SANTIAGO SOILS

A SUMMARY OF PERTINENT DATA FOR USE IN CLASSIFICATION AND INTERPRETATION

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SOIL CONSERVATION SERVICE
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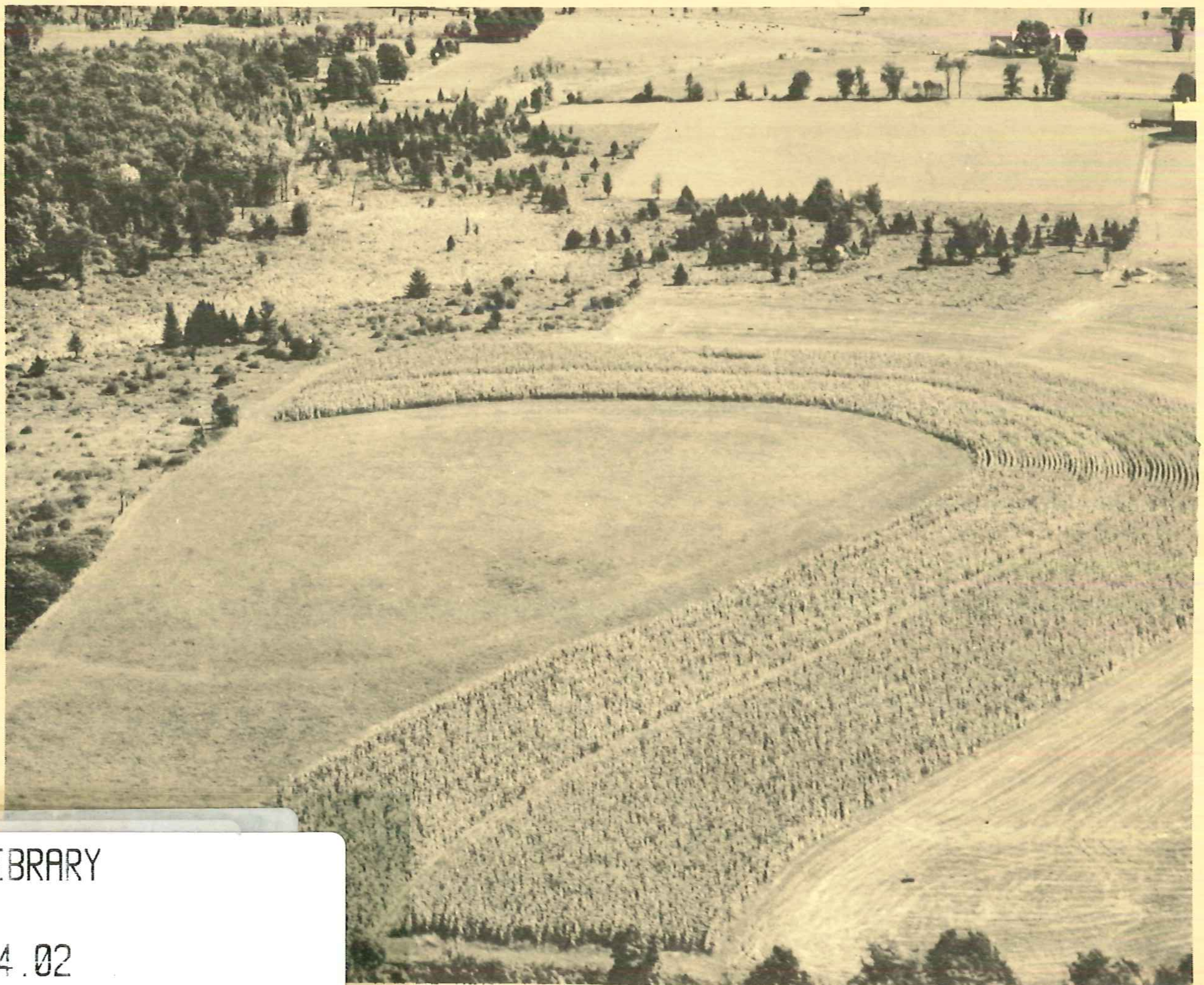

A C K N O W L E D G M E N T S

This benchmark soil report has been prepared by the United States Department of Agriculture, Soil Conservation Service of Wisconsin and Minnesota in cooperation with the Soil Survey Division of the Wisconsin Geological and Natural History Survey, the Wisconsin Agricultural Experiment Station of the University of Wisconsin and the Wisconsin Department of Agriculture.

This material is tentative and subject to amendment.

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SECTION I

GENERAL CHARACTERISTICS OF THE SANTIAGO SERIES

General Characteristics

The Santiago Series comprises well drained Gray-Brown Podzolic soils having part of their sola developed in thin to moderately thin multiple loess of Wisconsin age (33) and part in underlying acid, reddish-colored, loam, sandy loam or sandy clay loam glacial till of Wisconsin age and Patrician source (44). These soils occupy gently undulating to rolling upland relief, with slopes ranging from 0 to 30 percent or more, but having dominant slopes of 2 to 12 percent. Santiago soils are well drained and their permeability is moderate. Surface runoff is slow to rapid, depending on the slope. Internal drainage is medium.

These soils are associated physiographically with soils of the Milaca, Otterholt, *Jewett, and *Lafont series. Whereas, the Santiago series have loess thicknesses over glacial till of 12 to 30 inches, with portions of the B horizon in both the loess and the till, the B horizon of Milaca soils developed entirely in till. Otterholt soils, however, have developed in 30 to 42 or more inches of loess over till and have their entire sola in the silty loess. Soils of the *Jewett series are Brunizems intergrading to Gray-Brown Podzolics and are distinguished from the Santiago soils primarily by their slightly darker colored, thicker A_1 horizons and their thinner, more weakly-expressed A_2 horizons. The *Lafont soils generally are more strongly leached than are the Santiago soils and possess a bisequa profile that consists of a Podzol upper sequum and a Gray-Brown Podzolic lower sequum.

Santiago soils are the well drained catenary associate of the moderately well drained Freeon, somewhat poorly (imperfectly) drained Freer, poorly drained Auburndale and very poorly drained Adolph soils.

It is estimated that 80 to 90 percent of the Santiago soils now are under cultivation. Owing to their geographic position and generally favorable soil characteristics, they comprise some of the older farming lands of Minnesota and Wisconsin. Good yields of corn, potatoes, barley, oats and tame hay are grown. The few areas of steeper Santiago soils support good stands of mixed hardwoods and conifers, including sugar maple, basswood, aspen, ironwood, red oak, white ash, elm, yellow birch, paper birch, and white pine.

*Tentative series.

Distribution

Santiago soils occupy areas of loess-mantled, Cary-age and Patrician-source glacial till in the northwestern part of Wisconsin and the east-central part of Minnesota. There are approximately 263,000 acres of these soils in the two-state area. By far the greater part of this acreage is in Wisconsin, Minnesota having mapped only little more than 15,000 acres. Figure 1 indicates the distribution but not acreage of Santiago soils in the two states. Table 1 records the acreage by states and by counties.

Table 1. Estimated acreage of Santiago soils by states and counties.*

State	County	Acres
Wisconsin	Barron	31,550
	Burnett	5,400
	Chippewa	17,400
	Dunn	3,350
	Lincoln	2,000
	Pierce	2,400
	Polk	77,300
	Price	few
	Rusk	27,250
	Sawyer	22,750
	St. Croix	38,700
	Taylor	1,100
	Washburn	17,900
		Total - 247,100
Minnesota	Benton	300
	Mille Lacs	1,700
	Kanabec	500
	Washington	12,970
		Total - 15,470

*Acreage figures in Wisconsin are based on projection from a 2 percent statistical sample survey and, in Minnesota, from measured acreage provided by Alex Robertson, State Soil Scientist, SCS, Minnesota.

