Characteristics of Spodosols Developed on a Sandy Topo-biosequence in Northern Michigan[1]

J. B. Collins and E. P. Whiteside[2]

ABSTRACT

Seven pedons, representing five soil series, were sampled in a relatively straight line along a sandy, topo-biosequence of Spodosols in northern Michigan. The wet end of the transect is in a poorly-drained organic bog, and the dry end of the transect is on a well-drained sand ridge. The characteristics, degree of development and classification of the Spodosols, in relation to the different natural drainage classes, were investigated. In addition, the distribution of the soils was compared with the distribution of the vegetation along the slope of the study site.

The site index of jack pine (*Pinus banksiana*) and the depths of plant roots increase as the depths to the water table or ortstein layer increase. Certain plant species have their maximum cover on one or more given soil series, but the overall vegetation is best described as a *Pinus banksiana* forest--*Chamaedaphne calyculata* bog transition.

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[2] Graduate Assistant and Professor of Soil Science, Michigan State University, respectively. The senior author is now Assistant Professor of Soil Science at Prairie View A & M College.

Chemical, physical and mineralogical data show that the intensity of weathering increases with proximity to the soil surface. These data also show that the somewhat poorly-drained profiles along the edge of the bog, and poorly-drained profiles in the bog are the most and least weathered, respectively.

The maximum spodic horizon development occurs along the edge of the bog in these profiles that are subjected to a combination of alternately wet conditions and flushing moisture regimes.

Starting at the wet end of the toposequence, the sequence of soils is as follows: Histic Haplaquods (Kinross) → Aeric Haplaquods (Saugatuck) → Entic Haplaquods (AuGres) → Entic Haplorthods (Croswell and Graycalm). At the family level, all the soils of the toposequence are classified as sandy, mixed, frigid, except for the Saugatuck series which also includes an ortstein layer. The above differ from the current classifications of Kinross as a Typic Haplaquod, Saugatuck as a mesic family, and Graycalm as an Alfic Udipsamment.

Additional key words for indexing: **toposequence, Aquods and** Orthods, spodic horizons.

Introduction

A gradation in the moisture regime occurs along the slope of a toposequence, and the soils have developed under different natural drainage conditions. In humid areas the well-drained soils of the toposequence are subjected to leaching and oxidizing conditions for the greater part of the year, while the soils with a high water table are subjected to more limited leaching and more reducing conditions for the greater part of the year (Russell, 1966). Milne (1936) introduced the concept of the soil catena for those soils that have developed from a similar parent material but differ in characteristics of the solum owing to differences in the natural drainage.

Glinka (1927) described the characteristics of some Podzol soil profiles developed under different moisture regimes as having differences of considerable magnitude. He attributed the differences to the natural drainage and other features of the topography. Johnsgard (1938) studied some Ground-Water Podzols and associated soils, and indicated that the various profiles in the association appeared to owe their distinctively different morphological characteristics to differences in the natural drainage of the site on which they occurred. He observed that the order in which the soils occur, as one proceeds from sites of the poorest natural drainage toward successively better drainage, is as follows: Bog Soil, Bog Transition Phase Ground-Water Podzol, and Dry Sandy Podzol. From their study of a hydrologic Podzol series, Mattson and Lunnemark (1939) reported that, starting

at the wet end of the series, the sequence of soils is as follows: Peat Podzol, Humus Podzol and Iron Podzol.

There is a close relationship between the vegetation, natural drainage, and type of soil profile that develops at a particular site. A high water table and reducing conditions are inimical to root development of many plants. These also slow up decomposition of organic matter and favor shallow rooting plants and peat formation (Russell, 1966). Warming (1895) proposed three classes of plants (hydrophytes, xerophytes, and mesophytes) characteristic of wet, dry, and moist habitats, respectively. The vegetation of the hydrologic sequence of podzols studied by Mattson and Lonnemark (1939) consisted of pine and spruce forest with a variable ground vegetation. The sequence of ground vegetation from the wet to the dry end was as follows: *Polytrichum commune*, *Ledum palustre*, *Vaccinium uliginosum*, *Empethrum nigrum*, *Vaccinium myrtillus*, *Calluna vulgaris*, *Vaccinium vitis idea*, and *Cladonia*. Bouma *et al.* (1969) found that Podzols on well drained sites are indicated by the growth of heather and blueberries, and on moderately well drained sites *Calluna* sp. and *Vaccinium* sp. are always dominant. Byer (1965) described the vegetation at the site used in the present study as a *Pinus-Chamaedaphne* transition.

