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ABSTRACT

RELATING SOIL WETNESS TO SELECTED SOIL PROPERTIES

By

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Soil morphological features, particularly soil color are a key for the inference of depth to a seasonally high water table.

Depths to saturated zones were monitored over a 4-year period on three hydrosequences. Water contents (% by volume) were measured biweekly using a neutron moisture meter. These measurements were compared with water contents of undisturbed cores for the same depths to determine the saturated zone. Soil temperatures at 30, 50, 60, and 90 cm were measured biweekly.

A set of criteria relating soil color with depth and duration of the saturated zone was found in this study of loamy soils. Horizons that have a matrix color with a chroma of 4 or more are never saturated if gray argillans and mottles are absent, but are saturated for 14-16 weeks if faint mottles and gray argillans are present. Horizons that have a matrix color with a chroma 3 are saturated for 12-14 weeks if gray argillans or some faint mottles or both are present. Horizons that

have a matrix color with a chroma 2 are saturated for 22-24 weeks if gray argillans and non gray mottles are present. Horizons that have a matrix color with a chroma of 1 are saturated for 26-28 weeks if distinct and prominent mottles are present. Horizons that have matrix colors with a chroma of 0 with distinct or prominent mottles or both are saturated for more than 32 weeks. This study suggests that soils with horizons having a 3 chroma matrix with mottles and/or gray argillans are aquic intergrades.

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INTRODUCTION

Natural drainage is defined as the frequency and duration of periods when the soil is free of saturation (USDA, 1951). According to this concept, soil scientists have assigned soils to seven drainage classes, ranging from poorly drained to excessively drained. The downward flow of water through a soil is affected by permeability and location of the water table. Therefore, fluctuations of a seasonal water table have posed particular problems to many soil uses and management, and are often problems whenever near the soil surface. Crop growth, building, septic tank operation, waste disposal, and off-road traffic may be impaired or limited by periodic high water tables. To assist planners in making land-use decisions, such as evaluation of soil productivity, determination of land area to be drained, and use for both agricultural and nonagricultural purposes, detailed soil information is needed. This information includes evaluation of ground water behavior. The later could be carried out in a satisfactory manner through monitoring of soil moisture regimes for long periods of time, plus detailed soil descriptions and some important physical and chemical properties. Such information would pave the way to find reliable criteria from morphological features to estimate the depth and duration of saturated soil zones.

Conspicuous soil features such as soil matrix colors, coating colors, mottles, and concretions are being used in the soil-survey program as evidence of different degrees of wetness. Soil Survey Staff (1975) have indicated that mottles occur as a result of fluctuations of groundwater levels and periodic soil saturation. More specifically, mottles with chromas of 2 or less have been used in the USDA Soil Taxonomy System as indicators of significant soil saturation.

Alternation of oxidation and reduction is an essential process in the development of gley. This phenomenon is caused by anaerobic conditions or reduction reaction involving the reduction and mobilization of iron. The intensity of reduction in soil saturated with water depends on the activity of microorganisms and the content of decomposible organic matter (Brummer, 1973).

Reduction occurs due to the deficiency of oxygen which occurs as a result of rising water table and activities of different microorganisms. Therefore, the reduced iron compounds either would be removed from the soil with downward movement of the water, or would be redistributed within the soil. These oxidation-reduction cycles are commonly characterized by the formation of various colors within the soil profile ranging from gray to reddish-brown colors.

In this study, depth and duration of saturated zone were related to soil morphological features. To meet this objective the following secondary objectives were identified:

1. Monitor the depth of saturated zone throughout the year in soils occurring in three representive hydro-sequences in two counties (Clinton and Ionia) in Michigan.

2. Study the relationship between soil morphological features and depth and duration of saturated zone, in an attempt to find reliable criteria for predicting the zone of saturation.

3. Determine saturated hydraulic conductivity in the laboratory and in-situ, bulk density and water contents at 0.0, 0.06, 0.1, 0.33, 1, 3, 5, and 15 bar tensions.

LITERATURE REVIEW

A. General concept of gley mechanisms

Gley occurs under saturated conditions as a secondary process following intensive reduction and mobilization of iron (Ottow, 1973). The removal or loss of iron from the profile leaves the soil a neutral gray color with a low chroma, which has been associated with the saturated zone without respect to length of saturation (Soil Survey Staff, 1975). Thermodynamically, the transformation of trivalent iron to divalent iron requires energy. Anaerobic microorganisms are capable of decomposing organic matter and fixing nitrogen to maintain their activity. Organic matter and saturation are essential for the reduction of iron.

A proposed mechanism of gley formation is as follows (Ottow, 1973):

Inorganic fermentation (Clostridium sp.):

$$\text{energy source} \xrightarrow[\text{dehydrogenases}]{\text{substrate}} \bar{e} + H^{+} + ATP + \text{end products}$$

Iron oxide as hydrogen acceptor:

$$>Fe - OH + H^{+} + e^{-} \longrightarrow Fe^{+2} + 2H_2O$$

Gley formation:

$$2Fe(OH)_3 + Fe^{+2} + 2OH^- \rightleftharpoons Fe3(OH)_8$$

brown green-gray

Anaerobic, nitrogen-fixing clostridia, capable of reducing iron oxides vigorously, are proposed in this mechanism.

B. Matrix Color

The relationship of groundwater table to certain morphological soil features indicated that a chroma of 2 was related to a long period of saturation in that horizon (Gile, 1958; Fanning et al., 1973; Laing, 1973; McKeague et al., 1973; Veneman and Boding, 1982). A similar study was carried out on four seasonally saturated soils to determine if each soil had an aquic moisture regime (Vepraskas and Wilding, 1983). Despite the significant periods of saturation and reduction, a chroma of 2 or less was not found in all soils. Rather, a chroma of 3 was found on ped surfaces in some saturated horizons. Therefore, Vepraskas and Wilding (1983) recommended chromas of 3 and less as indicative of an aquic moisture regime. This chroma, 3, has been reported on ped surfaces in Bg horizons of soils included in several studies (Buringh, 1960; McKeague et al., 1969, 1973; Laing, 1973; Vepraskas et al., 1974). The B-horizon of somewhat poorly drained soils had a chroma of 3 after kneading (Richardson and Hole, 1979). Values of 4 or 5 with mottles were often associated with a chroma of 3 in all these studies. A chroma of 2 or less have been questioned as a suitable criterion for soils developed on red parent materials or reddish-brown deposits (McKeague and Cann, 1969). Several studies that were conducted on the relationship between soil morphology and soil water regimes have indicated that matrix colors with hue of 2.5Y and values of 5 and 6, were found in horizons that were saturated with water for a significant period of time (Gile, 1958; Simonson and Boersma, 1972; Fanning et al., 1973; Laing, 1973; McKeague et al., 1973; and McArthur and Russell, 1978).

In several studies, matrix colors with a hue of 5Y and a value of 5 were associated with horizons that were saturated for prolonged periods (Gile, 1958; Simonson and Boersma, 1972; Laing, 1973; McKeague et al., 1973; Veneman and Bodine, 1982). Hues of 5Y and 2.5Y with low chromas and in connection with mottles were applicable criteria for identifying the degree of soil wetness with inference of reducing conditions and removal of iron compounds in the profile (Soil Survey Staff, 1951). The yellow hues were not common in soils that have been derived from red parent materials, in spite of excess soil water and restricted downward movement of groundwater. Hues of 5YR and 10YR, in association with mottles, were found in poorly drained soils having red parent materials (Laing, 1973).

C. Mottles with Depth and Color

Mean highest water table (MHW) and mean lowest water table (MLW) in several soils were determined on the basis of measurements of groundwater levels (Van Wallenburg, 1973). Brown mottles with hues of 5YR-10YR began above the MHW. Distinct brown mottles with hues of 2.5Y-10YR were abundant below the MHW. Therefore, the presence and location of brown mottles at a certain depth did not give a reliable indication of water-table levels. Distinct gray mottles, mostly with hues of 2.5Y to 10G and chromas of 1 or less, were always found between MHW and MLW. The upper boundary of the horizon with distinct gray mottles was located between 10 and 50 cm below the MHW in different profiles. The position of this layer with respect to the MHW was dependent on texture, parent material and soil structure. The MLW was related to the depth of the G-horizon. Similar results had been reported by Schelling (1960). He noted that gray mottling was always a reliable indicator for estimating mean highest water table, but he didn't indicate the hue or chroma of these mottles. Profile descriptions of soils in representative topo-sequences revealed that mottles with low chromas of 2 or less on ped exteriors and high chromas of 6 or more inside peds occurred in zones that were saturated for short periods of time (Blume, 1968; Veneman and Bodine, 1982; Richardson and Lietzke, 1983). Mottles with low chromas of 1 inside peds and with high chromas of 5 or more on ped exteriors and a lack of manganese coatings or nodules occurred in almost continously saturated zones (Veneman et al., 1976; Richardson and Lietzke, 1983). Horizons that were saturated for short periods of time, and periods of several months near saturation, had mottles with a chroma of 2 inside the peds with few manganese mottles (Veneman et al., 1976). Thus, mottles with low chromas of 2 or less inside peds and high chromas on ped surfaces often occurred in soil horizons that were saturated with water for significant periods of time.

Several studies have been conducted on the relation between types of mottling and different soil moisture regimes ranging from well-drained to very poorly drained soils (Veneman et al., 1976; Richardson and Hole, 1979; Richardson and Lietzke, 1983). Their studies showed that mottles with a chroma of 1 inside peds and high chromas of 6 to 8 on ped exteriors were dominant in poorly drained soils; mottles with a chroma of 2 inside peds were correlated with somewhat poorly drained soils; and mottles with chromas of 3 or more inside peds were dominant in moderately well drained soils. Zobeck et al., (1983) related the depth of low chroma mottles, 2 or less, to the depth of water table. They reported that these mottles were observed in the 50-100 cm zone of well drained soils, in the 25-50 cm zone of moderately well drained soils, and in the 0-25 cm zone of poorly drained soils. Light gray to light brownish gray (10YR 7/2-6/2) mottles commonly occurred at depths that were saturated 50 percent of the time (Daniels et al., 1971). The depths at which faint and distinct mottling occurred were found to be highly correlated with a high degree of soil wetness (Simonson and Boersma, 1972). To illustrate this, certain relationships between the occurrence of both types of mottling and water-table levels are listed below.

Type of soils	Depths of faint mottles	Avg. percentage of time the water table was above the depth
Willamette (well drained)	127.0 cm	90.3, 91.0, 88.1, 73.2, 16.2, 0.5 (January through June, respectively)
Woodburn (moderately well drained)	76.2 cm	
Amity (somewhat poorly drained)	33.0 cm	
Concord (poorly drained)	15.2 cm	
Dayton (poorly drained)	15.2 cm	

Type of soils	Depths of distinct mottles	Avg. percentage of time the water table was above that depth
Willamette (well drained)	152.4 cm	93.4, 95.0, 94.0, 86.3, 43.0, 9.1 (January through June, respectively)
Woodburn (moderately well drained)	114.3 cm	
Amity (somewhat poorly drained)	94.0 cm	
Concord (poorly drained)	15.2 cm	
Dayton (poorly drained)	15.2 cm	

Distinct mottles with some grayer-colored mottles with hues of 2.5Y and 5Y occurred in horizons that were saturated for a long period of time.

D. Concretions

Arshad and Arnaud (1980) studied some soils of Saskatchewan and reported that the presence of concretions was most evident under conditions of restricted drainage. These conditions are suitable for resegregation of Fe, Al, Mn, and organic matter in concretionary forms with B-horizons. The contents of both Fe and P increased with the decreasing size of concretions, whereas the amount of Mn was directly related to the size of concretions. Distribution and development of concretions have been reported under different soil moisture regimes (Simonson and Boersma, 1972; Richardson and Hole, 1979; Arshad and Arnaud, 1980). Concretions were absent in well-drained soils; abundant in somewhat poorly drained soils, and few in poorly drained soils. A recent study showed that there are few concretions in the soil zone which is normally saturated, while plentiful in zones with fluctuating water tables (Richardson and Lietzke, 1983).

A study of gray hydromorphic soils of the Hawaiian Islands indicated that all soils, with the exception of those moderately well and well-drained soils, showed a drop in free iron, Fe_2O_3, at depths around 50 cm (20 in.) (Hussian and Swindale, 1974). This depth coincided with the depth of the water table. The vertical distribution of free MnO_2 and Fe_2O_3 decreased with the increasing hydromorphism (the process that leads to the development of properties caused by poor drainage conditions). Bloomfield (1952) indicated the the gley horizon might contain high free iron due to periodic aeration and oxidation of ferrous iron. Thus, free iron analysis may not be a reliable method in differentiating soils of different moisture regimes. Maclead (1973) reported that the ratio of ammonium acetate extractable Mn to total Mn increased significantly as the groundwater was approached in some soils of eastern England. The ratio of ammonium acetate extractable Fe to total Fe was small compared with Mn. The ratio of iron was between 0.09-0.5 and that for Mn of 0.49-2.41.

Field studies on the soils southwest of Paris indicated that the thickness of A_2 horizons in poorly drained soils was related to the fluctuation of water-table levels (Fedoroff, 1973). The same study showed that the gray color of the AB horizon was related to the duration of the impedence. McArthur and Russell (1978) noted that the thickness of A_2 horizon increased with restricted drainage. Criteria for the classification of Weiesenboden soils of Iowa, which have been developed under conditions of periodically high water tables were dependent on the thickness of the A horizon and the presence of a strongly mottled, light olive gray gley horizon below the lower B horizon (Riecken, 1945). In southern Ontario and parts of Quebec, the difference in characteristics between A_2 and B_2 horizons became less distinct as drainage became poorer (Stobbe, 1952).

MATERIALS AND METHODS

A. Field Work

Three representative hydrosequences were selected and sampled for this study. Hydrosequences 1 and 2 are situated in Clinton County within one-half mile of each other, near the town of Maple Rapids. Both hydrosequences are composed of three series: Marlette, Capac, and Parkhill. The third hydrosequence is situated in Ionia County near the town of Palo, and is composed of Marlette, Capac, and Brookston.

The soils on the upper slopes (pedons M1, M2, and M3) are representative of the Marlette series, which is classified as fine-loamy, mixed, mesic Glossoboric Hapludalf. Pedons M1 and M3 are well-drained soils, while pedon M2 is moderately well drained soil. The soils on the foot slopes (pedons C1, C2, and C3) are the somewhat poorly drained Capac series which is classified as fine-loamy, mixed, mesic Aeric Ochraqualf. Pedons P1 and P2 occur on toe-slope positions and are representative of the Parkhill series, which is poorly drained and is classified as fine-loamy, mixed, mesic Mollic Haplaquept. Pedon B1 is representative of the poorly drained Brookston series, which is classified as fine-loamy, mixed, mesic, Typic Argiaquoll. These pedons have been described elsewhere (Cremeens, 1983).

The parent material of the hydrosequences in both counties is glacial till. The forest vegetation on the well-drained Marlette soil in hydrosequence 1 consists of Shagbark Hickory (Carya ovata), White Oak (Quercus alba), and Northern Red Oak (Quercus rubra); on the somewhat poorly drained Capac soil, consists of Sugar Maple (Acer succharum), White Oak, and Shagbark Hickory; and on the poorly drained Parkhill soil, consists of White Oak, Quaking Aspen (Populas tremuliodes), and Swamp White Oak (Quercus bicolor), (Cremeens, 1983). This poorly drained site also has a dense cover of Yellow Nutsedge (Cyperus esculentus). Hydrosequence 2 is situated in a 150-acre woodlot consisting of America Basswood (Tilia Americana), Sugar Maple, and Northern Red Oak on the well-drained Marlette soil; Sugar Maple, Northern Red Oak, Red Maple (Acer rubrum), and Shagbark Hickory on the somewhat poorly drained Capac soils; and White Oak, White Ash, (Fraxinus Americana), and Swamp White Oak on the poorly drained Parkhill soil. Yellow Nutsedge occurs on most parts of the poorly drained site. Hydrosequence 3 is situated in a wooded area consisting of Pin Oak (Quercus palustris), White Oak, and Shell Bark Hickory (Carya laciniosa) on the well-drained Marlette soil; Shagbark Hickory, Bitter Nut

Hickory (Carya cordiformis), White Oak, and Quaking Aspen on the somewhat poorly drained Capac soil; and Sugar Maple, American Basswood, and Slippery Elm (Ulmus rubra) on the poorly drained Brookston soil.

Five undisturbed soil cores were taken from each of four depths (30, 60, 90, 120 cm), at which percent moisture was determined every two weeks using a neutron moisture meter. Neutron moisture meter access tubes with an inside diameter of 51 mm and lengths of 1.5-3.0 meters were installed at all sites. Access tubes were aluminum tubing with one end sealed with a rubber stopper and silicon sealer. A hole was augered near each of the sampled pedons using a bucket auger with a 63.5 mm diameter bucket. A restrictive layer such as coarse fragments or water prevented augering to 3.0 meters in some of the sites. The aluminum tubes were inserted into the holes and the annular space around the tubes was filled with soil material and sealed tightly to above the soil surface to prevent seepage.

Saturated hydraulic conductivity was measured in-situ for three different depths, (50, 100, and 150 cm). The tubes, consisting of aluminum tubing with an inside diameter of 3.6 cm, were installed near each neutron moisture access tube at each site. The 50 cm tubes were not installed at sites M1 and M3. In-situ hydraulic conductivities were measured in the observation wells by pumping water out of the wells and measuring the rates at which the water levels rose in the wells. A Soiltest model Dr 760A water-level indicator is battery operated, and a needle moves once the end of the drop source comes into contact with water.