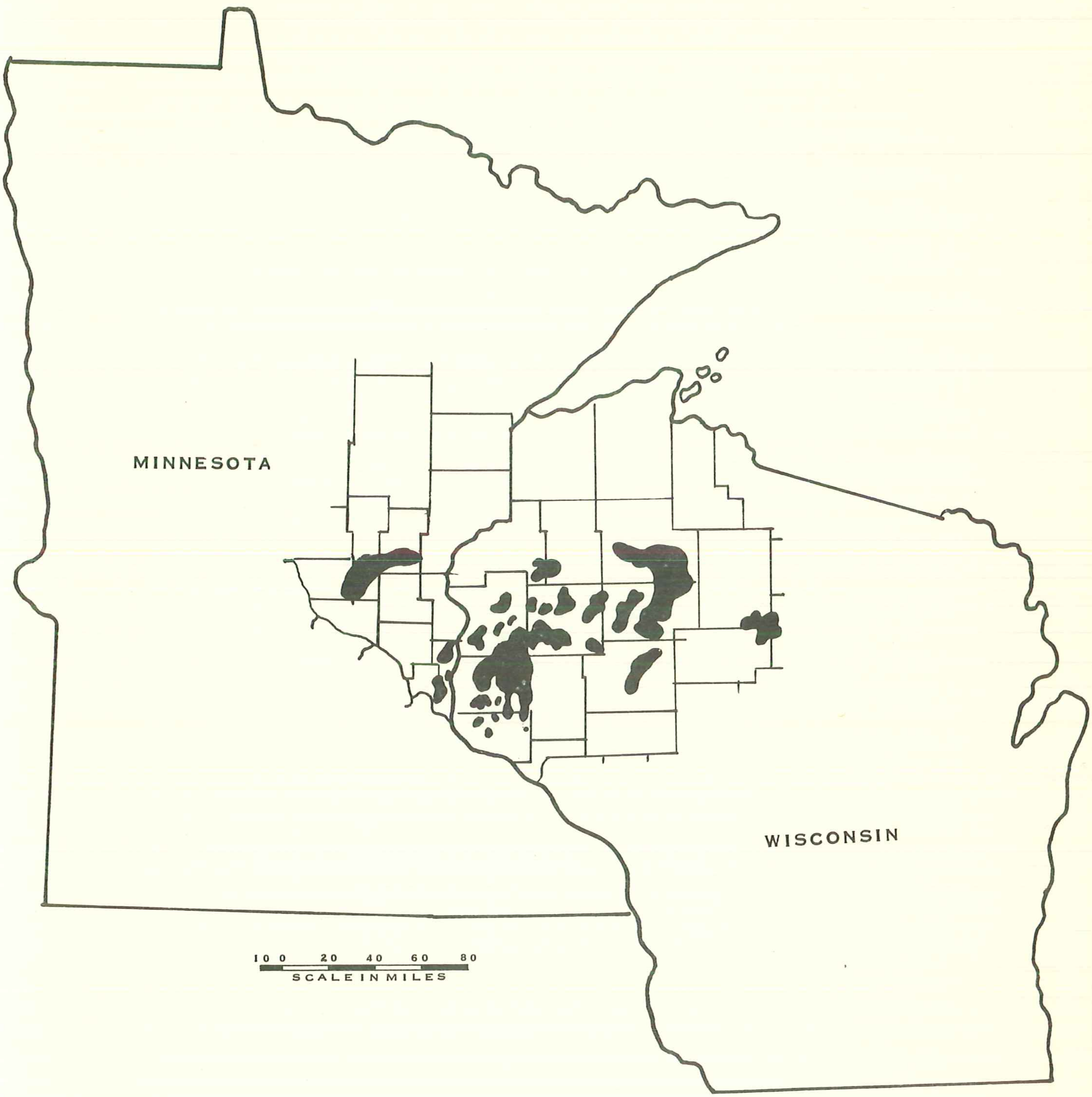

FIGURE I. LOCATION OF MAJOR AREAS OF SANTIAGO AND ASSOCIATED SOILS IN MINNESOTA AND WISCONSIN.

Geology

The two-storied parent material in which Santiago soils are formed consists of thin to moderately thin, loess over reddish-colored loam, sandy loam, and less frequently, sandy clay loam glacial till.

The loessial parent material in which the upper story of these soils is developed most likely is a multiple loess of Wisconsin age (33). At the time of deposition, the parent loess probably contained free carbonates. However, the process of soil development and subsequent leaching of the soil profile has resulted in a loss of these carbonates (39). The loess material now is acid. The probable sources of aeolian silts that mantle these soils are the local outwash plains and the flood plains of the Mississippi River and its tributaries. The silty material undoubtedly was deposited by the melting of the glacial ice sheet and, later, picked up by the winds and re-deposited as a thin to moderately thick mantle on the surrounding glacial uplands. The loess is thickest on the bluffs adjoining the Mississippi River and its major tributaries and thins eastward or westward from the river valley or northward over the areas of young drift.

The acid glacial drift that constitutes the lower story of the Santiago soils is of the Cary or third substage of the Wisconsin glaciation (23). Generally, it has a loam or sandy loam texture, often gravelly or cobbly, and occasionally has lenses, pockets, or strata of loose sand and gravel. The drift is red or reddish-brown in color, having hues that range from 5YR to 2.5YR. This reddish color presumably is derived from material from the upper Keweenawan sandstones and shales and the Huronian iron formation. It was picked up by the ice sheet in the Lake Superior region as it moved from the Patrician center into Wisconsin and Minnesota. This Cary-age drift from the northeast commonly is known as the Young Red Drift of Minnesota (44).

In the southern part of the area of Santiago soils, the glacial drift becomes so thin on ridgetops and other places that the land surface appears almost unglaciated. Farther north, in this same general area, however, the glacial till and glaciofluvial deposits are thick enough to control the topography and give character to the drainage.

Physiography and Drainage

Santiago soils are entirely within the Superior Upland physiographic division of the United States (18). They occupy morainic land forms that range from level or gently sloping-ground moraines to steep ridges and knolls. In the southern part of the area of Santiago soils, that part generally north of the Driftless Area, the till is thin and the relief is controlled by the underlying bedrock. Here, few marshes or ponds may be found. In the north area of the soils' occurrence, however, the loess-mantled glacial till is interspersed with kames, eskers and pitted outwash. The landform exhibits every gradation in relief between simple, smooth ridges with low gentle slopes to the most complex aggregation of knobs and ridges, spotted with enclosed kettles and pits. Many lakes, ponds and marshes occur in this area of thick glacial till.

The drainage pattern in the area of these soils is typical of thick, young drift having no great relief. Directions of stream flow have resulted mainly by chance. Except for their natural tendency to move generally in the direction of lower elevations, the streams have meandered or wandered broadly. There are numerous primary streams in the area of the youthful red till, but few tributaries. The reason for this is that subordinate feeder streams have not had enough time to develop. The interstream areas, normally traversed by tributary streams, are occupied by closed basins, kettles, and pits. Lakes in the area of the Santiago soils, especially in the northern section, are numbered in the hundreds and marshes are measured by the square mile.

Climate

The climate of the area occupied by Santiago soils is humid-continental, characterized by long, cold winters and short but warm and humid summers. As in other parts of the northern Mississippi Valley, extremes of temperature prevail; the summers are warm with abundant precipitation and winters are cold and relatively dry (27,50). The climate of the area is not influenced to any great extent by the Great Lakes but is affected appreciably by the general storms that move eastward along the Canadian border and north-eastward through the Mississippi Valley.

Santiago soils lie between the 40^{o} and 50^{o} F. average annual temperature lines and within the 28- and 32-inch average annual precipitation zones. July temperatures in this general area average 67^{o} to 71^{o} F., and January temperatures average 9^{o} to 10^{o} F. The period of greatest precipitation includes the months of April through September, during which time rainfall averages 20 inches. The average annual precipitation generally is adequate for good crop production.

Cold winters greatly influence soil temperatures as reflected in their greater than 40-inch average depth of frost penetration (35).

The average last killing frost in the spring and first killing frost in the fall are on May 10 and October 5, respectively, in the southern part of the soil area and on May 25 and September 25, respectively, in the northern part. This provides an average of 150 frost-free days in the southern part and 120 frost-free days in the northern part (34).

The annual average relative humidity (local noon, July) within the area of Santiago soils ranges from 50 in East-central Minnesota to 60 in Northwestern Wisconsin (34,35).

SECTION II

DESCRIPTION OF THE SANTIAGO SERIES

Short History of the Series

The Santiago Series was established in Mille Lacs County, Minnesota, in 1927. The earliest available description of the series, submitted with the Soil Survey Report for Mille Lacs County in 1927, describes the soil as having a 20- to 30-inch thickness of loess with part of its B horizon developed in the loess and part in the underlying glacial till. Again, in 1939, the series was similarly described in the Soil Survey Report for Kanabec County, Minnesota. In the following years, however, the concept was changed somewhat by Mark Baldwin and I.J. Nygard. Baldwin, in 1941, submitted an official description of the established series to which Nygard applied revisions in 1946 and 1952. As a result of their efforts, the concept of the Santiago Series was revised to include a wider range of loess depths (12 to 30 inches) in order to accommodate the range in sola thickness of soils in both East-central Minnesota and Northwestern Wisconsin (4,32).

Neither the Mille Lacs and Kanabec County Soil Survey Reports nor Baldwin's 1941 official series description emphasize any characteristic of the Santiago profile that would tend to disqualify it as a typical Gray-Brown Podzolic soil. Nygard's revised description does, however, show certain morphological characteristics of the profile that tend to alienate it from our modern concept of a typical Gray-Brown Podzolic soil. For instance, the presence of a thick A_2 and the occurrence of bleached silt rather than clay films on ped faces in the B horizon points to Aubert's (2) Sols lessivés (strongly leached Gray-Brown Podzolic soils) rather than Sols brun lessivés (central concept of Gray-Brown Podzolic soils). The 1958 Soil Survey Report for Barron County, Wisconsin describes several such exceptional features in the profile, indicating the Santiago soils to be Gray-Brown Podzolic soils intergrading to Gray-Wooded soils (38). This conclusion is based primarily on the presence of very thin A_1 horizons, thick, bleached A_2 horizons, and well-defined zones of degradation in the upper B. The modern, revised description of the Santiago series, submitted by the author from Barron County, Wisconsin, in 1961, reemphasizes these features, both in the profile description and in the range of characteristics. Otherwise, the previous basic concepts of the series as established by Baldwin and Nygard remain essentially unchanged.

Genesis and Morphology

Soils of the Santiago Series in northwestern Wisconsin and northeastern Minnesota occupy a transitional belt that is characterized by an intermingling of soils of several great soil groups. This transitional belt or "tension zone" is difficult to define precisely as to areal scope but appears to follow a rather broad linear pattern that extends northwesterly through Clark, St. Croix and Polk counties, Wisconsin, to a point midway along the Minnesota state line (10). The belt narrows somewhat at this point but continues in the same northwesterly direction across Minnesota (25).