This study was conducted to investigate the degree of development, characterization and classification of the Spodosols in relation to the different natural drainage classes. In addition, the distribution of

the soils was compared with the distribution of the vegetation along the slope of the study site.

DESCRIPTION OF THE STUDY AREA AND OF THE PEDONS SAMPLED

The study area is located in the northern part of Michigan's lower peninsula in south central Crawford County. It is located in what is known as the "Jack Pine Area" of Michigan. The soil parent materials are extensive areas of sandy and gravelly tills and outwash plains of late pleistocene age. These plains are pitted with glacial kettle holes. It is along the border of one such depressional area that the study site is located. This kettle is occupied by a poorly-drained, acid bog of the type known as "leatherleaf" for the dominant shrub cover.

The area selected for study extends from out in the bog to the well-drained soil on a sand ridge. Hence, the study area is a Pinus-Chamaedaphne transition, a sandy topo-biosequence, and it includes nearly the whole range of spodic horizon development commonly observed in Michigan (from a Brown Podzolic, Graycalm to the Ground Water Podzol, Saugatuck with an ortstein subsoil).

Seven pedons, representing five soil series, were described and sampled in a relatively straight line along the slope gradient. The resulting soil profile descriptions are shown below in Table 1.

METHODS OF ANALYSIS

Hydrogen ion activity was determined on air dry samples with the Hellige-Truog colorimetric kit and with a Beckman Zeromatic pH meter using the following soil-liquid ratios: 1:1 soil-H_2O, 1:2 soil-0.01M $CaCl_2$, and 1:2 soil-1.0N KCl (Agronomy No. 9, part 2, 1965).

Cation exchange capacity was determined by the NaAc method (Soil Survey Investigation Report No. 1, 1967).

Calcium, magnesium, potassium and sodium were extracted by use of a 1.0N NH_4Ac solution. The leachate was analyzed for calcium and magnesium by use of a 303 Model Perkins-Elmer Atomic Absorption Spectrophotometer, and for sodium and potassium by use of a Coleman Flame Photometer (Jackson, 1958).

A Leco carbon analyzer, Model 598-500, with digital readout was used to determine the total carbon content of a 0.1 gram sample. The iron and aluminum of a 2.0 gram sample were extracted by use of a 0.1M $Na_4P_2O_7$ solution, and the extract was analyzed with a 303 Model Perkins-Elmer Atomic Absorption Spectrophotometer. In addition, iron and aluminum were also extracted by use of the dithionite-citrate method (Soil Survey Investigation Report No. 1, 1967).

The pipette method was used for the mechanical analysis of the < 2 mm soil material.

The clay minerals were identified by standard X-ray diffraction techniques (Agronomy No. 9, part 1, 1965). The minerals of the fine sand fraction (0.25-0.10 mm) were determined by standard mineralogical

procedures and the relative abundance estimated by counting on regularly spaced traverses with the aid of an automatic recorder (Heinrich, 1965).

Site index measurements for Jack Pine (Pinus banksiana) were made by using the method of Gevorkiantz (1956). The vegetation was investigated by analyzing the data collected from quadrats (1 x 1 meter) that were randomly located in the study area (100 x 100 meters) Byer (1960 and 1965).

RESULTS AND DISCUSSION

Variations in the depths to the water table and in the depths to which most roots occur

Except for sites No. 6 and No. 7, each of the profiles has horizons that were subjected to a permanent water table, Table 2, and except for site No. 7 each of the profiles has horizons that were subjected to a water table for a considerable part of the year during the course of these observations (June to September of 1969 and 1970).

From Table 2 it is apparent that:

1. The plant roots do not extend very deep, 7.6 cm to 15. cm, into the permanent water table of the Kinross soil in the bog.
2. The plant roots do not extend very deep, 7.6 cm to 10. cm, into the ortstein layer of the Saugatuck and Saugatuck-Au Gres profiles.
3. The plant roots stop in the zone of fluctuation of the water table in the Au Gres-Croswell and Croswell-Graycalm profiles.
4. Except for sites No. 1 and No. 2, maximum depths to the water table are below the depths to which most roots occur.

These observations are in agreement with those of Joffe (1941) and Russell (1966). Joffe (1941) concluded that the avoiding of the ortstein layer by plant roots in not merely a mechanical problem but

is also one of aeration. Russell (1966) indicated that the reducing conditions created by impeded drainage and a high water table are very inimical to root development.

