content of the soil obtained by dividing the total water content W by the length L, and $D(\theta)$ is the known diffusivity function. This assumes an exponential relationship of diffusivity and water content first shown to exist by W. R. Gardner (1958) and greatly facilitates the solution of the diffusion flow equation (12). There is no evidence to support this assumption for all soils, particularly heterogeneous soils.

Using equation (13), W. R. Gardner and Hillel (1962) predicted the rate of evaporation at a very high potential evaporation during the falling rate stage from a homogeneous bare soil. Results were then translated to match the end of the initial constant rate stage at lower potential evaporations to predict the corresponding falling rate stage of evaporation.

Although all the initial boundary conditions were not met in the humus-soil cores, equation (13) was solved for the diffusivity function

$$D(\theta) = (-dW/dt)\,4L^2/W\pi^2 \qquad (14)$$

and average diffusivities as a function of average water contents within the cores were computed.

Plots of the computed diffusivities as a function of water content can be separated into four groups by humus type corresponding to those previously discussed. This is to be expected because (-dW/dt), or E, was the primary variable used in separating the evaporation curves into the four hydrologic groups. The results are presented in Figure 24 for one sample from each group. A similar curve exists for all sampling sites included in each group. Results in Figure 24 are for the high potential evaporation; those computed for the low potential evaporation are comparable but approximately ten per cent lower indicating that boundary conditions were not met.

Diffusivities for mulls without an F horizon and duff-mulls approach a somewhat constant value after an

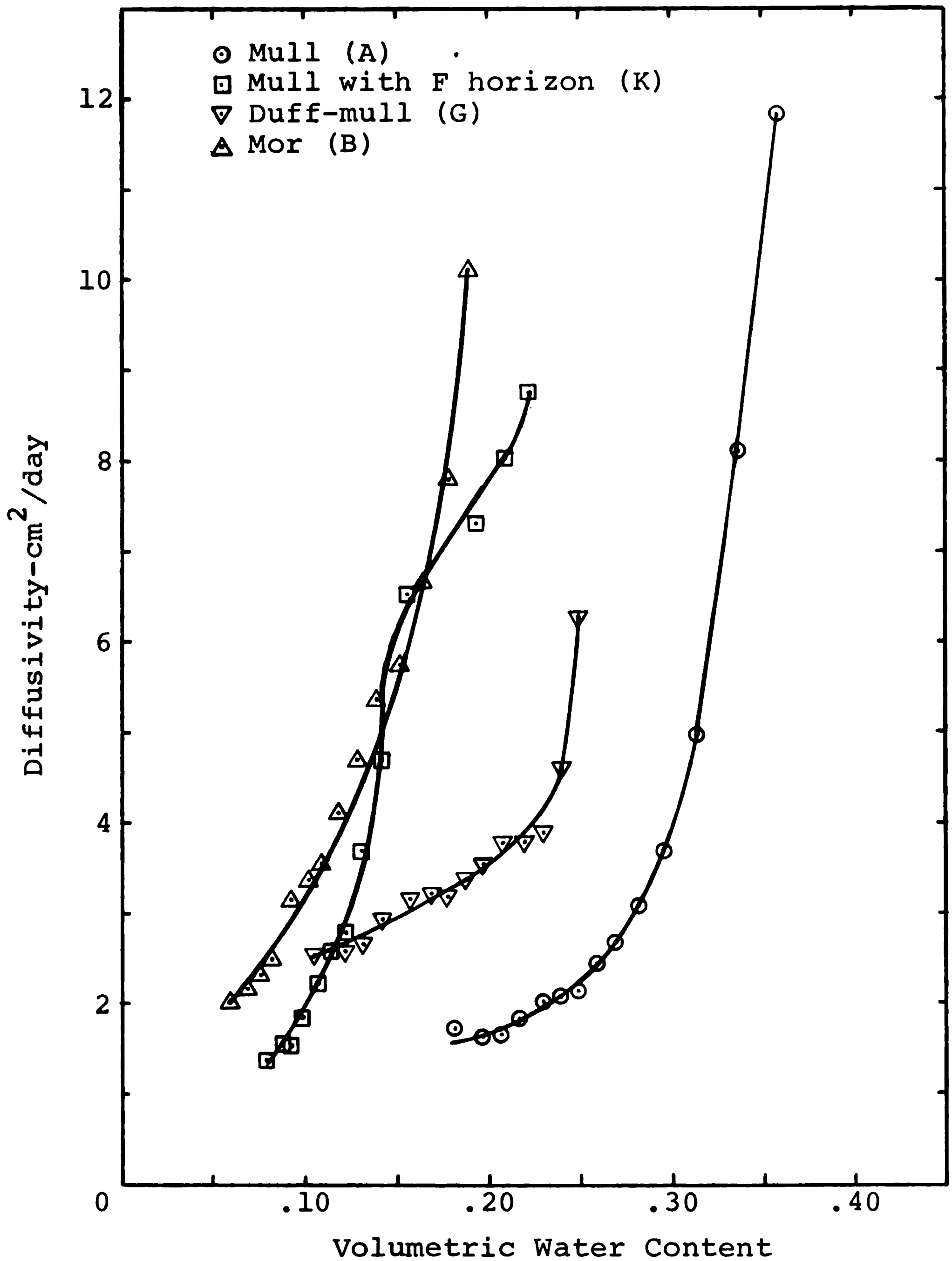

Figure 24. Average diffusivities as a function of water content for representative mull, mull with F horizon, duff-mull, and mor humus types.

initial rapid decline at the start of evaporation. In contrast, the mulls with an F horizon and mors show a relative uniform decrease in diffusivity with decrease in water content. These results must be interpreted as due to an interaction of the humus and mineral soil constituents and not the humus alone because the diffusivities computed are an average for the total core. However, these results do provide a verification of the grouping of humus types by the associated rates of evaporation and suggests a range of diffusivities to expect.

Effects of F horizon removal on evaporation

To determine the role of the F horizon in evaporation one humus-soil core from each sampling site was placed in the environment chamber at the high potential evaporation for 53 days with humus horizons intact. This same procedure was followed for another 53 days after the cores were rewet and the F horizon removed. The resulting changes in evaporation rate and shape of cumulative evaporation curve were similar for each of the humus samples contained in the four hydrologic groups previously described. These results were presented for one humus-soil core from each hydrologic group in Figures 25 and 26. Complete results for cores before and after F horizon removal, including average depth of the F horizon, are presented in Appendix III.

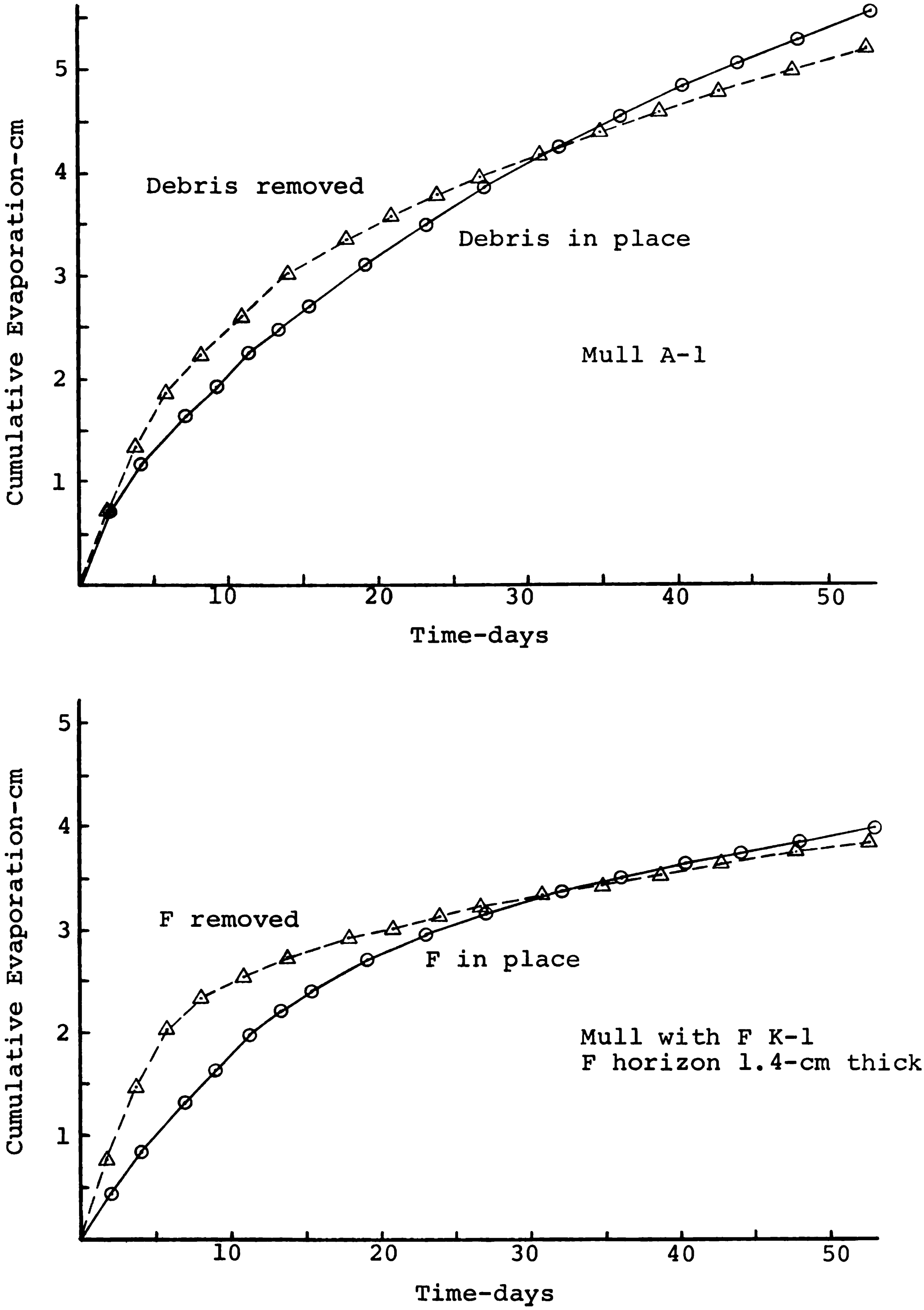

Figure 25. Effect of F horizon removal on cumulative evaporation from mull and mull with F horizon humus types.

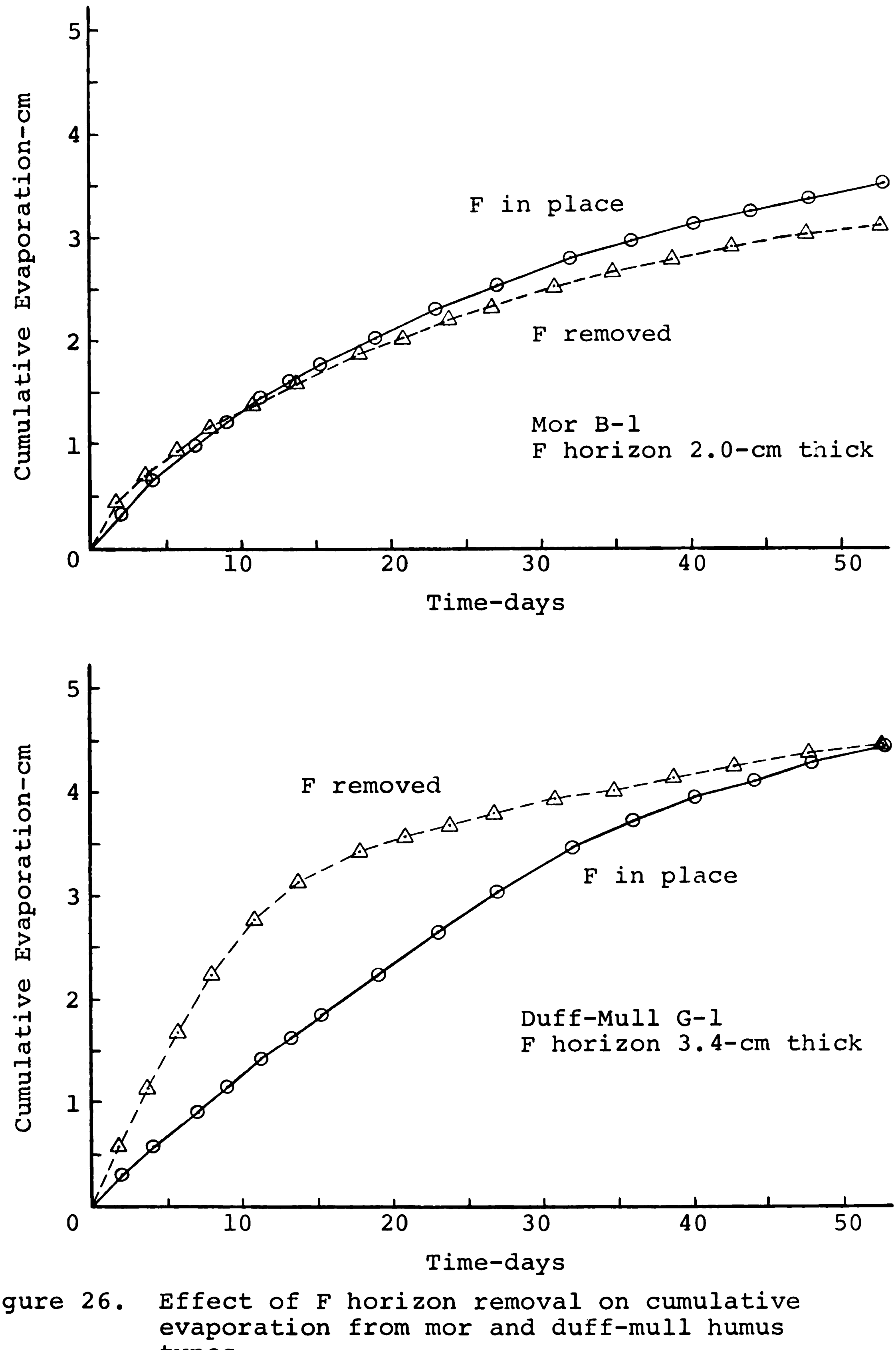

Figure 26. Effect of F horizon removal on cumulative evaporation from mor and duff-mull humus types.