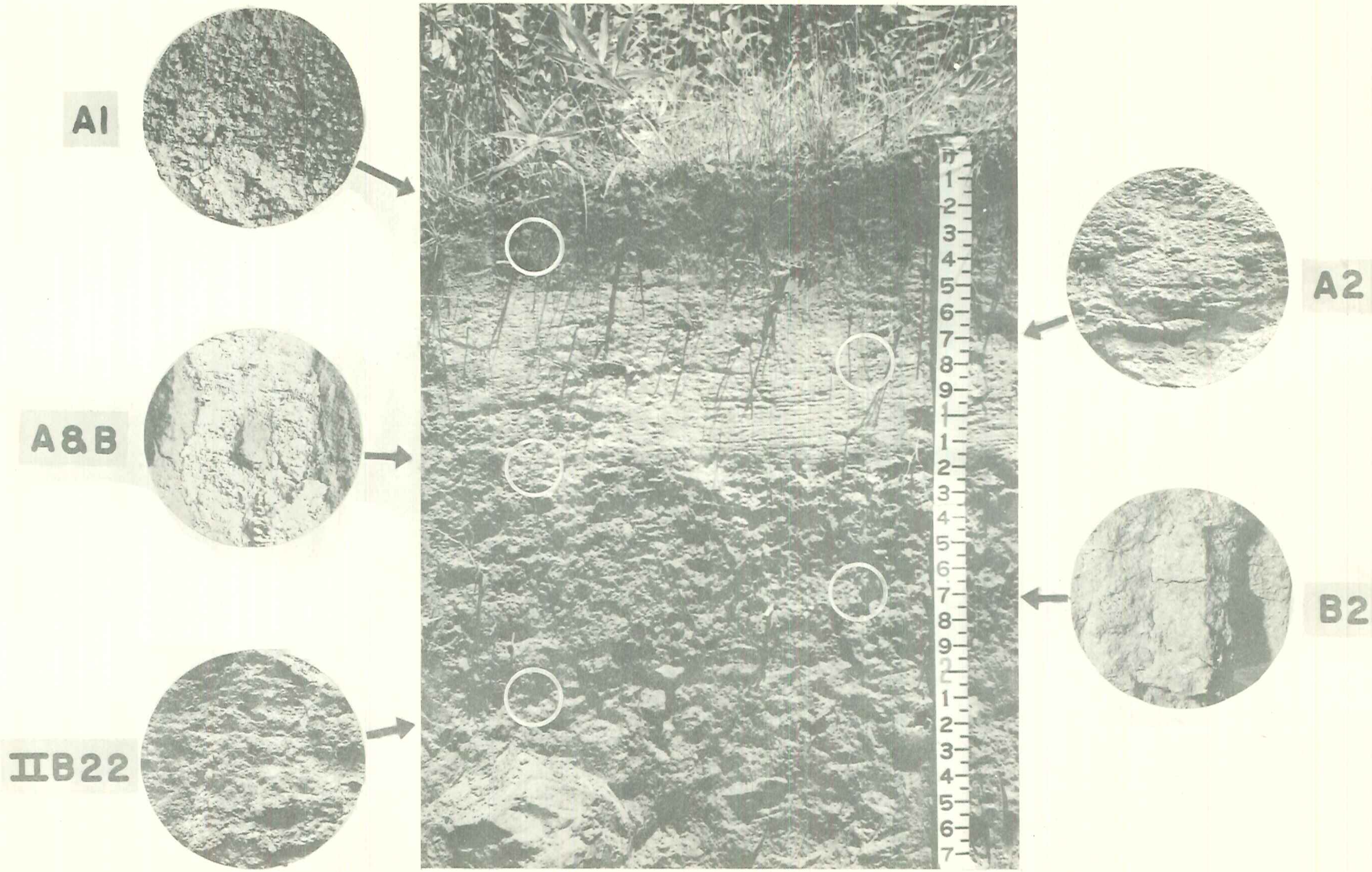

FIGURE 2. PROFILE OF SANTIAGO SILT LOAM

Soils in the northern part of this transitional belt consist, in large part, of Gray-Wooded soils (Eutroboralfs), strongly-leached Gray-Brown Podzolic soils (Glossoboralfs), Podzols (Normorthods) and Podzols that are intergrading to Gray-Brown Podzolics (Alfic Normothods). In the southern part of the belt, the soils consist dominantly of Gray-Brown Podzolics (Normudalfs), Brunizems (Hapludolls and Argiudolls) and Gray-Brown Podzolic soils that are intergrading to Brunizems (Mollic Normudalfs).

The complex pattern of these great soil groups and frequent overlapping of their soil forming processes are reflected in the intergrade soils of the area and the polygenic characteristics of their profiles. For example, Santiago soils in the southern part of this transitional zone are more nearly Gray-Brown Podzolics but vary from the central concept in evidences of destruction of the B horizon. These evidences consist of bleached silt on the ped faces and the beginning of bleached tongues of the A into the B horizons. These features classify the soil as Glossoboralfic Normudalfs in the 7th Approximation (1963).

As one moves north through the transitional zone, however, characteristics associated with increased leaching of the profile are noted. This is reflected in a more advanced destruction or degradation of the illuvial B horizon. These soils would be classified as Typic Glossoboralfs in the 7th Approximation (1963).

Such degradation is shown by an intermingling or tonguing of albic into argillic horizons. Appearance of these tongues in the Santiago sola is sufficiently unique, it is thought, to question the inclusion of these soils with the typical Gray-Brown Podzolic great soil group. Where leaching is sufficient, some Santiago soils display a B horizon in the upper part of the A_2 that is too thin or weakly expressed to constitute a spodic horizon.

To understand the genesis of Santiago soils, one must consider all of the five factors of soil formation that operate in the tension belt of Wisconsin and Minnesota. These include the influences and interrelationships of parent material, climate, vegetation, relief, and time.

Santiago soils are developed in two-storied parent materials consisting of moderately thin to moderately thick blankets of aeolian silt (loess) over loamy glacial till. They are influenced in their current development by the combined action of cool, humid to subhumid climate and mixed deciduous and coniferous forests. These factors of parent material, climate and vegetation are further conditioned by undulating to rolling, convex relief. The magnitude of the combined influence of these four factors is, of course, a function of time, thought to be approximately 11,000 years.

Santiago soils, however, are not a product solely of the present environment. Their sola display polygenic characteristics that imply both biotic and climatic changes since soil formation time zero--set roughly at 9,000 B.C. when rapid deglaciation began.

Climatic changes for the Santiago soil area in Wisconsin and Minnesota, inferred from forest history studies conducted by Cleónique (11), Curtis (15), Zumberge and Potzger (37,51), indicate that a cool to cold, moist climate prevailed during the period of first post-glacial tree growth, approximately 11,000 years ago. At this time frost-free periods undoubtedly were short. Available moisture apparently was abundant during growing seasons and snow was deep during the winter.

This cold period lasted about 2,000 years and was followed by a warming climate until about 3500 to 4000 years ago when the climate was warmest and driest since the retreat of the ice sheet. Shifts in vegetative types that took place in Wisconsin during this warming period can be attributed to a northward lateral shift of the continental climate to a region 40 to 60 miles north of its present limits (15). The general location and width of this northward climatic shift closely approximates the present boundaries of the soil tension belt in Wisconsin.

The warming era was, in turn, followed by cooling of the climate that has prevailed to the present time (44).

The warm climate in the post-glacial period and its adapted forest growth may account for the generally Gray-Brown Podzolic features in the medium textured Santiago soils of northern Wisconsin. The following era of cool climate and increased rainfall that began about 4,000 years ago may explain the changing of profile features in the otherwise typical Gray-Brown Podzolic soils. Increased leaching of the profile under the higher rainfall most likely explains the partial destruction of argillic horizons in these soils and occasional development in their upper profiles of incipient Podzol sequa.

The genesis and resultant morphology of Santiago soils are expressed generally in prominent horizons within the solum. These horizons consist of a thin, dark-colored surface layer (A_1 horizon) overlying a leached, light-colored platy A_2 horizon that often intermingles with or tongues into an underlying blocky B horizon of clay and sesquioxide accumulation.

Differentiation of these horizons is the result of (1) accumulation of organic matter in the surface layer, (2) leaching of carbonates and exchangeable bases from the solum, (3) movement of silicate clays and associated sesquioxides from the A horizon and their accumulation in the B horizon, (4) partial destruction or degradation of the upper part of the illuvial B, (5) occasional incipient Podzol development in the upper albic horizon and (6) weak fragipan development.

Organic matter has accumulated in the uppermost mineral layer of all but a few uncultivated Santiago soils to form a thin A_1 horizon. In places, this horizon may be so thin as to be virtually absent. Much of the organic matter present is in the form of humus. However, above the mineral soil on virgin sites, fresh or partially decomposed leaf litter occurs. Organic acids produced in the decomposition of this litter very likely contribute to the reduction and solubility of iron and aluminum and to subsequent acid leaching of the profile.