The average range in the depths to the water table for the individual soil series as represented in the toposequence are as follows: Kinross, 15-38 cms; Saugatuck, 38-69 cms; Au Gres, 69-89 cms; Croswell 89-147 cms, and Graycalm, 147 cms+.

Much of the variation in the depths to the water table can be accounted for by the amount and frequency of precipitation and accumulation of run off and seepage water in the bog. However, the fact that some sites varied considerably more than others, means that soil properties and vegetation are also important. The relatively high silt content of the upper part of the Au Gres-Saugatuck profile helps to explain the variations at this site. Some of the variation is due to the consumption rate of moisture by the plants, since plant activity was at a high level during the daylight periods that the measurements were made.

Soil reaction

Regardless of suspending media, pH's generally increase from the lowest values in the organic surface or upper A horizons to higher values in the A2 horizons and then continue to increase to the highest values in the C or lower B horizons (Figure 1). The differences in soil pH with depth vary from 1.0 to 1.6 pH unit in each profile.

There is an irregular, but net increase in pH as the natural

drainage improves from poor to well. However, the lowest pH does not occur out in the bog at the Kinross sites, but along the edge of the bog at the Saugatuck site.

The pH's measured in water, in 0.01M $CaCl_2$ and in 1.0N KCl with the glass electrode are on the average 0.6, 0.9 and 1.2 pH units lower than those measured with the Truog Kit, respectively. However, there are smaller differences in the pH's as measured in the three suspending media with the glass electrode.

Particle size distribution

The total sand percentages of these soils range from 80 to 99%. In the better drained soil, the total sand percentages are higher in the A horizons than in the upper B horizons and increase to values in the C or lower B horizons that are higher than those in the A or upper B horizons. In the two Kinross soils, in the bog, the total sand percentages increase with depth. In each horizon of the seven profiles (Figure 2), three sand fractions are dominant: medium sand (68-43%) > fine sand (39-16%) > coarse sand (21-5%).

Total silt percentages are usually highest in the A and upper B horizons and tend to drop off rather sharply to low values in the lower part of the profiles (Figure 3). The silt is about equally divided between coarse silt (50-20u) and fine silt (20-2u).

Much of the silt may have weathered from the sand fraction, since its distribution in the profile follows the usual pattern of increasing intensity of physical weathering, i.e., increasing with proximity to

the soil surface. St. Arnaud (1961) demonstrated that significant amounts of sand were lost from the coarse sand fraction of the Ae and C1 horizons of a Grey Wooded soil when they were subjected to 200 cycles of freezing and thawing.

Except for the two Kinross soils, where the maximum clay occurs in the A2 horizons, there are slight clay accumulations (Figure 3) in the B_2 horizons.

Using the totals of the fine materials (silt plus clay) in the profiles the following sequence is apparent: No. 4 Saugatuck-Au Gres > No. 5 Au Gres-Croswell = No 6 Croswell-Graycalm = No. 7 Graycalm > No. 3 Saugatuck > No. 2 Kinross (better drained) > No. 1 Kinross (organic surface). This suggests that:

1. The excess moisture at the wet end of the transect has severely reduced weathering.
2. Deficiency of moisture at the dry end of the transect has slightly reduced weathering.
3. Conditions favoring formation and accumulation of clay and silt occur along that portion of the transect where the water table in the soil profile is subjected to considerable fluctuations.
4. The organic mat on the Kinross soils may have reduced frost action.

<u>Cation exchange capacity and exchangeable bases</u>

Cation exchange capacity and exchangeable bases (sum Ca, K, Mg,

Na) are always highest in the organic matter-rich A1 horizons (Figure 4). Exchangeable bases tend to decrease with increasing depth from the A1 horizon. Cation exchange capacity (sum of bases plus $BaCl_2$-TEA extractable acidity), for the five less well-drained profiles, shows a maximum in the upper B horizons and then decrease to lower values in the C or lower B horizons. For the two best drained profiles (Nos. 6 and 7), CEC values show a continuous decrease from the highest values in the A1 horizons to the lowest values in the A'2 horizons, with an increase being exhibited by the A2' & B2t' horizons.

In each of the seven profiles, the exchangeable bases are predominantly calcium. Exchangeable base contents are highest along the edge of the bog in the Saugatuck profile and lowest in the two Kinross soils in the bog.

