AN EVALUATION OF THE DRAINAGE AND SUBSIDENCE OF SOME ORGANIC SOILS IN QUEBEC

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Five wooded and six cultivated sites were chosen on organic soils in Southwestern Quebec for this study. Various physical properties such as ash content, bulk density and hydraulic conductivity were measured at each site, along with weekly and continuous water table readings at each site. At the end of the 3-yr study, subsidence rates were determined. The results show that cultivation of organic soils has increased ash content and bulk density, and decreased hydraulic conductivity. Subsidence rates in the cultivated areas varied from 1.0 to 7.0 cm/yr for the 3-yr period. No loss in elevation was recorded for the virgin sites. Water table levels in the cultivated sites were unusually low, exceeding 130 cm in some years. Drainage needs of organic soils vary with time and should be evaluated accordingly.

Cinq sites boisés et six sites cultivés sur sol organique ont fait l'objet d'une étude agro-hydrologique. Plusieurs propriétés physiques, telles les cendres, la densité apparente et la conductivité hydraulique, ont été mesurées à chaque site ainsi que les variations hebdomadaires et continuelles de la nappe phréatique à chaque site. Après trois années d'études, on a déterminé les taux d'affaissement des sols organiques. Les résultats ont démontré que la mise en valeur des sols organiques a augmenté les cendres et la densité apparente et diminué la conductivité hydraulique. Les taux d'affaissements dans les sites cultivés ont varié de 1.0 à 7.0 cm/année pour la période de 3 ans. On a enregistré aucune baisse en élévation dans les sites boisés. Les niveaux de la nappe phréatique dans les sites cultivés étaient inhabituellement bas, excédant parfois 130 cm. Les besoins en drainage des sols organiques varient dans le temps et devraient être évalué en conséquence.

INTRODUCTION

Adequate drainage is an important prerequisite for developing organic soils for commercial crop production. The physical properties of organic soils are distinctly different from those of mineral soils. Organic soils evolved from the incomplete decomposition of mosses, sedges and wood under a wet anaerobic environment. Natural drainage conditions in organic soils are generally poor for most agricultural uses because of restricted outlet. Development of these soils requires lowering of the water table. Organic soils settle when the water table is lowered. This condition, defined as subsidence, may also be due to such factors as compaction, decomposition or oxidation, wind and water erosion, and fire; but, initially, the single most important factor is drainage.

The organic soils in southwestern Quebec, where this study was conducted, were formed mostly in shallow lake and pond basins left by the retreating Champlain Sea (McKibbin and Stobbe 1936). The combined action of geology, topography, biology and climate assisted in the formation of these soils. The growth or accumulation of organic material is slow and may vary from a few centimetres to several metres per hundred years (Jasmin et al. 1977); however, the rate of subsidence is approximately 2.1 cm/yr for organic soils under cultivation in Quebec (Millette 1976).

Eight principal areas of organic soils can be found west of the Richelieu River; they range in size from about 360 to over 6500 ha. In 1971, a detailed soil survey of 20 000 ha showed that 13 000 ha had an organic soil depth of 0.60 m or more, of which 8500 ha had a soil depth of 1.20 m or more. Of the total area, over 4400 ha are now used for vegetable production; the rest of area is either uncultivated, wooded or used for other purposes (Jasmin et al. 1977). Most of these areas are within a radius of 56 km from Montreal.

In Quebec, until recently, little was known about the drainage, physical properties and subsidence of organic soils. Drainage of organic soils has been recognized by many authors as an important problem (Irwin 1966; Stephens 1969; Rayment and Cooper 1968; Van der Elst 1969; Galvin 1976). In addition, organic soil physical properties, such as ash content, bulk density and hydraulic conductivity, change as the soil decomposes (Päivänen 1973). Furthermore, the organic soil subsidence rate is directly proportional to the water table level (Jongedyk et al. 1950; Mirza and Irwin 1964; Stephens 1956).