Removal of the F horizon had the greatest effect on mulls that originally had an F and duff-mulls. Evaporation rates increased during the early stages and later decreased such that total cumulative evaporation at 53 days was similar to that when the F horizon was intact. Because the initial quantity of water retained in the core was less after removal of the F horizon, removal resulted in a greater fractional loss. Removal of the F horizon on the mors resulted in little change in the initial evaporation rate but the rate generally decreased at later times. The total cumulative evaporation when the F was removed was less than when the F was intact.

Mulls not having an F horizon are represented by core A in Figure 25. This core does show a change in evaporation rate that is probably due to two factors. Undecomposed debris consisting of leaf petioles and veins and several small twigs, as shown in the photograph Figure 5b, were removed from the surface of the core at the same time the F horizon was removed from the other cores. Although only 5-grams in dry weight, these may have been enough to act as a form of stubble mulch keeping the turbulent air layer further above the soil surface. A second contributing factor may have been a 0.6-cm lower initial water content at the time the organic matter was removed from the surface. Core M, the other mull similar to core A, had nothing removed from its surface and the evaporation curves were the same during both experiments providing a check on the conditions in the environment chamber.

In summary, removal of the F horizon has its greatest effect on mulls and duff-mulls indicating that the F horizon serves a functional role as a mulch even though it initially retains and then later loses water by evaporation. The removal of the F horizon from mors has little effect on the initial rate of evaporation. This indicates only slight mulching effect from an F when underlain by a continuous H horizon in contrast with duff-mulls where the H horizon is generally not continuous and contains mineral matter above or intermixed due to faunal activity.

Infiltration and redistribution of water

Simulated rainfall was applied to a single humus-soil core from each of the ten sampling sites. The intensity of simulated rainfall was 3.0 cm/hour and duration was between 30- and 40-minutes. The initial entrance of water into the core and its subsequent redistribution was followed by gamma attenuation. Water content measurements were continued until the wetting front reached the end of the core, generally after 1.5- to 3-hours. The sample from site M, a mull, developed a few surface cracks during the drying period prior to infiltration and therefore yielded erratic and non-representative data.

Movement of water into and within the humus-soil cores was rapid due to the coarse textured soils and exhibited little difference between humus types. However, some observations can be made regarding differences in water transmission and retention properties of the humus horizons. Changes in water content as a function of depth and time for three of the nine completed cores are presented in Figure 27. These are a mull (A-3), a mull with F horizon (K-4), and a duff-mull (F-2). Cores A-3 and F-2 received approximately 2-cm of water in 40-minutes and K-2 approximately 1.5-cm in 30-minutes. Average times of water content measurement are noted in Figure 27. Solid lines denote water content profiles during water application and dashed lines after application ceased. Horizon depths are also noted. A complete tabulation of volumetric water contents as a function of depth and time for each core are presented in Appendix IV.

Water advanced into the soil as a wetting front maintaining the non-uniform shape of the initial water content profile except at the surface and end of the wetting front. This phenomena results from the matric suction-water content relationship for absorption varying with the heterogeneous soil. Only after the soil becomes sufficiently wet and water has moved into deeper layers does the water content profile become more uniform with depth. Core A-3, Figure 27, is a good example of this phenomena.

Infiltration and advance of the wetting front were similar in the mulls with and without F horizons, and also similar in the mors and duff-mulls. After entering the

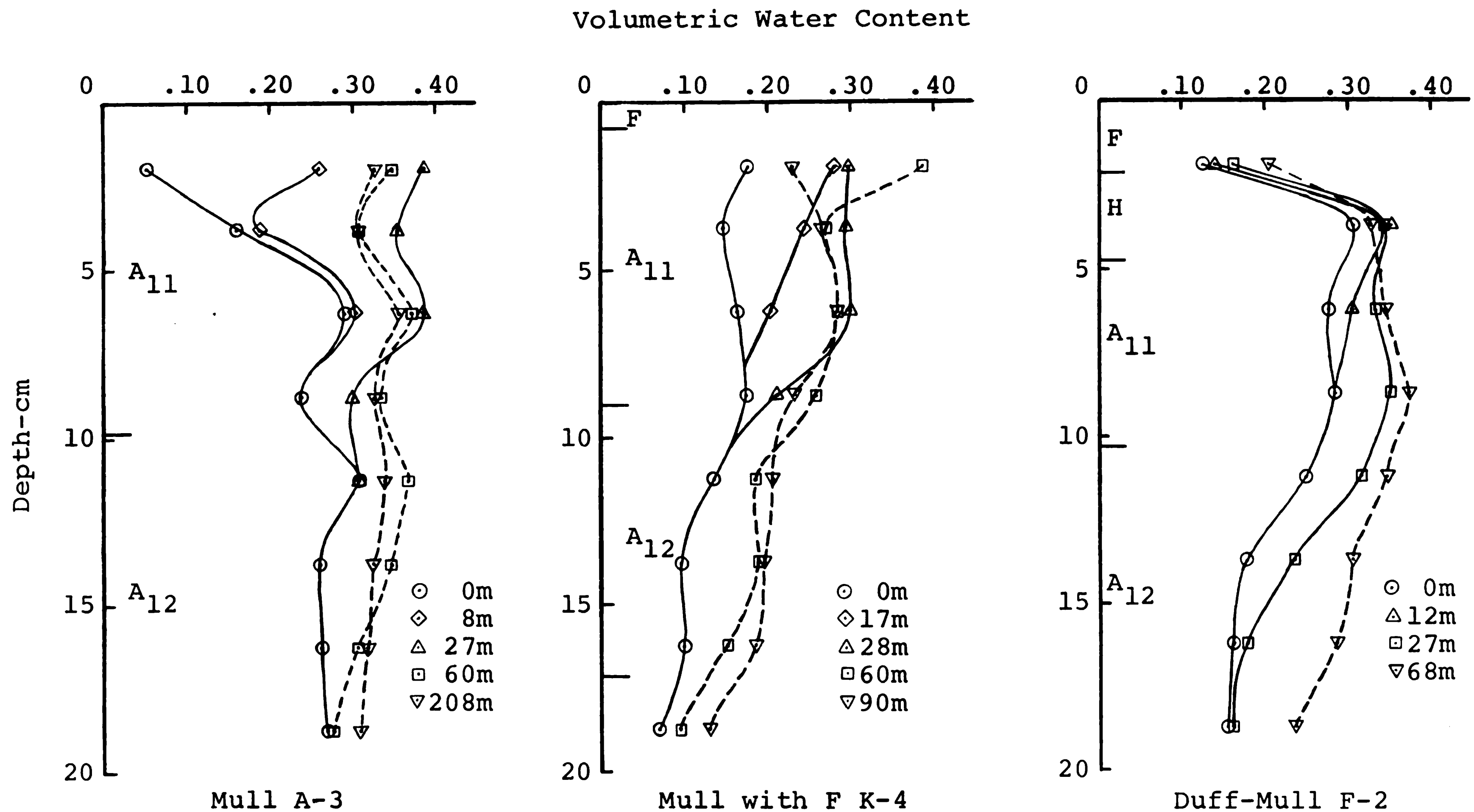

Figure 27. Infiltration and redistribution of water at average times in minutes for representative mull, mull with F, and duff-mull humus types.

soil the wetting front advances in mulls more slowly than in mors and duff-mulls. This is attributed not only to finer soil textures in some mulls but also to incorporated organic matter and improved structure.

Although the F horizon was visibly wet during infiltration, the results from duff-mull F-2 in Figure 27 show the actual water content to increase little during the period of infiltration. This is also true for the H horizon where the water content during infiltration increased from 0.31 to 0.34 g/cm^3, as compared to the water content at 40-mb tension of approximately 0.50 g/cm^3. Apparently in dry organic layers there is a resistance to wetting as previously noted and infiltrating water only wets the organic matter particle surfaces and not the smaller pores. This apparent resistance to wetting was observed in all mor and duff-mull cores except mor B-5.

Because of the resistance to wetting, water moves rapidly through the porous organic matter into the underlying soil. The organic matter does not act as a sponge, at least not during the initial phases of infiltration. It would be expected that for precipitation of long duration, longer than the 30- or 40-minutes used here, more water would be absorbed as the resistance to wetting is reduced with time. However, when precipitation beings, dry organic matter layers serve only to break raindrop impact and provide a means of quick transfer to the mineral soil. Little water is initially retained in the organic matter.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The objectives of this study were 1) to determine the hydrologic influence of forest humus on evaporation and the distribution of water within the humus-soil complex during evaporation; 2) to determine the movement of water into and through humus horizons during infiltration and percolation; and 3) to establish a hydrologic basis for the morphological humus types recognized in White's (1965) proposed humus classification system for the Lake States Region.

Ten sampling sites were chosen in the forested regions of Michigan including a variety of soil and forest conditions and the common humus types of mull, duff-mull, and mor. One other humus type common to the Lake States Region, a pseudo-duff-mull was also sampled. Relatively undisturbed samples 16.5-cm in diameter and 25.4-cm deep were excavated from the humus-soil profile and evaporation experiments were conducted in a laboratory environment chamber under controlled conditions of temperature, relative humidity, air turbulence, and radiant energy. By changing the relative humidity, two different evaporation experiments were conducted on the same samples at potential evaporations from a free water surface of 0.76 and 0.43 cm/day. Average water content changes in 2.5-cm depth increments were determined by the attenuation of a gamma beam transmitted through the humus-soil core.

This study supports the hypothesis that soils with biologically incorporated humus, mulls and duff-mulls, are hydrologically different from mors or mors with colloidal infiltration of organic matter (pseudo duff-mulls).

The humus types included in this study may be logically separated into four hydrologic groups, each apparently not influenced by the site to site variations in mineral soil characteristics. Although based primarily on the change in rate of evaporation with time during a 51- to 53-day period of constant potential evaporation, other hydrologic properties observed during evaporation and infiltration for each humus type also fit into the four hydrologic groupings. The four groups listed by humus type are 1) mulls without an F horizon; 2) mulls with an F horizon; 3) mors, including pseudo duff-mulls; and 4) duff-mulls. These four groups consist of humus types as recognized by White (1965) for the Lake States Region with only the additional distinction being made in the mulls for the presence or absence of an F horizon. This distinction is necessary in hydrologic considerations because of the influence of the F horizon on evaporation.

For every sample included in this study the cumulative evaporation at any time was greater at the high potential evaporation than that at the low potential evaporation. An initial constant rate stage of evaporation of several days duration equal to the evaporation from a free water surface as documented in the literature for homogeneous bare soils (Lemon, 1956; Gardner and Hillel, 1962; Fritton, et al., 1967) was not observed in this study. Thus, during the early stages of evaporation the presence of organic matter, either as separate horizons or incorporated with mineral soil, reduced the initial evaporation loss as compared with that from bare soil.

The falling rate stage of evaporation in the mulls without an F horizon corresponded closely with that described in the literature for homogeneous bare soils where the rate of evaporation depended primarily on the water transmitting properties of the soil and not on atmospheric conditions. In the case of humus types with an organic layer above mineral soil a change to a higher potential evaporation resulted in a significant change in the rate of evaporation. Thus, the presence of organic layers reduce the rate of evaporation to some value lower than the maximum water transmitting properties of the humus-soil complex.

Because of the increased organic matter in the mineral soil horizons and its influence on soil structure and water holding capacity, the mulls and duff-mulls held more water after saturation and subsequent drainage at 40-mb tension than the mors. The mors lost by evaporation a greater fraction of the total initial water content--approximately 80 per cent as compared with approximately 60 per cent for the mulls and duff-mulls at the high potential evaporation. However, since mulls and duff-mulls had a greater water holding capacity, the actual evaporative loss in terms of water depth was generally greater. Results were similar at the low potential evaporation. The difference in evaporation loss between the two potential evaporations ranged from 0.6- to 1.2-cm with an average of 0.9-cm loss for all humus types. This difference represented approximately 0.04 g/cm^3 volumetric water content over the total depth of the core.

Water was observed to flow against the humus-soil water content gradient during evaporation in response to an assumed matric suction gradient. Thermal gradients were assumed negligable. The amount of water loss was governed by the matric suction-water content relationships for each horizon as influenced by the organic matter present. The initial water loss was uniform with depth but as the matric suction gradient increased, greater loss occurred near the surface. Below the 10-cm depth the loss was generally uniform with depth and also uniformly decreasing with time for all humus types. Although the total loss at 50-days from the upper 10-cm was approximately the same for both potential evaporations, the loss during the first 16-days was generally greater at the high potential evaporation. As is the case for loss from the total core, mors had a greater fractional loss in the upper 10-cm. However, the actual total water loss in the upper 10-cm was similar for all humus types. The loss from the 4- to 5-cm thick organic horizons in mors and duff-mulls was generally similar to that lost from the first 5-cm of mineral soil. In the mulls the loss from the upper 5-cm was about twice that of the 5- to 10-cm depth.

During evaporation the F horizon ceased to lose significant amounts of water sometime between 16 and 30 days, regardless of the potential evaporation used in this study. However, the H horizon when present continued to lose water at a decreasing rate for the entire period of study.

The removal of the F horizon had the greatest effect on evaporation from mulls with an F horizon and duff-mulls. In both groups the initial rate of evaporation was increased, but at 53-days the total loss was approximately the same despite the fact that the total water content of the core was greater when the F was present. The shape of the cumulative evaporation curves, or the changes in rate of evaporation with time, for these two groups after the F horizon was removed resembled that of mulls without an F horizon. Removal of the F horizon from mors had little effect on the rate of evaporation and only a slight effect on the total cumulative evaporation at 53 days.

Although there was no direct correlation in change in rate of evaporation with thickness of F horizon removed, there was evidence that a small amount of twigs and undecomposed leaf petioles and veins on the surface of a mull reduced evaporation by providing a thicker layer of non-turbulent air at the soil surface.

When a simulated rainfall of 1.5- to 2-cm in 30- to 40-minutes was applied to a humus-soil core that had been previously dried by evaporation, the water advanced quickly through the soil as a wetting front maintaining the non-uniform shape of the initial water content profile except in the surface layer and at the end of the wetting front. Only after the soil had reached a high water content did the water content profile become more uniform with depth. Infiltration and advance of the wetting front were similar in the mulls with and without F horizons and also similar in the mors and duff-mulls. The rate of wetting front advance was slower in the mulls due to increased organic matter in the mineral soil. These results agree with those earlier reported by Trimble, <u>et al.</u> (1951).