Organic matter in and on the surface of virgin sites of Santiago soil is derived in large part from original stands of hardwoods, including sugar maple (Acer saccharum), basswood (Tilia americana), yellow birch (Betula lutea), paper birch (Betula papyrifera), ironwood (Ostrya virginiana), northern red oak (Quercus borealis), white ash (Fraxinus americana), quaking aspen (Populus tremuloides), big toothed aspen (Populus grandidentata) and American elm (Ulmus americana), as well as some hemlock (Tsuga) and white pine (Pinus strombus).

Obviously, the kind of vegetation determines the nature of the organic humus in Santiago soils and, thereby, played an important role in their development. However, the precise role of the present tree cover and resultant leaf litter remains obscure. We cannot say with any degree of certainty that the Santiago profile as herein described is determined in large part by present differences in specific litter. More correctly, we may state that the influence of plants and plant remains on Santiago profiles is the cumulative effect of varying ecological conditions over many centuries. As pointed out by Mackney (31), "Studies of soils relative to the present vegetation may not decisively demonstrate the affects of vegetation on soil formation. Both past and present ecological conditions combine with other factors to determine the degree of solum development".

Leaching of carbonates and salts apparently has occurred to greater or lesser extent in all Santiago soils. It is thought that decomposition of the organic matter produced organic acids that have contributed to an acid leaching of the profile. The results apparently have been lowered base status and formation of acid sola. Consequently, base saturation in these soils is less, frequently much less, than 60 percent in some part of the B_2.

The range in base saturation, often rather wide among soils in a relatively small area, may be attributed partly to ecological differences but also to differences in microclimate. For instance, interception of rainfall by the woodland canopy may result in an uneven distribution so that patches of more or less leached soils may occur. Indirectly, leaching also permits translocation of silicate clay minerals, organic matter and sesquioxides from eluvial horizons (A_2) to related illuvial horizons (B).

An important initial step in the development of Santiago soils probably involves reaction that results in the movement and subsequent accumulation in the sola of clay, sesquioxides and organic matter. Though not fully understood, the process involves the fractionation of the mineral species and the mechanical movement and/or movement in chemically altered form of clay minerals from the zone of eluviation. The result is a substantial loss in clay and other material from the A_2 horizon. Continued eluviation leads to a concentration in the A_2 of bleached quartz and other resistant minerals in silt- and sand-size particles. The bleached color of the A_2 is determined primarily by the color of the mineral separates that remain after clay and organic matter have been removed. The translocated materials that are carried into the B horizon contribute to an illuvial concentration in the B of silicate clay, iron, aluminum and humus, generally in combination. This illuvial B, including the portion developed in the loess as well as that in the till, possesses more total clay and possibly more fine clay than the A_2 horizons above or the C horizon below.

Clay films occur only occasionally on the surfaces of blocky structural peds in the B horizon of these soils. Where they occur, the films are thin, patchy layers on ped faces, with the long axes of the clay particles lying parallel to the surface on which they are deposited. This translocated clay, in areas of maximum accumulation, tends to enter the natural cracks of the soil and extend into crevasses and openings left by plant roots, worms, and insects.

There is evidence in most Santiago soils that horizons of silicate clay accumulation were formed and, later, partly destroyed. This condition becomes more prominent in Santiago profiles as one moves from south to north. In its initial phase, degradation or destruction of the B horizon strips the clay films from the primary ped faces in the upper B, leaving bleached silt or sand coatings. Water, moving along vertical and to a lesser extent horizontal cleavage planes, flushes the altered or unaltered clay from the ped faces, leaving behind skeletal frameworks of bleached silt and sand.

An explanation that the light-colored coats in Santiago profiles are infiltrations of bleached silt and sand from the A_2 horizon above is not in agreement with field investigations conducted by the writer (8,9,10). Coats and tongues of bleached silt that extend along vertical structural cleavage plans in the loess mantle have been observed to change abruptly to bleached sand at the loess-till boundary. This supports the concept of "in place" formation rather than transportation and accumulation of the bleached grains.

The apparent degradation is not complete in many of these soils. This is suggested by the presence of oriented clays within and on the surfaces of structural peds that still persist in the illuvial horizon beyond the elutriated and bleached surfaces of major cleavage planes. Along vertical cleavage faces, the soil exhibits a more advanced phase of apparent degradation. Clay films and matrical clay are removed, leaving behind thickening coats of bleached silt and sand. Such B-horizon destruction results ultimately in an intermingling or interfingering of A_2 and B horizons. Often, the degradation is manifest in a display of tongues of bleached silt and sand 5 to 15 millimeters or more in thickness. These tongues extend deeply into or, in rare instances, completely through the B (8). Isolated remnants of B material often are observed in the lower part of the albic or A_2 horizon. An advance in degradation ordinarily is accompanied by a thickening of the A_2 horizon until, in some instances, the B_2 horizon in the loessial material virtually disappears. See Figure 3.

In other Santiago soils, usually those located in the northern part of the area where temperature and rainfall favor intense leaching of the profile and development of mor (raw) humus, a thin Podzol sequum may be observed in the surface few inches. Genesis of this Podzol sequum is characterized by rather high physical, chemical, and biological activities (21). Generally, however, this incipient Podzol sequum is too thin and too close to the surface to be diagnostic as series differentia. Where sufficiently thick and strongly expressed, the Podzol sequum identifies the bisequa *Lafont series (Figure 3)which is a Podzol soil intergrading to Gray-Brown Podzolic (9,10).

A Santiago soil that possesses slight Podzol influence in its solum may be identified largely by the presence of weak chroma in the upper few inches of the A_2 horizon. The chroma fades away, however, toward the middle of that horizon. In this minimal stage of Podzol development, a portion of the bleached A_2 may remain between the Podzol B and the argillic horizon. Under continued Podzol influence this strongly-leached Gray-Brown Podzolic profile may become typically Podzol. Stobbe and Wright (42,43) point to similar progressive stages in the degradation of Gray-Brown Podzolic soils in Canada. As soils intergrade toward the Podzol great soil group, they found that the A_1 became thinner, the fine-textured B_2 horizon weathered away and the podzol B and its associated A_2 became more strongly developed. They observed, also, that when the heavy B_2 weathered sufficiently so that it lost its important role in the moisture regime of the soil, the soil became a Podzol.

The genetic theory advanced by Frei and Cline (12,20) is that the upper Podzol B is formed in the strongly leached eluvial horizon of an earlier Gray-Brown Podzolic solum. This would imply a chronosequence from Gray-Brown Podzolic to Podzol profiles, as the percentage of siliceous material increases and the base status decreases in the A horizon. Though agreeing with this theory, the author joins with Gardner and Whiteside (21) in suggesting the further possibility that two kinds of B horizons may be developing simultaneously on the climatic border between Podzol and Gray-Brown Podzolic soils.

RELATIVE POSITIONS OF PEDOGENIC HORIZONS IN THE SANTIAGO AND THE RELATED BISEQUA LAFONT SOILS

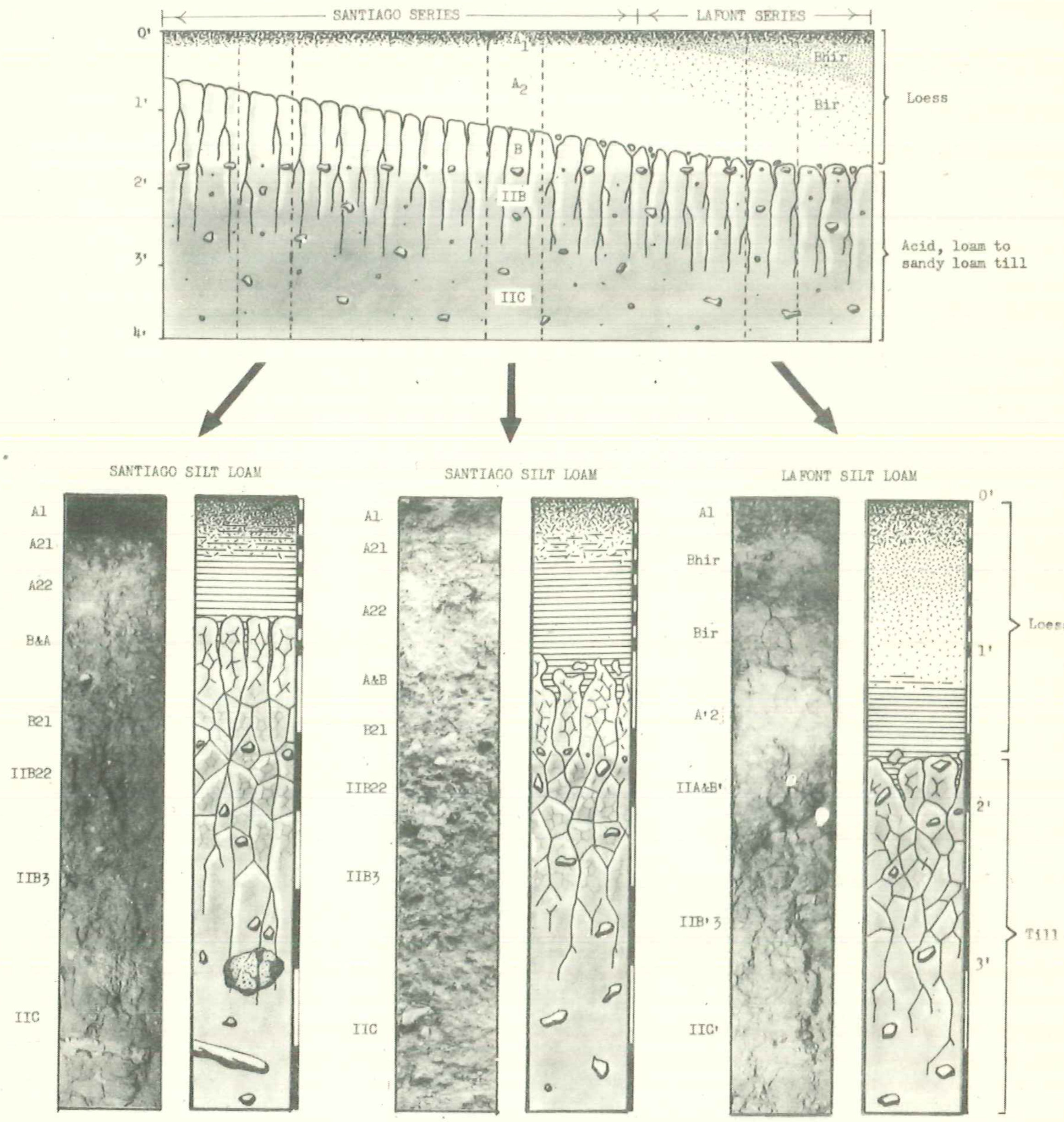

Figure 3.