OBJECTIVES

The objectives of this study were to determine for these soils (1) some physical properties such as ash content, bulk density and hydraulic conductivity, (2) their short-term subsidence rates, and (3) water table fluctuations on drained cultivated sites and undrained uncultivated sites.

MATERIALS AND METHODS

Six drained and five undrained sites were selected within the eight principal organic soil deposits in Southwestern Quebec (Fig. 1). The drained sites were all cultivated and in production, whereas the undrained sites were uncultivated wooded sites near their corresponding cultivated site. These sites are described in Table I. Initially, each site was sampled to determine ash content (5 g of water-free soil burnt in a muffle furnace at 550°C for 5 h), bulk density (on a dry weight basis), depth of organic soil over the underlying mineral soil, and in situ saturated hydraulic conductivity using the auger hole technique (Table II).

Permanent bench marks were established near each site in 1975 when the study began. At each site, ground elevations were recorded in 1975 and again in 1978 to determine quantitatively organic soil subsidence (Table II).

In the springs of 1975, 1976 and 1978, five wells (perforated electrical conduit tubes 1.50 m long and 20 mm in diameter) were installed at each site except in cultivated site VI where the wells were not installed in 1976 and 1978. In the cultivated sites, two wells were placed within 1 m of the drains or ditches and the other three midway between the drains or ditches. For the uncultivated wooded sites, the wells were installed at the four corners and at the center of a 35-m square. Because of farming activities the wells had to be installed after seeding in the cultivated sites and they were removed before harvest operations. In the uncultivated wooded sites the wells were installed as early as possible in the spring.

At each site, small orifice raingauges, as described by Gambel and Daniels (1967), were installed. Weekly precipitation was recorded; at the same time the weekly water table levels were measured.

During the 1978 season, water table recorders were installed at four of the five wooded sites, whereas one recorder was installed in a drained field in 1975.