Thermocouples were installed in each of the sampled pedons at depths of 30, 50, 60, and 90 cm. Soil temperatures were measured every two weeks using an Omega Digital temperature indicator, model 199.

B. Laboratory Analyses

Bulk density was determined using undisturbed cores (Soil Survey Staff, 1972). Soil moisture contents at 0, 0.06, 0.1, 0.33, and 1 bar tensions were determined using undisturbed soil cores. Disturbed samples were used for determining soil moisture contents at 3, 5, and 15 bar tensions using porous plate apparatus (Soil Survey Staff, 1972). The undisturbed soil cores for three pedons, C2, P2, and B1, were resaturated for estimating their moisture contents at 0, 0.01, 0.02, 0.03, 0.04, 0.05 and 0.06 bar tensions.

Results and Discussion

Seasonal variations in the depths of the saturated zones in nine forested sites representing four soil series are shown in Figs. 1, 2 and 3. These figures were constructed from neutron moisture meter data (Appendix A), and volumetric water contents at saturation for undisturbed cores (Table 1 and 2).

The data obtained with the neutron moisture meter was supported by measurements of water table levels in series of pipes in each site (Table 3).

Marlette series

The Bt1 horizon (28-63 cm) of pedon M1 has a brown matrix color with a chroma of 4 and argillans (clay films) with a chroma of 2 (Table 4). The 30 cm depth was saturated for 4 weeks and the 60 cm depth was saturated for 6 weeks (Fig. 1). The same colors suggest that there is no significant difference between 4 and 6 weeks soil saturation as far as reduction is concerned. This is probably due to a short period, 1-2 weeks, when the soil temperature (Table 5) was above biological zero (5 $^{\circ}$C) and the horizon was saturated for both depths. The 30 and 60 cm depths were also near saturation for an additional 2-4 weeks when the soil temperature was above 5 $^{\circ}$C. In

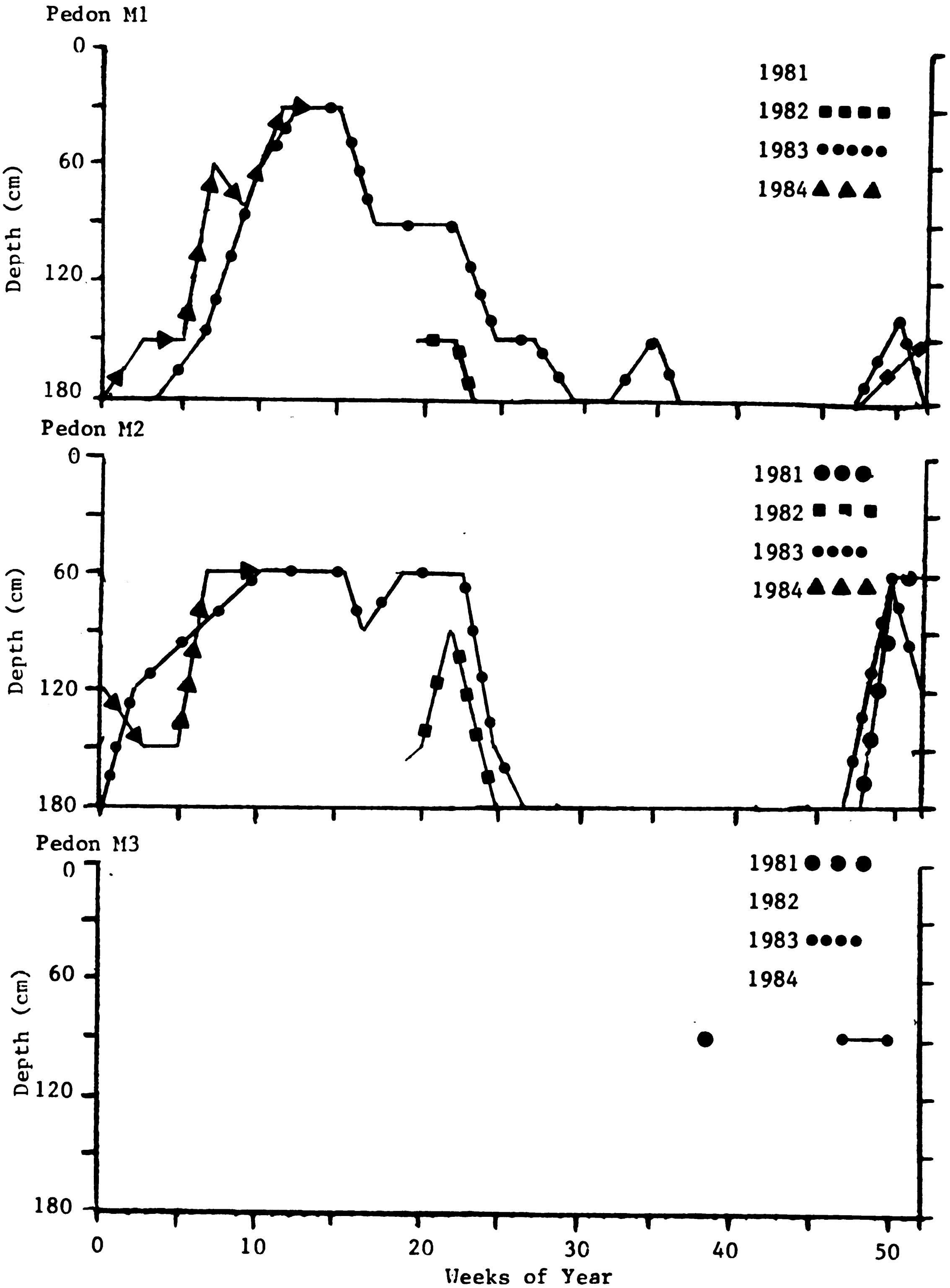

Fig. 1 - Fluctuations of saturated zone in three Marlette pedons based on neutron moisture meter data.

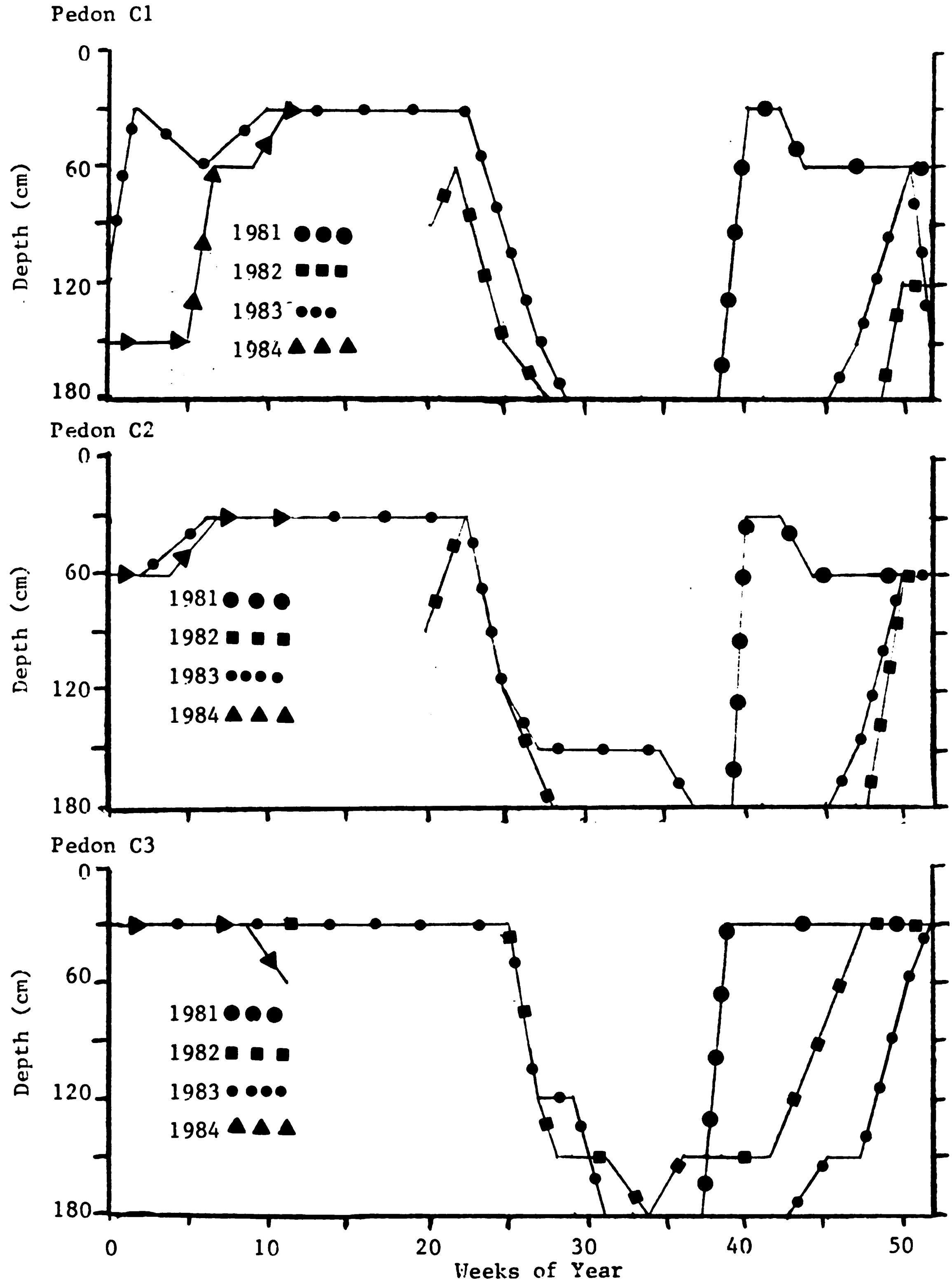

Fig. 2 - Fluctuations of saturated zone in three pedons of Capac series.

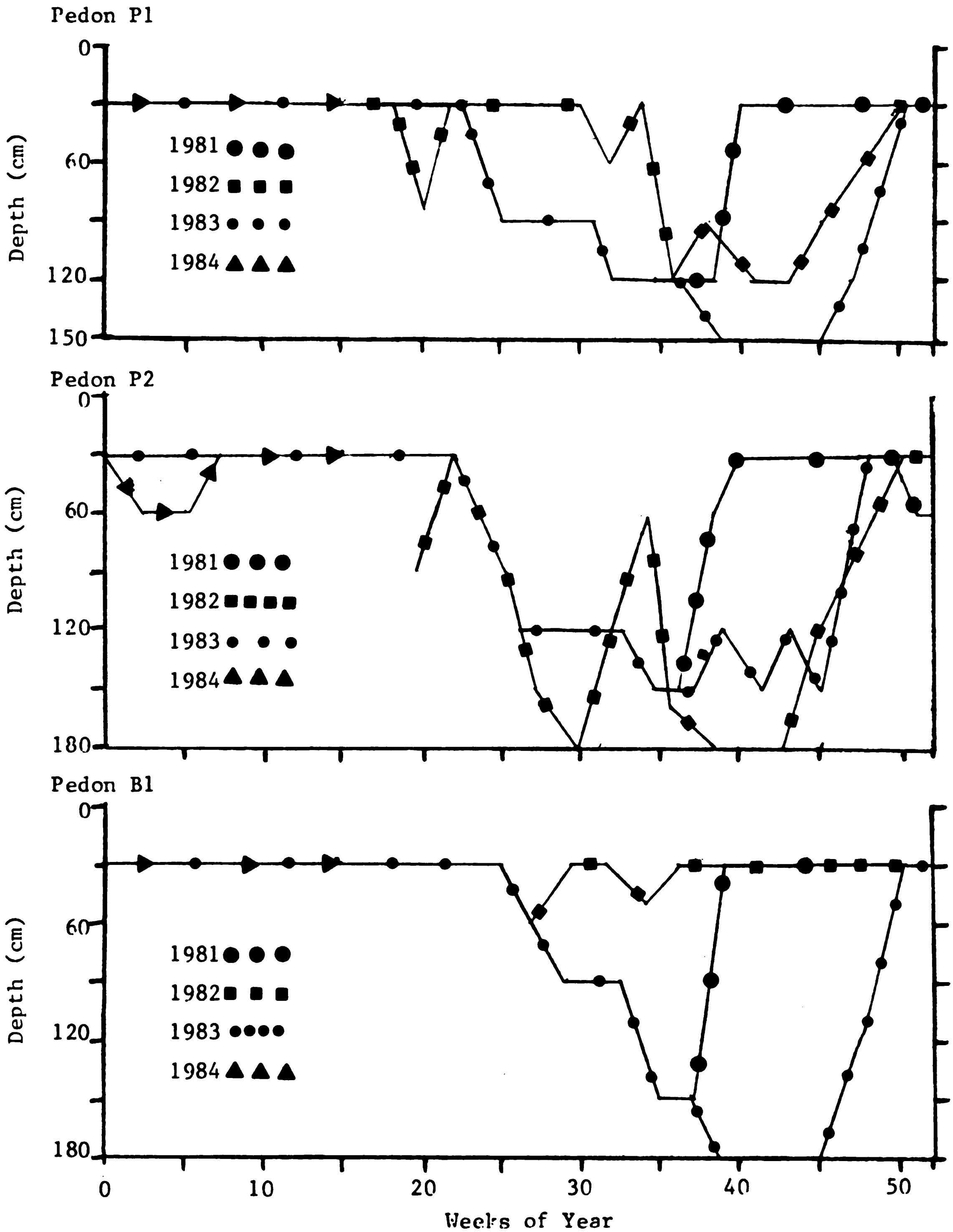

Fig. 3 - Fluctuations of saturated zone in two Parkhill pedons and one Brookston pedon.

TABLE 1

MOISTURE CONTENTS (% BY VOLUME) OF 30, 60, 90 AND 120 CM DEPTHS AT DIFFERENT TENSIONS

Pedon No.	Depth (cm)	Tension (bar)							
		0	0.06	0.1	0.33	1	3	5	15
M1	30	40.4	33.0	31.7	30.5	29.2	16.8	13.7	7.9
	60	45.2	38.5	37.4	35.9	34.8	16.8	13.5	7.9
	90	39.9	32.9	31.6	30.1	29.1	21.5	18.6	14.9
	120	38.7	31.4	30.7	28.3	27.2	16.8	15.3	9.7
M2	30	42.8	33.4	32.9	32.2	31.4	18.5	18.0	14.9
	60	41.3	34.7	34.2	33.2	32.7	23.8	20.2	16.7
	90	39.2	30.1	29.5	28.4	27.3	18.1	16.7	14.0
	120	38.1	29.8	28.9	28.2	27.3	18.5	17.1	14.1
M3	30	39.4	30.8	29.4	27.7	26.9	14.5	12.3	8.8
	60	42.7	35.5	34.8	32.8	31.7	15.4	13.7	11.4
	90	39.3	32.4	31.3	28.5	27.6	11.5	10.9	6.2
	120	37.4	31.4	30.1	28.3	27.5	11.2	10.8	6.1
C1	30	43.8	37.1	36.2	35.2	34.8	18.9	14.9	13.2
	60	41.3	33.9	33.6	32.7	31.9	20.3	18.0	14.1
	90	37.5	30.7	28.9	27.2	25.2	20.0	18.0	14.1
	120	34.9	29.2	28.6	27.1	25.0	19.4	16.7	14.4
C2	30	41.3	39.5	31.2	27.9	26.4	12.8	9.7	7.9
	60	40.0	31.2	39.9	26.2	24.6	12.8	11.0	7.9
	90	39.2	30.2	28.6	25.4	23.9	12.7	10.9	7.8
	120	39.3	31.9	30.4	27.2	25.5	17.2	15.3	10.5
C3	30	40.4	29.0	26.4	23.9	22.6	13.2	11.5	7.9
	60	41.1	29.4	27.1	23.2	21.9	12.8	10.5	7.9
	90	40.1	28.5	25.2	22.5	21.7	12.7	10.5	7.7
	120	34.9	26.6	24.2	21.9	20.6	10.1	9.3	5.3

TABLE 1--continued

Pedon No.	Depth (cm)	Tension (bar)							
		0	0.06	0.1	0.33	1	3	5	15
P1	30	59.1	49.6	47.6	47.6	46.9	26.9	22.4	18.4
	60	55.7	46.9	46.3	45.3	44.6	27.8	24.6	21.0
	90	50.1	44.6	43.9	43.5	43.2	23.4	19.9	15.8
	120	40.6	36.6	35.9	34.9	34.4	18.5	15.4	12.3
P2	30	49.9	42.0	40.4	38.4	37.5	18.5	16.3	12.3
	60	44.1	36.1	34.3	32.3	30.8	16.3	14.5	11.4
	90	39.7	35.5	34.0	31.9	30.5	16.3	14.4	12.3
	120	37.7	33.4	31.6	30.3	29.1	16.3	13.9	10.4
B1	30	48.4	35.1	32.1	29.8	28.5	10.6	9.2	7.0
	60	46.7	36.2	35.2	30.8	29.6	11.0	10.2	7.8
	90	46.5	37.8	35.2	32.5	31.3	10.6	8.3	7.0
	120	46.9	40.7	38.7	36.4	35.0	10.6	8.3	7.0