Within the broad group of soils regarded as Gray-Brown Podzolic in the United States, Aubert (2) distinguishes several soils in the order of their podzolic evolution. Santiago soils are categorized within this grouping. From the least to the most strongly leached, Aubert's grouping includes Sols bruns légèrement lessivés, Sols bruns lessivés, Sols lessivés, Sols podzolisés and Sols podzoliques. Sols bruns lessivés are the central concept of Gray-Brown Podzolic soils. Sols lessivés, of which Santiago soils are a member, are strongly leached Gray-Brown Podzolic soils. According to Aubert, they have a moder (raw) humus, a strongly leached A_2 and evidence of B horizon destruction. The most leached members of the series, called "Sols Podzoliques," might apply to the *Lafont soils. These soils are closely related to the Santiago but display a Podzol upper sequum.

Often, Santiago soils with or without thin podzol sequa occur side by side with sandier soils identified as monosequum Podzols. A possible explanation is offered by Duchaufour (16), Scheys, et. al. (40). They state that soils with characteristic Sols lessivés features (such as those evident in the Santiago series) appear to have entered the youthful phase in development toward Podzols. Unlike coarser textured soils, they resist Podzol development, possibly through the influence of higher percentages of colloidal particles in their profiles. Eventual illuviation of these colloids and consequent impoverishment of bases develops in the Santiago profile a strongly mor humus. And this mor humus, as suggested earlier, assists in modifying profile features to favor eventual Podzol development.

Santiago soils often are observed to have weak to firm fragipan development in the acid, loamy glacial till underlying the B horizon and, less frequently, extending upward into that portion of the illuvial B developed in till. The same may be said for Santiago soils that display incipient spodic horizons. These soils may exhibit fragipan development in the underlying till, in the lower part of the illuvial B or even in the eluvial horizon that separates the two B horizons. Consequently, the formation of fragipan cannot be ascribed solely to Gray-Brown Podzolic or to Podzol influence, nor can it be associated with any particular horizon.

The fragipan, where developed in Santiago soils, is formed roughly parallel to the soil surface at depths of 16 to 30 inches. The pan, though itself a horizon, may underlay or be superimposed over a variety of other horizons.

The genesis of the fragipan in Santiago soils is not clearly understood. By some, its presence is attributed to the weight of glaciers, by others to the influence of permafrost or to other events in the Pleistocene.

Description

The Santiago series comprises well drained Gray-Brown Podzolic soils with B horizons developed partly in loess and partly in underlying acid, reddish-colored, loamy or sandy glacial till. Profiles of Santiago soils are characterized by intermingling of A_2 and B_2 horizons or by the penetration of A_2 horizons into B_2 horizons as tongues or thick coatings on ped surfaces. The morphology of these soils suggests degradation or partial destruction of the upper B horizons. The Santiago soils are the well drained member of a drainage sequence which includes the moderately well drained Freeon series and the somewhat poorly (imperfectly) drained Freer series. Santiago soils also have some characteristics in common with the Milaca, Otterholt, *Lafont, and Granton series. Otterholt soils have solol developed entirely in loess, and Milaca profiles have developed almost entirely in glacial till and so lack the silty upper horizons of Santiago soils. *Lafont soils have developed in parent material similar to that of Santiago soils but differ in having Podzol horizons as an upper sequum. Granton soils have developed in thinly loess-mantled clay loam till and differ from Santiago soils in having moderately fine textured B_2 horizons. Santiago soils are relatively extensive and important to agriculture.

<u>Soil Profile:</u> Santiago silt loam

A_1	0 - 3"	Very dark brown (10YR 2/2) silt loam; moderate fine granular and angular blocky structure; friable; slightly acid; clear smooth boundary. 1 to 4 inches thick.
A_{21}	3 - 8"	Brown (10YR5/3) silt loam marginal to silt; weak very thin platy structure; very friable; medium acid; clear smooth boundary. 3 to 5 inches thick.
A_{22}	8 - 11"	Dark grayish-brown (10YR4/2) silt loam marginal to silt; moderate thin platy structure; very friable; medium acid; clear irregular boundary. 3 to 6 inches thick.
A&B	11 - 17"	Dark grayish-brown (10YR4/2) tongues of silt loam marginal to silt with moderate medium platy structure, interfingered with dark brown (10YR4/3) silt loam with moderate medium subangular blocky structure; vesicular; friable to very friable; thin bands of strong brown (7.5YR5/6) silt loam border the dark grayish-brown silty tongues; medium acid; clear smooth boundary. 2 to 6 inches thick.
B_{21}	17 - 21"	Dark brown (7.5YR4/4) heavy silt loam; weak medium prismatic structure parting when disturbed to moderate medium subangular blocks; firm; thick coats of dark grayish brown (10YR4/2) on blocky ped faces in upper part; strongly acid; clear smooth boundary. 2 to 6 inches thick.
II B_{22}	21 - 27"	Reddish-brown (5YR3/4) heavy loam; weak coarse prismatic structure parting when disturbed to moderate medium subangular blocks; firm; strongly acid; gradual smooth boundary. 3 to 6 inches thick.

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II B_3	27 - 32"	Reddish-brown (5YR3/4) loam; weak coarse subangular blocky structure; firm to friable; medium acid; clear smooth boundary. 3 to 7 inches thick.
II C	32 - 48"	Reddish-brown (5YR4/4) loam; weak coarse platy structure, nearly massive; firm to friable; slightly acid; glacial till. Many feet thick.

Range in Characteristics: Thickness of the loess mantle ranges from about 1 to 2½ feet, but some portions of the B horizons are formed in the underlying till in all profiles. Available data indicate that base saturation of the B horizons is commonly less than 60 percent and may range as low as 40 percent. Consistence may be slightly hard or hard in B3 and upper C horizons, suggesting an incipient fragipan. Cobbles and stones may occur at the surface or throughout the profiles. The soils vary somewhat from north to south in the characteristics thought to indicate degrees of degradation of B horizons. In the northerly areas, the soils commonly have intermingled A&B horizons, or thick A2 horizons penetrating the B_2 horizons in tongues and thick coatings which partially or wholly surround the upward extensions or isolated remnants of B horizon material. Some profiles in the northern areas have brownish colors in the upper A_2 horizons, suggesting a very weak expression of the B horizons of a Podzol sequum. These incipient horizons are too thin and too easily destroyed by cultivation to be diagnostic for the series. In more southerly areas, Santiago profiles may have somewhat thinner A2 horizons and the intermingled A&B horizons are less evident. In the upper B horizons, clay films commonly are absent, or nearly so, and the silty A_2 horizon materials occur as relatively thin coatings on ped surfaces. Tonguing of A_2 horizons downward may also be less pronounced than in profiles farther north. The underlying till in which lower B horizons are developed is commonly loam or sandy loam, but may range to light sandy clay loam in some areas. The till ranges in color from hues of 5YR to 2.5YR. Colors given are for moist conditions unless otherwise stated.

Topography: Undulating to gently rolling upland.

Drainage and Permeability: Well drained; runoff is medium to rapid; internal drainage is medium; permeability is moderate.