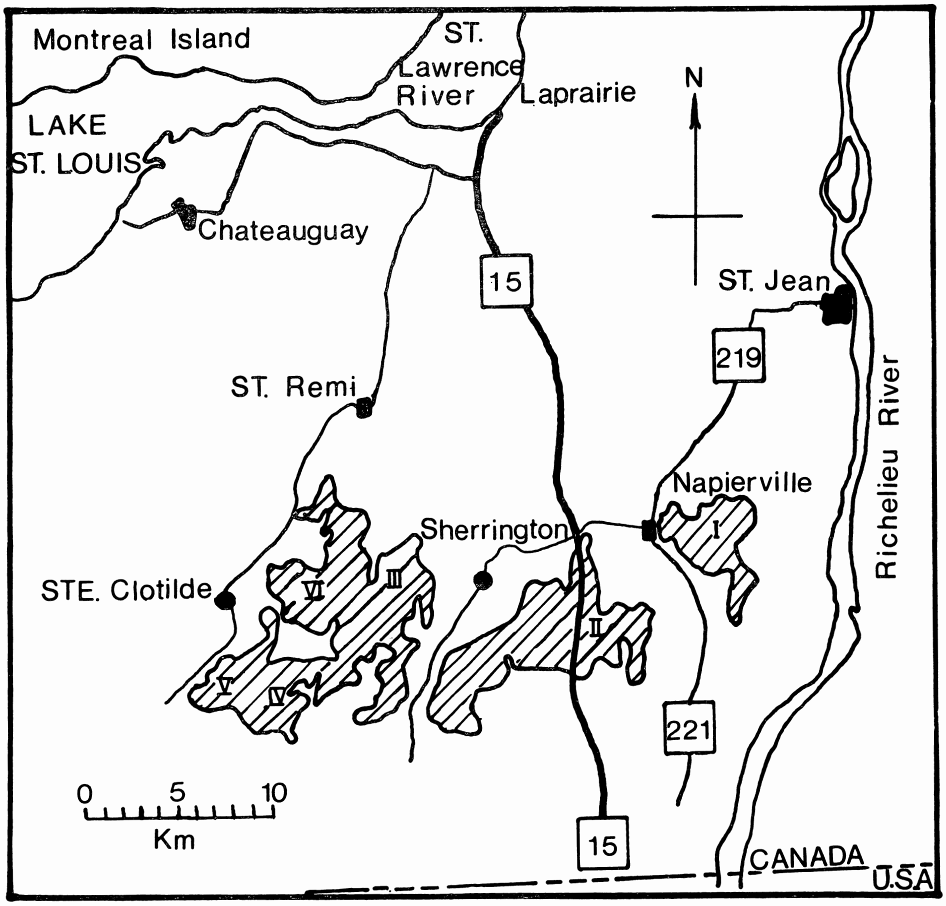

Figure 1. Map showing the locations of the major organic soil deposits south of Montreal. Field observation sites are indicated by numerals.

TABLE I. LOCATION, DESCRIPTION AND USE OF THE ORGANIC SOIL AT THEIR RESPECTIVE SITES

Site	Location	Description of site and soil type
		Cultivated
I	St-Blaise Bog	Sod production since the mid-1960s ditches every 40 m; Mesic Fibrisol†
II	Napierville Bog	Highly intensive production of carrots for more than 20 yr subsurface drains every 13.3 m, controlled drainage outlet; Humic Mesisol
III	Sherrington-Ste-Clothilde Bog	Field developed in the early 1970s, potatoes and carrot production, ditches every 70 m; Typic Mesisol
IV	Sherrington-Ste-Clothilde Bog	Experimental field, not commercial, developed in 1972, low pH site, ditches every 40 m; Mesic Fibrisol
V	Sherrington-Ste-Clothilde Bog	Highly intensive production of carrots, onions, lettuce and celery for more than 25 yr, subsurface drains every 20 m, controlled drainage outlets; Humic Mesisol
VI	Sherrington-Ste-Clothilde Bog	Highly intensive experimental site, developed in 1938, subsurface drains every 40 m; Typic Mesisol
		Uncultivated
I	St-Blaise Bog	Undeveloped wooded area, ditches nearby; Fibric Mesisol
II	Napierville Bog	Undeveloped wooded area, ditches nearby; Fibric Humisol
III	Sherrington-Ste-Clothilde Bog	Undeveloped wooded area, large ditch nearby; Sphagno-Fibrisol
IV	Sherrington-Ste-Clothilde Bog	Undeveloped wooded area, ditches nearby; Mesic Fibrisol
V	Sherrington-Ste-Clothilde Bog	Undeveloped wooded area, no ditches; Fibric Mesisol

†Soil classification according to unpublished report: *Inventaire et étude du potentiel maraîcher des dépôts de sols organiques de la région du sud de Montréal*, by Hamel, Malouin, Ruel et al. Drummondville, Quebec.

RESULTS AND DISCUSSION

Physical Properties

At the selected sites a wide range of physical properties existed (Table II). For organic soils these properties depend largely on the degree of decomposition which is expressed as percent ash content on a dry weight basis (Table II). The greatest differences in properties occurred between the cultivated sites and the uncultivated sites. Cultivation of the organic soils seems to have increased ash content and bulk density, but reduced the hydraulic conductivity.

The surface layer (0–15 cm) and the lower layer (15–30 cm) of the cultivated sites were well mineralized (high ash content) because of liming and fertilization, followed by heavy tillage. In the uncultivated sites the ash content for both layers was somewhat less than the ash content in the corresponding cultivated sites.

The bulk density values were almost the same for all uncultivated sites and for both depths (Table II). In the cultivated sites, the bulk densities were almost twice as great as those in the uncultivated sites. Drainage and tillage operations appeared to have caused this densification. The hydraulic conductivity values for the uncultivated sites were all greater than those obtained in their corresponding cultivated sites. Furthermore, the hydraulic conductivity in cultivated site VI had reduced to the extent that the 40-m spacing of the drains (see Table I) was inadequate. For proper drainage, drain spacing, according to Hooghougt's formula, would have to be less than 5 m. Egglesman (1978) explains that when the organic soil is drained the structure of the peat material is modified. Coarse pores which were filled with water initially are later emptied and compressed, reducing the air and water permeability.