TABLE 2

MOISTURE CONTENTS (% BY VOLUME) OF 30, 60, 90 AND 120 CM DEPTHS IN THREE PEDONS AT DIFFERENT TENSIONS

Pedon No.	Depth (cm)	Tension (bar)						
		0	0.01	0.02	0.03	0.04	0.05	0.06
C2	30	39.3	36.2	35.4	34.8	34.1	33.4	32.8
	60	38.3	35.4	34.7	34.0	33.3	32.6	31.7
	90	37.5	34.3	33.2	32.9	32.0	31.3	30.5
	120	38.0	35.2	34.5	34.0	33.3	32.6	32.0
P2	30	51.8	45.1	44.0	43.3	42.6	42.0	41.7
	60	42.5	39.2	38.3	37.7	37.0	36.3	35.7
	90	39.1	36.7	36.2	35.9	35.4	35.0	34.7
	120	38.0	35.1	34.3	33.8	32.8	31.7	29.3
B1	30	49.8	41.3	39.5	37.9	36.7	35.7	35.1
	60	46.8	41.6	40.1	38.8	37.7	36.6	35.9
	90	46.2	42.3	41.2	40.1	38.9	37.8	37.0
	120	46.2	43.4	42.6	41.8	41.0	40.2	39.9

TABLE 3

WATER TABLE FLUCTUATIONS (DEPTHS IN CM)
IN NINE PEDONS

PN*	WD**	1983				1984										
		N		D		J		F		M		A		M		J
M1	100	–	–	–	–	–	–	53	67	16	29	27	60	69	40	
	150	–	–	150	–	150	150	28	67	16	26	27	60	69	–	
M2	50	–	–	–	–	–	–	–	–	40	45	37	–	49	–	
	100	–	–		–	–	–	63	75	47	51	47	59	60	64	
	150	–	–		140	150	150	66	76	45	51	47	59	60	64	
M3	100	–	90	90	–	–	–	–	–	–	–	–	–	–	–	
	150	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
C1	50	–	–	40	–	–	–	43	45	14	19	13	21	24	27	
	100	–	–	46	–	–	–	40	44	17	24	16	27	27	28	
	150	–	150	41	140	148	150	41	43	14	20	16	28	28	28	
C2	50	–	–	50	43	47	–	16	39	10	5	7	16	23	27	
	100	–	–	59	49	48	64	14	39	16	12	13	17	25	29	
	150	–	150	109	93	64	63	56	38	47	32	28	20	32	39	
C3	50	–	–	–	33	32	40	13	30	–	5	4	16	23	15	
	100	–	–	67	33	34	41	14	33	60	10	12	19	25	19	
	150	150	150	67	30	37	43	13	34	60	10	9	17	26	18	
P1	50	–	–	32	26	29	25	20	10	4	–	–	2	3	5	
	100	–	–	31	27	28	23	21	11	5	–	–	5	6	7	
	150	148	109	30	29	27	21	23	12	4	–	–	3	4	7	
P2	50	–	28	20	32	40	46	23	27	20	10	–	13	20	13	
	100	–	30	23	30	40	47	24	23	20	12	13	10	23	15	
	150	150	33	21	33	40	43	20	25	20	14	10	13	21	19	
B1	50	–	–	5	15	24	27	9	13	20	–	–	10	14	9	
	100	–	–	5	12	24	25	12	14	20	3	3	12	13	12	
	150	–	120	5	11	24	23	11	14	21	3	4	11	15	10	

*Pedon Number. **Well Depth (cm).

TABLE 4

SOME MORPHOLOGICAL PROPERTIES OF NINE PEDONS*
(FROM CREMEENS, 1983)

Horizon	Depth (cm)	Texture	Structure	Color		
				Matrix	Mottles	Coatings
Pedon M1						
A	0-10	SiL	2fgr	10YR 4/2		
E	10-19	SiL	1fpl	10YR 6/3		
BE	19-28	L	2msbk	10YR 5/4		
Bt1	28-64	L	2msbk	10YR 4/4		10YR 4/2
Bt2	64-97	CL	2msbk	10YR 4/3		10YR 4/2
BC	97-104	SiL	2csbk	10YR 4/3	f1f 10YR 4/4	10Y 3/2
C1	104-165	SiL	1cpl	10YR 5/3	f1f 10YR 5/6	
C2	165+	SiL	1cpl	10YR 4/3	m3f 10YR 5/6	
Pedon M2						
A	0-12	SiL	2mgr	10YR 4/2		
E/B	12-26	SiL	1mpl	10YR 5/6		
			2msbk	10YR 6/6		
Bt1	26-40	SiCL	2msbk	10YR 4/4		10YR 4/2
Bt2	40-84	SiCL	2mabk	10YR 4/4	f1f 10YR 5/4	10YR 4/2
BC	84-108	SiL	3cpl	10YR 4/4	f2f 10YR 5/4	10YR 4/2
			2msbk			
C1	108-165	SiL	3cpl	10YR 5/2	f2f 10YR 5/4	
			2msbk			
C2	165+	SiL	3cpl	10YR 5/3	c1f 10YR 5/4	
Pedon M3						
A	0-12	L	2mgr	10YR 4/2		
B/E	12-32	L	1mpl	7.5YR 4/4		
			2fsbk	10YR 5/2		
Bt1	32-48	L	3fsbk	7.5YR 4/6		10YR 4/3
Bt2	48-86	L	2msbk	7.5YR 5/4		7.5YR 4/2
BC	86-127	SiL	3mpl	10YR 5/3		7.5YR 3/4
			2mabk			
C	127+	L	3cpl	10YR 4/3	f1d 5YR 5/6	
			2cabk			

TABLE 4--continued

Horizon	Depth (cm)	Texture	Structure	Color: Matrix	Color: Mottles	Color: Coatings
Pedon C1						
A	0-12	L	2fgr	10YR 3/2		
BA	12-25	L	2msbk	2.5Y 6/2	m2p 7.5YR 5/6	
Btg1	25-40	L	2msbk	5Y 6/2	m3p 7.5YR 5/8	
Btg2	40-110	CL	2msbk	5Y 5/1	c3d 10YR 4/6	10YR 4/2
C	110+	SL	2mbk	10YR 5/3		
Pedon C2						
A	0-22	L	2mgr	10YR 3/1		
B/E	22-32	SL	1fsbk	10YR 5/3 10YR 6/4	f1f 7.5YR 5/6	
Bt	32-53	L	2mabk	10YR 5/3	c2d 7.5YR 4/4 & f2f 10YR 5/2	7.5YR 4/2
Btg	53-97	L	2msbk	2.5Y 4/2	c2d 7.5YR 4/4 & f2d 10YR 5/3	10YR 5/2
BC	97-125	SL	1msbk	2.5Y 4/2	m2p 7.5YR 5/6 & c1d N 5/0	10YR 5/2
2C	125+	SiL	2cpl 1cabk	2.5Y 4/4	c3d N 5/0 & m1d 10YR 4/6	
Pedon C3						
A	0-17	SL	2fgr	10YR 3/1		
B/E	17-33	L	2fsbk	10YR 4/4 10YR 5/3		10YR 4/2
Bt	33-58	L	2fsbk	10YR 4/4	c1d 2.5Y 5/2 & c2d 7.5YR 4/6	10YR 4/3
Btg	58-85	L	2msbk	2.5Y 5/2	c2d 10YR 4/4 & c1d 10YR 5/2	10YR 4/2
BC	85-160	SL	2cpl 2fpl	10YR 5/6	m1d 10YR 6/1 & c2d 5YR 5/4	5YR 5/4
C	160+	L		10YR 6/3	m2f 10YR 6/1 & f3d 7.5YR 4/4	

TABLE 4--continued

Horizon	Depth (cm)	Texture	Structure	Color		
				Matrix	Mottles	Coatings
Pedon P1						
A	0-16	SiL	2mgr	10YR 3/1		
BA	16-25	SiCL	2fsbk	2.5Y 4/2	f2d 10YR 5/1 & f1d 7.5YR 5/6	
Bg1	25-46	SiCL	3mabk 2fabk	5Y 4/1	c2p 7.5YR 4/6 & c1d 10YR 4/4	
Bg2	46-85	SiCL	3mabk 3fabk	N 5/0	m3p 7.5YR 4/6 c1d 10YR 4/4	
Bg3	85-119	SiCL	2mabk 2fabk	N 5/0	m2d 10YR 4/4 & 10YR 4/6	
C	119+	SiL	2mabk	10YR 5/3	m3d N 5/0 & c2d 7.5YR 4/4	
Pedon P2						
A	0-23	SiL	3vfsbk	10YR 3/2		
Bg1	23-53	L	2fsbk	5Y 4/1	f1d 10YR 4/3 f1p 5YR 4/6	
Bg2	53-91	L	2msbk 2fsbk	5Y 5/1	c1p 7.5YR 5/6	
C	91+	L	m	2.5Y 4/2	c2d 10YR 5/3 & 7.5YR 5/6	N 6/0
Pedon B1						
A	0-25	SL	2mgr	10YR 2/1		
BA	25-40	SL	2fsbk	5Y 4/1	f1d 10YR 4/2	
Btg1	40-58	L	1msbk 2fsbk	5Y 5/2	c2d 10YR 5/4	5Y 5/1
Btg2	58-95	L	1cpr 2msbk	5Y 5/1	f1d 10YR 4/4	N 5/0
BC	95-170	SL	1fsbk	5Y 5/1	m1p 7.5Y 5/6	5Y 5/2
C	170+	L	m	10YR 4/4	c2d N 5/0	

*Abbreviations according to Soil Survey Staff, 1951.

TABLE 5

TEMPERATURE (°C) FLUCTUATIONS
IN NINE PEDONS

Pedon No.	Depth (cm)	1983										1984									
		A		S		O		N		D		J		F		M		A		M	
M1	30	17	18	16	10	11	9	6	5	3	3	2	0–1	1	1	1	2	6	8	7	7
	50	16	17	17	11	12	9	7	6	4	3	2	2	1	2	2	2	5	7	7	7
	60	16	17	17	11	13	9	7	6	4	4	3	2	2	2	2	2	5	7	7	7
	90	15	15	16	12	13	10	7	7	5	5	4	3	3	3	3	3	4	5	6	7
M2	30	16	17	16	11	11	9	7	6	3	2	2	0–1	1	1	1	2	5	8	6	6
	50	15	16	16	12	12	10	8	6	4	3	2	2	2	2	2	2	4	6	6	6
	60	15	16	16	12	12	10	8	6	5	4	3	2	2	2	2	2	4	6	6	6
	90	14	14	15	12	13	10	9	7	5	5	4	3	3	3	3	3	4	5	5	6
M3	30	16	18	15			9	7	6	3	2	3	0–1	1	1	1	2	5	7	7	7
	50	15	18	16			10	7	6	4	3	3	2	2	2	2	2	5	6	6	7
	60	15	17	16			10	8	6	4	4	4	3	2	2	2	2	5	6	6	7
	90	14	16	15			10	9	7	5	5	5	4	3	3	3	3	4	5	6	7
C1	30	15	17	16	11	11	9	7	6	3	3	2	1	1	1	1	2	6	8	7	6
	50	15	16	16	11	12	9	8	6	4	3	3	1	1	2	2	2	5	7	7	7
	60	15	16	16	12	12	10	8	6	4	4	3	2	2	2	2	2	5	6	6	7
	90	14	14	15	12	13	10	9	7	5	5	4	3	3	3	3	3	5	4	6	6
C2	30	16	17	16	11	11	9	7	5	3	2	1	1	1	1	1	2	5	8	7	6
	50	16	16	16	11	12	10	7	6	4	2	2	1	1	1	1	2	5	7	6	6
	60	16	16	16	12	12	10	8	6	4	3	2	2	2	2	2	2	5	6	6	6
	90	15	15	15	12	13	10	9	7	5	4	3	3	3	3	3	3	4	4	6	6
C3	30	15	18	16	11		9	6	6	2	1	1	1	1	1	1	2	6	8	8	7
	50	15	17	16	12		10	7	5	4	2	2	1	2	2	2	2	6	7	7	7
	60	14	16	16	12		10	7	5	4	2	2	2	2	2	2	2	6	7	6	7
	90	13	15	15	12		10	8	6	5	3	3	3	3	3	3	3	5	4	6	8

TABLE 5--continued

Pedon No.	Depth (cm)	1983										1984									
		A		S		O		N		D		J		F		M		A		M	
P1	30	16	17	16	12	12	10	7	6	3	3	2	2	2	2	2	2	6	8	7	7
	50	15	16	16	12	13	10	7	7	4	4	4	3	3	3	3	3	5	6	7	7
	60	15	16	16	12	13	10	8	7	5	5	4	3	3	3	3	3	5	6	7	7
	90	13	14	15	13	13	11	9	8	6	6	5	4	4	4	4	4	5	4	6	6
P2	30	17	17	16	11	11	10	6	5	2	2	1	1	1	1	1	2	6	9	8	7
	50	16	17	16	12	12	10	7	5	5	2	1	2	2	2	2	2	5	8	7	7
	60	16	16	16	12	12	10	7	6	5	3	2	2	2	2	2	3	5	7	7	7
	90	15	15	15	13	13	11	8	6	7	4	3	3	3	3	3	3	5	6	6	7
B1	30	16	18	16	11		9	7	6	3	1	1	1	1	1	1	2	6	9	8	7
	50	15	17	16	12		10	7	6	4	1	1	1	2	2	2	2	6	8	7	7
	60	15	16	16	12		10	8	6	4	2	2	2	2	2	2	3	5	7	7	7
	90	14	15	15	12		10	9	7	5	3	3	3	3	3	3	3	5	6	6	8

this study, near saturation is defined as water held between 0.00-0.005 bar tension. The water contents (% by volume) at this range of tension were obtained from soil moisture characteristic curve of each depth (Appendix B).

Argillans with a chroma of 2 are also found in the Bt2 horizon (64-97 cm), but the matrix color has a chroma of 3 rather than 4. The change in the matrix color may be related to a longer period, 12-14 weeks, of saturation in the 90 cm depth and 4-6 weeks when the soil temperature was above 5 °C. The 90 cm depth had soil moisture tension values near saturation for 2-4 weeks, however, the soil temperature was below 5 °C during this time.

Faint mottles with chromas of 6 were found in the C horizon (104-165 cm). The 120 cm depth was saturated for 12-14 weeks but the soil temperature was above 5 °C for only 4-6 weeks. This depth was near saturation for 2-4 weeks but the soil temperature was below biological zero.

Using the morphological features given in Soil Taxonomy, (Soil Survey Staff, 1975), the predicted saturated zone should be at 97 cm where mottles occur. However, saturation occurs as high as 30 cm in this pedon. In some other parts of the United States, well drained soils have high water tables; for example, the well drained Williamette soil in Oregon had a water table at 50 cm depth for a few months each year, and the matrix had a chroma of 3 rather than 2 or less (Simonson and Boersma, 1972). In Indiana, the well drained Zanesville soil had a water table at 0.5 cm depth for 13 percent of the year and the matrix had chromas of greater than 2 (Franzmeier et al., 1983). A well drained soil in Ohio had water tables within 50 cm of the soil surface for at least 3 months in the spring (Zobeck and Ritchie, 1984).

Pedon M3 differed considerably from pedon M1 in the fluctuations of the saturated zone throughout the study (Fig. 1). The Bt1 (32-48 cm) and the Bt2 (48-86 cm) horizons were never saturated during any time of the year. Neither horizon has mottles. The Bt1 has matrix color of 7.5YR 4/6 and argillans with a color of 10YR 4/3. The Bt2 horizon has a 7.5YR 5/4 matrix color and 7.5YR 4/2 argillans. The color of the argillans (chroma of 2) suggests reduction of iron compounds may have occurred, but the horizon was not saturated. However, the horizon was near saturation for 2-4 weeks during 1983. The soil temperature was greater than 5 °C for 1-2 weeks during this time. Because of mechanical problems with the meter no data are available for spring 1982 or spring 1984. The chromas of matrix and argillans in the Bt1 horizon of pedon M1 and Bt2 horizon of pedon M3 are identical. The length of time the Bt1 of M1 was saturated and above 5 °C and the Bt2 of M3 was near saturation and above 5 °C is similar, 1 to 2 weeks. This could be the reason for the similarity of morphological features in horizons.

Apparently, reduction of iron compounds is possible in soils that have their moisture tension approaching zero at the time the soil temperature is above biological zero. Pickering and Veneman (1984) found gray streaking patterns of fragipans in unsaturated soil horizons and related it to reduction which occurred during wet conditions, but not saturations, when soil temperatures were above 5 °C.

The BC horizon (86-127 cm) has a matrix chroma of 3 and argillans with a chroma of 4. A perched water table was observed for short periods, less than 3 weeks, at 90 cm. The low hydraulic conductivity in the 90 cm depth (Table 6 and Fig. 4) probably slowed down the water movement and caused a perched water table. This depth was also near saturation for an additional 14-16 weeks but the soil temperature was above 5 °C for only 4-6 weeks. Chromas of 3 were observed on ped surfaces of soils that were saturated and had reducing conditions for up to 3 months (Vepraskas and Wilding, 1983). This implies that a chroma of 2 or less is not the only criteria for reduction of iron compounds. Apparently near saturation conditions have a significant effect on the soil morphology.

The Bt1 horizon (26-40 cm) of pedon M2, moderately well drained, has a similar matrix chroma, 4, and argillans color value and chroma of 4/2, as the Bt1 horizon of pedon M1 and the Bt2 horizon of pedon M3. The Bt1 horizon of pedon M2 was not saturated, but it was near saturation for 4-6 weeks. The soil temperature was above 5 $^{\circ}$C for 1-2 weeks, similar to that of the Bt2 horizon of pedon M3.