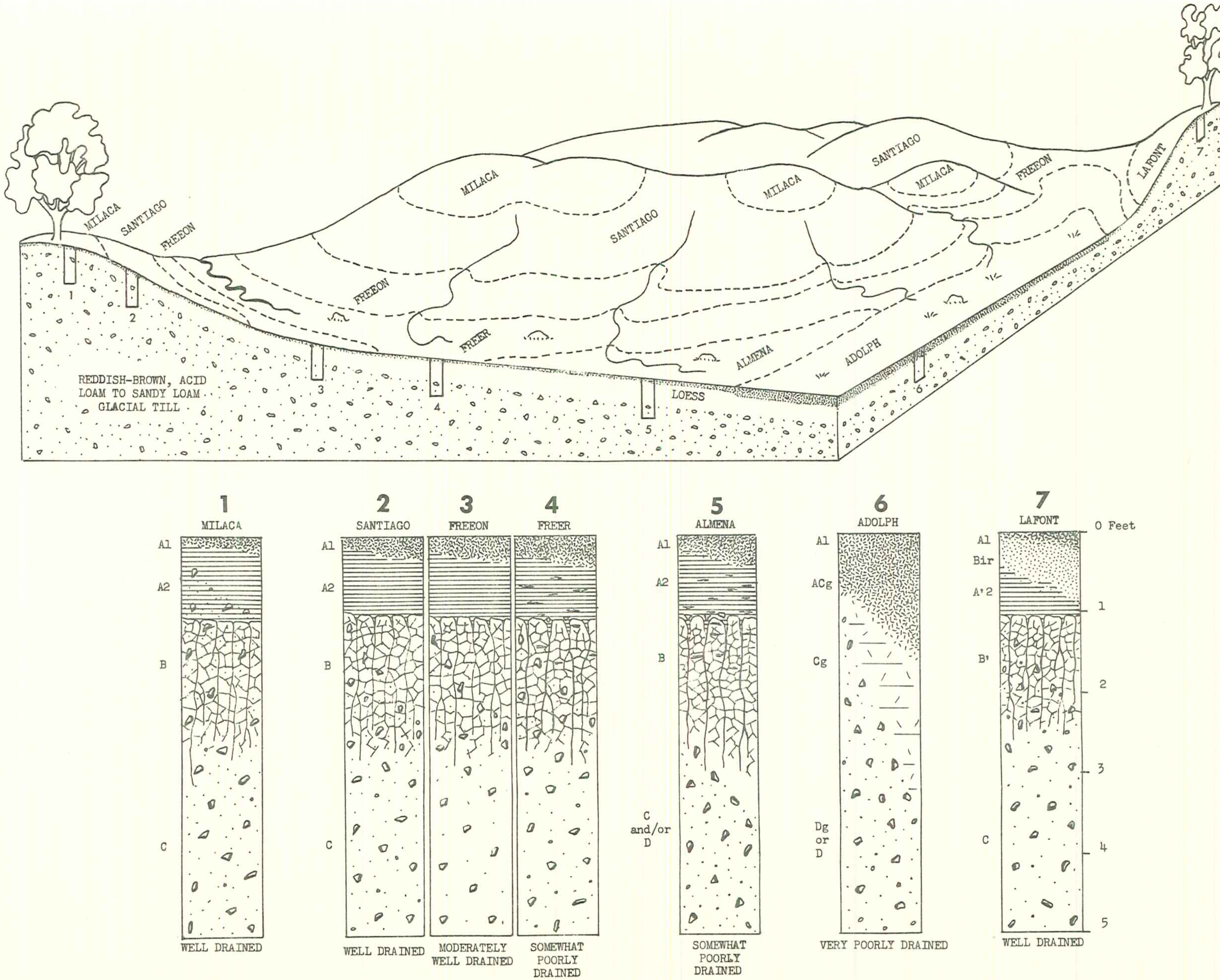
Vegetation: Original stand consisted of hardwoods, including sugar maple, basswood, iron wood, red oak, ash, elm and poplar trees, with some white pine.

Use: Most of this soil has been cleared for cropland.

Distribution: Northwestern Wisconsin and east-central Minnesota.

Type Location: Barron County, Wisconsin, SW¼, NW¼, Section 36, T33N, R14W, Turtle Lake Township.

Series Established: Mille Lacs County, Minnesota, 1927.



A TYPICAL LANDSCAPE SHOWING RELATIONSHIP OF SANTIAGO TO SOME ASSOCIATED SOILS

Figure 4.

SECTION III

MAPPING UNITS OF SANTIAGO SOILS
Silt Loam and Stony Silt Loam Types

Santiago silt loam, 0 to 2 percent slopes

This soil occupies nearly level areas on gently undulating to rolling ground moraine.

It is similar in profile characteristics to the one described as representative of the series. There is only slight or no apparent erosion, and the soil has most of its original surface layer remaining. There is good drainage, but drainage is not excessive. Since much of the rainfall is absorbed, there is little runoff and no serious erosion hazard.

In a few areas this unit includes small areas of Freeon or Otterholt silt loam soils that are too small to map separately. Internal drainage of the Freeon inclusions is only moderate, and the subsoil is faintly mottled red or yellow at depths between 18 and 36 inches. Where loess depths exceed 30 inches, Otterholt soils occupy parts of the unit.

Minnesota has mapped no Santiago soils on 0 to 2 percent slopes because mottling usually is found in the lower B on this gradient. The soil is identified as belonging to the Freeon series.

This is a productive soil that has no serious limitations for intensive row cropping. Corn, oats, hay and pasture are major crops. Yields are higher than on other soils of the Santiago series. Capability unit I-1.

Santiago silt loam, 2 to 6 percent slopes

This soil generally occupies mild slopes on the gently undulating to rolling relief of the glacial uplands.

The profile of this soil is similar to the one described as representative except that it generally has a slightly thinner loess mantle and reduced solum thickness where slopes approach 6 percent. Though erosion is negligible, the hazard of erosion is greater than on 0 to 2 percent slopes.

This mapping unit includes small areas of moderately well drained Freeon silt loam that are too small to map separately.

This is the most extensive of the Santiago soils. Nearly all of it has been cleared and is now under cultivation. Crops grown are similar to but yield expectancy is slightly less than that of the less sloping units. Though highly productive, care is needed to prevent losses of soil through erosion. Capability unit IIe1.

Santiago silt loam, 2 to 6 percent slopes, moderately eroded

This soil generally occupies the steeper part of the 2 to 6 percent slope range on the gently undulating to rolling glacial relief.

It differs from the profile described as representative in having a lighter colored and thinner surface layer with lower organic matter content. Between one-third and two-thirds of the surface soil has been lost through erosion. In a few spots, the original surface layer has been mixed with the subsoil through tillage. Although most areas have 8 to 10 inches of the original surface layer remaining, a few units may show occasional spots of exposed brown and dark brown heavy silt loam subsoil.

Continued use of this soil for clean tilled crops has permitted loss of the surface soil. This has served to reduce organic matter content and, subsequently, fertility and to lower available moisture supply.

Nearly all of this soil has been cleared and planted to corn, oats, barley, hay or other climatically adapted crops. Yields are slightly lower than on the less eroded soil, and there is a greater need for practices to control erosion. If erosion control is employed, along with other good management practices, the soil may be cropped rather intensively and will remain highly productive. Capability unit IIe1.

Santiago silt loam, 6 to 12 percent slopes

This soil commonly occupies the sloping sides of gently undulating to rolling moraines in the glacial uplands. It is an extensive soil in the Santiago series, ranking second in area only to the gently sloping units.

The surface layer as well as the entire solum of this soil are somewhat thinner than those of the nearly level representative profile or its gently sloping associates. Less than one-third of the original surface layer has been lost through erosion.

Included in this mapping unit are small areas of Milaca soil, as well as small areas of Santiago soils displaying very weak podzol influence. This Podzol influence is most common in Santiago soils in the northern part of the area of their occurrence.

Though active erosion is negligible, medium surface runoff contributes to a moderate erosion hazard.

Although this soil is adapted to the same crops as the less sloping Santiago soils, it is too steep for intensive cultivation. Crop yields usually are lower, the soil is more difficult to work and manage, and greater care is necessary to control erosion. Capability unit IIIe1.

Santiago silt loam, 6 to 12 percent slopes, moderately eroded

This soil commonly occupies moderately long side slopes on gently undulating to rolling moraines in the glacial uplands.

From one-third to two-thirds of its original surface layer has been lost through erosion. As a result of the erosion, the surface layer is lighter colored and contains less organic matter than that of the representative Santiago profile. In a few spots, the brown or dark brown subsoil is exposed. Solum thickness, too, is less than that of the representative profile.

Occasional spots of Milaca soils having less than 12 inches of loess over glacial till are included because they are too small to separate on the map.

Continued row cropping of this soil has resulted in a substantial loss of surface soil and a subsequent reduction in organic matter, fertility, available moisture supply and absorptive surface. Much of the rainfall is lost through surface runoff, and unprotected areas now cropped are being damaged further by erosion. Erosion hazard remains high. Close-growing crops are maintained as much of the time as possible to conserve the soil. In general, the soil is too steep for intensive cultivation. When erosion is controlled, however, occasional row crops may be grown. Capability unit IIIe1.

Santiago silt loam, 6 to 12 percent slopes, severely eroded

This soil occupies moderately long side slopes on gently undulating to rolling moraines in the glacial uplands. It is severely eroded primarily because of its intensive use for row cropping.

More than two-thirds of the original surface layer of this soil has been removed through water erosion, and, in many places, part of the subsoil is gone. The present plow layer, a mixture of the original surface soil and subsoil, has a lighter color than uneroded units. Patches of dark brown and brown subsoil are exposed in more than two-thirds of the area.

Occasional spots of exposed till, the eroded remnant of Milaca soils are included because they are too small to separate on the map.

The capacity to absorb surface water is seriously reduced in this soil, contributing to further erosion through surface runoff. Its organic matter content and original nutrient supply are virtually depleted. Small stones and gravel lie on the surface.

If this soil is to be cropped, it will need to be limed, fertilized and erosion controlled. It is better suited for the production of small grains, hay or pasture. Capability unit IVe1.

Santiago silt loam, 12 to 20 percent slopes

This soil most often occupies moderately steep slopes on rolling ground moraines and on hilly, terminal or recessional moraines, steep ridges and knolls.