Subsidence Rates

Agricultural use of organic soils lowered the surface elevation whereas within the uncultivated sites, a slight increase in elevation was recorded at all sites (Table II) over the period studied. Nevertheless, within the cultivated sites, the subsidence rate varied considerably. At sites I and II, due to the nature of operation, subsidence rates were high, whereas at sites III and IV, which were drained and developed in the last 10 yr, the subsidence rates were close to expected values of 3-3.5 cm/yr for the first decade after drainage (Yevdokimova 1976). The long-term subsidence rate of 2.1 cm/yr reported by Millette (1976) taken at site VI had decreased to 1.4 cm/yr over the period studied (Table II). This value compares with the subsidence rate of 1.0 cm/yr reported between 1967 and 1976 by Irwin (1977) at the Holland Marsh, Ontario. The majority of subsidence in the first few years after drainage and commencement of cultivation is due to settlement and loss of buoyancy. In later years, oxidation, wind and water erosion, compaction, and fire will continue to cause additional subsidence.

TABLE II. PHYSICAL PROPERTIES OF THE ORGANIC SOILS STUDIED AND SUBSIDENCE RATE FROM 1975 TO 1978

Site	Ash content (% dry wt) 0-15 cm	15-30 cm	Hydraulic conductivity† (m/day)	Bulk density Dry wt basis (g/cc) 7.5-15 cm	15-30 cm	Depth of soil (cm)	Subsidence rate
				Cultivated			
I	17.0	13.9	0.175	0.267	0.190	280	5.0
II	16.6	16.6	0.056	0.290§	0.270§	165	7.0
III	18.0	13.7	0.220	0.234	0.283	230	2.3
IV	17.9	14.5	0.400§	0.239	0.276	250	3.0
V	20.6	19.3	0.568	0.298	0.307	180	1.0
VI	20.7	19.6	0.014	0.286	0.198	143	1.4
				Uncultivated			
I	10.8	10.1	0.886	0.149	0.159	240	+0.5‡
II	12.2	12.4	0.223	0.171	0.179	235	+1.7
III	15.0	9.3	0.105	0.166	0.170	260	+0.7
IV	16.2	14.9	0.516	0.159	0.162	300	+1.7
V	12.8	15.8	0.700§	0.140	0.139	200	+1.0

†Calculated down to 1.20 m using the auger hole method.
‡+ indicates an increase in elevation.
§Estimated.

Water Table Fluctuations

Fluctuations in water table depth varied in the cultivated sites, for the duration of this study from year to year, and among sites (Figs. 2, 3 and 4). The water table depth at sites II, III and V was consistently greater than at sites I, IV and VI in 1975 and 1978 (except VI), reaching depths greater than 130 cm. However, during the wet summer of 1976, the water table depth only reached 100 cm at all of the sites, with an important rise in August due to the heavy rainfall.

In general, the water table level dropped from early spring until mid-September in all of the sites for all 3 yr. However, heavy summer rainfalls did raise the water table in June 1975 (Fig. 2), August 1976 (Fig. 3) and June 1978 (Fig. 4), but the drainage thereafter lowered the water table level at all of the sites.

Even on the drained sites, the water table reacted quickly to heavy rainfall (Fig. 5). In site VI, a 22.1-mm rainfall resulted in a 210-mm rise of the water table, almost a 10:1 ratio. However, the drainage over the next 24 h was slow and the water table was lowered by only 40 mm. An additional rainfall of 23.6 mm caused the water table to rise 170 mm, bringing it up to 36 cm below soil surface. The hydraulic conductivity at this site was extremely low. The wide spacing of the drains was inadequate and did not lower the water table sufficiently within 24 h after a heavy rainfall. For proper management of truck crops grown on organic soils, drainage coefficients of 2-4 cm/day should be used for design purposes (U.S. Dep. Agric., Soil Conserv. Serv. 1972).