During simulated rainfall the F and H horizons resisted wetting and water moved rapidly through them into the underlying soil. The actual water content of the F and H horizons increased only slightly as the surfaces of the organic matter particles were wetted and not the smaller pores. Thus, the ability of humus to hold water for later infiltration as suggested by Trimble and Lull (1956) is not evident in this study. It could be postulated that as continued wetting occurs during storms of long duration the resistance to wetting reduces with time and the humus increases in water content. But it is doubtful that humus initially retains large quantities of water if the underlying soil's percolation rate is not exceeded. When the percolation rate is exceeded the humus horizons, because of the high porosity, can hold water and offer a resistance to reduce overland flow.

It would be difficult to translate the results of this study to actual quantitative estimates of evaporative loss throughout the year under conditions within the forest. Many factors are involved that were not included in the laboratory study. Under field conditions evaporation as well as transpiration losses will occur simultaneously and because there is generally a high concentration of roots within or near the humus horizons due to greater availability of nutrients and water, the combined losses could considerably alter the quantitative results of this study. In the field there are also varying conditions of potential evaporation as related to wind, humidity, temperature, and radiation and their diurnal and seasonal fluctuations. Repeated wetting and drying, as affected by hysteresis and diurnal temperature changes within the longer natural soil profile will result in conditions different from those in the laboratory and consequently result in different rates of evaporation. During a period of evaporation under field conditions there is usually a downward movement of water in unsaturated soil in response to gravity, much more so than that which occurred in the laboratory samples where effects of gravity are negligible. It is expected that the downward movement of water in the field will remove water from the surface layers and will result in a reduced evaporation loss as compared with the loss at the same potential evaporation in the laboratory.

Although these results cannot be used for quantitative field estimates, the results do indicate the relative differences in hydrologic properties between humus types from one geographical region and their relation to a proposed humus classification system. Hydrologic properties alone cannot be used to classify humus and morphologic characteristics and degree of biological activity as proposed by White (1965) must still be used as a practical basis for field classification. However, hydrologic properties parallel the humus classification system and support the validity of the distinct types as found in the Lake States Region.

The results of this study provide a basis for additional investigation in two general areas. One study would be a detailed investigation of several samples similar to those used in this study where not only water content but matric suction and temperature are also measured throughout the sample depth. This is not a simple task because non-destructive placement of tensiometers and temperature sensors is difficult. There is also the problem of keeping continuous contact between the tensiometer and humus as the humus shrinks during drying. If these problems can be solved, the validity of the unsaturated soil flow equations may be tested for the non-homogeneous system and the magnitude and direction of vapor and liquid flow in response to temperature and suction gradients can be determined. If the effects of different potential evaporations are desired in a future study, the differences between potential evaporations must be greater than the 0.33 cm/day used in this study. A greater difference can be achieved by varying the temperature and radiation input as well as relative humidity.

Another area in which the results of this study would be useful is the establishment of field plot studies to determine the actual role of the various humus types in the forest hydrologic cycle.[2] The gamma attenuation instrumentation used in this study to measure water contents proved successful under laboratory conditions and based on

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[2]A preliminary field investigation was originally included as part of this study's objectives but was cancelled when the gamma attenuation instrument was lost and damaged during shipment at the beginning of the field season and not returned in operating condition for several months.

results of field measurements of snow and sediment density (Smith, Willen, and Owens, 1965; McHenry and Dendy, 1964) could be used in the field to measure water contents after careful calibration. Temperature sensitivity of the detector photomultiplier tube and difficulty in determining actual volumetric water contents to serve as a point of reference at the beginning are problems which must be overcome before this instrumentation can be successful in the field. This latter problem is reduced somewhat if relative volumetric water contents will meet the objectives of the field investigation.

Water contents as determined by gamma attenuation and related matric suctions at each depth increment on controlled field plots can provide estimates of evaporation, transpiration, and downward movement. Results of this type will only be estimates until the problems presented by continuous wetting and drying and hysteresis can be solved. In a slowly changing system as found in the field, however, it may be possible to use an average soil water conductivity or diffusivity for each distinct homogeneous layer to represent the unsaturated flow in light of the other problems presented by heterogeneity and non-uniform removal of water by plant roots in the soil profile.

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APPENDIX

APPENDIX I. CUMULATIVE AND CUMULATIVE FRACTIONAL EVAPORATION AS A FUNCTION OF POTENTIAL EVAPORATION AND TIME; AND INITIAL WATER CONTENTS FOR EACH HUMUS-SOIL CORE.

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME		CORE: A-2		A-3		A-4		A-5		A-AVG	
DAYS	HOURS	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.4	.042	0.7	.077	0.5	.051	0.6	.075	0.6	.060
3.3	80	0.8	.080	1.3	.146	1.1	.112	1.3	.161	1.1	.122
6.4	154	1.2	.122	1.8	.201	1.8	.176	2.0	.237	1.7	.181
9.3	224	1.6	.158	2.2	.240	2.2	.221	2.3	.284	2.1	.222
12.3	296	2.0	.192	2.5	.272	2.6	.258	2.7	.322	2.4	.257
15.3	368	2.3	.223	2.7	.299	2.9	.289	2.9	.356	2.7	.288
18.3	440	2.6	.251	3.0	.324	3.2	.318	3.2	.386	3.0	.316
21.4	513	2.8	.276	3.2	.347	3.4	.343	3.4	.412	3.2	.341
24.3	584	3.1	.301	3.4	.368	3.6	.367	3.6	.437	3.4	.364
29.3	704	3.5	.340	3.7	.402	4.0	.405	3.9	.480	3.8	.403
33.3	800	3.8	.368	3.9	.427	4.3	.434	4.2	.509	4.0	.431
37.3	896	4.0	.393	4.1	.450	4.6	.459	4.4	.537	4.3	.456
41.3	992	4.3	.417	4.3	.472	4.8	.485	4.6	.565	4.5	.481
50.3	1208	4.9	.473	4.8	.524	5.5	.549	5.2	.628	5.1	.540
INITIAL WATER CONTENT (CM)		10.3		9.1		10.0		8.2		9.4	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME		CORE: A-2		A-3		A-4		A-5		A-AVG	
DAYS	HOURS	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP	CUM EVAP CM	CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.4	.041	0.5	.058	0.4	.042	0.4	.052	0.4	.047
3.6	87	0.7	.074	1.1	.115	0.8	.083	0.8	.103	0.9	.093
6.6	159	1.2	.116	1.8	.192	1.4	.142	1.4	.174	1.4	.154
9.6	231	1.4	.140	2.3	.248	1.9	.192	2.0	.243	1.9	.203
12.6	303	1.6	.165	2.6	.282	2.3	.235	2.4	.300	2.3	.242
16.6	399	1.9	.192	2.9	.314	2.7	.276	2.8	.345	2.6	.278
19.6	470	2.1	.210	3.1	.332	2.9	.295	3.0	.371	2.8	.298
23.6	566	2.3	.233	3.3	.355	3.2	.327	3.2	.400	3.0	.324
26.6	638	2.5	.250	3.5	.371	3.4	.345	3.4	.419	3.2	.342
32.6	783	2.9	.292	3.8	.411	3.8	.388	3.7	.464	3.6	.384
37.6	903	3.1	.311	4.0	.427	4.0	.410	3.9	.483	3.8	.403
41.6	999	3.3	.326	4.1	.438	4.2	.424	4.0	.497	3.9	.417
49.7	1193	3.5	.352	4.3	.457	4.4	.449	4.2	.521	4.1	.440
52.6	1263	3.6	.363	4.3	.466	4.5	.459	4.3	.533	4.2	.451
INITIAL WATER CONTENT (CM)		10.0		9.3		9.8		8.0		9.3	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

CORE:		B-2		B-3		B-4		B-5		B-AVG	
TIME		CUM EVAP	CJM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.2	.038	0.3	.073	0.2	.048	0.3	.055	0.3	.052
3.3	80	0.5	.079	0.6	.155	0.5	.106	0.6	.121	0.5	.111
6.4	154	0.9	.136	1.0	.252	0.8	.183	1.0	.213	0.9	.190
9.3	224	1.2	.182	1.4	.329	1.1	.252	1.3	.287	1.3	.254
12.3	296	1.5	.239	1.6	.393	1.4	.314	1.6	.353	1.6	.315
15.3	368	1.9	.289	1.8	.445	1.7	.371	1.9	.411	1.8	.369
18.3	440	2.1	.332	2.0	.490	1.9	.418	2.2	.465	2.1	.416
21.4	513	2.4	.373	2.2	.527	2.1	.459	2.4	.512	2.3	.458
24.3	584	2.6	.412	2.3	.557	2.2	.497	2.6	.556	2.4	.496
29.3	704	3.0	.473	2.5	.606	2.5	.555	2.9	.628	2.7	.556
33.3	800	3.3	.515	2.6	.637	2.7	.597	3.1	.663	2.9	.594
37.3	896	3.6	.554	2.7	.663	2.8	.630	3.3	.704	3.1	.630
41.3	992	3.8	.594	2.9	.689	3.0	.664	3.4	.735	3.3	.663
50.3	1208	4.4	.690	3.1	.743	3.3	.726	3.7	.789	3.6	.733
INITIAL WATER CONTENT (CM)		6.4		4.1		4.5		4.7		4.9	