These data suggest that the amount and distribution of bases in the soils are related to the movement of water through the profile which may be at a minimum in the Kinross soils. Bases are highest along the edge of the bog, in the Saugatuck profile, probably as a result of enrichment by drainage water from the surrounding better-drained soils. In addition, the data also shows evidence of nutrient cycling where bases are returned to the soil surface by the vegetation, enriching the A1 horizons and the A2 horizons of the better-drained soils.

Mineralogy of sand and clay fractions

The largest percentage of the feldspars were identified as

orthoclase and albite which are more resistant to weathering than the calcium feldspars. The garnets were dark in color, such as melanite and grossularite, and hence contain no iron. The sums of quartz and feldspars plus garnets, and pyroxenes plus amphiboles, of the fine sand fraction, were used as resistant and weatherable primary minerals, respectively.

The variations in the mineral percentages and the mineral ratios within and among the profiles, indicate that the seven soil profiles have developed in heterogeneous materials. However, the mineral suite is the same for all profiles which indicates similarity in the original parent materials.

The ratios of resistant mineral/weatherable mineral generally tend to decrease with increasing depth, which means that the intensity of weathering decreases with increasing depth. These ratios also show that the soils in the bog and the soils along the edge of the bog are the least and most weathered, respectively.

Quartz is the only mineral that accounts for more than 40% but less than 90% of the mineralogical composition of the fine sand fraction of these soils. Hence, these soils have mixed mineralogy (Soil Taxonomy - 1970).

The clay fraction of all horizons contain kaolinite and quartz. The clay of the least altered horizons of the seven profiles contain the following clay minerals: illite, chlorite, and chlorite-vermiculite intergrade. Each of the spodic horizons in the seven profiles

contain chlorite-vermiculite intergrade.

The distribution of discrete illite, chlorite and kaolinite in the profiles suggests that these clay minerals are being weathered out of the upper parts of the profiles.

Montmorillonite occurs only in the A1 or A2 horizons and has probably formed in situ from illite, chlorite and chlorite-vermiculite intergrade, through vermiculite (Franzmeier et al. - 1963, and Ross - 1965).

Vegetation along the topo-biosequence

The site index of jack pine (Pinus banksiana) increases as natural drainage improves from poorly to well-drained (Figure 5). The relatively low site index at the wet end of the transect can be explained by the presence of the high water table and the associated poor aeration. The relatively high index at the dry end of the transect can best be explained by the absence of a high water table and the presence of the thin Bt bands which serve to increase the available water and nutrient supplies within the reach of plant roots. These conclusions are in agreement with the tree growth observations of vanEck (1958) and Shetron (1970).

Byer (1960 and 1965) studied the vegetation along the moisture and slope gradient used in this study. The discussion which follows is based on his investigations.

The species area curves show that the flora of Kinross is the richest in species, and that of the organic bog is the poorest (Figures

6 and 7). Graycalm is intermediate between the two, and the total flora increases as the depth to the water table decreases from the well-drained Graycalm soil to the less well-drained Saugatuck soil along the edge of the bog. This strongly suggests that the organic bog is the most unfavorable habitat for the plants that occur in the area, more so even than the well-drained sandy soil.

Both the lichen and moss covers decrease sharply from the Graycalm site to the Croswell-Graycalm site, and then increase again between the Croswell-Graycalm site and the Kinross soils. This is explained by the fact that mosses are probably no so much restricted by moisture conditions as they are by accumulation of deep leaf litter.

Tree cover is much greater on the dry end of the gradient than it is in the bog. This is due to the variation in the depths to the water table along the gradient. Shrub cover increases steadily from the well-drained Graycalm soil to the organic soil in the bog. The high shrub cover on the organic soil in the bog is at least partially a consequence of the low tree cover and partially as a result of the peculair adaptation of Chamaedaphne. Herb cover decreases sharply on Saugatuck and continues to decrease on the Kinross soil and the organic soils. This indicates that each layer of the vegetation inhibits the one below it.

Certain plant species have their maximum cover on one of more given soil series. However, several species, such as, Pinus banksiana

and Vaccinium angustifolium span the entire moisture gradient, and demarcations between the vegetation groups are by no means very sharp. Hence, the vegetation is best described as a Pinus banksiana forest-Chamaedaphne calyculata bog transition.

Total carbon and extractable iron and aluminum (% elemental)

All profiles show a subsurface maximum of carbon and aluminum and each profile, except the two Kinross soils, show a subsurface maximum of iron (Figures 8 and 9). The iron and aluminum maxima occur in the same horizon of all profiles, except the Kinross soils which do not show an iron maximum and the Saugatuck-Au Gres profile which shows a second maximum of alumina but not of iron. The carbon maximum occurs below the aluminum maximum in profiles Nos. 3 and 5, but in the other profiles the two occur in the same horizon.