The Bt2 and BC horizon (40-108 cm) have identical matrix, mottles and argillans colors. The matrix and argillans colors are similar to those of the Bt1 horizon. The Bt1 is free of mottles, but the Bt2 and BC horizons have few, faint 10YR 5/4 mottles. The 60 cm depth was saturated for 12-14 weeks and the 90 cm depth was saturated for 14-16 weeks. The soil temperatures were greater than 5 $^{\circ}$C during only 4-6 weeks. The two depths were near saturation for an additional 2-4 weeks when the soil temperatures were above 5 $^{\circ}$C.

TABLE 6

BULK DENSITY AND HYDRAULIC CONDUCTIVITY OF NINE PEDONS

Pedon No.	Depth (cm)	Laboratory (core method)		Depth	In-Situ H.C.
		B.D.*	H.C.** (mean)		
		gm/cm^3	cm/hr		cm/hr
M1	30	1.69	3.15	100	3.75
	60	1.64	0.42	150	0.88
	90	1.79	0.41		
	120	1.79	0.71		
M2	30	1.53	2.44	50	3.50
	60	1.60	4.22	100	4.13
	90	1.63	2.80	150	1.00
	120	1.64	1.43		
M3	30	1.72	0.45	100	no water
	60	1.62	0.72	150	no water
	90	1.69	0.69		
	120	1.76	0.30		
C1	30	1.62	2.11	50	2.65
	60	1.67	0.90	100	2.65
	90	1.72	0.30	150	0.80
	120	1.79	0.33		
C2	30	1.66	0.50	50	1.90
	60	1.71	0.23	100	1.00
	90	1.70	0.13	150	1.20
	120	1.70	0.13		
C3	30	1.65	0.98	50	2.70
	60	1.66	1.76	100	3.00
	90	1.67	1.09	150	1.50
	120	1.86	0.55		

TABLE 6--continued

Pedon No.	Depth (cm)	Laboratory (core method)			In-Situ H.C.
		B.D.*	H.C.** (mean)		
		gm/cm^3	cm/hr		cm/hr
P1	30	1.51	9.50	50	--
	60	1.57	4.50	100	8.00
	90	1.58	2.83	150	--
	120	1.83	1.52		
P2	30	1.43	2.00	50	3.80
	60	1.60	0.42	100	0.45
	90	1.69	0.30	150	0.37
	120	1.71	0.29		
B1	30	1.51	7.30	50	8.75
	60	1.57	3.50	100	2.95
	90	1.59	1.35	150	1.60
	120	1.57	0.30		

*B.D. = Bulk Density

**H.C. = Hydraulic Conductivity, mean of hydraulic conductivity for cores without roots, holes, etc.

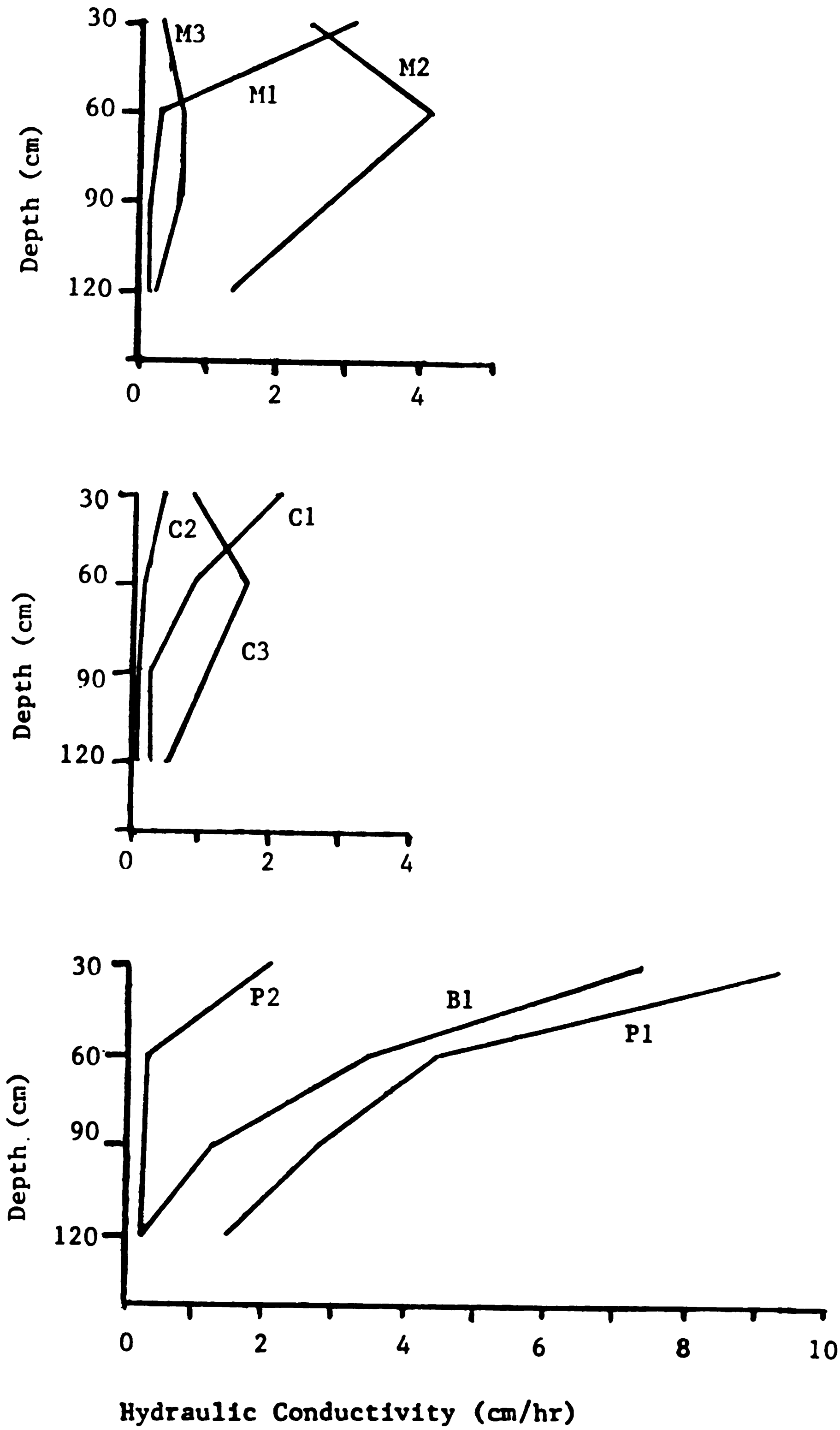

Fig. (4) Hydraulic conductivity (cm/hr) in nine pedons of four soil series.

The Cl horizon (108-165 cm) has a matrix chroma of 2 and 10YR 5/4 mottles. It was saturated for 22-24 weeks but soil temperature was above 5 °C for only 8-10 weeks. This horizon was near saturation for 4-6 weeks but the soil temperature was above 5 °C for 1-2 weeks.

Capac Series

The results for three pedons (Fig. 2) show that the saturated zones had similar patterns of fluctuations throughout the study. In pedon Cl, the Btgl horizon (25-40 cm) has a matrix with a chroma of 2 and prominent mottles with a chroma of 8. The 30 cm depth was saturated for 16-18 weeks but the soil temperature was above 5 °C for only 8-10 weeks. This depth was also near saturation for 2-4 weeks with the soil temperature above 5 °C for 1-2 weeks.

The underlying Btg2 horizon (40-110 cm) has a matrix with a chroma of 1, distinct mottles with a chroma of 6 and argillans with a chroma of 2. These features indicated that the reduction of iron is somewhat higher than that in Btgl horizon. The 60 and 90 cm depths were saturated for 20-22 weeks but the soil temperature was above biological zero (5 °C) for only 8-10 weeks of this period. Both depths were near saturation for 1-2 weeks but the soil temperatures were below 5 °C.

In pedon C2, the Bt horizon (32-53 cm) has a matrix with a chroma of 3, faint, distinct 7.5YR 4/4 and 10YR 5/2 mottles and argillans with a chroma of 2. The 30 cm depth was saturated for 16-18 weeks, but the soil temperature was above 5 °C for only 8-10 weeks of this period. It was near saturation for 2-4 weeks but the soil temperature was below 5 °C. The same duration of water table and soil temperature were observed in the Btg1 horizon of pedon C1. However, the Btg1 horizon has a matrix with a chroma of 2. While the Bt has a matrix with a chroma of 3. This suggests that a horizon having a matrix with a chroma of 3, mottles and grayish argillans is saturated for a significant period of time.

The Btg horizon (53-97 cm) has a matrix with a chroma of 2, distinct mottles with chromas of 3 and 4 and argillans with a chroma of 2. The 60 and 90 cm depths were saturated for 22-24 weeks but the soil temperature was above 5 °C for only 8-10 weeks. The two depths were near saturation for 1-2 weeks but the soil temperatures were below 5 °C.

The colors of the matrix and argillans in the BC horizon (97-125 cm) are similar to those of the Btg, but the mottles have chromas of 0 and 6 rather than 3 and 4. The 120 cm depth was saturated for 25-26 weeks but the soil temperature was greater than 5°C for 8-10 weeks. This depth was near saturation for an additional 2-4 weeks but the soil temperature was above 5°C for only 1-2 weeks. Mottles of similar chromas of 0 and 6 were also observed in the C horizon, but the soil matrix has a chroma of 4 rather 2 even though the horizon was saturated for 26-28 weeks and the soil temperature was above 5°C for 8-10 weeks as in the BC horizon. It appears that gray colors (chromas of 2 or less) can be produced in the matrix or mottles when the horizon is saturated for 8-10 weeks and the soil temperature is above 5°C.

In pedon C3, the B/E horizon (17-33 cm) lacks mottles and a gray matrix, but it has argillans with a chroma of 2. The 30 cm depth was saturated for 20-22 weeks (Fig. 2), but the soil temperature was above 5°C for only 8-10 weeks. It was near saturation for 4-6 weeks when the soil temperature was above 5°C. A similar matrix color was observed in the B/E horizon (22-32 cm) of pedon C2 in which the 30 cm depth was saturated for 16-18 weeks and the soil temperature was above 5°C for 8-10 weeks of this period. This depth was also near saturation for 2-4 weeks but the soil temperature was below 5°C. The B/E horizon of pedon

C2 has faint mottles with a chroma of 6 but lacks argillans. The B/E horizon of pedon C3 lacks mottles but has argillans with a chroma of 2. The gray argillans may reflect the period of time the horizon was near saturation.

The data of water table levels (Table 3) show that the B/E horizon in pedon C3 was saturated for 8-10 weeks and the B/E horizon in pedon C2 was saturated for 10-12 weeks. During these periods of saturation in both horizons, the soil temperature was above 5 °C for 4-6 weeks. Therefore as noted earlier in pedon M1 and M3, a matrix chroma of 3, with or without mottles, and argillans with chromas of 2 or less could occur in horizons that are saturated or nearly saturated for 4-6 weeks and soil temperature is above 5 °C.

The Bt horizon (33-58 cm) has a matrix with a chroma of 4, distinct mottles with chromas of 2 and 6, and argillans with a chroma of 3. The 30 cm depth was saturated for about 20-22 weeks during which the soil temperature was above 5 °C for 8-10 weeks. The Btg horizon (58-85 cm) has a matrix with a chroma of 2, distinct mottles with chromas 2 and 4 and argillans with a chroma of 2. It was saturated for 26-28 weeks but the soil temperature was above 5 °C for 8-10 weeks. It was also near saturation for 4-6 weeks when the soil temperature was above 5 °C.

The BC horizon (85-160 cm) has a matrix with a chroma of 6, distinct mottles with chromas of 2 and 5 and argillans with a chroma of 4. The 90 and 120 cm depths were saturated for 28-30 weeks but the soil temperature was above 5 °C for 8-10 weeks. The two horizons were near saturation for 4-6 weeks when the soil temperature was above 5 °C. As noted earlier, both Bt and BC horizons had some gray mottles rather than a gray matrix even though they were saturated for a long period of time. Franzmeier et al. (1983) reported that a horizon without a gray matrix and with other gray features was saturated for several months if it is located above a horizon that had a matrix with a chroma of 2 or less and it was saturated most of the time if it is located below that horizon.

Parkhill Series:

All subhorizons of the B horizons of pedons P1 and P2 have matrix colors with chromas of 2 or less (Table 4). This suggests the horizons are saturated for long periods of time. The Bg1 horizons of pedon P1 (25-46 cm) and pedon P2 (25-53 cm) have identical matrix colors (5Y 4/1) and distinct and prominent mottles with chromas of 3-6. The 30 cm depth in both pedons was saturated for

26-28 weeks (Fig. 3) but the soil temperatures were above 5 °C for only 10-12 weeks. Both horizons were near saturation for 1-2 weeks when the soil temperature was below 5 °C.

In pedon P1, the Btg2 and Bg3 (46-119 cm) horizons have identical matrix colors (N 5/0) and distinct and prominent mottles with chromas of 4 and 6. The 60 and 90 cm depths were saturated for more than 32 weeks, but the soil temperatures were above 5 °C for only 12-14 weeks. The two depths were near saturation for 2-4 weeks and the soil temperature was above 5 °C.

The Bg2 horizon (53-91 cm) of pedon P2 has a matrix with a color of 5Y 5/1, and distinct mottles with a chroma of 6. This horizon was saturated for 30 weeks but the soil temperature was above 5 °C for only 10-12 weeks. It was also near saturation for 1-2 weeks when the soil temperature was above 5 °C.

Matrix colors with hues of 5Y and N and chromas of 2 or less and the presence of mottles appear to be good indicators of long periods of saturation. In other studies these colors were also associated with horizons that were saturated for a long period of time (Simonson and Boersma, 1972; Veneman and Bodine, 1982).

Brookston Series:

In pedon B1, the BA horizon (25-40 cm) has a matrix color (5Y 4/1) similar to that in the Bg1 horizons of pedon P1 and P2. Distinct mottles with a chroma of 2 were present in the BA horizon but not in the Bg1 horizons. The 30 cm depth was saturated for at least 28 weeks each year but the soil temperature was above 5 °C for only 12-14 weeks. This depth was near saturation for 1-2 weeks when the soil temperature was above 5 °C.

The Btg1 (40-58 cm), Btg2 (58-95 cm) and BC (95-176 cm) horizons had matrices with a hue of 5Y, a value of 5 and chromas of 1 or 2, distinct or porminent mottles and argillans with hues of 5Y or N, a value of 5, and chromas of 2 or less. These horizons were saturated for at least 30 weeks each year but the soil temperatures were above biological zero (5 °C) for only 12-16 weeks. These horizons were also near saturation for 2-6 weeks when the temperatures were above 5 C.

Summary and Conclusions

The position of a seasonally high water table in soils, has been inferred from the soil color pattern for many years. Soils with high water table levels have a grayish color (chroma of 2 or less), matrix or mottles or some combination of these features (Soil Survey Staff, 1975). The following criteria relating soil color with depth and duration of the zone of saturation have been found in this study of loamy soils.

1. Horizons that have a matrix color with a chroma of 4 or more are:

   a- never saturated if mottles and gray (chroma of 2 or less) argillans are absent.

   b- either saturated or near saturation for 3-6 weeks (1-2 weeks above 5°C) if mottles are absent and gray argillans are present.

   c- saturated for 14-16 weeks (4-6 weeks above 5°C) if some faint mottles with chromas greater than 2 and gray argillans are present.

2. Horizons that have a matrix with a chroma of 3 are:

   a- saturated for 2-4 weeks (1-2 weeks above 5°C) if gray mottles are absent and argillans with chromas greater than 2 are present.

   b- saturated for 12-14 weeks (4-6 weeks above 5°C) if gray argillans or some faint mottles (chromas greater than 2) or both are present.

   c- saturated for 16-18 weeks (8-10 weeks above 5°C) if gray argillans and some gray mottles are present.

3- Horizons that have hues of 2.5Y or 5Y or N with a chroma of 2 are:

a- saturated for 16-18 weeks (8-10 weeks above 5 °C) if distinct or prominent mottles (chromas greater than 2) are present and gray argillans are absent.

b- saturated for 22-24 weeks (8-10 weeks above 5 °C) if gray argillans and mottles with chromas greater than 2 are present.

c- saturated for 25-28 weeks if some mottles, but not all, have chromas of 2 or less.

d- saturated for at least 30 weeks if distinct and/or prominent mottles and gray argillans with hues of N or 5Y are present.

4- Horizons that have hues of 2.5Y or 5Y or N with a chroma of 1 are:

a- saturated for 20-22 weeks (8-10 weeks above 5 °C) if distinct mottles (chromas greater than 2) and gray argillans are present.

b- saturated for 26-28 weeks (10-12 weeks above 5 °C) if both distinct and prominent mottles are present.

c- 28-30 weeks (10-12 weeks above 5 °C) if all mottles are present.

d- saturated for at least 30 weeks (12-16 weeks above 5 °C) if gray mottles are present, or gray argillans with hues of N or 5Y and non-gray mottles are present.

5- Horizons that have matrix colors with a chroma of 0 and distinct or prominent mottles or both are saturated for more than 32 weeks (12-14 weeks above 5 °C).

The above criteria do not apply in deep horizons such as C horizons because reduction is low either due to lack of soluble carbon compounds to serve as energy for organisms, or the alkaline materials retard the rate of reduction, or both.

Aquic intergrades to udic moisture regimes are indicated by matrix colors with a chroma of 3, mottles and gray argillans.