POTENTIAL EVAPORATION = 0.43 CM/DAY

CORE:		B-2		B-3		B-4		B-5		B-AVG	
TIME		CUM EVAP	CJM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.028	0.2	.052	0.2	.036	0.2	.039	0.2	.037
3.6	87	0.3	.055	0.4	.102	0.3	.067	0.3	.078	0.3	.074
6.6	159	0.5	.087	0.7	.161	0.5	.109	0.5	.128	0.6	.118
9.6	231	0.7	.122	0.9	.213	0.7	.151	0.8	.178	0.8	.162
12.6	303	0.9	.155	1.1	.259	0.9	.192	1.0	.229	1.0	.204
16.6	399	1.2	.197	1.3	.315	1.1	.240	1.2	.289	1.2	.255
19.6	470	1.3	.225	1.5	.353	1.2	.275	1.4	.331	1.4	.290
23.6	566	1.6	.265	1.7	.404	1.4	.324	1.6	.388	1.6	.338
26.6	638	1.8	.297	1.9	.439	1.6	.359	1.8	.429	1.8	.373
32.6	783	2.2	.379	2.2	.523	2.0	.441	2.2	.530	2.2	.460
37.6	903	2.5	.416	2.3	.553	2.1	.482	2.4	.575	2.3	.498
41.6	999	2.6	.443	2.4	.570	2.3	.508	2.6	.605	2.5	.524
49.7	1193	2.9	.485	2.5	.598	2.4	.549	2.7	.649	2.6	.562
52.6	1263	3.0	.502	2.6	.611	2.5	.568	2.8	.671	2.7	.580
INITIAL WATER CONTENT (CM)		5.9		4.2		4.4		4.2		4.7	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	TIME HOURS	C-2 CUM EVAP CM	C-2 CUM FRAC EVAP	C-3 CUM EVAP CM	C-3 CUM FRAC EVAP	C-4 CUM EVAP CM	C-4 CUM FRAC EVAP	C-5 CUM EVAP CM	C-5 CUM FRAC EVAP	C-AVG CUM EVAP CM	C-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.2	.044	0.3	.064	0.2	.028	0.2	.053	0.2	.044
3.3	80	0.4	.093	0.5	.117	0.5	.059	0.4	.109	0.4	.088
6.4	154	0.8	.160	0.8	.183	0.8	.098	0.7	.176	0.7	.144
9.3	224	1.0	.215	1.0	.241	1.0	.134	0.9	.231	1.0	.193
12.3	296	1.3	.272	1.2	.302	1.3	.168	1.1	.285	1.2	.242
15.3	368	1.6	.324	1.5	.358	1.5	.201	1.3	.339	1.5	.287
18.3	440	1.8	.374	1.7	.411	1.8	.233	1.5	.392	1.7	.332
21.4	513	2.0	.421	1.9	.459	2.0	.265	1.7	.439	1.9	.373
24.3	584	2.2	.467	2.1	.507	2.3	.295	1.9	.490	2.1	.415
29.3	704	2.6	.541	2.4	.581	2.7	.347	2.2	.567	2.5	.481
33.3	800	2.8	.589	2.6	.631	3.0	.386	2.4	.619	2.7	.527
37.3	896	3.1	.636	2.8	.674	3.3	.424	2.6	.665	2.9	.569
41.3	992	3.3	.679	2.9	.708	3.5	.461	2.7	.706	3.1	.608
50.3	1208	3.7	.763	3.2	.773	4.2	.543	3.0	.782	3.5	.686
INITIAL WATER CONTENT (CM)		4.8		4.1		7.7		3.8		5.1	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	TIME HOURS	C-2 CUM EVAP CM	C-2 CUM FRAC EVAP	C-3 CUM EVAP CM	C-3 CUM FRAC EVAP	C-4 CUM EVAP CM	C-4 CUM FRAC EVAP	C-5 CUM EVAP CM	C-5 CUM FRAC EVAP	C-AVG CUM EVAP CM	C-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.038	0.2	.049	0.2	.022	0.1	.035	0.2	.033
3.6	87	0.3	.071	0.3	.087	0.3	.041	0.3	.070	0.3	.062
6.6	159	0.5	.110	0.5	.128	0.5	.064	0.4	.107	0.5	.095
9.6	231	0.6	.147	0.7	.164	0.7	.085	0.5	.141	0.6	.125
12.6	303	0.8	.183	0.8	.199	0.8	.106	0.6	.176	0.8	.154
16.6	399	1.0	.227	1.0	.242	1.0	.131	0.8	.214	0.9	.190
19.6	470	1.1	.257	1.1	.274	1.2	.150	0.9	.241	1.1	.215
23.6	566	1.3	.301	1.3	.315	1.4	.175	1.0	.286	1.2	.251
26.6	638	1.4	.336	1.4	.351	1.5	.195	1.1	.318	1.4	.280
32.6	783	1.8	.423	1.8	.454	1.9	.250	1.5	.411	1.8	.359
37.6	903	2.0	.467	2.0	.498	2.2	.281	1.6	.461	2.0	.399
41.6	999	2.1	.499	2.1	.527	2.3	.302	1.8	.495	2.1	.426
49.7	1193	2.3	.546	2.3	.576	2.7	.342	2.0	.552	2.3	.472
52.6	1263	2.4	.567	2.4	.598	2.8	.358	2.1	.578	2.4	.493
INITIAL WATER CONTENT (CM)		4.2		4.0		7.8		3.6		4.9	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	HOURS	CORE: D-2 CUM EVAP CM	D-2 CUM FRAC EVAP	D-3 CUM EVAP CM	D-3 CUM FRAC EVAP	D-4 CUM EVAP CM	D-4 CUM FRAC EVAP	D-5 CUM EVAP CM	D-5 CUM FRAC EVAP	D-AVG CUM EVAP CM	D-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.2	.077	0.2	.087	0.2	.077	0.2	.063	0.2	.076
3.3	80	0.4	.154	0.5	.183	0.5	.157	0.4	.127	0.5	.154
6.4	154	0.8	.266	0.8	.296	0.8	.252	0.7	.210	0.8	.254
9.3	224	1.1	.362	1.1	.382	1.0	.334	0.9	.281	1.0	.337
12.3	296	1.3	.462	1.3	.454	1.3	.418	1.1	.346	1.3	.417
15.3	368	1.6	.542	1.4	.512	1.5	.495	1.4	.411	1.5	.487
18.3	440	1.8	.619	1.6	.564	1.7	.568	1.5	.464	1.7	.551
21.4	513	2.0	.676	1.7	.604	1.9	.632	1.7	.511	1.8	.603
24.3	584	2.1	.734	1.8	.641	2.1	.694	1.8	.554	2.0	.653
29.3	704	2.3	.806	2.0	.694	2.3	.774	2.0	.617	2.2	.720
33.3	800	2.5	.845	2.1	.734	2.5	.818	2.2	.661	2.3	.762
37.3	896	2.5	.877	2.2	.762	2.6	.852	2.3	.699	2.4	.795
41.3	992	2.6	.899	2.2	.791	2.7	.875	2.4	.736	2.5	.823
50.3	1208	2.7	.938	2.4	.854	2.8	.922	2.7	.807	2.7	.878
INITIAL WATER CONTENT (CM)		2.9		2.8		3.0		3.3		3.0	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	HOURS	CORE: D-2 CUM EVAP CM	D-2 CUM FRAC EVAP	D-3 CUM EVAP CM	D-3 CUM FRAC EVAP	D-4 CUM EVAP CM	D-4 CUM FRAC EVAP	D-5 CUM EVAP CM	D-5 CUM FRAC EVAP	D-AVG CUM EVAP CM	D-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.070	0.2	.068	0.2	.063	0.1	.047	0.2	.061
3.6	87	0.3	.125	0.4	.129	0.3	.114	0.3	.092	0.3	.114
6.6	159	0.5	.190	0.6	.206	0.5	.176	0.5	.145	0.5	.178
9.6	231	0.6	.249	0.8	.279	0.7	.234	0.6	.196	0.7	.238
12.6	303	0.8	.310	1.0	.345	0.8	.287	0.8	.243	0.8	.294
16.6	399	1.0	.381	1.2	.414	1.0	.347	0.9	.296	1.0	.357
19.6	470	1.1	.429	1.3	.457	1.1	.388	1.1	.335	1.1	.400
23.6	566	1.2	.491	1.5	.512	1.2	.444	1.2	.389	1.3	.457
26.6	638	1.4	.537	1.6	.554	1.4	.484	1.4	.426	1.4	.497
32.6	783	1.6	.645	1.9	.651	1.6	.584	1.7	.526	1.7	.598
37.6	903	1.7	.678	2.0	.680	1.7	.622	1.8	.567	1.8	.634
41.6	999	1.8	.705	2.0	.700	1.8	.643	1.9	.596	1.9	.658
49.7	1193	1.9	.740	2.1	.731	1.9	.678	2.0	.640	2.0	.695
52.6	1263	1.9	.762	2.2	.749	2.0	.698	2.1	.660	2.0	.715
INITIAL WATER CONTENT (CM)		2.5		2.9		2.8		3.2		2.9	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	TIME HOURS	CORE: E-2 CUM EVAP CM	E-2 CUM FRAC EVAP	E-3 CUM EVAP CM	E-3 CUM FRAC EVAP	E-4 CUM EVAP CM	E-4 CUM FRAC EVAP	E-5 CUM EVAP CM	E-5 CUM FRAC EVAP	E-AVG CUM EVAP CM	E-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.3	.034	0.2	.030	0.3	.050	0.2	.036	0.3	.037
3.3	80	0.7	.081	0.5	.064	0.7	.117	0.5	.080	0.6	.084
6.4	154	1.2	.150	0.8	.115	1.3	.196	0.9	.135	1.1	.148
9.3	224	1.7	.214	1.2	.161	1.6	.249	1.2	.185	1.4	.202
12.3	296	2.2	.274	1.5	.209	1.9	.295	1.6	.234	1.8	.253
15.3	368	2.6	.324	1.9	.256	2.1	.335	1.9	.281	2.1	.299
18.3	440	3.0	.364	2.2	.302	2.4	.368	2.2	.324	2.4	.340
21.4	513	3.2	.397	2.5	.348	2.5	.398	2.4	.363	2.7	.377
24.3	584	3.5	.428	2.8	.392	2.7	.427	2.7	.400	2.9	.412
29.3	704	3.8	.472	3.3	.461	3.0	.473	3.0	.454	3.3	.465
33.3	800	4.1	.501	3.7	.508	3.2	.506	3.3	.492	3.6	.502
37.3	896	4.3	.527	4.0	.546	3.4	.532	3.5	.524	3.8	.532
41.3	992	4.5	.553	4.2	.580	3.6	.558	3.7	.553	4.0	.561
50.3	1208	4.9	.606	4.7	.651	3.9	.614	4.1	.610	4.4	.620
INITIAL WATER CONTENT (CM)		8.2		7.3		6.4		6.6		7.1	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	TIME HOURS	CORE: E-2 CUM EVAP CM	E-2 CUM FRAC EVAP	E-3 CUM EVAP CM	E-3 CUM FRAC EVAP	E-4 CUM EVAP CM	E-4 CUM FRAC EVAP	E-5 CUM EVAP CM	E-5 CUM FRAC EVAP	E-AVG CUM EVAP CM	E-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.024	0.2	.024	0.2	.038	0.2	.026	0.2	.027
3.6	87	0.4	.049	0.3	.048	0.5	.075	0.3	.053	0.4	.055
6.6	159	0.7	.085	0.6	.077	0.8	.128	0.6	.086	0.6	.093
9.6	231	1.0	.121	0.8	.106	1.1	.180	0.8	.119	0.9	.129
12.6	303	1.2	.158	1.0	.133	1.4	.229	1.0	.152	1.2	.165
16.6	399	1.6	.204	1.2	.169	1.8	.287	1.3	.192	1.5	.210
19.6	470	1.9	.238	1.4	.196	2.0	.321	1.5	.222	1.7	.242
23.6	566	2.2	.285	1.7	.234	2.2	.358	1.7	.263	2.0	.283
26.6	638	2.5	.319	2.0	.267	2.4	.382	1.9	.293	2.2	.313
32.6	783	3.1	.391	2.7	.365	2.7	.441	2.5	.374	2.7	.391
37.6	903	3.3	.419	3.1	.417	2.9	.466	2.7	.414	3.0	.428
41.6	999	3.5	.438	3.3	.449	3.0	.482	2.9	.438	3.1	.451
49.7	1193	3.7	.466	3.7	.501	3.1	.509	3.2	.481	3.4	.488
52.6	1263	3.8	.479	3.8	.521	3.2	.520	3.3	.498	3.5	.503
INITIAL WATER CONTENT (CM)		7.9		7.3		6.2		6.5		7.0	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	TIME HOURS	CORE: F=2 CUM EVAP CM	CORE: F=2 CUM FRAC EVAP	F=3 CUM EVAP CM	F=3 CUM FRAC EVAP	F=4 CUM EVAP CM	F=4 CUM FRAC EVAP	F=5 CUM EVAP CM	F=5 CUM FRAC EVAP	F-AVG CUM EVAP CM	F-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.3	.034	0.2	.033	0.2	.030	0.3	.037	0.2	.034
3.3	80	0.4	.061	0.4	.066	0.4	.064	0.5	.075	0.5	.067
6.4	154	0.7	.096	0.7	.109	0.7	.108	0.9	.124	0.8	.109
9.3	224	0.9	.127	1.0	.149	1.0	.146	1.2	.168	1.0	.147
12.3	296	1.2	.159	1.2	.189	1.2	.185	1.5	.210	1.3	.186
15.3	368	1.4	.188	1.5	.226	1.5	.222	1.8	.252	1.5	.222
18.3	440	1.6	.217	1.7	.257	1.7	.257	2.1	.293	1.8	.256
21.4	513	1.8	.244	1.9	.287	1.9	.287	2.4	.329	2.0	.287
24.3	584	2.0	.271	2.0	.315	2.1	.321	2.7	.365	2.2	.318
29.3	704	2.3	.315	2.3	.360	2.5	.374	3.1	.421	2.6	.368
33.3	800	2.5	.346	2.5	.391	2.7	.411	3.4	.461	2.8	.403
37.3	896	2.8	.376	2.7	.421	3.0	.446	3.7	.500	3.0	.436
41.3	992	3.0	.405	2.9	.449	3.2	.478	3.9	.535	3.2	.467
50.3	1208	3.5	.476	3.4	.523	3.6	.546	4.6	.623	3.8	.543
INITIAL WATER CONTENT (CM)		7.3		6.5		6.7		7.3		6.9	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	TIME HOURS	CORE: F=2 CUM EVAP CM	CORE: F=2 CUM FRAC EVAP	F=3 CUM EVAP CM	F=3 CUM FRAC EVAP	F=4 CUM EVAP CM	F=4 CUM FRAC EVAP	F=5 CUM EVAP CM	F=5 CUM FRAC EVAP	F-AVG CUM EVAP CM	F-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.027	0.2	.028	0.2	.023	0.2	.027	0.2	.026
3.6	87	0.3	.046	0.3	.052	0.3	.045	0.3	.051	0.3	.048
6.6	159	0.5	.065	0.5	.081	0.5	.070	0.5	.078	0.5	.073
9.6	231	0.6	.084	0.7	.109	0.6	.094	0.7	.103	0.7	.097
12.6	303	0.7	.102	0.9	.136	0.8	.116	0.9	.128	0.8	.120
16.6	399	0.9	.126	1.1	.169	1.0	.141	1.1	.161	1.0	.149
19.6	470	1.0	.143	1.2	.193	1.1	.162	1.3	.184	1.1	.170
23.6	566	1.2	.166	1.4	.224	1.3	.191	1.5	.216	1.3	.199
26.6	638	1.3	.186	1.6	.248	1.4	.213	1.6	.239	1.5	.221
32.6	783	1.7	.240	2.0	.309	1.9	.283	2.1	.304	1.9	.283
37.6	903	1.9	.266	2.2	.336	2.1	.315	2.3	.339	2.1	.313
41.6	999	2.0	.285	2.3	.355	2.3	.335	2.5	.364	2.3	.334
49.7	1193	2.2	.318	2.5	.384	2.5	.371	2.8	.407	2.5	.369
52.6	1263	2.3	.332	2.5	.397	2.6	.386	2.9	.425	2.6	.385
INITIAL WATER CONTENT (CM)		7.0		6.4		6.8		6.9		6.8	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	TIME HOURS	CORE: G-2 CUM EVAP CM	G-2 CUM FRAC EVAP	G-3 CUM EVAP CM	G-3 CUM FRAC EVAP	G-4 CUM EVAP CM	G-4 CUM FRAC EVAP	G-5 CUM EVAP CM	G-5 CUM FRAC EVAP	G-AVG CUM EVAP CM	G-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.2	.029	0.2	.028	0.2	.037	0.2	.034	0.2	.032
3.3	80	0.4	.064	0.3	.053	0.5	.079	0.5	.072	0.4	.067
6.4	154	0.7	.109	0.5	.088	0.9	.132	0.8	.121	0.7	.113
9.3	224	1.0	.150	0.8	.122	1.2	.182	1.0	.164	1.0	.155
12.3	296	1.3	.197	1.0	.157	1.5	.230	1.3	.207	1.3	.198
15.3	368	1.6	.238	1.2	.188	1.8	.276	1.6	.252	1.5	.239
18.3	440	1.8	.274	1.4	.220	2.1	.318	1.9	.296	1.8	.278
21.4	513	2.0	.309	1.6	.252	2.3	.359	2.1	.337	2.0	.315
24.3	584	2.3	.344	1.8	.286	2.6	.396	2.4	.377	2.2	.351
29.3	704	2.7	.403	2.1	.342	3.0	.456	2.8	.444	2.6	.412
33.3	800	2.9	.445	2.4	.386	3.2	.497	3.1	.500	2.9	.457
37.3	896	3.2	.483	2.6	.425	3.5	.535	3.4	.547	3.2	.498
41.3	992	3.5	.524	2.9	.466	3.7	.568	3.7	.590	3.4	.538
50.3	1208	4.1	.611	3.5	.567	4.2	.643	4.2	.676	4.0	.625
INITIAL WATER CONTENT (CM)		6.6		6.2		6.5		6.3		6.4	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	TIME HOURS	CORE: G-2 CUM EVAP CM	G-2 CUM FRAC EVAP	G-3 CUM EVAP CM	G-3 CUM FRAC EVAP	G-4 CUM EVAP CM	G-4 CUM FRAC EVAP	G-5 CUM EVAP CM	G-5 CUM FRAC EVAP	G-AVG CUM EVAP CM	G-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.030	0.1	.020	0.2	.029	0.1	.022	0.2	.025
3.6	87	0.4	.059	0.2	.038	0.4	.059	0.2	.042	0.3	.050
6.6	159	0.6	.097	0.4	.059	0.7	.097	0.4	.068	0.5	.081
9.6	231	0.8	.134	0.5	.082	0.9	.134	0.6	.095	0.7	.112
12.6	303	1.0	.169	0.7	.104	1.1	.169	0.7	.122	0.9	.142
16.6	399	1.3	.212	0.9	.134	1.4	.210	0.9	.154	1.1	.178
19.6	470	1.5	.241	1.0	.153	1.6	.240	1.0	.178	1.3	.204
23.6	566	1.7	.281	1.2	.183	1.9	.280	1.2	.214	1.5	.240
26.6	638	1.9	.311	1.3	.208	2.1	.310	1.4	.240	1.7	.268
32.6	783	2.4	.391	1.8	.276	2.8	.421	1.9	.319	2.2	.353
37.6	903	2.7	.439	2.0	.315	2.9	.427	2.1	.360	2.4	.386
41.6	999	2.9	.469	2.2	.342	3.1	.463	2.3	.389	2.6	.416
49.7	1193	3.2	.528	2.5	.393	3.4	.506	2.6	.438	2.9	.467
52.6	1263	3.3	.551	2.6	.413	3.5	.524	2.7	.459	3.0	.487
INITIAL WATER CONTENT (CM)		6.1		6.4		6.8		5.8		6.3	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	HOURS	CORE: H=2 CUM EVAP CM	CUM FRAC EVAP	H=3 CUM EVAP CM	CUM FRAC EVAP	H=4 CUM EVAP CM	CUM FRAC EVAP	H=5 CUM EVAP CM	CUM FRAC EVAP	H-AVG CUM EVAP CM	CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.3	.053	0.2	.046	0.2	.027	0.4	.068	0.3	.048
3.3	80	0.7	.122	0.5	.102	0.4	.062	1.0	.161	0.6	.112
6.4	154	1.3	.224	0.9	.180	0.6	.107	1.7	.291	1.1	.201
9.3	224	1.8	.317	1.3	.250	0.9	.149	2.3	.383	1.6	.274
12.3	296	2.3	.395	1.6	.314	1.2	.190	2.6	.440	1.9	.334
15.3	368	2.6	.451	1.9	.366	1.4	.231	2.9	.482	2.2	.382
18.3	440	2.9	.494	2.1	.411	1.6	.271	3.1	.518	2.4	.423
21.4	513	3.1	.529	2.3	.449	1.9	.309	3.2	.545	2.6	.457
24.3	584	3.2	.560	2.5	.485	2.1	.346	3.4	.568	2.8	.489
29.3	704	3.5	.605	2.8	.539	2.4	.405	3.6	.606	3.1	.537
33.3	800	3.6	.632	3.0	.575	2.7	.447	3.7	.629	3.3	.570
37.3	896	3.8	.653	3.1	.607	2.9	.483	3.8	.649	3.4	.597
41.3	992	3.9	.677	3.3	.638	3.1	.518	4.0	.669	3.6	.624
50.3	1208	4.2	.722	3.6	.700	3.6	.596	4.2	.712	3.9	.681
INITIAL WATER CONTENT (CM)		5.8		5.1		6.0		5.9		5.7	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	HOURS	CORE: H=2 CUM EVAP CM	CUM FRAC EVAP	H=3 CUM EVAP CM	CUM FRAC EVAP	H=4 CUM EVAP CM	CUM FRAC EVAP	H=5 CUM EVAP CM	CUM FRAC EVAP	H-AVG CUM EVAP CM	CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.040	0.2	.032	0.1	.025	0.3	.050	0.2	.036
3.6	87	0.4	.083	0.3	.066	0.3	.046	0.6	.108	0.4	.075
6.6	159	0.8	.142	0.6	.108	0.4	.072	1.0	.186	0.7	.127
9.6	231	1.1	.197	0.8	.151	0.6	.098	1.5	.264	1.0	.177
12.6	303	1.4	.255	1.0	.193	0.7	.125	1.9	.332	1.2	.225
16.6	399	1.7	.327	1.3	.249	0.9	.158	2.2	.397	1.6	.281
19.6	470	2.0	.371	1.5	.288	1.1	.183	2.4	.429	1.7	.316
23.6	566	2.3	.422	1.8	.338	1.3	.216	2.6	.468	2.0	.359
26.6	638	2.4	.444	2.0	.374	1.4	.242	2.8	.492	2.1	.386
32.6	783	2.8	.519	2.4	.456	1.8	.310	3.1	.549	2.5	.456
37.6	903	2.9	.545	2.6	.492	2.1	.348	3.2	.569	2.7	.486
41.6	999	3.0	.565	2.7	.514	2.2	.374	3.3	.584	2.8	.507
49.7	1193	3.2	.590	2.9	.550	2.5	.417	3.4	.605	3.0	.538
52.6	1263	3.2	.604	3.0	.564	2.5	.433	3.5	.616	3.1	.552
INITIAL WATER CONTENT (CM)		5.3		5.3		5.9		5.6		5.5	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