The occurrence of the iron, aluminum and carbon maxima and the relationship of these maxima to the water table (Table 2) in each of the seven profiles suggest that these three constituents may move independently or in association with each other, and that the water table has played an important role in the occurrence of the carbon maxima in all except the two better-drained profiles. In addition, it appears that the development of the spodic horizon under submerged conditions may not necessarily be dependent upon the occurrence of a water table which descends periodically below the B horizon. However, the water table must be below the B horizon for the accumulation of

iron. In fact, iron is being lost from the profiles of the Kinross and Saugatuck soils. The low content of iron in these three profiles probably explains why no mottles were observed as they were described in the field.

The maximum spodic horizon development occurs in the profiles No. 3 and 4, along the edge of the bog, that have been subjected to a combination of alternating wet conditions and flushing moisture regimes.

Pyrophosphate extracts more aluminum than iron from the B horizons of all profiles. In addition, pyrophosphate extractable aluminum appears to be a good indicator of spodic horizon development, since its maximum values were obtained from the ortstein layer of the Saugatuck profile and slightly higher values were obtained from the well than from the poorly-drained soils.

Classification of the soils

Only two of the seven profiles studied, Saugatuck and Saugatuck-Au Gres (representing the range of the Saugatuck series), meet the first of the three spodic horizon criteria (cemented horizon > 2.5 cm thick) listed in Soil Taxonomy (1970, unedited)-Table 3. Each of the seven profiles has a subhorizon that meets the second spodic horizon criterion (sandy or coarse loamy with sand grains covered with cracked coatings). Each of the seven profiles meet criterion 3a and 3b, respectively. Except for the two better-drained sites, Croswell-Graycalm and Graycalm, each of the profiles has a subhorizon that

meets criterion 3d, all profiles have spodic horizons by revised spodic horizon criteria proposed below. Criterion 3c was not tested since the data are sufficient to indicate that the horizons of these profiles are not cambic.

Considering the above and other data collected in this study, the five soil series of the toposequence were placed in the new soil classification system as follows:

Kinross=Histic Haplaquod; sandy, mixed, frigid.

Saugatuck=Aeric Haplaquod; sandy, mixed, frigid, ortstein.

Au Gres=Entic Haplaquod; sandy, mixed, frigid.

Croswell=Entic Haplorthod; sandy, mixed, frigid.

Graycalm=Entic Haplorthod; sandy, mixed, frigid.

These placements differ from current placements of these soils as follows: Kinross is a Typic Haplaquod; Saugatuck is mesic; and Graycalm is an Alfic Udipsamment.

According to the results of the saturated sodium pyrophosphate quick test (Munsell color values of 7 or lower and chromas of 3 or higher) developed by Lietzke (1968), each of the seven profiles has an horizon that qualifies as spodic. Each of the profiles has a subhorizon that qualifies as spodic, according to the then current spodic horizon criteria as refined by Lietzke (1968)-Table 4.

Using Lietzke's (1968) refinement, Kinross and Saugatuck would be Humods and the other soils would be Orthods. Using the current placement, the two better drained soil series are Orthods and the

three less well-drained soil series are Aquods.

The present criteria (Soil Taxonomy, 1970) recognizes the high water table in the less well-drained soils at the suborder level, while the criteria as refined by Lietzke (1968) recognizes the relatively high percent of carbon in those same soils at the same level of the classification system.

In view of the above and other data collected in this study, the following revisions are proposed:

a. Reduce criterion 3a (% pPO_4Fe + Al/% clay) of Soil Taxonomy from $\geq$ .15 to $\geq$ .06; and, reduce criterion 3b (% pPO_4Fe + Al% dith.-cit. Fe + Al) of Soil Taxonomy from $\geq$ .45 to $\geq$ .30. These proposed revisions of the current spodic horizon criteria would include in the range of the spodic horizons, those in the soils used in this study. The current criteria under 3; excludes some of the most developed subhorizons, e.g. B_2h horizons of Kinross, and $B_{22}h$ of Saugatuck, which meet one or both of the first 2 criteria of spodic horizons; but require all these properties of less developed horizons to exceed these proposed limits, if they do not meet one of the first 2 criteria, even though they exceed the accumulative index, 3d, which the above most developed horizons also exceed!

b. A less preferable alternative is [illegible] to the earlier spodic horizon criteria as refined by Lietzke, or revision of

those criteria so that No. 1 (% Tot. C + % dith.-cit. Fe + Al/% clay) is raised from $\geq$ .12 to $\geq$ .30, and No. 2 (% dith.-cit. Fe + Al) is reduced from $\geq$ .8 to $\geq$ .7.