The importance of a chroma of 3 in recognizing the degree of soil wetness was reported in other studies (Daniels et al., 1971; Franzmeier et al., 1983; Vepraskas and Wilding, 1983). This criterion should be considered for adoption in Soil Taxonomy.

The color criteria for the four soil drainage classes included in this study of loamy soils are as follows:

1. Matrix colors with chromas of 3-6 and hues of 7.5YR-10YR and no mottles above about one meter are dominant in B horizons of well drained soils. These horizons are saturated for 6-14 weeks (2-6 weeks above 5 °C) and may be near saturation for an additional 14-16 weeks (4-6 weeks above 5 °C).

2. Matrix colors with chromas of 4 and hues of 10YR and faint mottles below 40 cm are dominant in B horizons of moderately well drained soils. These horizons are saturated for 12-16 weeks (4-6 weeks above 5 °C) and near saturation for 4-6 weeks (1-2 weeks above 5 °C).

3. Matrix colors with chromas of 2-4 and hues of 2.5Y and 10YR and distinct to prominent mottles are dominant in B horizons of somewhat poorly drained soils. These horizons are saturated for 16-28 weeks (8-10 weeks above 5 °C).

4. Matrix colors with chromas of 0-1 and hues of 5Y and N and distinct to prominent mottles are dominant in B horizons of poorly drained soils. These horizons are saturated for 28-32 weeks (12-16 weeks above 5 °C).

APPENDIX A

Table 7. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON M1.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		21.4	26.7	26.5	26.6	25.6		23.6	
	60																		22.0	23.0	29.2	30.2	29.9		29.5	
	90																		22.0	22.0	29.0	29.8	28.8		29.1	
	120																		23.8	24.0	26.3	26.7	26.1		26.8	
	150																		25.2	24.7	26.5	26.7	26.0		$\overline{61.5}$ *	
	180																		25.7	26.1	26.9	26.6	26.6		63.7	
	210																		27.6	27.7	31.0	28.3	27.5		58.8	
	240																		29.3	30.2	44.8	38.5	36.6		40.7	
1982	30	27.3								21.7		26.7	25.0	16.8	16.9	16.5		23.4	16.7	17.6	14.1	13.2	20.4		25.2	
	60	29.6								28.5		29.5	28.0	22.5	22.0	21.3		24.5	22.0	21.8	22.1	20.9	22.5		30.5	
	90	44.2								30.2		30.1	28.2	25.3	23.9	23.0		25.4	24.3	24.2	23.1	23.4	23.9		30.8	
	120	61.4								28.8		34.6	27.5	25.2	24.5	23.5		23.8	23.8	23.4	26.0	24.0	24.5		27.3	
	150	64.0								$\overline{64.9}$		$\overline{65.5}$	27.8	26.0	25.8	25.0		24.4	28.4	24.8	22.8	25.0	25.2		26.7	
	180	60.7								69.1		68.7	34.2	26.8	26.2	25.2		25.1	25.1	25.0	26.5	25.1	25.6		27.7	
	210	42.4								67.6		66.0	66.2	32.5	29.6	26.2		25.9	25.4	25.9	26.9	22.8	23.7		27.2	
	240	42.7								42.8		42.2	45.7	30.6	28.2	29.0		26.7	27.9	26.2	28.7	28.1	26.7		37.8	
1983	30	25.4		24.7		38.1	$\overline{66.1}$	$\overline{58.4}$	25.8	35.8	38.7	36.2	19.3	18.1	14.3	19.5	17.6	15.6	12.8	22.3	21.5	26.9	21.5	23.4	29.4	30.0
	60	30.4		30.1		$\overline{66.1}$	67.3	66.9	35.3	43.6	42.0	43.6	29.8	26.3	22.7	26.0	24.0	23.5	22.7	24.4	24.7	31.8	25.9	25.1	30.0	33.5
	90	29.9		30.4		68.8	70.8	43.5	$\overline{43.7}$	$\overline{42.4}$	$\overline{43.3}$	$\overline{42.4}$	30.5	25.7	23.5	24.0	24.8	24.0	23.2	23.5	23.6	28.9	25.0	28.3	38.4	34.3
	120	27.3		35.8		63.0	62.9	40.8	40.4	40.8	40.2	41.0	30.4	28.0	25.8	26.8	31.0	28.9	25.5	26.0	25.7	31.4	25.0	30.2	37.1	34.2
	150	27.3		$\overline{65.2}$		66.9	47.3	46.9	47.7	46.8	46.8	47.2	$\overline{41.8}$	$\overline{38.8}$	36.1	33.7	38.6	34.5	32.9	31.5	31.4	36.4	32.0	29.9	$\overline{59.2}$	33.2
	180	30.0		66.5		67.2	51.7	51.6	51.3	51.5	51.0	50.0	50.9	45.2	$\overline{42.4}$	$\overline{40.0}$	37.4	34.3	33.7	31.8	31.3	33.4	31.3	30.8	59.9	34.2
	210	34.4		66.8		67.4	45.8	45.9	46.0	46.3	45.0	46.3	45.3	44.6	40.7	37.9	37.7	36.9	35.0	34.1	34.0	33.0	34.0	32.5	58.6	39.0
	240	41.0		40.1		40.7																				
1984	30	29.0	27.0	36.9	29.3	$\overline{45.4}$																				
	60	29.4	28.5	$\overline{46.7}$	44.5	52.0																				
	90	38.1	37.0	41.4	$\overline{42.3}$	49.3																				
	120	37.8	37.5	43.1	44.2	49.0																				
	150	$\overline{43.3}$	$\overline{42.2}$	42.5	42.5	45.0																				
	180	45.0	44.2	42.0	43.0	45.0																				
	210	40.9	41.2	41.5	40.4	43.4																				

* Line indicates saturation

Table 8. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON M2.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		22.8	30.6	32.9	33.2	31.8		28.5 *	
	60																		26.5	35.2	39.0	38.7	37.8		44.4	
	90																		26.3	33.6	36.5	36.8	35.2		46.1	
	120																		27.7	29.9	33.3	34.1	33.0		59.8	
	150																		27.3	28.3	30.0	30.0	29.7		61.3	
	180																		28.9	29.5	30.7	30.8	30.0		54.8	
	210																		30.8	30.8	34.9	33.2	33.1		47.4	
	240																		32.8	31.8	36.8	34.1	34.0		43.0	
1982	30	27.5								27.0		33.0	28.8	20.6	24.0	22.9		28.0	21.5	22.7	19.1	21.3	29.9		32.4	
	60	34.8								32.7		35.4	31.9	28.9	27.6	28.1		33.6	28.5	28.8	27.1	27.0	29.2		34.6	
	90	30.9								31.4		43.0	30.4	28.4	27.0	27.1		29.9	27.2	26.5	26.3	25.5	26.4		29.8	
	120	56.8								32.4		63.2	29.3	28.4	27.5	27.0		29.3	27.3	26.3	25.4	25.4	26.1		29.0	
	150	59.3								49.9		60.1	30.9	29.1	27.9	26.7		28.9	26.8	27.2	25.2	27.6	29.0		36.5	
	180	42.6								43.9		45.5	42.7	33.3	29.2	27.5		29.8	28.0	29.1	27.4	32.2	32.6		39.0	
	210	41.4										44.5	43.7	38.9	35.2	30.4		36.4	31.3	32.6	32.0	34.7	33.5		37.5	
	240	41.4												40.2				39.1				35.2	36.0		40.0	
1983	30	33.4		32.5		35.8	35.5	36.8	35.7	36.0	36.8	31.7	27.6	26.8	22.6	31.2	24.7	24.4	20.6	29.8	29.0	35.1	30.3	31.0	39.6	30.2
	60	35.2		34.4		56.5	57.1	60.0	40.1	50.4	61.9	48.5	31.0	28.5	26.2	27.8	25.2	25.1	25.5	28.7	27.5	31.6	29.2	33.3	45.8	35.7
	90	32.1		54.9		63.1	62.9	64.8	64.6	65.0	65.5	65.1	29.8	28.1	25.7	24.7	25.0	24.7	24.7	25.5	25.7	28.4	27.1	31.3	52.9	38.2
	120	68.4		66.5		69.8	68.8	67.4	68.1	68.8	68.4	69.4	30.4	29.0	27.1	26.5	29.5	28.6	25.4	25.6	26.1	28.1	26.7	29.3	59.0	40.6
	150	46.1		45.0		48.4	47.4	47.9	48.1	46.8	47.0	46.6	39.2	35.4	32.6	31.1	32.7	31.5	29.8	29.7	30.0	36.2	29.1	34.3	59.8	50.1
	180	43.7		43.5		44.3	44.3	43.8	44.8	44.2	44.9	42.9	41.9	38.6	35.8	33.4	35.6	34.9	32.3	32.1	32.5	36.6	33.7	36.5	57.7	49.2
	210	42.8		43.5		44.4	43.4	43.2	43.8	44.5	43.0	42.9	43.0	39.4	38.5	36.3	37.8	37.0	34.5	34.5	33.4	38.1	35.7	36.3	49.1	38.5
	240	42.1		42.8		45.8	42.6	43.4	43.1	42.9	43.9	43.4	43.0	42.5	40.9	38.7	38.7	38.4	38.0	37.0	37.7	38.8	37.7	38.9	47.2	41.4
1984	30	29.2	30.8	39.3	33.2	39.7																				
	60	35.3	35.5	45.3	41.5	44.3																				
	90	36.0	36.0	47.0	42.4	48.2																				
	120	37.9	37.4	45.4	45.4	45.4																				
	150	48.7	46.5	43.3	42.3	43.0																				
	180	47.4	45.6	44.3	44.0	43.5																				
	210	47.0	46.0	45.1	42.4	41.4																				

* Line indicates saturation.

Table 9. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON M3.

Year	Depth (cm)	J		F		M		A		M		J		J		A		S		O		N		D	
1981	30																	21.4		30.2	29.0	28.2			
	60																	22.8		31.3	30.2	31.5			
	90																	22.4		* $\overline{44.3}$	35.5	35.6			
	120																	25.1		38.2	36.0	35.9			
	150																	23.8		35.7	32.8	33.2			
	180																	21.7		34.0	30.3	32.0			
	210																	20.7		34.6	28.0	31.5			
	240																	16.7		22.6	21.5	22.8			
1982	30	28.8								27.0		32.8	29.9	22.0	24.0	27.3	21.0	25.7	26.9	22.0	22.1			30.6	
	60	32.3								31.0		32.2	30.3	25.5	25.9	26.3	24.2	25.7	25.7	24.6	26.0			31.9	
	90	35.3								35.2		33.6	33.8	27.2	27.9	28.1	26.9	26.9	26.3	27.0	26.5			36.4	
	120	35.1								35.5		37.0	35.4	33.1	32.9	31.0	28.5	29.8	28.1	26.8	28.5			36.4	
	150	32.2								33.5		36.3	34.4	34.5	33.1	32.4	30.4	31.2	29.9	28.3	30.6			34.9	
	180	33.4								32.5		33.6	32.1	31.7	32.0	31.9	29.9	31.3	20.9	30.1	28.6			31.7	
	210	29.3								32.0		35.6	32.1	29.0	30.2	28.7	28.2	28.9	27.5	27.9	25.1			33.8	
	240	12.8								29.2		36.0	33.0	33.0	28.9	27.0	26.4	26.3	26.0	24.9	28.2			34.0	
1983	30	30.1		27.9		31.6	31.2	30.9	29.6	30.9	31.0	30.2	22.9	21.0	19.2	19.6	15.8	16.9	27.0	29.5		30.1	30.1	30.5	30.4
	60	31.9		30.5		32.3	32.3	31.9	31.6	32.0	31.5	31.9	26.9	25.2	23.6	24.8	22.9	23.3	25.8	29.4		30.7	38.5	39.4	31.9
	90	36.0		34.6		37.4	36.7	37.0	37.3	36.6	36.0	36.4	32.0	28.4	26.1	25.2	23.6	23.5	27.1	26.6		34.8	$\overline{43.8}$	$\overline{42.7}$	38.3
	120	35.7		33.9		$\overline{37.4}$	37.1	37.0	34.8	36.0	36.6	35.0	34.4	32.4	29.2	27.5	26.3	25.0	27.1	26.8		35.3	37.2	37.3	36.9
	150	33.2		31.9		34.8	34.1	33.9	33.0	34.2	33.9	33.0	32.4	31.0	28.7	27.1	24.7	25.2	24.7	24.9		33.0	34.4	34.3	34.0
	180	29.7		29.0		32.3	31.5	30.6	31.0	30.9	30.8	30.7	30.1	28.0	25.2	23.4	22.1	21.4	21.1	21.3		31.7	33.0	33.3	32.4
	210	33.1		32.2		34.7	34.4	33.9	32.6	34.1	33.3	34.1	32.2	31.6	28.3	26.3	22.5	21.9	21.2	21.3		32.7	34.4	35.0	35.1
	240	31.0		30.0		33.0	32.0	32.5	31.0	32.4	31.0	31.8	29.2	28.4	25.9	22.3	18.8	17.4	16.9	17.1		25.1	25.9	25.1	24.2
1984	30	28.9	29.2	30.3	29.2	30.4																			
	60	32.0	32.8	32.4	33.1	34.3																			
	90	34.8	33.2	34.3	36.4	36.4																			
	120	35.5	36.7	36.2	36.9	35.2																			
	150	33.2	33.4	33.6	32.3																				
	180	33.9	33.0	33.1	33.0																				
	210	32.7	33.1	34.1	34.3																				

* Line indicates saturation.

Table 10. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON C1.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		26.9	30.3	* $\overline{47.5}$	$\overline{43.8}$	34.2		35.3	
	60																		24.0	25.1	61.2	60.8	$\overline{62.5}$		$\overline{61.6}$	
	90																		23.4	26.2	62.5	62.8	62.9		62.4	
	120																		23.9	25.9	64.9	66.1	65.1		65.3	
	150																		25.5	27.2	61.3	63.1	62.8		63.0	
	180																		28.4	29.1	43.8	50.1	51.6		48.8	
	210																		27.2	28.2	42.3	42.6	43.0		41.7	
	240																		31.0	29.7	52.9	42.2	42.0		41.6	
1982	30	36.2								33.3		41.9	31.2	24.2	24.6	23.4		31.0	23.6	25.0	22.7	22.8	28.1		33.1	
	60	$\overline{62.0}$								33.7		$\overline{65.2}$	31.4	26.7	26.7	27.7		29.6	26.1	26.1	25.1	24.8	25.0		31.3	
	90	64.0								$\overline{65.8}$		66.4	31.8	27.4	24.8	25.8		27.5	24.4	24.3	24.0	23.5	24.6		31.3	
	120	64.2								67.9		65.1	32.9	27.5	26.5	25.3		26.9	24.4	24.5	23.4	24.4	23.6		60.8	
	150	64.4								70.1		68.9	$\overline{69.1}$	28.4	27.2	26.7		26.8	25.7	24.7	24.4	26.0	24.1		58.2	
	180	48.5								65.5		64.1	67.5	$\overline{41.7}$	27.9	27.0		26.7	25.5	25.0	24.4	28.6	26.5		46.4	
	210	41.0								45.4		44.4	63.1	63.4	29.6	28.3		27.4	27.2	26.0	25.6	33.3	32.8		45.1	
	240	40.7								42.4		42.7	44.8	44.7	45.8	31.2		36.5	34.2	29.2	26.6	34.9	33.9		42.9	
1983	30	44.2		35.3		$\overline{63.0}$	$\overline{63.2}$	$\overline{65.1}$	$\overline{64.8}$	$\overline{67.2}$	$\overline{64.9}$	$\overline{67.1}$	29.9	27.4	25.3	25.4	25.2	24.3	23.3	29.3	15.4	23.1	31.9	32.7	42.5	34.2
	60	62.9		$\overline{64.1}$		64.1	64.0	66.0	66.0	65.3	65.5	66.9	32.0	27.1	25.1	24.1	23.3	23.1	24.0	26.1	23.0	28.3	29.3	31.0	$\overline{44.5}$	39.5
	90	66.4		65.1		66.3	68.0	69.7	70.3	69.7	67.8	69.7	32.4	28.8	25.6	23.9	23.9	22.7	22.9	24.7	22.9	25.9	28.2	32.3	45.3	36.3
	120	67.9		68.4		69.0	69.0	69.7	69.8	70.7	69.5	70.1	$\overline{69.5}$	29.2	27.3	25.4	27.8	24.4	23.6	24.9	24.2	26.5	27.2	33.4	43.2	33.6
	150	69.8		70.0		69.8	69.1	70.6	70.9	71.6	69.0	70.0	71.1	$\overline{51.3}$	32.9	28.7	31.9	28.1	27.0	28.5	27.9	31.5	31.9	$\overline{43.3}$	44.3	$\overline{44.0}$
	180	46.9		54.0		69.9	45.2	45.9	47.1	49.0	42.0	45.4	45.6	46.0	39.8	34.2	25.4	32.5	30.4	30.3	30.5	31.7	32.1	42.5	43.0	42.3
	210	45.0		44.0		46.1	44.4	44.2	44.9	44.3	42.9	44.4	44.3	43.9	41.3	26.7	27.0	34.5	32.7	32.0	32.3	32.4	32.9	42.4	42.2	42.0
	240			42.9		45.8	42.3	42.7	42.0	42.9	42.3	42.6	43.1	42.7	42.0	28.6	29.6	36.5	33.8	32.9	32.6	32.9	34.7	43.4	42.0	41.5
1984	30	33.7	33.9	42.4	42.3	$\overline{46.3}$																				
	60	38.1	37.7	$\overline{43.4}$	$\overline{44.1}$	46.0																				
	90	35.4	36.3	43.4	44.3	46.4																				
	120	32.5	32.2	42.0	41.2	42.4																				
	150	$\overline{42.5}$	$\overline{43.7}$	43.4	45.3	45.0																				
	180	42.0	41.5	41.0	42.8	41.2																				
	210	41.8	41.7	41.1	40.1	41.4																				

* Line indicates saturation

Table 11. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON C2.