CORE:		K-2		K-3		K-4		K-5		K-AVG	
TIME		CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.3	.051	0.3	.049	0.2	.040	0.3	.039	0.3	.045
3.3	80	0.7	.121	0.5	.103	0.5	.092	0.7	.107	0.6	.106
6.4	154	1.3	.228	0.9	.177	0.9	.164	1.3	.196	1.1	.192
9.3	224	1.9	.326	1.4	.270	1.3	.239	1.8	.272	1.6	.277
12.3	296	2.4	.412	1.8	.346	1.7	.309	2.2	.339	2.0	.352
15.3	368	2.7	.464	2.1	.402	2.0	.368	2.5	.368	2.3	.406
18.3	440	2.9	.506	2.3	.450	2.3	.412	2.8	.426	2.6	.448
21.4	513	3.1	.536	2.5	.486	2.5	.445	3.0	.457	2.8	.480
24.3	584	3.3	.562	2.7	.520	2.6	.475	3.1	.484	2.9	.510
29.3	704	3.5	.603	2.9	.567	2.9	.517	3.4	.524	3.2	.552
33.3	800	3.6	.629	3.1	.599	3.0	.547	3.6	.551	3.3	.580
37.3	896	3.8	.652	3.3	.625	3.1	.567	3.7	.574	3.5	.604
41.3	992	3.9	.675	3.4	.650	3.3	.590	3.9	.598	3.6	.627
50.3	1208	4.2	.721	3.6	.698	3.5	.640	4.2	.646	3.9	.675
INITIAL WATER CONTENT (CM)		5.8		5.2		5.5		6.5		5.8	

POTENTIAL EVAPORATION = 0.43 CM/DAY

CORE:		K-2		K-3		K-4		K-5		K-AVG	
TIME		CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.2	.034	0.2	.034	0.2	.030	0.2	.029	0.2	.031
3.6	87	0.4	.078	0.4	.069	0.3	.062	0.4	.061	0.4	.067
6.6	159	0.7	.132	0.6	.113	0.6	.106	0.7	.106	0.6	.114
9.6	231	1.0	.192	0.8	.158	0.8	.149	1.0	.153	0.9	.162
12.6	303	1.3	.245	1.0	.198	1.1	.192	1.2	.197	1.2	.208
16.6	399	1.7	.314	1.3	.252	1.4	.249	1.6	.253	1.5	.267
19.6	470	2.0	.364	1.5	.293	1.6	.290	1.9	.294	1.7	.310
23.6	566	2.3	.423	1.8	.349	1.9	.342	2.2	.345	2.1	.364
26.6	638	2.5	.458	2.1	.391	2.1	.380	2.4	.379	2.3	.401
32.6	783	2.8	.522	2.5	.462	2.5	.455	2.8	.448	2.7	.476
37.6	903	3.0	.547	2.7	.510	2.7	.482	3.0	.477	2.8	.503
41.6	999	3.0	.564	2.9	.541	2.8	.500	3.1	.494	2.9	.525
49.7	1193	3.2	.591	3.0	.574	2.9	.526	3.3	.521	3.1	.551
52.6	1263	3.2	.602	3.1	.588	3.0	.538	3.4	.533	3.2	.564
INITIAL WATER CONTENT (CM)		5.4		5.3		5.5		6.3		5.6	

APPENDIX I. (CONTINUED).

POTENTIAL EVAPORATION = 0.76 CM/DAY

TIME DAYS	TIME HOURS	M-2 CUM EVAP CM	M-2 CUM FRAC EVAP	M-3 CUM EVAP CM	M-3 CUM FRAC EVAP	M-4 CUM EVAP CM	M-4 CUM FRAC EVAP	M-5 CUM EVAP CM	M-5 CUM FRAC EVAP	M-AVG CUM EVAP CM	M-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.3	32	0.7	.094	0.4	.059	0.6	.077	0.7	.093	0.6	.081
3.3	80	1.3	.178	1.0	.130	1.3	.167	1.2	.169	1.2	.161
6.4	154	1.9	.251	1.7	.225	1.8	.237	1.7	.232	1.8	.236
9.3	224	2.2	.298	2.2	.295	2.1	.281	2.0	.276	2.1	.288
12.3	296	2.5	.341	2.6	.351	2.4	.316	2.3	.316	2.5	.331
15.3	368	2.8	.376	2.9	.390	2.6	.347	2.5	.349	2.7	.366
18.3	440	3.1	.414	3.2	.422	2.8	.374	2.7	.379	2.9	.397
21.4	513	3.3	.436	3.4	.452	3.0	.396	2.9	.406	3.1	.423
24.3	584	3.4	.462	3.6	.477	3.2	.418	3.1	.431	3.3	.447
29.3	704	3.7	.502	3.9	.517	3.4	.454	3.4	.473	3.6	.487
33.3	800	3.9	.527	4.1	.545	3.6	.481	3.6	.501	3.8	.514
37.3	896	4.1	.552	4.3	.569	3.8	.506	3.8	.528	4.0	.539
41.3	992	4.3	.576	4.4	.590	4.0	.530	4.0	.554	4.2	.563
50.3	1208	4.7	.628	4.8	.639	4.5	.587	4.4	.614	4.6	.617
INITIAL WATER CONTENT (CM)		7.5		7.5		7.6		7.2		7.4	

POTENTIAL EVAPORATION = 0.43 CM/DAY

TIME DAYS	TIME HOURS	M-2 CUM EVAP CM	M-2 CUM FRAC EVAP	M-3 CUM EVAP CM	M-3 CUM FRAC EVAP	M-4 CUM EVAP CM	M-4 CUM FRAC EVAP	M-5 CUM EVAP CM	M-5 CUM FRAC EVAP	M-AVG CUM EVAP CM	M-AVG CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.8	42	0.5	.064	0.4	.050	0.4	.054	0.4	.054	0.4	.055
3.6	87	1.0	.132	0.8	.097	0.8	.109	0.8	.109	0.8	.112
6.6	159	1.7	.223	1.2	.159	1.5	.187	1.3	.180	1.4	.187
9.6	231	2.2	.292	1.7	.223	1.9	.249	1.6	.231	1.9	.249
12.6	303	2.5	.331	2.2	.285	2.2	.289	1.9	.272	2.2	.295
16.6	399	2.8	.368	2.7	.354	2.5	.328	2.2	.310	2.6	.340
19.6	470	3.0	.390	3.0	.392	2.7	.350	2.4	.334	2.8	.367
23.6	566	3.2	.415	3.3	.432	2.9	.375	2.5	.355	3.0	.395
26.6	638	3.3	.433	3.5	.457	3.1	.393	2.7	.381	3.1	.417
32.6	783	3.6	.476	3.9	.511	3.4	.435	3.0	.429	3.5	.463
37.6	903	3.8	.494	4.1	.529	3.5	.455	3.2	.450	3.6	.483
41.6	999	3.9	.508	4.2	.543	3.6	.469	3.3	.465	3.7	.497
49.7	1193	4.0	.529	4.3	.563	3.8	.494	3.5	.488	3.9	.519
52.6	1263	4.1	.540	4.4	.573	3.9	.504	3.5	.500	4.0	.530
INITIAL WATER CONTENT (CM)		7.6		7.7		7.8		7.1		7.5	

APPENDIX II. VOLUMETRIC WATER CONTENT AS A FUNCTION OF DEPTH, TIME, AND POTENTIAL EVAPORATION; AND BULK DENSITY FOR EACH HUMUS-SOIL CORE.