Less than one-third of the surface layer of this soil has been lost through erosion. It has a somewhat lighter-colored and thinner surface layer and a generally thinner solum than that of the representative profile.

Some spots of Milaca soils are included because they are too small to separate on the map. Weak Podzol influence is observed in the surface layer of some areas of this soil but most often are too small and too weakly expressed for individual recognition.

Most of this soil is covered by timber or is used for pasture. Because it is moderately steep, it is severely limited in its use for crops. If it is used for crops, intensive management practices are needed to control erosion. Moderate to good yields may be expected if fertility is kept at a high level and other good management is applied. Capability unit IVe1.

Santiago silt loam, 12 to 20 percent slopes, moderately eroded

This soil occupies moderately steep slopes on rolling ground moraine and on hilly terminal or recessional moraines, steep ridges and knolls.

This soil has lost one-third to two-thirds of its original surface layer as a result of water erosion. The present surface layer is thinner, lighter colored and contains less organic matter than that of the representative Santiago profile. In a few small areas, brown or dark brown heavy silt loam subsoil is exposed.

Some spots of Milaca soils are included because they were too small to separate on the map.

The loss of surface soil has reduced the supply of organic matter, lowered fertility and impeded water infiltration. Runoff is very rapid; consequently, the soil is subject to accelerated erosion if cultivated.

Only a small part of this soil is used for grain and hay crops. The cropping systems best suited to it are ones in which corn and small grains are grown to only a limited extent. Steeper soils included in mapping are best suited to permanent pasture or forests. Capability unit IVe1.

Santiago silt loam, 12 to 20 percent slopes, severely eroded

This soil occupies moderately steep slopes on rolling ground moraine and on hilly terminal or recessional moraines, steep ridges and knolls.

These moderately steep soils are dominantly eroded woodland pastures that have been overgrazed or cultivated fields that have not been protected properly against runoff of surface waters.

This soil has lost most of its original surface layer and, in places, part of its subsoil. Dark brown or brown subsoil is exposed in more than two-thirds of the unit. The present plow layer is low in organic matter, plant nutrients and absorptive capacity.

Occasional spots of exposed till, the eroded remnant of Milaca soils are included because they are too small to separate on the map.

This moderately steep soil is subject to continued erosion if planted to row crops. It is best adapted to forage crops or trees. Capability unit VIe1.

Santiago silt loam, 20 to 30 percent slopes

This soil occupies steep slopes along draws and hillsides in the area of rolling glacial moraines.

There is only slight or no apparent erosion. It has thinner surface and subsoil layers than less sloping Santiago soils. Its stronger slopes and low organic matter content contribute to rapid runoff of surface water and to a subsequent drouthy profile. The soil has a severe erosion hazard.

This unit includes small areas of Milaca and *Lafont silt loams that are too small to map separately.

This soil is difficult to manage and cultivate because of its steep slopes. It can be used, however, for pastures of alfalfa-bromegrass or bluegrass, but the pasture should not be overgrazed. Moderate to good yields of forage may be expected where the fertility is maintained at a high level. Capability unit VIe1.

Santiago silt loam, 20 to 30 percent slopes, moderately eroded

This soil occupies steep slopes along draws and hillsides in the area of rolling glacial moraines.

Between one-third and two-thirds of the original surface layer of this soil has been removed through erosion. In a few places plowing has mixed part of the brown or dark brown subsoil with the surface soil. This soil has a thinner surface layer and subsoil than less sloping units. Its low organic matter content, loss of spongy surface structure and steep slopes makes this unit especially susceptible to drouthiness and erosion.

This soil includes small areas of exposed till, the eroded remnant of Milaca soils.

If the areas can be fertilized and otherwise renovated, moderate yields of hay and pasture can be obtained. The soil needs to be kept under a good cover of vegetation. For best yields and to control further erosion, pastures and woodlands must be managed carefully. Capability unit VIe1.

<u>Santiago silt loam, 20 to 30 percent slopes, severely eroded</u>

This soil occupies steep slopes along draws and hillsides in the area of rolling glacial moraines.

This soil has lost nearly all of its surface layer and in some places, part of its subsoil through erosion. Its depleted organic matter content, exposure of less permeable subsoil and lack of vegetal cover make this soil especially susceptible to continued erosion.

Occasional spots of exposed till, the eroded remnant of Milaca soils, are included because they are too small to map separately.

To control further erosion, many cultivated areas of this soil have been taken out of cultivation. The soil is too steep for row crops. If adequate amounts of lime and fertilizer are applied and the soil seeded to legumes and grasses, fairly high yields of pasture are obtained. Under good management, fairly high yields of timber, also, are obtained. Capability unit VIIe1.

<u>Santiago stony silt loam, 6 to 12 percent slopes</u>

This soil occupies the sloping sides of undulating to rolling moraines in the glacial uplands.

There is only slight or no apparent erosion and the soil has most of its original surface layer remaining. The surface layer, as well as the entire solum of this soil, are somewhat thinner than those of the representative profile. It also has abundant cobbles and stones on the surface and throughout the profile.

Small areas of Milaca soils are included in mapping.

These soils have a moderately high level of natural fertility and moisture supplying capacity. Their stony surface, however, restricts their use to meadow, pasture, woodland or wildlife. Some areas that have been cleared of surface rocks give moderate to good pasture yields. The more sloping areas of this soil have a water erosion hazard if vegetative cover is removed. Capability unit VIs6.

<u>Santiago stony silt loam, 12 to 20 percent slopes</u>

This soil occupies the moderately steep sides of rolling to hilly moraines in the glacial uplands.

Less than one-third of the surface layer has been lost through erosion. It has a somewhat lighter-colored and thinner surface layer and a generally thinner solum than does the representative profile. It also has an abundance of cobbles and stones on the surface and throughout the profile.

Spots of Milaca and *Lafont stony soils, too small to delineate, are included in mapping.

The stony nature and severe water erosion hazard of this soil limits its use to forage production, woodland or wildlife. If surface stones are removed, this soil may be renovated one year out of five. Capability unit VIs6.

Santiago stony silt loam, 20 to 30 percent slopes

This soil occupies steep slopes along draws and hillsides in the area of rolling glacial moraines.

There is only slight or no apparent erosion, and the soil retains most of its original surface layer. It has a thinner surface and subsoil layer and a much higher percentage of cobbles and stones on the surface and throughout the profile than does the representative profile.

In a few places, spots of Milaca and *Lafont silt loams are included.

This soil has a very rapid surface runoff and a moderate erosion hazard when cleared. The stony nature, severe water erosion hazard and steep slopes limit its use to pasture, woodland and wildlife. It is seldom economically feasible to remove surface rocks for pasture improvement. Topdressing permanent pasture is practical for increasing production, but renovation generally is not practical. Capability unit VIIs6.

SECTION IV

MEASURED SOIL PROPERTIES

The physical and chemical properties of Santiago silt loam are given in this section. Although laboratory data are from sampling sites in Wisconsin, the State Soil Scientist and field soil scientists of the Soil Conservation Service in Minnesota concur in the results obtained and conclusions reached.

Soils from three sampling sites in northwestern Wisconsin were analyzed by the Soil Conservation Service Laboratory in Lincoln, Nebraska. Two sets of the data are from virgin sites in St. Croix County (22) (Samples S-60-Wis-55-2 and S-60-Wis-55-3) and one is from Barron County (17,38), the southern and generally northern parts, respectively, of the Santiago soil area in Wisconsin. Additional analyses on subsoil fertility were conducted by Beatty and Corey (3,4) on the above St. Croix County sites as well as on one site in each of Dunn and Chippewa counties, Wisconsin. Engineering properties of these soils were determined from three sampling sites, other than those mentioned above, in St. Croix and Dunn counties (6,7).

Mechanical Analysis

Results from the complete mechanical analysis of a typical Santiago silt loam profile (22) are listed by horizons in Table 2. Size distribution of soil particles throughout this, as well as other Santiago profiles (38), shows an accumulation of 2-micron and smaller clay particles in the soil's two-storied B horizon.

Table 2. Mechanical Analysis of a Representative Santiago Silt Loam (22).

Horizon	Depth in.	Very Coarse, Coarse and Medium Sand 2-.25mm. %	Fine and Very Fine Sand .25-.05mm. %	Silt [a] 2-50μ %	Int. III [b] 2-20μ %	Silts, re-calculated to a clay-free basis [c]	Clay <2μ %	Textural Class
A_1	0-2	17.4	17.1	56.7	25.2	62	8.3	Silt Loam
A_{21}	2-5	16.9	17.7	57.1	24.4	62	8.3	Silt Loam
A_{22}	5-9	16.4	17.5	56.6	24.0	63	9.5	Silt Loam
B & A	9-15	13.5	15.4	56.1	23.4	66	15.0	Silt Loam
B_{21}	15-19	16.2	17.5	46.8	18.8	58	19.5	Loam
II B_{22}	19-25	29.8	30.5	22.7	9.2	27	17.0	Fine Sandy Loam
II B_3	25-36	29.5	39.1	18.5	7.3	21	12.9	Fine Sandy Loam
II C_1	36-53	28.8	43.8	17.0	7.4	19	10.4	Fine Sandy Loam
II C_2	53-65	62.6	28.6	4.8	2.9	5	4.0	Coarse Sandy Loam

[a] According to United States Department of Agriculture scheme of classification of soil separates.