Year	Depth (cm)	J		F		M		A		M		J		J		A			O		N		D	
1981	30																	*	$\overline{59.8}$	$\overline{63.3}$	33.5		31.8	
	60																		59.9	60.0	$\overline{61.2}$		$\overline{61.0}$	
	90																		60.2	61.9	62.4		62.9	
	120																		58.3	60.0	60.3		60.7	
	150																							
	180																							
	210																							
	240																							
1982	30	32.3								29.0		$\overline{61.5}$	29.2	22.0	22.7	23.0		25.4	20.2	20.4	30.4		39.4	
	60	$\overline{56.5}$								31.3		62.2	30.8	28.5	25.1	24.3		24.1	23.2	23.4	25.5		$\overline{60.2}$	
	90	60.1								$\overline{39.9}$		63.3	34.2	29.1	26.0	25.6		24.2	23.2	23.0	25.0		62.3	
	120	57.8								62.4		63.0	$\overline{63.5}$	31.1	29.7	28.8		26.4	25.3	22.2	27.7		60.0	
	150	59.8								61.7		63.4	63.5	33.1	31.5	29.0		29.0	28.5	28.1	31.0		65.2	
	180	65.9								69.2		67.9	70.8	$\overline{64.9}$	$\overline{35.4}$	32.5		32.2	31.0	31.0	31.8		69.7	
	210	48.5								64.5		68.5	66.9	72.6	72.0	34.0		46.2	32.0	32.8	48.6		51.0	
	240	40.9								47.0		50.2	50.1	64.3	57.1	62.8		71.5	33.1	47.9	48.0		45.5	
1983	30	30.7		$\overline{59.3}$		$\overline{72.9}$	$\overline{74.0}$	**	$\overline{74.2}$	$\overline{75.4}$	**	$\overline{73.1}$	27.1	24.0		23.4	20.7	19.5	26.2	29.6	30.2	34.5	39.5	39.8
	60	$\overline{42.5}$		67.9		68.1	65.1		67.0	68.7		67.8	29.9	26.6	24.1	23.8	21.2	19.6	24.2	28.2	29.0	30.3	$\overline{45.0}$	$\overline{43.3}$
	90	64.3		65.0		66.2	65.3		65.4	67.8		67.2	32.0	29.5	27.5	28.4	27.8	25.9	21.5	26.4	27.0	31.0	46.3	44.1
	120			62.1		63.5	61.2		63.1	63.0		62.0	$\overline{62.8}$	31.6	31.9	32.6	34.9	32.3	26.4	29.7	30.0	38.2	40.3	39.7
	150			63.0		64.0	62.8		65.6	64.2		64.0	64.4	$\overline{54.6}$	$\overline{43.8}$	$\overline{39.5}$	$\overline{46.3}$	$\overline{35.8}$	32.5	35.8	34.5	$\overline{50.4}$	47.4	47.4
	180			60.8		60.6	61.8		55.2	62.0		61.9	59.9	57.8	47.6	47.3	46.3	45.1	39.7	41.3	$\overline{40.1}$	59.3	48.0	48.0
	210			48.3		49.0	47.4		50.9	47.8		47.0	47.1	47.3	42.1	45.8	46.7	46.2	45.8	47.5	48.3	57.2	47.3	46.6
	240																							
1984	30	33.2	32.8	$\overline{43.2}$	$\overline{43.6}$	$\overline{45.0}$																		
	60	$\overline{42.3}$	$\overline{42.3}$	43.8	44.0	45.4																		
	90	45.4	44.8	43.0	43.5	44.3																		
	120	42.4	41.8	42.3	41.4	41.4																		
	150	46.4	46.1	44.4	42.0	43.4																		
	180	47.0	46.4	45.4	44.3	45.3																		
	210	46.4	46.3	44.5	46.1	43.5																		

* Line indicates saturation.

** Because the soil surface was covered with water, it was not possible to take readings.

Table 12. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON C3.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		33.3	51.2 *	46.1	60.2	41.3			
	60																		23.1	64.9	68.5	65.8	68.1			
	90																		17.4	60.4	63.9	67.9	63.9			
	120																		18.5	73.4	69.5	68.7	72.4			
	150																		20.5	48.3	44.6	59.6	45.0			
	180																		27.8	42.5	42.7	43.8	42.5			
	210																		30.4	42.4	42.7	43.4	41.9			
	240																		32.2	43.3	43.6	43.5	42.9			
1982	30	63.8								42.2		**	53.2	34.9	35.1	37.0		31.0	35.2	36.8	34.2	36.0			65.3	
	60	66.8								35.9			70.7	28.0	30.4	32.5		28.7	31.0	31.6	30.9	30.4			69.5	
	90	69.9								70.0			69.3	28.5	26.7	26.9		22.7	39.7	28.1	29.0	31.8			70.5	
	120	52.1								71.7			73.5	35.7	28.8	27.4		26.3	34.7	31.2	33.9	74.3			65.2	
	150	44.0								51.0			51.3	52.0	35.3	55.2		34.6	64.6	69.5	72.2	55.7			53.1	
	180	42.7								44.9			45.4	44.3	53.9	54.3		47.0	53.3	56.5	56.0	47.2			45.8	
	210	42.0								45.0			44.3	44.3	45.9	46.9		43.9	45.6	47.9	46.0	45.0			45.7	
	240	44.0								43.8			43.0	42.8	45.0	44.1		44.4	44.3	44.0	43.9	42.7			43.5	
1983	30	63.1		45.9		68.1	63.7	66.5	62.0	65.8	64.7	66.0		28.2	24.0	24.5	23.9	19.7	20.4		29.2	30.8	34.8	33.4	39.6	41.4
	60	71.0		66.0		69.2	70.3	68.9	73.1	70.0	71.3	71.8		26.7	22.3	18.1	16.0	17.5	16.9		22.7	26.7	36.2	37.2	44.1	42.7
	90	67.3		69.9		70.6	70.0	69.0	71.2	71.7	69.9	71.1		26.1	22.3	22.4	23.3	17.2	16.4		18.4	24.5	27.1	35.8	42.4	41.2
	120	62.1		72.2		72.0	64.3	65.9	62.2	64.8	59.3	60.1		43.9	41.4	33.9	30.4	23.6	19.9		23.5	25.4	32.4	32.7	45.4	44.4
	150	47.8		51.4		52.1	51.8	51.7	50.8	52.2	49.0	47.9		50.1	42.8	33.9	31.4	22.6	20.0		20.5	21.0	39.5	41.3	42.3	41.3
	180	44.7		44.6		45.6	44.3	44.0	45.1	45.6	44.0	43.1		44.2	44.4	37.9	36.7	28.5	25.0		25.0	25.2	41.7	42.8	44.2	42.3
	210	43.2		44.2		45.1	43.9	45.3	44.5	44.5	43.5	44.5		43.2	42.4	40.4	39.5	32.1	28.9		29.0	28.5	42.4	43.3	42.0	42.0
	240	43.3		42.0		43.2	41.7	42.8	42.0	42.7	43.1	42.0		41.5	42.3	42.1	42.5	35.3	31.8		32.0	35.1	43.1	41.7	43.6	43.4
1984	30	41.4	38.3	43.4	44.1	37.7																				
	60	42.4	42.9	45.2	43.3	44.1																				
	90	41.5	41.4	42.4	43.0	44.3																				
	120	43.8	43.5	43.2	41.5	40.3																				
	150	42.0	42.1	42.3	43.4	42.4																				
	180	43.2	42.9	44.3	42.6	42.5																				
	210	41.8	41.3	42.4	40.5	40.7																				

* Line indicates saturation.

** Because the soil surface was covered with water, it was not possible to take readings.

Table 13. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON P1.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		34.5	36.7	**	**	65.0		**	**
	60																		31.7	32.3			66.7			
	90																		34.6	42.0			63.0			
	120																	*	64.4	64.9			66.0			
	150																		80.6	79.3			83.6			
	180																		62.0	62.6			61.9			
	210																		63.9	56.7			50.5			
	240																		46.8	49.3			45.0			
1982	30	67.4								56.9		59.4	60.1	64.3	66.9	49.7		62.1	28.9	44.5	33.3	28.8	14.9		71.9	
	60	64.3								54.7		56.0	55.6	60.2	59.6	56.9		61.1	49.4	47.0	45.1	40.9	48.7		71.8	
	90	55.2								52.3		54.9	54.8	56.4	56.0	53.3		55.9	43.9	58.8	42.0	41.5	67.6		57.6	
	120	51.0								44.8		50.7	51.9	53.9	53.7	52.3		51.8	56.9	59.1	52.0	49.3	54.9		52.8	
	150	45.8								41.1		43.4	46.7	53.1	53.1	53.6		54.4	55.3	55.0	54.4	53.6			52.4	
	180	39.9								41.4		40.7			53.5	53.8										
	210																									
	240																									
1983	30	74.1		78.1		**	73.8	79.6	74.0	**	**	77.9	46.7	14.5	39.7	46.6	38.4	34.8	32.6	41.2	40.1	44.5	43.5	40.5	59.4	59.4
	60	73.7		72.2			62.8	71.2	71.2			66.3	45.3	53.8	51.1	51.6	46.6	40.3	36.6	44.7	44.0	47.8	49.1	51.5	59.0	59.4
	90	64.2		61.9			54.7	61.9	61.9			62.3	62.4	59.3	58.3	52.0	50.0	43.7	36.7	43.0	42.1	46.4	49.3	49.8	59.3	59.0
	120	58.6		54.2			53.4	53.9	54.9			54.8	53.3	53.3	53.7	54.1	54.0	49.8	40.7	42.0	40.6	44.2	40.4	53.2	54.4	54.4
	150	55.7		55.4			54.0	56.7	57.6			56.5	56.0	54.8	55.4	55.0	47.4	47.4	47.9	44.6	45.2	44.9	43.4	52.6	53.5	54.2
	180																									
	210																									
	240																									
1984	30	59.5	60.1	62.1	62.8	**																				
	60	59.3	59.5	60.3	59.4																					
	90	59.2	59.2	60.1	59.4																					
	120	54.7	54.7	55.1	56.2																					
	150	54.2	54.3	54.0	52.3																					
	180																									
	210																									

* Line indicates saturation.

** Because the soil surface was covered with water, it was not possible to take readings.

Table 14. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON P2.

Year	Depth (cm)	J		F		M		A		M		J		J		A			S		O		N		D	
1981	30																		37.5	41.5	68.6	69.2	65.7		45.7	
	60																		36.9	64.5*	64.3	64.3	65.0		63.5	
	90																		31.4	63.1	63.1	63.6	61.9		63.7	
	120																		33.9	62.0	62.6	61.8	63.5		61.9	
	150																		63.5	64.1	63.7	64.7	64.7		64.0	
	180																		65.9	67.1	66.1	65.4	67.6		66.8	
	210																		65.2	61.6	53.4	53.4	56.0		54.1	
	240																		47.9	49.5	47.0	46.0	46.3		46.8	
1982	30	46.6								39.8		63.8	42.5	43.1	41.0	38.9		43.2	31.7	39.0	36.4	36.6	37.6		61.1	
	60	63.1								40.2		66.6	42.3	37.3	37.1	36.3		46.1	35.5	36.1	34.7	34.3	34.3		66.5	
	90	64.2								66.5		65.3	67.1	33.9	33.6	34.0		65.1	33.2	33.9	32.8	32.4	37.3		65.3	
	120	61.3								63.4		60.8	60.9	32.3	31.6	57.2		65.9	32.4	31.7	30.7	30.6	64.7		64.4	
	150	63.5								68.0		65.2	65.8	64.5	36.4	64.5		60.2	44.1	33.4	32.5	32.5	65.5		67.5	
	180	63.6								67.6		68.5	66.2	67.8	65.5	65.5		64.6	64.9	62.6	34.8	23.5	67.6		68.2	
	210	46.4								55.2		65.5	68.5	67.6	66.5	68.1		65.5	66.2	65.9	63.5	65.9	67.8		56.5	
	240	41.9								48.3		47.8	53.2	68.9	69.0	68.0		67.2	67.3	67.9	67.9	67.2	54.0		48.0	
1983	30	75.3		72.8		74.0	73.0	72.0	74.8	71.8	73.0	76.5	36.1	34.1	32.4	31.6	29.2	26.5	25.4	35.0	35.3	44.6	40.7	55.3	54.4	52.3
	60	66.3		66.6		67.0	67.3	69.5	69.9	68.0	69.6	69.1	38.1	34.5	33.9	33.6	32.3	27.9	24.2	33.9	33.6	41.1	38.9	58.2	58.0	58.4
	90	63.0		65.3		65.2	64.4	65.0	66.0	62.9	65.0	65.3	67.2	32.5	34.3	37.4	33.3	32.0	25.3	35.3	31.4	38.3	37.5	59.0	58.7	60.0
	120	65.6		63.0		65.4	65.3	66.0	66.5	66.4	66.8	65.5	66.9	66.4	43.9	42.3	40.6	37.3	33.9	40.5	35.6	40.4	37.0	58.3	58.4	58.7
	150	66.3		67.2		65.6	66.0	66.0	66.4	67.9	67.5	53.0	67.3	67.0	41.9	41.5	48.6	45.7	37.5	40.3	40.3	40.7	40.4	59.3	59.1	59.4
	180	69.9		66.8		68.4	67.2	62.7	58.2	53.2	53.2	52.1	59.1	53.0	51.7	49.0	50.0	51.8	48.8	50.3	50.3	50.0	51.8	60.1	58.8	58.5
	210	51.7		53.9		52.2	50.3	53.0	52.9	51.6	51.9	56.0	50.4	51.1	50.3	49.2	48.3	48.8	50.1	49.2	49.4	49.3	53.4	57.1	56.0	54.7
	240	48.0		47.4		47.4	46.9	48.9	48.2	47.1	48.2		48.0	47.6	47.8	47.3	44.7	45.8	48.4	47.4	48.0	47.6	52.2	50.1	51.1	50.3
1984	30	47.5	47.6	**	50.1	**																				
	60	57.2	56.8		55.3																					
	90	59.2	60.0		60.0																					
	120	58.7	58.4		59.2																					
	150	59.1	59.1		60.3																					
	180	58.5	57.0		58.0																					
	210	54.4	55.0		53.3																					

* Line indicates saturation.

** Because the soil surface was covered with water, it was not possible to take readings.

Table 15. SOIL MOISTURE READINGS (% BY VOLUME) OF PEDON B1.

Year	Depth (cm)	J	F	M	A	M	J	J	A	S	O	N	D
1981	30									39.2	69.0 69.0	70.5	
	60									32.9	63.4 61.5	63.0	
	90									32.7	62.2 61.8	63.4	
	120									32.2	63.2 62.2	62.9	
	150									* 52.1	76.5 74.5	69.3	
	180									50.0	44.8 45.4	58.0	
	210									42.4	41.0 41.4	42.5	
	240									42.0	42.0 42.0	42.8	
1982	30					75.1	** **	36.1 **	** 39.0	65.0 71.6	56.1 46.6		** **
	60					67.5		64.3	47.1	70.0 67.2	66.0 67.8		
	90					62.9		67.3	67.8	68.9 68.5	63.1 60.1		
	120					65.6		68.5	68.3	67.2 64.9	59.0 61.0		
	150					73.2		64.9	67.7	60.5 59.2	57.9 57.0		
	180					53.0		69.4	57.9	57.3 56.7	55.5 59.8		
	210					43.3		45.5	66.4	66.0 65.3	63.3 55.8		
	240					43.3		43.2	46.8	46.4 47.0	47.6 45.5		
1983	30	** **	** **	** **	** **	** **	** 50.9	44.7	38.5 34.3 28.8	27.5 35.6	39.8	41.4 42.0	49.4 50.9
	60						59.3	49.8 43.4	43.8 40.3 33.1	29.4 34.4	40.5	43.4 43.3	50.4 51.4
	90						56.9	55.6 50.1	48.8 47.3 39.1	33.2 33.2	36.0	44.4 43.0	48.5 48.7
	120						58.9	56.0 56.1	52.2 52.3 43.7	36.5 33.4	35.0	43.6 48.5	48.4 47.4
	150						57.4	56.7 57.2	57.0 56.9 48.2	44.8 41.2	42.5	43.8 48.4	46.3 47.0
	180						63.9	60.6 60.0	56.5 43.2 54.3	50.9 50.0	52.1	46.8 49.4	49.2 46.7
	210						45.2	44.7 45.6	43.2 42.3 44.1	43.4 42.9	44.0	47.2 45.2	45.7 48.5
	240						43.0	42.5	43.0 46.9 43.0	43.2 41.4	42.9	48.2 46.3	46.3 45.0
1984	30	48.7 48.0	50.7 52.1	48.4 **									
	60	51.0 50.4	51.4 52.3	51.3									
	90	47.6 48.4	48.9 49.2	47.6									
	120	46.8 47.1	47,3 48.8	45.8									
	150	44.0 45.2	45.4 44.2	43.6									
	180	48.1 47.7	48.4 47.2	45.5									
	240	45.4 44.4	45.1 45.4	44.0									

* Line indicates saturation.