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TABLE 1 - DESCRIPTION OF SOILS

Horizon	Depth (cms)	Color Main	Color Mottles	Structure	Consistence	Boundary
				KINROSS SAND (ORGANIC SURFACE) - NO. 1		
O1	33-18	10YR 7/2		Moderate coarse pl*	Soft	Abrupt smooth
O21	18-8	5YR 3/2		Weak coarse pl.	Soft	Abrupt smooth
O22	8-0	N 2/0		Weak fine sbk**	Friable	Abrupt smooth
A1	0-2.5	10YR 2/2		Single grain	Friable	Clear smooth
A2	2.5-28	10YR 4/2		Weak fine gr +	Loose	Clear wavy
B21h	28-53	5YR 3/3		Weak medium sbk	Friable	—
B22hir	53-69	5YR 4/3		Moderate coarse sbk	Firm	—
B23	69-94	7.5YR 4/3		Weak medium sbk	Firm	—
C1	94-127	10YR 4/3		Single grain	Loose	—
				KINROSS SAND (BETTER DRAINED) - NO. 2		
O21	5-38	10YR 2/2		Weak coarse sbk	Friable	Abrupt wavy
O22	38-0	N 2/0		Moderate coarse pl.	Friable	Clear smooth
A1	0-3.8	N/0		Weak fine gr	Friable	Clear smooth
A2	3.8-38	10YR 5/2		Single grain	Loose	Clear smooth
B21h	38-63	5YR 2/2		Weak medium sbk	Friable	—
B22hir	63-89	* 5YR 3/2		Moderate coarse sbk	Firm	—
B23	89-137	5YR 3/3		Weak medium sbk	Firm	—
				SAUGATUCK SAND - NO. 3		
O2	10-0	10YR 3/2		Weak medium sbk	Friable	Clear wavy
A1	0-2.5	N 2/0		Weak medium sbk	Friable	Abrupt smooth
A2	2.5-28	10YR 6/3		Single grain	Loose	Abrupt smooth
B21hirm	28-43	5YR 2/2		Strong coarse sbk and abk	Strongly cemented	—
B22hirm	43-61	5YR 2/3		Strong medium sbk and abk	Weakly cemented	—
B23hir	61-84	5YR 3/3		Moderate medium sbk	Firm	—
C1	84-118	7.5YR 4/2		Single grain	Loose	—
C2	118-155	10YR 4/3		Single grain	Loose	—

SAUGATUCK-AU GRES SAND - NO. 4

O1	8.9-2.5	7.5YR 3/2		Weak coarse gr	Friable	Abrupt smooth
O2	2.5-0	7.5YR 2/0		Weak fine gr	Friable	Abrupt smooth
A1	0-3.8	10YR 2/1		Weak medium gr	Friable	Abrupt smooth
A2	3.8-7.6	10YR 5/2		Weak fine gr	Loose	Abrupt smooth
B21hir	7.6-18	5YR 3/3,	7.5YR 5/3	Weak fine sbk	Firm	Clear smooth
B22hir	18-28	5YR 3/3,	7.5YR 5/3	Weak fine sbk	Firm	Clear smooth
A2'	28-41	10YR 5/3,	7.5YR 4/4	Weak medium sbk	Friable	Abrupt wavy
IIB21hir'	41-58	5YR 3/4,	7.5YR 4/4	Weak coarse sbk	Firm	Clear smooth
IIBhir'm	58-84	5YR 3/2		Massive chunks	Weakly cemented	Clear smooth
IIB3'	84-122	5YR 3/3		Massive chunks	Firm	Clear smooth
IIC1	122-147	7.5YR 4/3		Single grain	Loose	--

AU GRES-CROSWELL SAND - NO. 5

O2	2.5-0	10YR 3/2		Weak medium sbk	Friable	Abrupt smooth
A1	0-15	7.5YRN 2/0		Weak fine gr	Friable	Clear wavy
A2	15-25	10YR 6/1		Single grain	Loose	Gradual irregular
B21hir	25-36	5YR 4/6,	10YR 6/6	Moderate fine sbk	Friable	Clear wavy
B22hir	36-53	10YR 6/4,	7.5YR 6/6	Weak fine sbk	Friable	Clear wavy
B23h	53-71	10YR 5/4,	7.5YR 7/8	Weak fine gr	Friable	Clear wavy
B31	71-99	10YR 6/4,	7.5YR 7/8	Single grain	Loose	Clear wavy
B32	99-127	10YR 6/4,	7.5YR 7/8	Single grain	Loose	Clear wavy
C1	137-153	10YR 6/1		Single grain	Loose	—