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	A-2	0	.579	.354	.366	.351	.357	.361	.345	.363
		16	.240	.300	.338	.332	.347	.331	.284	.301
		30	.228	.212	.320	.325	.318	.344	.259	.241
		51	.157	.071	.249	.276	.288	.278	.210	.203
0.43	A-2	0	.444	.327	.402	.376	.372	.374	.340	.340
		17	.173	.243	.361	.344	.336	.322	.303	.286
		33	.105	.215	.317	.300	.338	.326	.254	.244
		53	.104	.149	.298	.301	.304	.300	.229	.211
DENSITY (G/CM^3)			.253	.454	.458	.517	.510	.509	.565	.595
0.76	A-3	0	.325	.304	.287	.272	.299	.325	.325	.309
		16	.073	.189	.220	.211	.239	.246	.224	.239
		30	.041	.090	.167	.180	.204	.222	.198	.198
		51	.017	.033	.121	.165	.203	.199	.179	.186
0.43	A-3	0	.291	.276	.367	.313	.371	.356	.357	.360
		17	.065	.133	.254	.194	.283	.247	.250	.265
		33	.007	.104	.270	.230	.262	.226	.209	.191
		53	.007	.077	.225	.193	.261	.222	.203	.200
DENSITY (G/CM^3)			.661	.616	.629	.659	.621	.596	.620	.620
0.76	A-4	0	.617	.368	.352	.395	.406	.402	.336	.337
		16	.341	.295	.336	.349	.349	.293	.235	.212
		30	.234	.198	.282	.317	.296	.260	.196	.201
		51	.262	.072	.215	.285	.267	.230	.180	.171
0.43	A-4	0	.541	.342	.344	.394	.402	.419	.331	.321
		17	.293	.309	.286	.340	.341	.311	.196	.172
		33	.231	.244	.275	.338	.320	.252	.170	.164
		53	.106	.056	.224	.283	.261	.234	.134	.135
DENSITY (G/CM^3)			.288	.496	.429	.465	.500	.575	.622	.646
0.76	A-5	0	.338	.288	.289	.292	.283	.260	.269	.316
		16	.073	.187	.235	.232	.227	.200	.179	.190
		30	.052	.089	.177	.187	.191	.164	.147	.170
		51	.043	.068	.146	.158	.168	.143	.115	.141
0.43	A-5	0	.379	.350	.361	.353	.326	.296	.286	.296
		17	.154	.234	.257	.218	.264	.202	.132	.123
		33	.098	.111	.226	.188	.234	.176	.113	.109
		53	.055	.069	.152	.161	.215	.162	.125	.081
DENSITY (G/CM^3)			.577	.612	.568	.572	.589	.691	.650	.666

APPENDIX II, (CONTINUED),

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	B-2	0	.265	.449	.536	.527	.222	.116	.131	.126
		16	.099	.381	.469	.440	.171	.054	.086	.101
		30	.055	.149	.386	.409	.163	.059	.084	.079
		51	.034	.066	.202	.305	.135	.034	.055	.052
0.43	B-2	0	.126	.354	.576	.587	.210	.109	.093	.084
		17	.050	.333	.499	.524	.193	.091	.090	.056
		33	.026	.130	.404	.440	.150	.057	.055	.039
		53	.016	.070	.287	.367	.124	.064	.050	.028
DENSITY (G/CM^3)			.002	.134	.232	.227	.650	.823	.797	.813
0.76	B-3	0	.358	.294	.155	.147	.100	.108	.100	.109
		16	.190	.252	.131	.119	.065	.093	.065	.073
		30	.197	.124	.069	.085	.036	.055	.044	.076
		51	.152	.140	.064	.050	.024	.045	.034	.074
0.43	B-3	0	.254	.188	.167	.192	.115	.130	.106	.120
		17	.135	.192	.085	.092	.056	.074	.069	.045
		33	.137	.202	.095	.103	.047	.057	.034	.042
		53	.006	.012	.044	.079	.045	.055	.053	.056
DENSITY (G/CM^3)			.254	.599	.793	.800	.818	.775	.771	.743
0.76	B-4	0	.332	.440	.271	.211	.106	.129	.096	.150
		16	.160	.320	.213	.153	.066	.091	.066	.137
		30	.135	.148	.138	.189	.062	.075	.051	.164
		51	.075	.097	.058	.119	.047	.068	.038	.106
0.43	B-4	0	.235	.408	.360	.196	.143	.093	.065	.203
		17	.132	.331	.298	.163	.101	.074	.063	.203
		33	.085	.131	.256	.229	.084	.051	.025	.136
		53	.001	.015	.196	.096	.070	.063	.053	.178
DENSITY (G/CM^3)			.094	.264	.548	.693	.827	.781	.752	.685
0.76	B-5	0	.412	.346	.143	.140	.130	.138	.167	.152
		16	.180	.286	.120	.094	.080	.095	.092	.088
		30	.106	.160	.090	.072	.043	.061	.077	.066
		51	.123	.093	.017	.034	.036	.062	.054	.049
0.43	B-5	0	.356	.322	.183	.186	.160	.133	.150	.138
		17	.271	.237	.117	.125	.101	.078	.089	.079
		33	.073	.170	.083	.093	.064	.065	.061	.058
		53	.061	.006	.055	.077	.072	.049	.075	.076
DENSITY (G/CM^3)			.257	.610	.859	.862	.836	.732	.784	.804

APPENDIX II. (CONTINJED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	C-2	0	.200	.441	.485	.111	.103	.106	.133	.177
		16	.013	.198	.488	.117	.097	.088	.099	.125
		30	.000	.032	.445	.107	.083	.061	.065	.096
		51	.011	.007	.126	.082	.047	.047	.042	.076
0.43	C-2	0	.088	.279	.360	.154	.115	.121	.105	.117
		17	.002	.133	.320	.117	.083	.084	.076	.083
		33	.016	.002	.262	.077	.061	.058	.059	.068
		53	.020	.011	.173	.059	.044	.046	.036	.059
DENSITY (G/CM^3)			.043	.135	.147	.759	.791	.756	.763	.766
0.76	C-3	0	.213	.246	.135	.087	.105	.127	.123	.123
		16	.035	.217	.135	.084	.069	.085	.085	.072
		30	.027	.075	.086	.045	.044	.072	.051	.046
		51	.045	.083	.030	.001	.010	.037	.036	.045
0.43	C-3	0	.163	.246	.165	.128	.101	.121	.108	.114
		17	.006	.100	.092	.069	.065	.082	.094	.106
		33	.003	.093	.129	.083	.058	.072	.038	.045
		53	.018	.037	.089	.059	.050	.042	.032	.031
DENSITY (G/CM^3)			.050	.411	.724	.753	.748	.747	.778	.795
0.76	C-4	0	.378	.346	.215	.174	.193	.209	.282	.417
		16	.149	.308	.201	.137	.152	.169	.223	.345
		30	.101	.278	.179	.120	.109	.125	.186	.286
		51	.143	.187	.141	.068	.074	.077	.132	.229
0.43	C-4	0	.248	.400	.284	.221	.207	.230	.271	.392
		17	.102	.337	.259	.190	.183	.201	.230	.321
		33	.091	.349	.254	.178	.172	.186	.198	.277
		53	.025	.247	.208	.149	.131	.147	.162	.233
DENSITY (G/CM^3)			.036	.364	.657	.728	.729	.712	.594	.499
0.76	C-5	0	.190	.337	.161	.150	.151	.126	.134	.117
		16	.021	.149	.148	.128	.122	.096	.093	.075
		30	.015	.109	.135	.100	.084	.074	.067	.048
		51	.021	.091	.048	.062	.059	.050	.054	.031
0.43	C-5	0	.107	.290	.220	.169	.151	.113	.070	.068
		17	.008	.112	.189	.126	.125	.075	.045	.068
		33	.004	.048	.137	.111	.091	.060	.031	.040
		53	.011	.022	.082	.084	.079	.056	.038	.036
DENSITY (G/CM^3)			.007	.132	.696	.710	.717	.752	.769	.792

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
			DEPTH (CM)							
0.76	D-2	0	.186	.261	.164	.125	.096	.055	.076	.065
		16	.059	.106	.064	.081	.046	.031	.039	.044
		30	.056	.069	.016	.047	.034	.010	.029	.035
		51	.021	.040	.010	.046	.023	.006	.027	.012
0.43	D-2	0	.112	.159	.139	.090	.067	.039	.045	.030
		17	.029	.064	.085	.077	.056	.030	.022	.021
		33	.023	.006	.016	.035	.037	.016	.010	.008
		53	.022	.015	.009	.006	.015	.008	.007	.004
DENSITY (G/CM^3)			.031	.203	.570	.720	.772	.792	.789	.815
0.76	D-3	0	.258	.256	.073	.140	.090	.077	.067	.069
		16	.054	.035	.084	.114	.080	.056	.039	.050
		30	.058	.061	.002	.053	.061	.036	.048	.036
		51	.046	.022	.025	.048	.038	.021	.018	.032
0.43	D-3	0	.167	.259	.109	.124	.083	.075	.218	.045
		17	.019	.084	.028	.069	.046	.039	.031	.037
		33	.002	.036	.027	.096	.049	.051	.024	.003
		53	.008	.012	.009	.035	.038	.039	.025	.025
DENSITY (G/CM^3)			.026	.231	.654	.666	.737	.758	.781	.801
0.76	D-4	0	.255	.257	.125	.132	.084	.075	.071	.065
		16	.194	.108	.099	.103	.058	.047	.060	.056
		30	.024	.075	.049	.073	.022	.033	.021	.050
		51	.056	.064	.032	.038	.022	.006	.020	.022
0.43	D-4	0	.170	.224	.138	.090	.085	.066	.046	.044
		17	.020	.112	.095	.069	.049	.026	.027	.014
		33	.018	.009	.055	.054	.037	.021	.003	.004
		53	.016	.012	.002	.026	.027	.029	.004	.006
DENSITY (G/CM^3)			.044	.317	.697	.724	.779	.788	.789	.806
0.76	D-5	0	.388	.284	.225	.138	.074	.080	.081	.082
		16	.315	.186	.176	.105	.053	.048	.061	.061
		30	.125	.080	.138	.101	.035	.031	.043	.057
		51	.117	.074	.058	.049	.024	.018	.021	.043
0.43	D-5	0	.370	.362	.224	.175	.111	.079	.063	.068
		17	.168	.269	.188	.146	.070	.059	.052	.045
		33	.109	.096	.135	.115	.053	.052	.044	.042
		53	.071	.030	.085	.098	.057	.059	.049	.049
DENSITY (G/CM^3)			.090	.331	.508	.694	.786	.791	.784	.807

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	E-2	0	.497	.308	.284	.281	.288	.293	.295	.301
		16	.353	.236	.219	.207	.193	.213	.207	.198
		30	.243	.096	.201	.195	.180	.187	.173	.191
		51	.174	.006	.114	.149	.136	.143	.138	.135
0.43	E-2	0	.456	.269	.333	.289	.290	.295	.274	.288
		17	.342	.289	.274	.232	.229	.238	.218	.218
		33	.154	.184	.188	.176	.187	.196	.179	.188
		53	.011	.065	.175	.181	.181	.155	.171	.154
DENSITY (G/CM^3)			.302	.453	.596	.676	.676	.672	.663	.656
0.76	E-3	0	.534	.333	.257	.267	.245	.222	.247	.265
		16	.518	.306	.197	.200	.170	.180	.176	.191
		30	.408	.227	.125	.130	.123	.111	.113	.147
		51	.295	.090	.110	.105	.079	.096	.099	.092
0.43	E-3	0	.368	.271	.299	.298	.261	.262	.247	.221
		17	.358	.215	.233	.213	.182	.204	.216	.193
		33	.376	.272	.193	.189	.142	.143	.114	.089
		53	.106	.101	.140	.151	.100	.108	.133	.095
DENSITY (G/CM^3)			.288	.653	.712	.679	.711	.747	.753	.726
0.76	E-4	0	.408	.311	.322	.219	.178	.214	.211	.244
		16	.233	.212	.273	.166	.139	.157	.146	.158
		30	.185	.138	.230	.153	.105	.130	.136	.145
		51	.147	.074	.145	.134	.083	.118	.111	.142
0.43	E-4	0	.369	.250	.269	.217	.195	.189	.180	.170
		17	.198	.198	.216	.154	.130	.126	.123	.118
		33	.083	.157	.176	.144	.109	.128	.111	.089
		53	.018	.045	.151	.112	.085	.095	.102	.099
DENSITY (G/CM^3)			.334	.506	.473	.713	.770	.731	.699	.677
0.76	E-5	0	.335	.254	.197	.199	.230	.258	.265	.279
		16	.277	.244	.150	.156	.181	.193	.221	.205
		30	.151	.184	.098	.106	.141	.160	.183	.170
		51	.127	.078	.070	.085	.123	.128	.153	.153
0.43	E-5	0	.372	.354	.267	.231	.267	.238	.244	.234
		17	.298	.289	.209	.175	.213	.195	.173	.188
		33	.201	.230	.136	.145	.166	.132	.156	.135
		53	.083	.165	.106	.115	.155	.151	.146	.110
DENSITY (G/CM^3)			.315	.628	.768	.749	.683	.559	.597	.628

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	F-2	0	.339	.515	.326	.313	.277	.220	.206	.180
		16	.298	.511	.315	.287	.232	.159	.164	.158
		30	.201	.496	.307	.266	.207	.158	.141	.139
		51	.096	.297	.267	.237	.181	.127	.135	.117
0.43	F-2	0	.317	.543	.380	.375	.319	.242	.197	.163
		17	.221	.492	.336	.324	.294	.218	.184	.171
		33	.132	.411	.283	.267	.242	.183	.163	.170
		53	.124	.331	.271	.256	.221	.177	.148	.132
DENSITY (G/CM^3)			.172	.143	.487	.577	.669	.719	.717	.753
0.76	F-3	0	.230	.351	.179	.380	.203	.259	.219	.186
		16	.015	.253	.153	.367	.193	.216	.185	.154
		30	.039	.080	.084	.357	.178	.206	.171	.146
		51	.018	.065	.041	.333	.151	.182	.144	.121
0.43	F-3	0	.215	.299	.198	.402	.248	.308	.265	.202
		17	.013	.190	.232	.440	.213	.243	.211	.161
		33	.008	.065	.107	.414	.195	.246	.199	.135
		53	.011	.047	.112	.358	.200	.221	.185	.123
DENSITY (G/CM^3)			.039	.068	.407	.335	.644	.655	.634	.658
0.76	F-4	0	.206	.538	.236	.270	.252	.223	.240	.262
		16	.057	.498	.220	.223	.193	.191	.188	.234
		30	.068	.433	.165	.174	.157	.144	.163	.180
		51	.030	.284	.099	.133	.133	.121	.121	.153
0.43	F-4	0	.135	.442	.300	.315	.222	.278	.236	.314
		17	.025	.395	.262	.261	.143	.219	.215	.252
		33	.016	.394	.236	.219	.152	.192	.216	.224
		53	.014	.217	.191	.210	.167	.178	.170	.202
DENSITY (G/CM^3)			.009	.418	.767	.705	.683	.742	.702	.709
0.76	F-5	0	.285	.493	.409	.295	.271	.280	.208	.225
		16	.095	.394	.385	.241	.214	.214	.165	.155
		30	.092	.186	.304	.187	.169	.201	.142	.139
		51	.062	.088	.178	.120	.108	.139	.104	.126
0.43	F-5	0	.237	.343	.490	.357	.186	.287	.225	.212
		17	.084	.283	.399	.307	.187	.260	.161	.174
		33	.069	.259	.340	.238	.114	.209	.128	.135
		53	.037	.099	.260	.208	.123	.220	.134	.134
DENSITY (G/CM^3)			.019	.099	.446	.569	.531	.495	.601	.675