** Because the soil surface was covered with water, it was not possible to take readings.

APPENDIX B

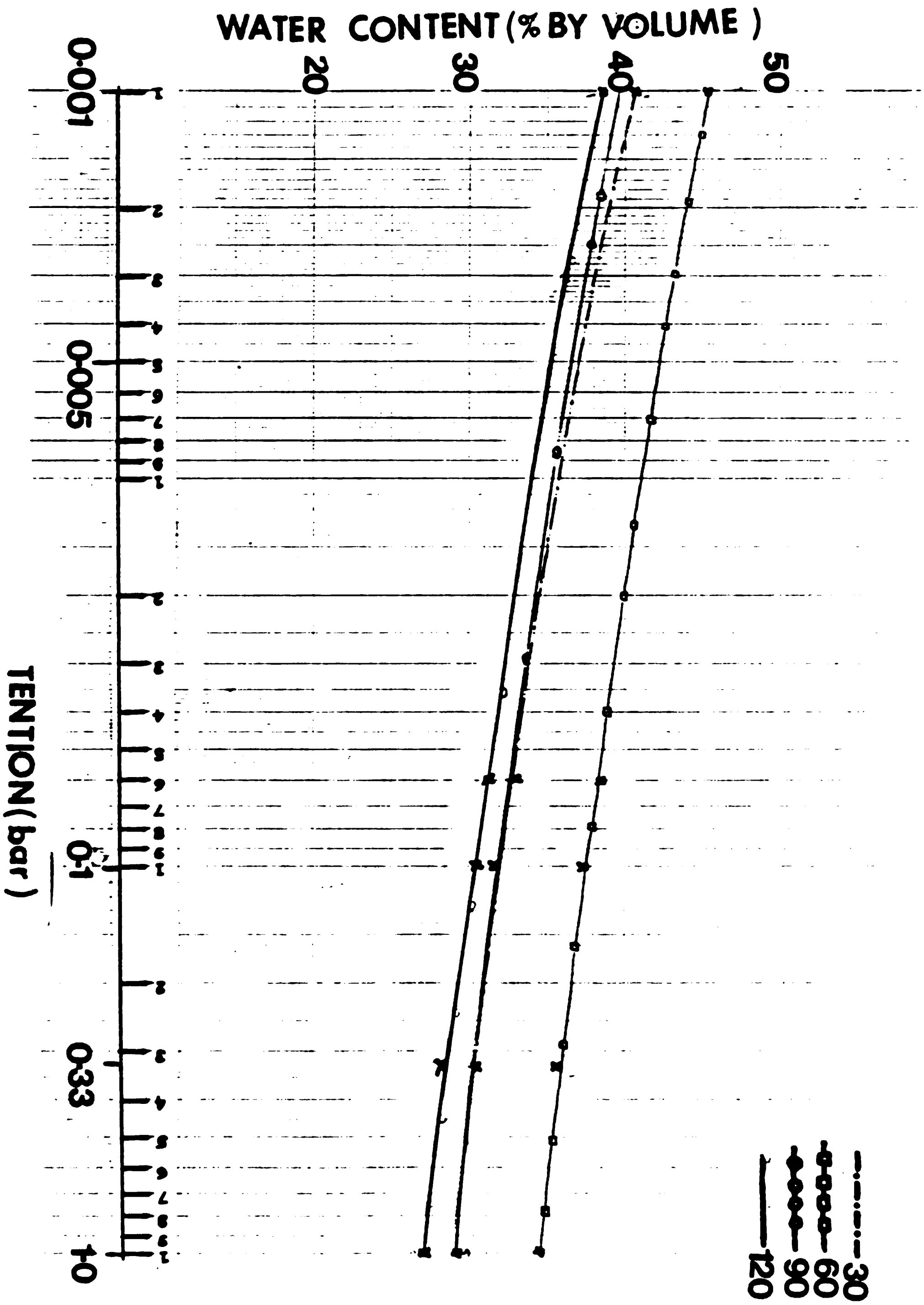

Figure 5. Soil moisture characteristic curves of pedon M1.

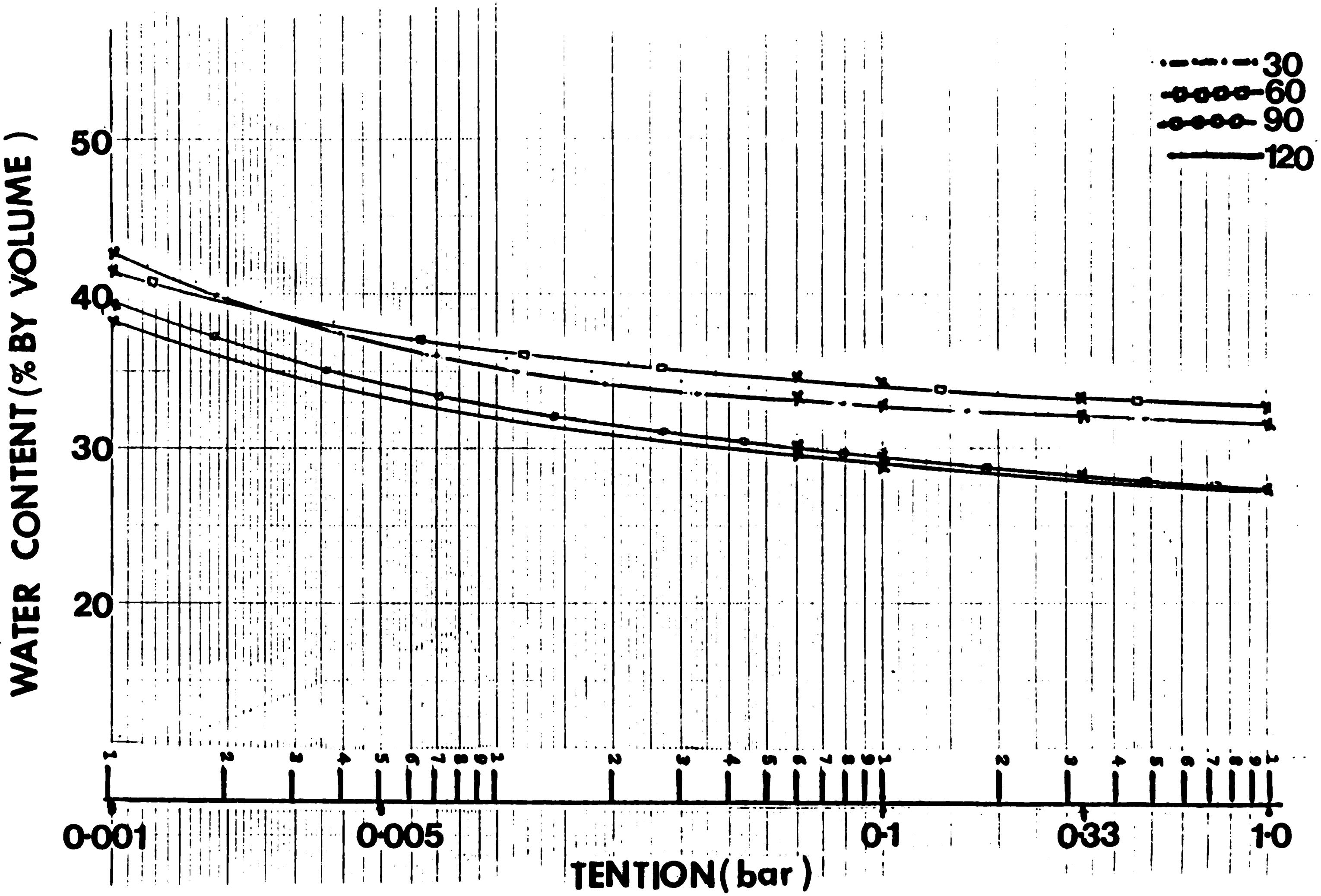

Figure 6. Soil moisture characteristic curves of pedon M2.

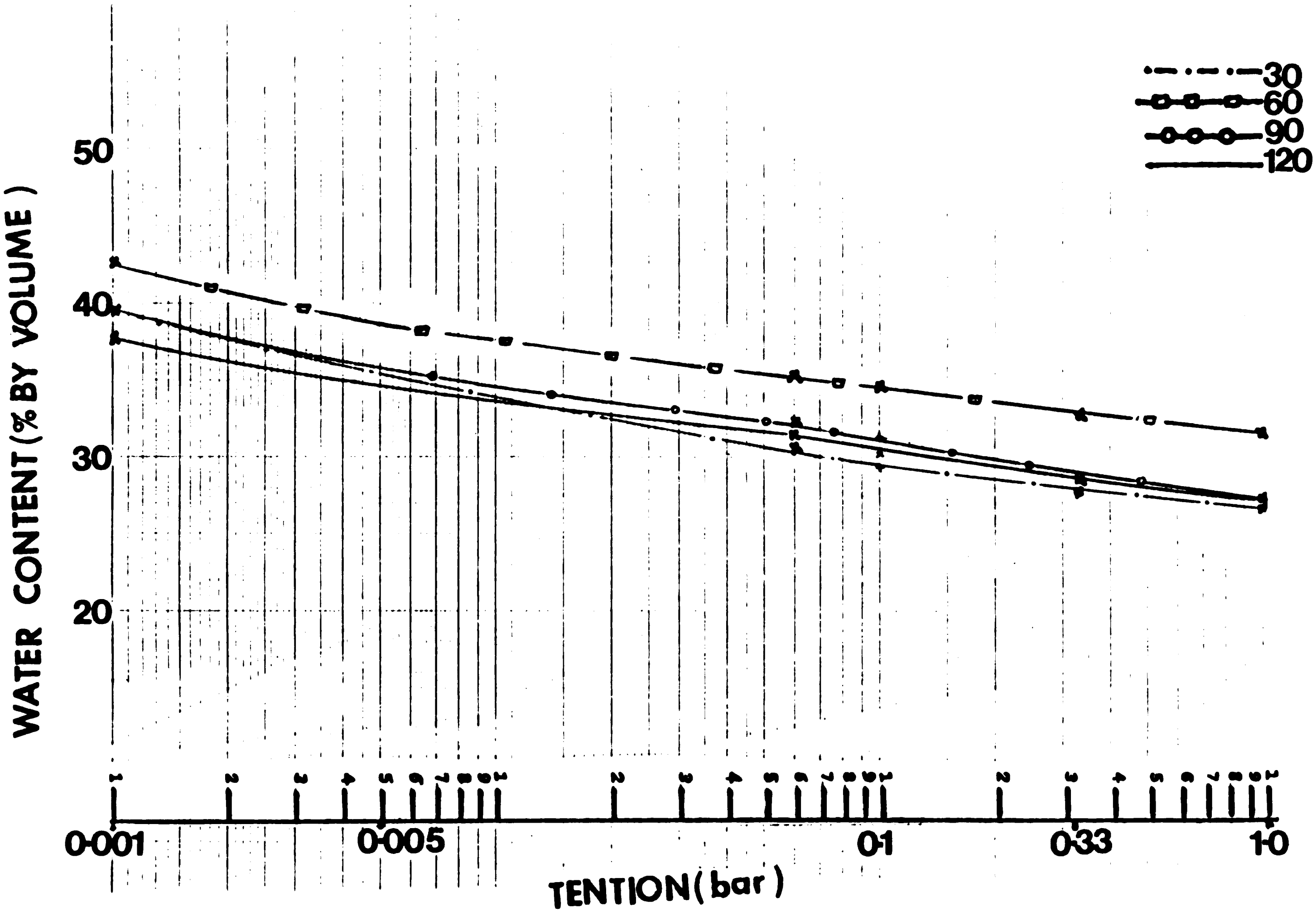

Figure 7. Soil moisture characteristic curves of pedon M3.

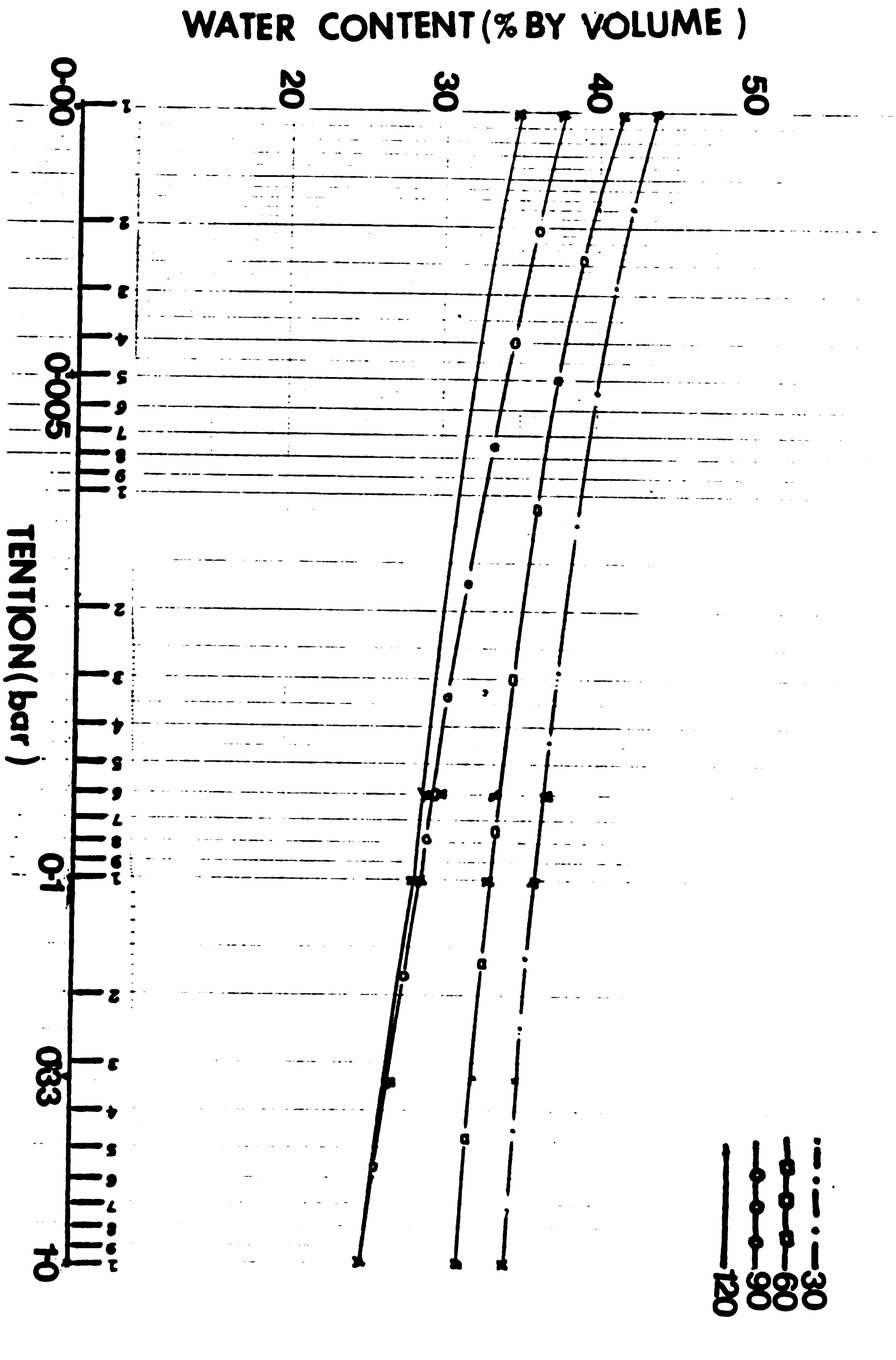

Figure 8. Soil moisture characteristic curves of pedon C1.