The water table fluctuations in the uncultivated sites followed the same pattern as the cultivated sites for the duration of this study (Figs. 6, 7 and 8). During the dry summer of 1975, the water table depth exceeded 90 cm for almost 2 mo at all sites, except site II. In 1975 and 1978, the water depth reached 60 cm by mid-July as compared with mid-May at the cultivated sites. Again, during the wet summer of 1976, the water table levels in the uncultivated sites remained at less than 90 cm, except at site II. At site II, the water table depth was influenced by a major ditch nearby.

The lowering of the water table in undrained uncultivated sites followed a particular pattern (Fig. 9), typical of the forested sites. During the period of highest evapotranspiration, from 1000h to 1600 h each day, the water level dropped, whereas during the nighttime the curve was almost horizontal showing no lowering the the water table. Similar results were reported by Heikurainen (1963).

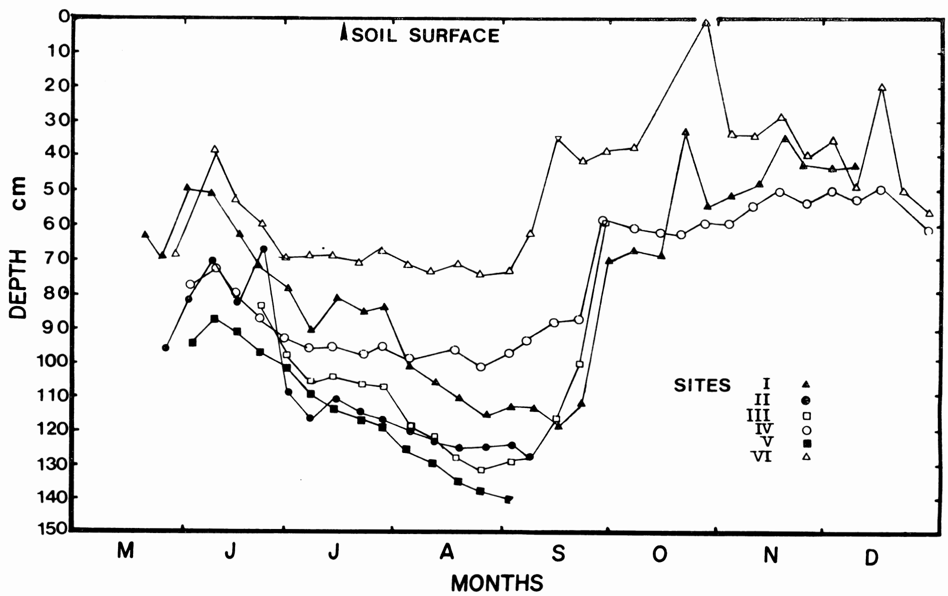

Figure 2. Water table depths observed midway between drains or ditches in 1975 at cultivated sites.