CROSWELL-GRAYCALM SAND - NO. 6

O2	1.3-0	10YR 3/2	Weak medium sbk	Friable	Abrupt smooth
A1	0-2.5	10YR 2/1	Weak medium gr	Friable	Abrupt smooth
A2	2.5-7.6	10YR 6/2	Weak medium gr	Loose	Abrupt wavy
B21hir	7.6-18	5YR 3/3	Weak fine sbk	Firm	Abrupt wavy
B22hir	18-46	7.5YR 4/4	Weak fine sbk	Friable	Clear smooth
B3	46-58	7.5YR 5/4	Weak fine sbk	Friable	Clear smooth
A2'	58-71	10YR 6/3	Weak fine pl	Slightly brittle	Abrupt wavy
A2' & B2t', 1	71-99	10YR 6/3 (A2), 7.5YR (5/8) & 7.5YR 5/4 (B2t), 5YR (5/8)	Single grain (A2) & Massive (B2t)	Loose (A2) & Slightly plastic (B2t)	Clear wavy
A2' & B2t', 2	99-125	10YR 7/3 & 10YR 6/4	Single grain (A2) & Massive (B2t)	Loose (A2) & Slightly plastic (B2t)	Clear wavy
C1	125-153	10YR 7/3	Single grain	Loose	—

GRAYCALM SAND - NO. 7

A1	0-2.5	10YR 2/1	Weak medium gr	Friable	Abrupt wavy
A2	2.5-7.6	10YR 6/2	Single grain	Loose	Abrupt wavy
B21hir	7.6-28	7.5YR 5/6	Weak fine sbk	Firm	Clear wavy
B22hir	28-58	10YR 6/6	Weak fine sbk	Firm	Clear wavy
A2'	58-76	10YR 7/4	Weak medium gr	Soft	Clear wavy
A2' & B2t', 1	76-140	10YR 7/4 (A2), 7.5YR 5/6 (B2t)	Weak fine gr (A2) & Weak fine sbk (B2t)	Soft (A2) & Slightly hard (B2t)	Clear wavy
A2' & B2t', 2	140-153	10YR 7/3 (A2, 7.5YR 5/6 (B2t)	Weak fine gr (A2) & Weak fine sbk (B2t)	Soft (A2) & Slightly hard (B2t)	—

* Pl-platy; ** sbk-subangular blocky; +-granular

NOTE: Soil texture and soil reaction appear in other sections.

TABLE 2 --Depths (cms) of water table and plant roots in each of the seven pedons.

Site No., Pedon Identity	Average Depths to Water Table	Range in Depths to Water Table		Maximum Variations in Depths to Water Table		Horizons Subjected to Water Table Fluctuations	Depths to Which Roots Occur	Horizons in Which Roots Occur
		1969	1970	1969	1970			
1, Kinross (organic surface)	15.	0-47	0-28	47.	28.	01,021,022,A1 upper A2	63.	01,021,022,A1,A2, upper B21h
2, Kinross (better drained)	28.	5-60	12-46	55.	34.	A1,A2, lower B21h	69.	021,022,A1,A2,B21h
3, Saugatuck	48.	15-76	38-56	63.	18.	Lower A2 B21hirm, B22hir$_m$, upper B23hir	37.	02,A1,A2 (not observed in B22hir$_m$ or below)
4, Saugatuck-AuGres	68.	28-99	51-89	71.	38.	A2', IIB21hir', IIBhir$_m$', IIB3'	66.	021,022,A1,A2 B21hir, B22hir, A2', IIB21hir', IIBhir$_m$' (end in this horizon)
5, AuGres-Croswell	89.	58-126	74-99	65.	22.	B23h, B31,B32	76.	02,A1,A2,B21hir, B22hir, B23
6, Croswell-Graycalm	147.	146->165	135->165	44.	30.	C2	140.	All except C2
7, Graycalm	>165.	>165.	>165.	>165.	>165.	None	165.	Throughout the profile

TABLE 3. --Application of spodic horizon criteria (Soil Taxonomy--1970, unedited) to the soils used in in this study.