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	G-2	0	.324	.344	.196	.191	.151	.220	.214	.254
		16	.155	.330	.176	.150	.117	.166	.173	.187
		30	.075	.290	.143	.140	.099	.154	.148	.149
		51	.101	.063	.117	.101	.081	.120	.119	.108
0.43	G-2	0	.232	.254	.229	.249	.169	.206	.231	.216
		17	.080	.247	.182	.198	.126	.152	.175	.160
		33	.040	.145	.124	.148	.118	.111	.124	.117
		53	.007	.069	.126	.126	.084	.113	.104	.091
DENSITY (G/CM^3)			.094	.316	.530	.644	.624	.593	.679	.700
0.76	G-3	0	.336	.309	.217	.174	.201	.186	.208	.219
		16	.270	.294	.194	.154	.165	.151	.174	.172
		30	.293	.273	.175	.133	.140	.142	.130	.136
		51	.105	.163	.149	.104	.108	.123	.107	.092
0.43	G-3	0	.265	.335	.292	.212	.239	.228	.239	.273
		17	.131	.314	.227	.173	.186	.193	.196	.246
		33	.087	.302	.214	.146	.181	.161	.148	.180
		53	.094	.237	.182	.144	.154	.147	.134	.181
DENSITY (G/CM^3)			.104	.375	.608	.718	.738	.724	.717	.720
0.76	G-4	0	.417	.374	.211	.364	.181	.153	.224	.259
		16	.254	.317	.172	.290	.135	.117	.147	.175
		30	.223	.290	.178	.273	.118	.106	.143	.160
		51	.171	.131	.100	.254	.082	.081	.106	.130
0.43	G-4	0	.340	.350	.291	.375	.155	.223	.252	.301
		17	.244	.307	.255	.281	.101	.155	.189	.241
		33	.106	.246	.233	.252	.077	.137	.162	.190
		53	.068	.144	.178	.206	.102	.099	.135	.156
DENSITY (G/CM^3)			.084	.285	.386	.462	.624	.658	.664	.669
0.76	G-5	0	.373	.305	.191	.199	.228	.223	.233	.230
		16	.271	.289	.150	.155	.179	.153	.184	.157
		30	.253	.236	.144	.122	.156	.130	.154	.115
		51	.128	.138	.103	.105	.142	.126	.129	.107
0.43	G-5	0	.270	.309	.271	.231	.218	.183	.172	.198
		17	.190	.353	.236	.178	.194	.159	.159	.173
		33	.140	.288	.169	.152	.168	.115	.116	.123
		53	.055	.186	.081	.106	.126	.097	.087	.121
DENSITY (G/CM^3)			.152	.453	.431	.619	.615	.668	.653	.685

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	H-2	0	.414	.333	.232	.235	.164	.196	.194	.188
		16	.122	.272	.163	.157	.075	.111	.128	.101
		30	.051	.095	.106	.146	.073	.089	.111	.073
		51	.072	.067	.019	.073	.066	.086	.090	.075
0.43	H-2	0	.292	.317	.248	.243	.192	.212	.200	.180
		17	.198	.283	.156	.150	.102	.144	.132	.120
		33	.020	.025	.104	.114	.094	.139	.109	.104
		53	.010	.035	.041	.083	.090	.095	.102	.101
DENSITY (G/CM^3)			.231	.450	.644	.706	.832	.841	.826	.800
0.76	H-3	0	.606	.351	.233	.187	.122	.141	.114	.115
		16	.356	.289	.198	.131	.081	.082	.065	.063
		30	.296	.168	.172	.115	.072	.065	.050	.073
		51	.190	.064	.065	.079	.068	.070	.044	.053
0.43	H-3	0	.494	.395	.294	.237	.137	.144	.121	.158
		17	.322	.309	.224	.169	.098	.092	.086	.105
		33	.209	.284	.189	.139	.071	.061	.052	.046
		53	.025	.031	.145	.122	.071	.074	.075	.077
DENSITY (G/CM^3)			.112	.390	.623	.728	.757	.755	.748	.756
0.76	H-4	0	.373	.346	.308	.268	.224	.186	.190	.189
		16	.244	.328	.290	.236	.178	.148	.140	.135
		30	.110	.237	.257	.189	.127	.126	.123	.120
		51	.103	.093	.176	.186	.120	.095	.095	.092
0.43	H-4	0	.323	.340	.392	.335	.288	.212	.201	.215
		17	.200	.328	.375	.322	.255	.185	.162	.185
		33	.125	.280	.350	.298	.226	.160	.150	.161
		53	.071	.164	.281	.226	.184	.134	.127	.130
DENSITY (G/CM^3)			.041	.135	.271	.633	.750	.787	.798	.782
0.76	H-5	0	.273	.239	.221	.190	.221	.207	.180	.172
		16	.008	.128	.145	.110	.142	.119	.094	.085
		30	.023	.028	.078	.086	.115	.115	.086	.090
		51	.021	.045	.046	.051	.087	.099	.082	.079
0.43	H-5	0	.301	.248	.289	.233	.252	.204	.196	.159
		17	.160	.161	.189	.127	.187	.136	.121	.099
		33	.008	.031	.135	.140	.148	.110	.125	.109
		53	.005	.020	.067	.105	.135	.125	.135	.125
DENSITY (G/CM^3)			.471	.572	.670	.693	.747	.795	.814	.802

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	DEPTH (CM) 1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
0.76	K-2	0	.319	.224	.280	.254	.230	.205	.169	.180
		16	.163	.173	.192	.163	.159	.109	.091	.086
		30	.342	.073	.172	.160	.145	.103	.084	.068
		51	.217	.008	.036	.101	.111	.106	.057	.056
0.43	K-2	0	.188	.273	.279	.288	.271	.220	.192	.165
		17	.028	.171	.188	.213	.192	.151	.112	.106
		33	.015	.026	.132	.146	.145	.120	.083	.075
		53	.023	.001	.062	.125	.140	.135	.108	.110
DENSITY (G/CM^3)			.130	.631	.591	.665	.660	.724	.780	.801
0.76	K-3	0	.387	.310	.196	.217	.176	.154	.176	.184
		16	.253	.273	.158	.163	.121	.095	.121	.129
		30	.240	.110	.139	.136	.101	.088	.095	.108
		51	.189	.070	.040	.083	.089	.065	.096	.093
0.43	K-3	0	.163	.353	.256	.212	.216	.165	.173	.197
		17	.103	.304	.196	.169	.138	.105	.135	.136
		33	.174	.269	.190	.164	.118	.069	.099	.119
		53	.030	.072	.126	.146	.119	.083	.090	.091
DENSITY (G/CM^3)			.165	.470	.603	.566	.698	.756	.775	.801
0.76	K-4	0	.619	.271	.203	.209	.174	.181	.175	.175
		16	.578	.221	.164	.166	.122	.121	.117	.094
		30	.477	.106	.130	.106	.136	.103	.099	.089
		51	.452	.062	.042	.120	.098	.094	.086	.088
0.43	K-4	0	.451	.293	.240	.231	.216	.202	.176	.131
		17	.334	.252	.206	.190	.172	.149	.122	.078
		33	.330	.174	.141	.157	.111	.123	.085	.051
		53	.189	.065	.113	.128	.124	.101	.079	.053
DENSITY (G/CM^3)			.344	.613	.584	.562	.591	.734	.760	.782
0.76	K-5	0	.496	.338	.290	.289	.241	.204	.175	.179
		16	.195	.248	.206	.198	.167	.127	.086	.097
		30	.199	.073	.160	.175	.137	.101	.058	.063
		51	.196	.046	.040	.141	.140	.093	.054	.071
0.43	K-5	0	.394	.312	.311	.325	.276	.206	.172	.183
		17	.334	.242	.257	.257	.219	.134	.115	.107
		33	.102	.118	.196	.209	.197	.106	.085	.094
		53	.089	.048	.136	.177	.158	.133	.087	.096
DENSITY (G/CM^3)			.187	.569	.556	.545	.640	.702	.736	.791

APPENDIX II. (CONTINUED).

POT. EVAP CM/DAY	SITE-CORE	TIME DAYS	1.9	3.8	6.4	8.9	11.4	14.0	16.5	19.0
			DEPTH (CM)							
0.76	M-2	0	.313	.273	.277	.276	.280	.251	.265	.258
		16	.064	.170	.178	.174	.188	.163	.181	.193
		30	.037	.094	.161	.147	.155	.134	.163	.166
		51	.018	.027	.106	.146	.145	.130	.149	.156
0.43	M-2	0	.315	.353	.334	.320	.318	.278	.278	.253
		17	.076	.188	.212	.194	.215	.190	.181	.169
		33	.006	.093	.176	.157	.184	.171	.156	.127
		53	.016	.046	.139	.147	.168	.163	.156	.148
DENSITY (G/CM^3)			.625	.621	.600	.686	.714	.752	.755	.753
0.76	M-3	0	.559	.330	.285	.248	.363	.279	.228	.233
		16	.234	.188	.198	.183	.251	.185	.159	.157
		30	.253	.085	.139	.148	.220	.170	.131	.139
		51	.215	.020	.065	.111	.175	.120	.083	.089
0.43	M-3	0	.415	.385	.343	.313	.373	.335	.270	.275
		17	.209	.187	.187	.181	.250	.215	.168	.195
		33	.104	.106	.180	.186	.246	.182	.110	.135
		53	.036	.049	.141	.135	.188	.176	.101	.146
DENSITY (G/CM^3)			.437	.752	.677	.616	.597	.760	.850	.883
0.76	M-4	0	.376	.236	.248	.296	.286	.263	.265	.274
		16	.043	.138	.186	.217	.190	.155	.177	.175
		30	.064	.065	.170	.200	.174	.148	.169	.157
		51	.083	.016	.102	.159	.132	.099	.116	.122
0.43	M-4	0	.296	.238	.290	.354	.334	.267	.311	.327
		17	.109	.160	.204	.225	.221	.188	.194	.217
		33	.028	.075	.185	.207	.203	.166	.189	.197
		53	.016	.015	.151	.182	.175	.139	.160	.183
DENSITY (G/CM^3)			.517	.547	.572	.690	.801	.832	.815	.811
0.76	M-5	0	.509	.294	.231	.272	.320	.306	.250	.312
		16	.241	.163	.174	.203	.257	.246	.169	.230
		30	.262	.094	.138	.171	.236	.213	.141	.209
		51	.219	.055	.059	.139	.212	.195	.106	.163
0.43	M-5	0	.460	.293	.279	.269	.323	.333	.272	.343
		17	.197	.171	.163	.187	.257	.263	.213	.259
		33	.173	.060	.140	.157	.230	.236	.200	.239
		53	.036	.045	.115	.169	.221	.238	.176	.189
DENSITY (G/CM^3)			.359	.618	.570	.466	.492	.638	.741	.717

APPENDIX III. CUMULATIVE AND CUMULATIVE FRACTIONAL EVAPORATION BEFORE AND AFTER F HORIZON REMOVAL FOR ONE HUMUS-SOIL CORE FROM EACH SITE - F HORIZON INTACT.

CORE:		A-1		B-1		C-1		D-1		E-1	
TIME		CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
2.0	48	0.7	.066	0.3	.068	0.3	.049	0.3	.093	0.3	.032
4.0	96	1.2	.108	0.7	.131	0.5	.086	0.6	.162	0.6	.063
7.0	167	1.6	.151	1.0	.199	0.7	.127	0.8	.241	0.9	.099
9.0	215	1.9	.179	1.2	.245	0.9	.158	1.0	.292	1.1	.125
11.2	269	2.2	.208	1.5	.293	1.1	.188	1.2	.346	1.3	.152
13.2	317	2.5	.228	1.6	.326	1.2	.213	1.3	.383	1.5	.173
15.2	365	2.7	.248	1.8	.356	1.3	.236	1.5	.420	1.7	.193
19.0	455	3.1	.287	2.0	.411	1.6	.281	1.7	.492	2.0	.233
23.0	551	3.5	.322	2.3	.462	1.8	.326	1.9	.557	2.4	.270
27.0	647	3.8	.355	2.5	.509	2.1	.368	2.1	.617	2.7	.306
32.0	767	4.2	.392	2.8	.560	2.4	.418	2.3	.678	3.1	.348
36.0	864	4.5	.419	2.9	.594	2.6	.455	2.5	.717	3.3	.380
40.2	965	4.8	.446	3.1	.628	2.8	.493	2.6	.757	3.6	.411
44.0	1057	5.0	.466	3.2	.653	3.0	.522	2.7	.784	3.8	.435
47.9	1150	5.3	.487	3.4	.675	3.1	.552	2.8	.811	4.0	.460
52.9	1270	5.5	.513	3.5	.704	3.4	.591	2.9	.840	4.3	.493
INITIAL WATER CONTENT (CM)		10.8		5.0		5.7		3.5		8.8	

CORE:		F-1		G-1		H-1		K-1		M-1	
TIME		CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP	CUM EVAP	CUM FRAC EVAP
DAYS	HOURS	CM		CM		CM		CM		CM	
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
2.0	48	0.3	.039	0.3	.050	0.6	.104	0.4	.072	1.1	.144
4.0	96	0.6	.069	0.6	.094	0.6	.118	0.8	.143	2.2	.280
7.0	167	0.8	.102	0.9	.147	1.0	.183	1.3	.222	2.8	.369
9.0	215	1.0	.125	1.1	.186	1.2	.232	1.6	.276	3.1	.409
11.2	269	1.2	.150	1.4	.230	1.5	.284	2.0	.334	3.4	.441
13.2	317	1.4	.168	1.6	.264	1.7	.321	2.2	.372	3.6	.463
15.2	365	1.5	.188	1.8	.298	1.9	.355	2.4	.405	3.7	.482
19.0	455	1.8	.224	2.2	.363	2.2	.413	2.7	.456	4.0	.515
23.0	551	2.1	.261	2.7	.430	2.5	.463	2.9	.497	4.2	.543
27.0	647	2.4	.298	3.0	.492	2.7	.509	3.2	.531	4.4	.570
32.0	767	2.8	.340	3.5	.560	3.0	.555	3.4	.566	4.6	.598
36.0	864	3.0	.375	3.7	.603	3.1	.586	3.5	.589	4.7	.617
40.2	965	3.3	.410	4.0	.640	3.3	.616	3.6	.613	4.9	.635
44.0	1057	3.6	.437	4.1	.665	3.4	.638	3.7	.629	5.0	.650
47.9	1150	3.8	.466	4.3	.690	3.5	.661	3.8	.649	5.1	.666
52.9	1270	4.1	.503	4.4	.719	3.7	.687	4.0	.672	5.3	.685
INITIAL WATER CONTENT (CM)		8.1		6.2		5.3		5.9		7.7	

APPENDIX III. (CONTINUED) - F HORIZON REMOVED.