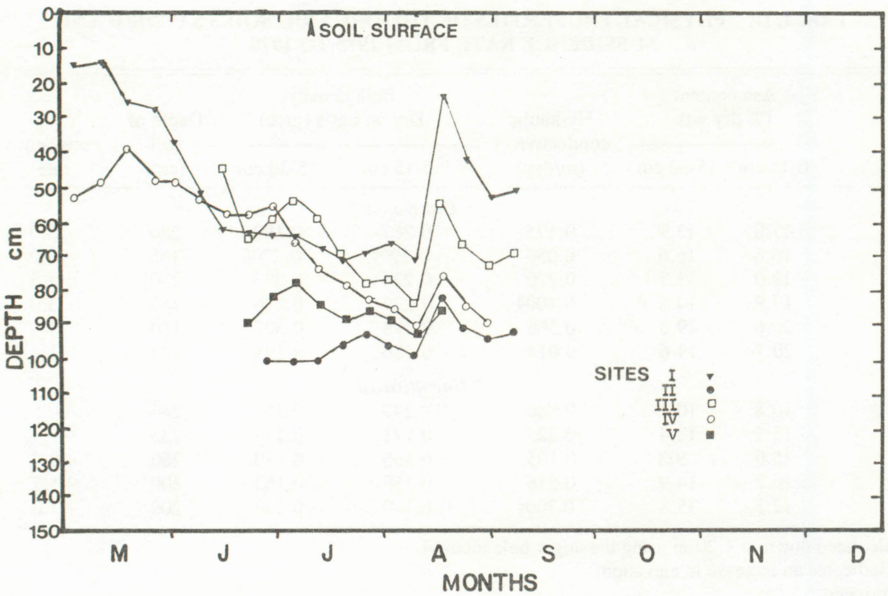

Figure 3. Water table depths observed midway between drains or ditches in 1976 at cultivated sites.

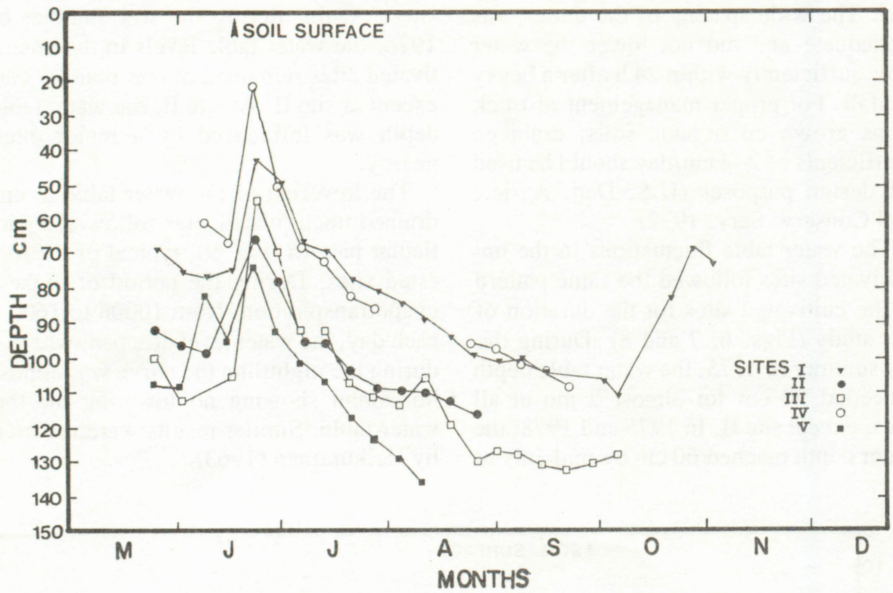

Figure 4. Water table depths observed midway between drains or ditches in 1978 at cultivated sites.

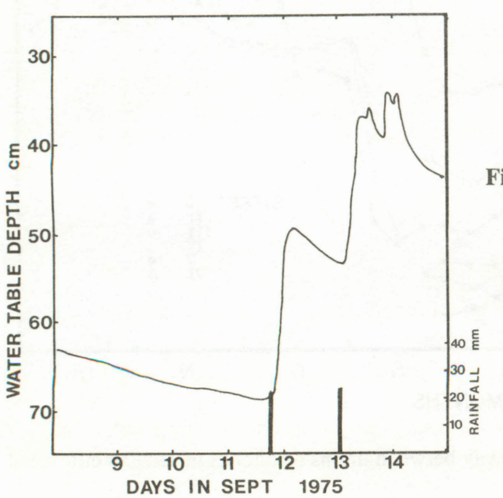

Figure 5. Water table depths observed in September 1975 midway between subsurface drain laterals at the Sainte-Clothilde Substation. The laterals were 40 m apart.