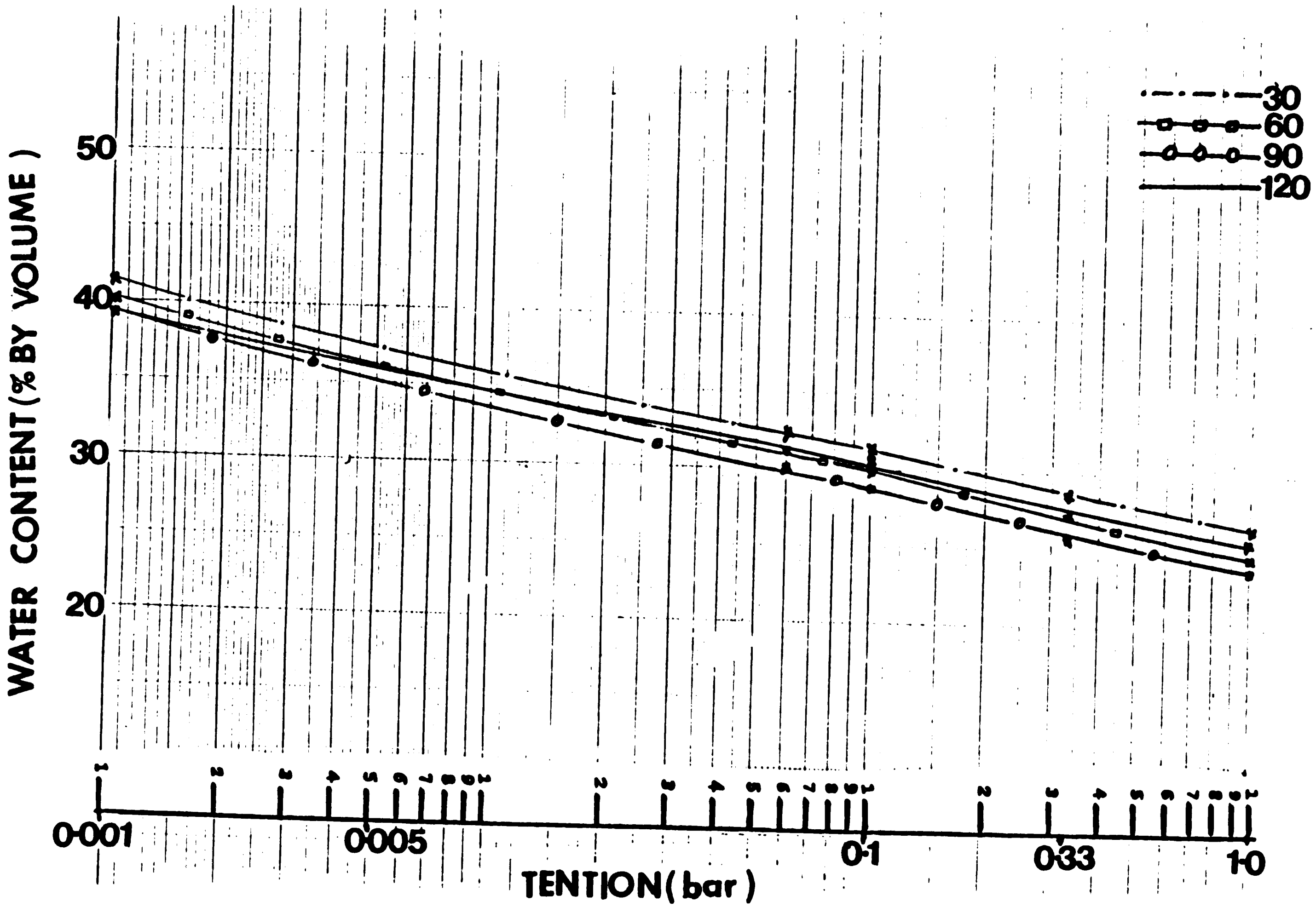

Figure 9. Soil moisture characteristic curves of pedon C2.

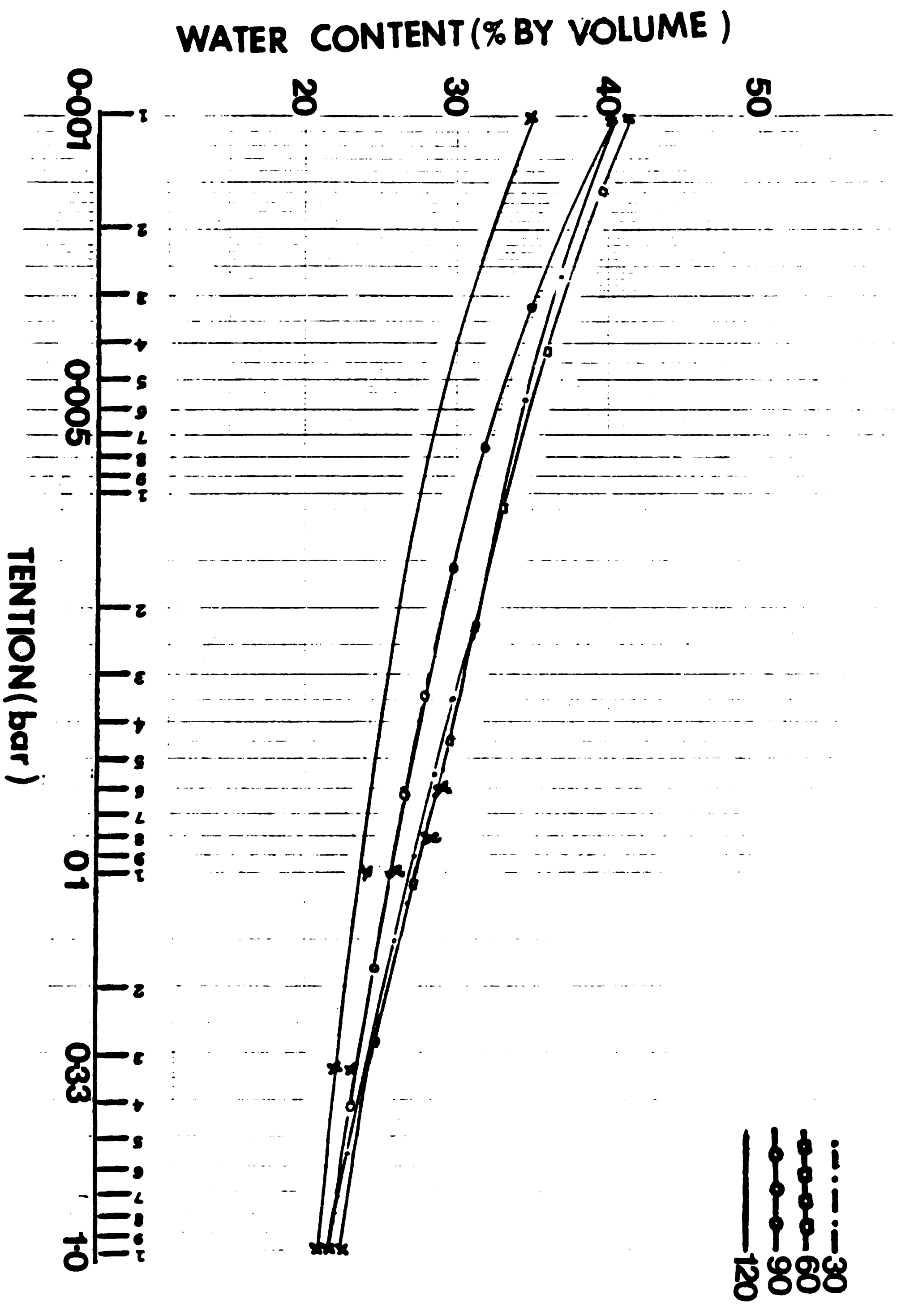

Figure 10. Soil moisture characteristic curves of pedon C3.

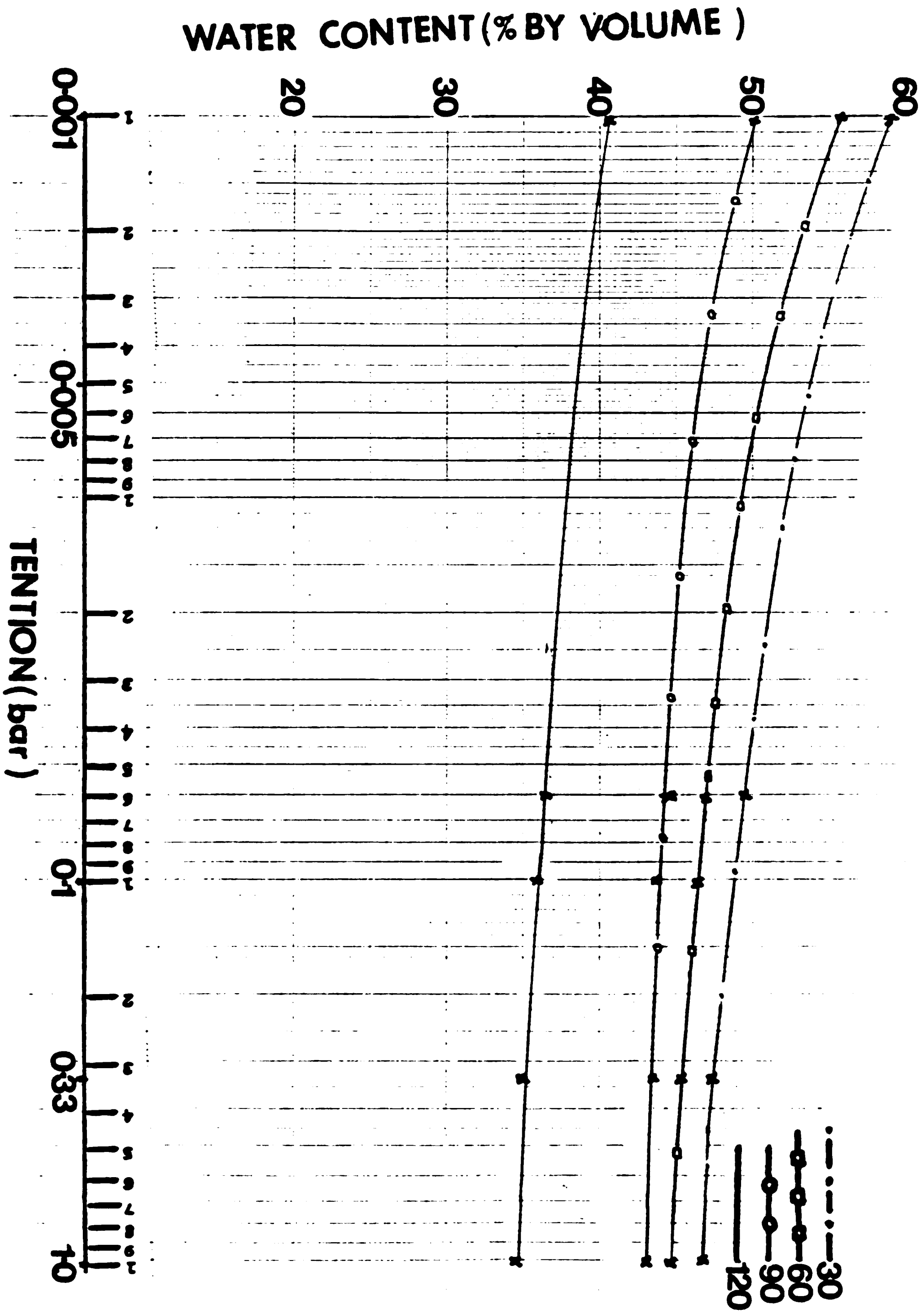

Figure 11. Soil moisture characteristic curves of pedon P1.

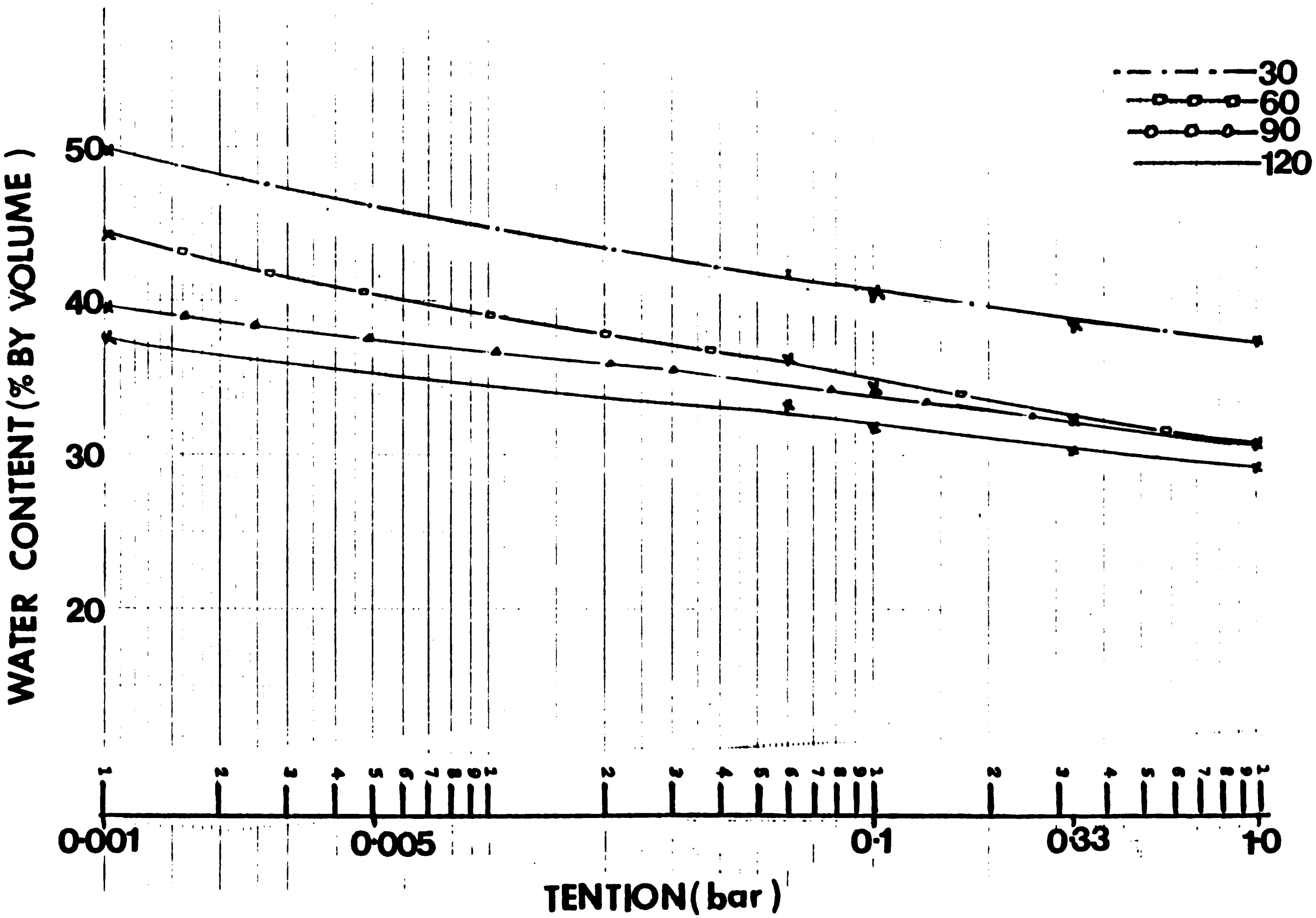

Figure 12. Soil moisture characteristic curves of pedon P2.

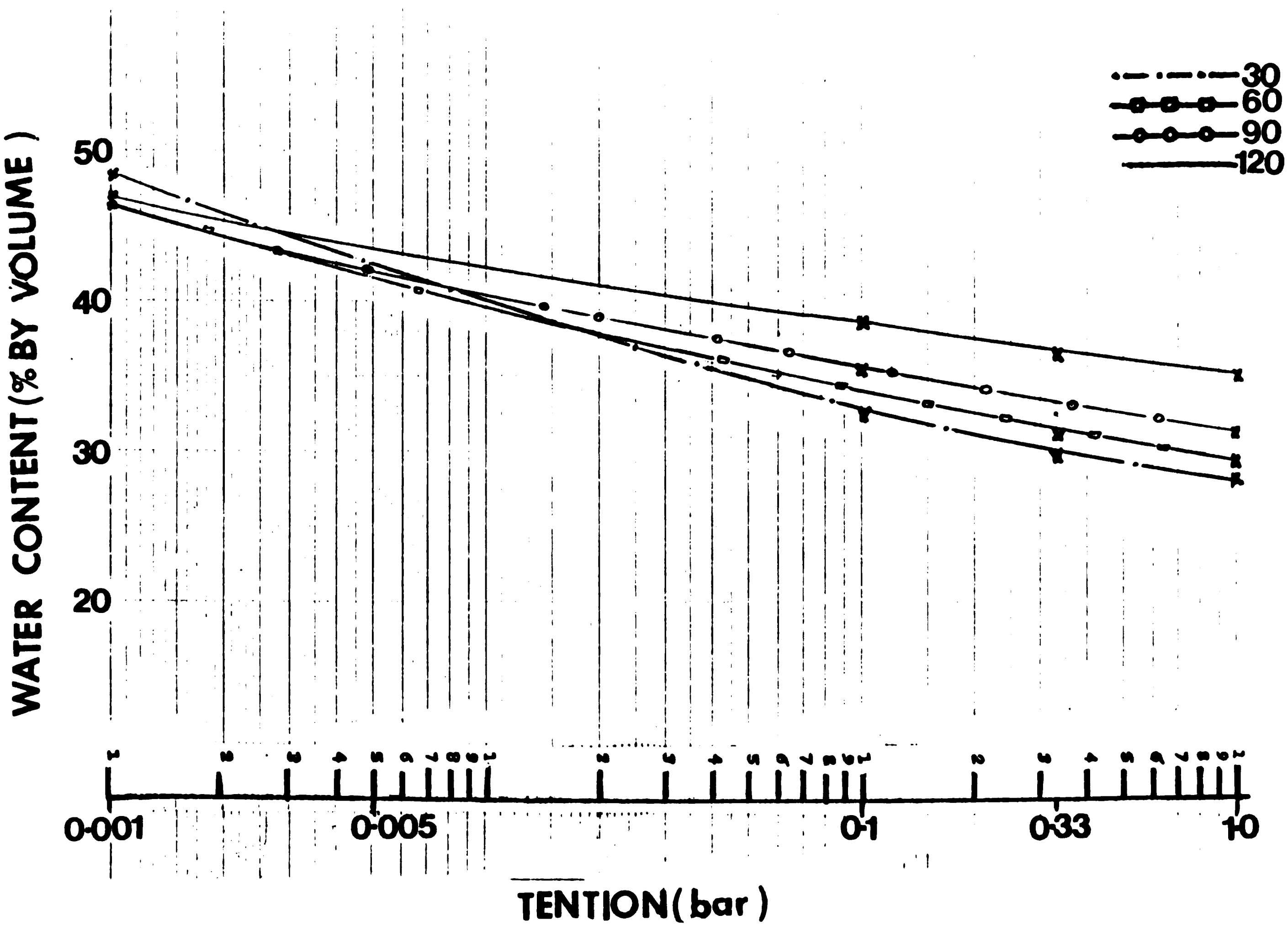

Figure 13. Soil moisture characteristic curves of pedon B1.

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