TIME DAYS	HOURS	CORE: A-1 CUM EVAP CM	A-1 CUM FRAC EVAP	B-1 CUM EVAP CM	B-1 CUM FRAC EVAP	C-1 CUM EVAP CM	C-1 CUM FRAC EVAP	D-1 CUM EVAP CM	D-1 CUM FRAC EVAP	E-1 CUM EVAP CM	E-1 CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.7	41	0.7	.069	0.4	.096	0.3	.062	0.4	.157	0.4	.045
3.7	88	1.3	.131	0.7	.159	0.5	.102	0.7	.251	0.7	.083
5.7	136	1.8	.182	0.9	.210	0.7	.136	0.9	.325	1.0	.119
8.0	192	2.3	.224	1.2	.258	0.9	.174	1.1	.394	1.3	.155
10.8	258	2.7	.262	1.4	.306	1.1	.213	1.3	.467	1.6	.195
13.8	330	3.0	.294	1.6	.356	1.3	.257	1.5	.531	2.0	.237
17.9	429	3.3	.328	1.9	.418	1.6	.311	1.7	.600	2.4	.287
20.7	497	3.6	.349	2.0	.456	1.8	.347	1.8	.638	2.6	.317
23.8	572	3.8	.369	2.2	.494	1.9	.385	1.9	.673	2.9	.349
26.7	641	3.9	.387	2.3	.524	2.1	.417	2.0	.702	3.1	.375
30.7	737	4.1	.408	2.5	.562	2.3	.457	2.0	.732	3.4	.405
34.8	834	4.4	.429	2.7	.594	2.5	.500	2.1	.759	3.6	.440
38.7	929	4.6	.448	2.8	.621	2.7	.537	2.2	.784	3.9	.469
42.7	1025	4.8	.468	2.9	.647	2.9	.576	2.3	.809	4.1	.496
47.7	1145	5.0	.489	3.0	.674	3.1	.617	2.3	.834	4.3	.526
52.7	1265	5.2	.509	3.1	.695	3.3	.658	2.4	.854	4.6	.553
INITIAL WATER CONTENT (CM)			10.2		4.5		5.1		2.8		8.3
F HORIZON THICKNESS (CM)		0.0			2.0		2.8		2.5		2.2

TIME DAYS	HOURS	CORE: F-1 CUM EVAP CM	F-1 CUM FRAC EVAP	G-1 CUM EVAP CM	G-1 CUM FRAC EVAP	H-1 CUM EVAP CM	H-1 CUM FRAC EVAP	K-1 CUM EVAP CM	K-1 CUM FRAC EVAP	M-1 CUM EVAP CM	M-1 CUM FRAC EVAP
0.0	0	0.0	.000	0.0	.000	0.0	.000	0.0	.000	0.0	.000
1.7	41	0.4	.047	0.6	.101	0.5	.101	0.8	.137	0.9	.120
3.7	88	0.7	.092	1.1	.201	1.0	.197	1.5	.269	1.7	.236
5.7	136	1.0	.136	1.7	.296	1.4	.281	2.0	.368	2.6	.347
8.0	192	1.3	.178	2.2	.398	1.7	.353	2.3	.421	3.1	.418
10.8	258	1.8	.241	2.7	.489	2.0	.410	2.5	.461	3.4	.463
13.8	330	2.3	.300	3.1	.554	2.3	.459	2.7	.494	3.7	.496
17.9	429	2.8	.374	3.4	.608	2.5	.508	2.9	.529	3.9	.529
20.7	497	3.1	.412	3.6	.635	2.7	.535	3.0	.549	4.0	.549
23.8	572	3.4	.446	3.7	.658	2.8	.563	3.1	.569	4.2	.569
26.7	641	3.6	.472	3.8	.676	2.9	.576	3.2	.585	4.3	.583
30.7	737	3.8	.501	3.9	.701	3.0	.611	3.3	.605	4.4	.602
34.8	834	4.0	.525	4.0	.720	3.1	.633	3.4	.624	4.6	.619
38.7	929	4.1	.546	4.1	.738	3.2	.654	3.5	.643	4.7	.634
42.7	1025	4.3	.565	4.2	.755	3.3	.674	3.6	.661	4.8	.650
47.7	1145	4.4	.585	4.4	.777	3.4	.696	3.7	.680	4.9	.668
52.7	1265	4.5	.602	4.5	.793	3.5	.714	3.8	.697	5.0	.683
INITIAL WATER CONTENT (CM)			7.5		5.6		5.0		5.5		7.4
F HORIZON THICKNESS (CM)		3.3			3.4		2.3		1.4		0.0

APPENDIX IV. CHANGE IN VOLUMETRIC WATER CONTENT DURING AND AFTER SIMULATED RAINFALL AS A FUNCTION OF DEPTH AND TIME FOR A HUMUS-SOIL CORE FROM EACH SITE.

CORE A-3, MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 2.0 CM IN 40 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME 1.9		TIME 3.8		TIME 6.4		TIME 8.9		TIME 11.4		TIME 14.0		TIME 16.5		TIME 19.0	
0	.050	0	.159	0	.290	0	.236	0	.302	0	.257	0	.260	0	.265
1	.101														
2	.132														
3	.170	5	.181												
6	.217														
7	.259	8	.183	9	.301										
11	.333	12	.216												
13	.355	14	.247	15	.297	16	.263	17	.300						
19	.368	21	.313	22	.325	23	.257	24	.309						
25	.385	26	.351	27	.382	29	.299	30	.307	31	.263				
32	.399	33	.334	35	.409	36	.351	37	.379	38	.321	40	.256	41	.236
49	.353	50	.316	51	.374	52	.358	53	.371	54	.348	55	.313	56	.258
58	.345	59	.303	60	.370	61	.331	62	.361	63	.343	64	.301	65	.273
90	.338	90	.298	90	.374	90	.338	90	.350	90	.330	90	.313	90	.291
137	.301	137	.290	137	.371	137	.327	137	.360	137	.326	137	.310	137	.297
208	.325	208	.308	208	.353	208	.325	208	.337	208	.321	208	.314	208	.304

APPENDIX IV. (CONTINUED).

CORE B-5, MOR HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.5 CM IN 30 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.037	0	.079	0	.092	0	.087	0	.086	0	.066	0	.073	0	.075
1	.047	2	.114												
4	.030	5	.125	6	.095										
7	.106	8	.148	9	.113										
11	.162	12	.219	13	.144	14	.099	16	.094						
17	.225	18	.203	19	.184	21	.121	22	.090						
23	.241	24	.230	26	.231	27	.146	29	.101	30	.065				
31	.312	32	.281	33	.232	34	.212	35	.135	37	.062				
38	.232	39	.255	40	.227	42	.194	43	.177	44	.073	45	.079		
46	.144	48	.261												
68	.207	69	.208	70	.202	71	.202	73	.160	74	.101	75	.080	76	.070
78	.189	79	.228												
120	.207	120	.208	120	.195	120	.184	120	.171	120	.114	120	.119	120	.086
240	.203	240	.218	240	.173	240	.168	240	.152	240	.110	240	.122	240	.113

APPENDIX IV. (CONTINUED).

CORE C-4, MOR HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.5 CM IN 30 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.060	0	.257	0	.232	0	.164	0	.155	0	.180	0	.216	0	.277
1	.072														
3	.087	4	.304												
5	.087	6	.290												
8	.090	9	.328	10	.254	11	.175								
13	.089	14	.311	15	.279	16	.191	17	.178	19	.187				
20	.094	21	.348	22	.323	23	.231	25	.191	26	.189				
27	.100	28	.394	29	.337	30	.258	32	.237	33	.212	34	.241	35	.293
37	.112	38	.348	39	.317	40	.251								
48	.120	49	.350	50	.298	51	.257	53	.248	54	.238	55	.238	56	.299
58	.077	59	.319	60	.285	61	.249								
95	.112	95	.327	95	.291	95	.247	95	.230	95	.221	95	.246	95	.280
160	.108	160	.310	160	.257	160	.231	160	.232	160	.222	160	.253	160	.301

APPENDIX IV. (CONTINUED).

CORE D-5, PSEUDO DUFF-MULL (MOR) HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.0 CM IN 20 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.6	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.060	0	.104	0	.161	0	.116	0	.080	0	.074	0	.062	0	.071
1	.084														
2	.096														
4	.094	5	.162	7	.178	8	.129								
9	.105	10	.136	11	.175										
13	.093	14	.139	16	.177										
17	.115	18	.150	19	.187										
21	.112	23	.159	24	.181	25	.139	26	.140	27	.176	28	.131	29	.112
31	.126	32	.153												
39	.139	40	.149	42	.182	43	.136	44	.139	45	.174	47	.131	48	.126
72	.128	73	.129	74	.198	75	.126	76	.134	77	.175	78	.142	79	.150

APPENDIX IV. (CONTINUED).

CORE E-5, MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 2.0 CM IN 40 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.080	0	.181	0	.141	0	.127	0	.182	0	.162	0	.185	0	.175
5	.147														
6	.116														
7	.119														
8	.128														
12	.139														
13	.130														
14	.142	15	.288												
21	.204	22	.304	23	.274	24	.212	25	.223	27	.168			28	.117
36	.174	37	.313	38	.283	39	.237	40	.234	41	.189	42	.167	43	.113
47	.145	48	.307	50	.286	51	.245	53	.247						
54	.168	55	.318	57	.277	58	.251								
66	.152	67	.309	69	.285	70	.235	71	.257	72	.219	73	.208	74	.164
76	.159	77	.304												
143	.175	146	.317	148	.280	149	.232	150	.250	151	.220	152	.208	153	.156
252	.185	252	.297	252	.239	252	.216	252	.235	252	.227	252	.213	252	.152
370	.201	370	.283	370	.271	370	.214	370	.233	370	.218	370	.200	370	.193

APPENDIX IV. (CONTINUED).

CORE F-2, DUFF-MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 2.0 CM IN 40 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.125	0	.306	0	.276	0	.283	0	.247	0	.177	0	.160	0	.152
1	.136													2	.155
3	.140														
4	.141	6	.342	7	.311									8	.134
10	.139	11	.351	12	.301	13	.280							14	.159
16	.136	17	.351	18	.315	19	.319							21	.140
23	.161	24	.343	25	.332	26	.350	29	.314	30	.234	31	.178	27	.157
33	.221	34	.382	35	.338	36	.371	37	.357	39	.270	40	.217	41	.173
48	.188	49	.342	50	.354	52	.394	53	.364	54	.302	55	.270	57	.212
65	.204	66	.328	67	.344	68	.372	70	.346	71	.302	72	.286	73	.232
74	.206	75	.321												
106	.216	106	.360	106	.348	106	.370	106	.351	106	.273	106	.244	106	.211
160	.221	160	.335	160	.328	160	.357	160	.339	160	.277	160	.244	160	.204
240	.202	240	.373	240	.325	240	.350	240	.326	240	.273	240	.240	240	.188

APPENDIX IV. (CONTINUED).

CORE G-4, DUFF-MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.5 CM IN 30 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.055	0	.115	0	.190	0	.241	0	.147	0	.123	0	.141	0	.180
2	.086														
3	.098														
4	.126	5	.179	6	.233	8	.256								
9	.145	10	.152	11	.251	13	.269	14	.164	15	.129				
17	.188	18	.172	19	.263	20	.284	21	.190	23	.134	24	.158		
25	.169	26	.232	28	.292	29	.293	30	.211	31	.158	32	.159	33	.191
35	.166	36	.267	37	.267										
45	.142	46	.244	47	.278	48	.314	50	.232	51	.207	52	.202	53	.203
55	.157	56	.269	57	.265	59	.296	60	.217	61	.195	62	.205	63	.235
110	.142	110	.250	110	.272	110	.288	110	.192	110	.168	110	.181	110	.207

APPENDIX IV. (CONTINUED).

CORE H-4, MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.5 CM IN 30 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.078	0	.194	0	.280	0	.251	0	.226	0	.141	0	.142	0	.172
2	.117	3	.217	4	.310	5	.249								
7	.122	8	.222	9	.330	10	.280	11	.279	13	.183				
14	.129	15	.204	16	.298	17	.312	19	.301	20	.216	21	.169	22	.156
24	.140	25	.238	26	.330	27	.341	28	.350	29	.267	31	.199	32	.167
33	.128	34	.227	36	.309	37	.347								
44	.123	45	.231	47	.314	48	.367	49	.344	50	.258	51	.234	52	.216
80	.126	80	.209	80	.343	80	.339	80	.336	80	.257	80	.250	80	.226
140	.120	140	.227	140	.314	140	.335	140	.329	140	.242	140	.227	140	.234
260	.111	260	.247	260	.313	260	.325	260	.308	260	.226	260	.223	260	.220

APPENDIX IV. (CONTINUED).

CORE K-4, MULL HUMUS TYPE; AMOUNT AND DURATION OF RAINFALL: 1.5 CM IN 30 MINUTES

TIME (MINUTES) AND DEPTH (CM)

TIME	1.9	TIME	3.8	TIME	6.4	TIME	8.9	TIME	11.4	TIME	14.0	TIME	16.5	TIME	19.0
0	.175	0	.144	0	.161	0	.172	0	.132	0	.093	0	.099	0	.068
1	.141	2	.150												
3	.175	5	.137												
6	.214	7	.158	8	.178	9	.167								
11	.178	12	.197	13	.179	14	.164								
16	.280	17	.243	18	.202										
20	.217	21	.298	22	.254	23	.165								
25	.236	26	.293	27	.299	28	.210	30	.118	31	.114	32	.116	33	.070
35	.301	36	.307	37	.295	38	.254	39	.190	41	.122				
42	.378	43	.292	44	.277	45	.246								
53	.387	54	.270	55	.281	56	.255	57	.183	59	.188	60	.149	61	.092
90	.229	90	.264	90	.281	90	.230	90	.204	90	.191	90	.182	90	.128