When designing drainage systems for organic soils, physical properties such as ash content, bulk density, hydraulic conductivity, subsidence rates and water table fluctuations should be considered before, during and after the soil has been developed. From this information future subsidence rates and drainability changes can be predicted to avoid any major surprises following the reclamation of these soils.

SUMMARY AND CONCLUSIONS

Drainage and cultivation have modified some of the physical properties of organic soils. The ash content and bulk density seemed to have increased, whereas the hydraulic conductivity has decreased.

Subsidence rates varied from 1.0 to 7.0 cm/yr at the six cultivated sites, whereas at the five uncultivated sites slight increases in elevation were observed. Throughout the cultivated sites the water table was unusually low during late summer months, sometimes exceeding 130 cm. Although no subsurface drainage occurred in the uncultivated sites, high evapotranspiration rates during the summer months lowered the water table.

Consideration must be given to these physical properties, subsidence rates and water table fluctuations to design effective drainage systems for organic soils.

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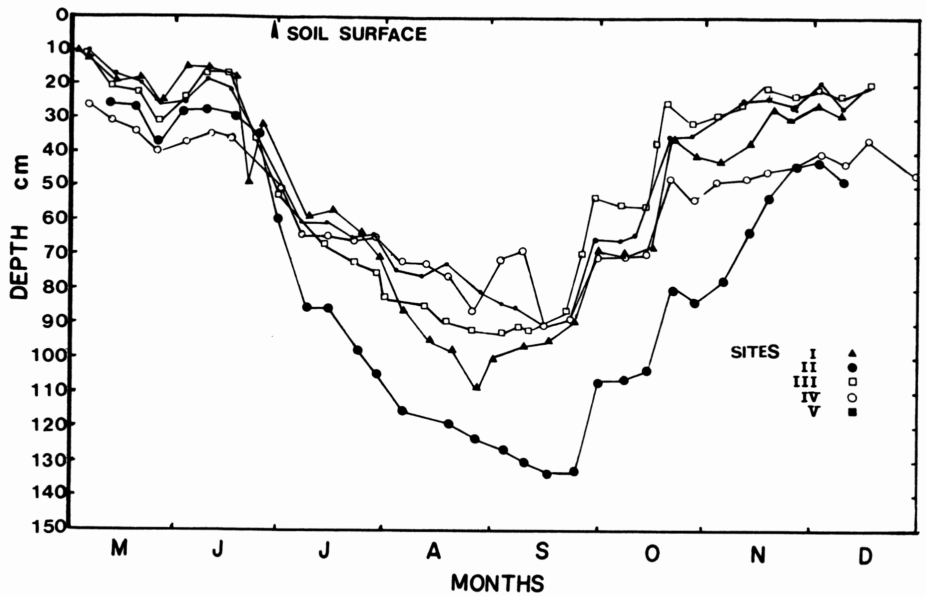

Figure 6. Water table depths observed at uncultivated sites in 1975.