Site Number, Pedon Identity	Horizons	3a $\frac{\% pPO_4 Fe+Al}{\% Clay}$ ≥ .15	3b $\frac{\% pPO_4 Fe+Al}{\% Dith.-cit. Fe+Al}$ ≥ .45	3d (CEC(pH 8.2)-1/2% Clay) X Thickness in cm) > 65.	Spodic Horizon Current	Spodic Horizon Revised 3a & 3b
1. Kinross (organic surface)	B21h	.07	.48	181.4	no	yes
	B22hir ✓	.07	.62	79.6	yes	yes
	B23	.09	.65	135.6	no	yes
				Total 396.6		
2. Kinross (better drained)	B21h	.06	.60	163.8	no	yes
	B22hir ✓	.07	.71	179.6	yes	yes
	B23	.10	.50	184.4	no	yes
				Total 527.8		
3. Saugatuck	B21hir$_m$ ✓	.23	.76	333.1	yes	yes
	B22hir$_m$ ✓	.06	.54	132.6	yes	yes
				Total 465.7		
	B23 ✓	.04	.48	122.1	yes	no
4. Saugatuck-AuGres	B21hir ✓	.07	.49	65.3	yes	yes
	B22hir ✓	.06	.86	109.1	yes	yes
	IIB21hir ✓	.15	.65	227.1	yes	yes
	IIBhir$_m$ ✓	.25	.44	135.1	yes	yes
				Total 536.6		
5. AuGres-Croswell	B21hir ✓	.13	.48	64.7	yes	yes
	B22hir ✓	.06	.30	44.8	yes	yes
	B23	.06	.30	12.1	no	yes
				Total 121.6		

CONTINUED

TABLE 3. --Continued

Site Number, Pedon Identity	Horizons	3a % pPO_4 Fe+Al / % Clay ≥ .15	3b % pPO_4 Fe+Al / % Dith.-cit. Fe+Al ≥ .45	3d (CEC(pH 8.2)-1/2% Clay) X Thickness in cm) > 65.	Spodic Horizon Current	Spodic Horizon Revised 3a & 3b
6. Croswell-Graycalm	upper B21hir	.12	.34	6.0	no	yes
	lower B21hir	.12	.62	32.5	no	yes
	B22hir ✓	.10	.37	45.5	yes	yes
	B3	.08	.38	16.3	no	yes
				Total 100.3		
7. Graycalm	upper B21hir ✓	.11	.47	26.4	yes	yes
	lower B21hir ✓	.09	.38	26.5	yes	yes
	B22hir	.07	.31	50.0	no	yes
				Total 103.8		

Notes:

m--Continuously cemented horizon > 2.5 cm thick.
✓--sand grains covered with cracked coatings.
yes--meet criteria 1 or 2 or 3a + 3b + 3d; totals = basedon 3a and 3b as revised

TABLE 4. --Application of spodic horizon criteria as refined by Lietzke (1968)

Site Number, Pedon Identity	Horizons	Tot. % C + Dith.-cit. Fe+Al / % Clay ≧ .12	Tot. C % + Dith.-cit. Fe+Al ≧ 0.8	Spodic Horizon	
				Lietzke	Revised
1. Kinross (organic surface)	B21h	.55	1.15	yes	yes
	B22hir	.42	.75	no	yes
	B23	.43	.51	no	yes
2. Kinross (better drained)	B21h	.52	1.30	yes	yes
	B22hir	.55	1.22	yes	yes
	B23	1.01	.91	yes	yes
3. Saugatuck	$B21hir_m$	.53	1.27	yes	yes
	$B22hir_m$	.36	1.21	yes	yes
	B23	.74	2.52	yes	yes
4. Saugatuck-Au Gres	B21hir	.45	3.92	yes	yes
	B22hir	.25	1.69	yes	no
	IIB21hir'	.77	2.39	yes	yes
	$IIBhir_m'$	1.12	1.23	yes	yes
5. AuGres-Croswell	B21hir	.30	1.29	yes	yes
	B22hir	.32	1.46	yes	yes
	B23h	.61	1.64	yes	yes
6. Croswell-Graycalm	Upper				
	B21hir	.35	1.76	yes	yes
	Lower				
	B21hir	.41	1.47	yes	yes
	B22hir	.36	1.03	yes	yes
	B3	.28	.71	no	no
7. Graycalm	Upper				
	B21hir	.46	1.61	yes	yes
	Lower				
	B21hir	.44	1.92	yes	yes
	B22hir	.35	1.28	yes	yes