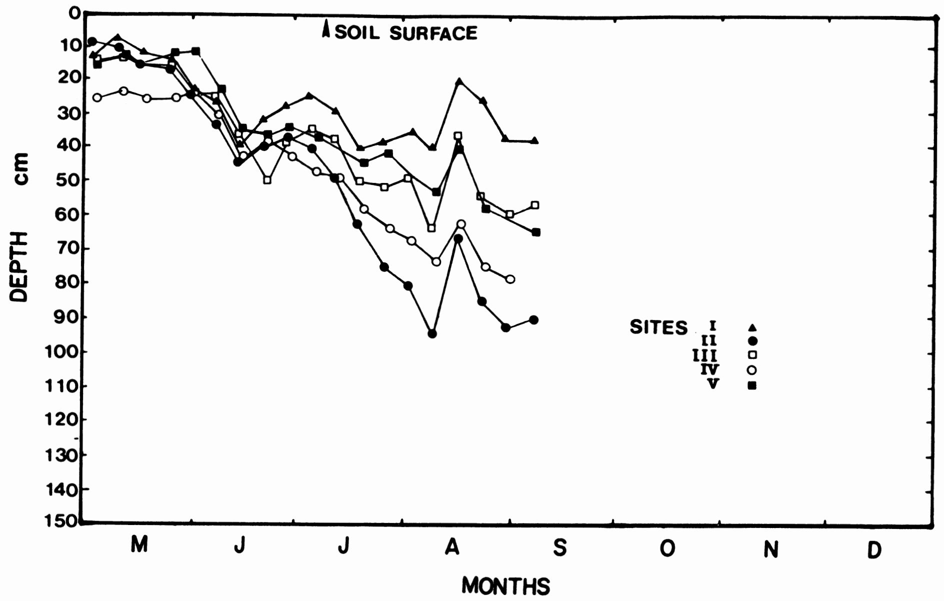

Figure 7. Water table depths observed at uncultivated sites in 1976.

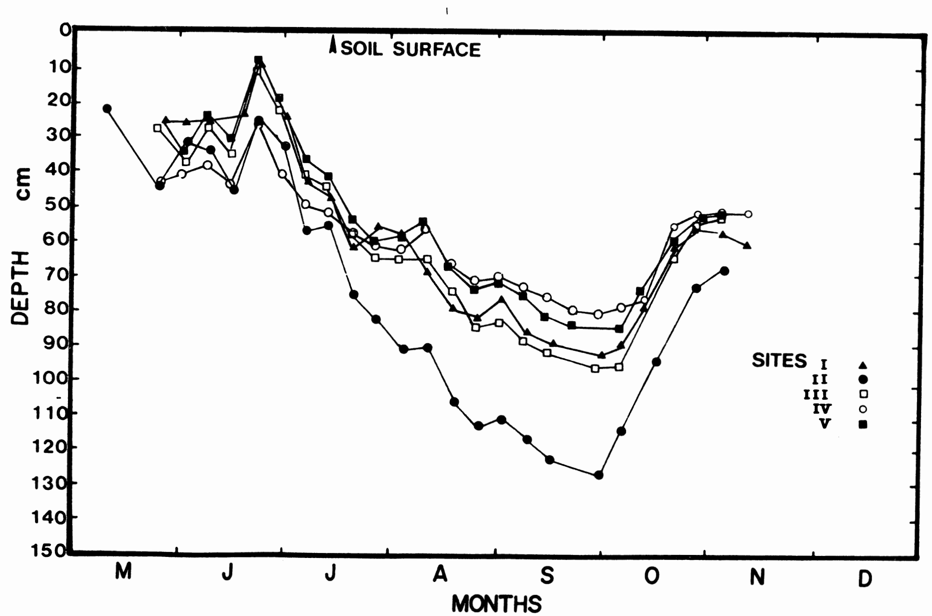

Figure 8. Water table depths observed at uncultivated sites in 1978.

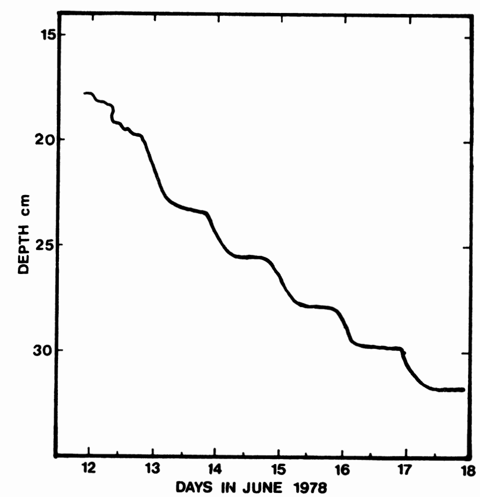

Figure 9. Typical water table recession at a wooded site in June 1978, during a week of no rainfall. The numbers are placed at noon of each day on the time line.

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