[b] According to International scheme of classification of soil separates.

[c] Using the formula $x = Y \frac{100}{z}$, where

x= percent of a separate in the total sand plus silt as 100.
y= percent of a separate on original data sheet.
z= percent of total silt and sand on original data sheet, which equals 100-clay.

The eluvial horizon of the sample profile (Table 2) is silt loam. However, the eluvial horizons of some Santiago soils have been subjected to such intense leaching and subsequent clay impoverishment that they have been reduced to a textural class consisting essentially of silt. This is most evident among the Santiago soils that exhibit a B horizon in their upper solum that is too thin or weakly expressed to constitute a spodic horizon. In these soils, tongues of bleached silt from the A2 horizon often extend deeply into the B horizon along strongly-developed vertical cleavage planes.

The highest content of clay in the sample profile is shown in Figure 5 to be accumulated in the B_2 horizon of the loess mantle, with somewhat smaller amounts being deposited in the B_2 horizon of the underlying till. The graph also shows that the clay increases to its maximum within a vertical distance of approximately 7 inches, easily falling within the 12-inch allowable range for a diagnostic argillic horizon (See Soil Classification: A Comprehensive System - 7th Approximation. SCS, USDA (47).

The weighted average percentage of clay in the upper B_2 of three soils observed is 18.7, ranging from a high of 23.3 percent in St. Croix County to a low of 17.9 in the northern-most Barron County site (38).

None of the B horizons that are developed in loess are finer textured than silt loam and none show an increase in clay over adjoining horizons of more than 5 percent. The upper B_2 horizon in each of the three profiles has a clay percentage slightly greater than that of the horizon above. However, the textural class remains the same.

That portion of the B_2 horizon formed in glacial till ranges in texture from loam to fine sandy loam. Clay accumulation in this horizon is somewhat higher than that in the underlying loam to sandy loam C horizon.

The portion of the B_2 horizon developed in the loess mantle of the sample profile (Table 2) has a silt content of approximately 47 percent and a coarse silt to fine silt ratio somewhat less than 1.5 to 1. This is in contrast to the 2 and 3 to 1 ratio observed in the B_2 horizon of deeper loessial soils (i.e. Seaton and some Otterholt soils) that lie in contiguous areas to the south (22).

Two-storied parent material is clearly evident in Santiago soils. The apparent lithologic discontinuity that is observed at 19 inches in the silt and sand values of the original data of Table 2 is further emphasized by a distinct change in the recalculated silt percentages.

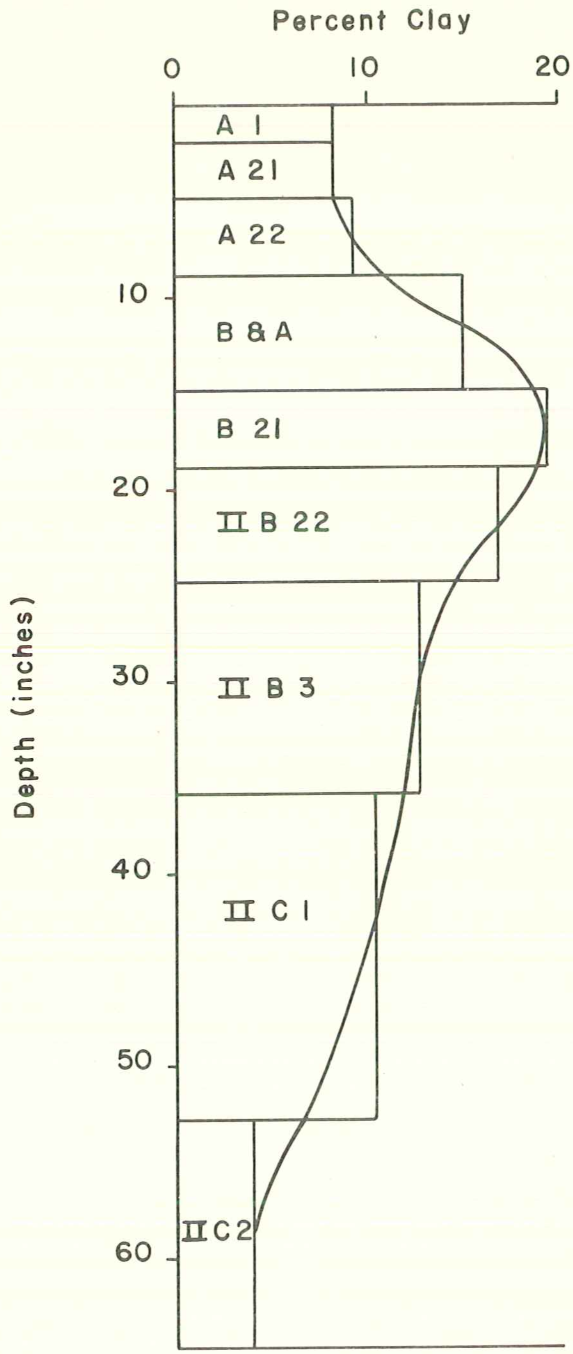


Figure 5. Clay distribution in depth within the profile of a representative Santiago silt loam (22).

Bulk Density

Bulk density values of soil horizons in a representative Santiago soil profile are given in Table 3. They are bulk densities at (1) field moisture--that is, at the moisture content of the soil at time of sampling, (2) field capacity, or at the moisture content as brought from air dryness to constant weight by adsorption against 30 cm water tension (which usually yields a moisture content near that at field capacity) and (3) oven dryness. All bulk density values are reported on the <2 mm soil separates.

Table 3. Bulk density values in a representative Santiago profile from St. Croix County, Wisconsin (22).

	Depth		Bulk Density at:									
			Field Moisture			30 cm tension			Oven Dryness			
Horizon	Inches	Texture	% Moisture	% b/ Total Pore Space	g/cc	% Moisture	% b/ Total Pore Space	g/cc	% Moisture	g/cc	lbs/cu. ft. a/	Percent Total Pore Space b/
A_{22}	5- 9	Sil	-	41	1.57	14.6	43	1.52	-	1.59	99.2	40
B & A	9-15	Sil	4.9	40	1.60	17.6	43	1.50	-	1.54	96.1	42
B_{21}	15-19	L	7.7	39	1.63	18.7	42	1.55	-	1.64	102.4	38
II B_{22}	19-25	Fsl	3.6	30	1.85	11.9	33	1.78	-	1.84	114.9	30
II B_3	25-36	Fsl	3.1	28	1.92	8.6	29	1.88	-	1.92	119.9	28

a/ Pounds per cubic foot = bulk density x 62.4 (wt. 1 cu. ft. water).

b/ Percent total pore space = $100 - \frac{\text{bulk density} \times 100}{2.65 \text{ (grain density)}}$

As expected, there is a tendency for bulk density of the Santiago soil to increase with depth. This is due, all or in part, to a lower content of organic matter, to less aggregation, to increased particle size and to increased compaction and corresponding decrease in pore space. This is especially true of the till portion of the soil profile that very likely has been subjected to great glacial pressures.

That oven dry bulk densities of the soil horizons are near maximum for the respective textures is shown by comparison with the 70 to 100 lbs/cu. ft. range assigned to most silty soils and with the 80 to 100 lbs/ cu. ft. range assigned to most sandy soils (51). The nearly 120 lbs/cu.ft. and 28 percent pore space exhibited by oven dry samples from the II B_3 horizon approaches the 125 lbs/cu. ft. and 25-30 percent pore space said by Lyon and Buckman to represent very compact subsoils (30).

Water-Holding Capacity

Data in Table 4 show that the water-holding capacity or percentage water retained in a representative Santiago (22) soil against 30 cm tension increases with increasing clay content. The range in data is from a minimum of 8.6 percent of water by weight of material less than 2mm in the IIB_3 to a maximum of 18.7 percent in the B_{21} horizon or horizon of maximum clay illuviation.

Table 4. Soil-water relations in a representative Santiago profile from St. Croix County, Wisconsin (22).

	Thickness	Clay Content	Moisture at wilting point (15 atm.)	Water-Holding Capacity (30 cm. tension)			Available Water		
Horizon	Inches	Percent	Percent	Per-cent	Inches per Inch	Inches per Horizon[a/]	Per-cent	Inches per Inch	Inches per Horizon[b/]
A_1	2	8.3	6.1	--	--	--	--	--	--
A_{21}	3	8.3	3.3	--	--	--	--	--	--
A_{22}	4	9.5	3.6	14.6	.22	.89	11.0	.17	.67
B & A	6	15.0	5.4	17.6	.26	1.58	12.2	.18	1.09
B_{21}	4	19.5	8.1	18.7	.29	1.16	10.6	.17	.66
II B_{22}	6	17.0	6.1	11.9	.21	1.27	5.8	.10	.62
II B_3	11	12.9	4.4	8.6	.16	1.78	4.2	.08	.87
II C	17	4.0	2.1	--	--	--	--	--	--

a/ Water-holding capacity (in inches) = percent water x bulk density x thickness (in inches).

b/ Available water (in inches) = $\frac{\text{Percent water (30 cm)} - \text{Percent water (15 atm.)}}{100}$ x bulk density x thickness of horizon (in inches).

The soil moisture at 30 cm tension (field capacity) minus the water held by that soil at 15 atmospheres tension, the latter value normally accepted as the permanent wilting point of plants, ranges from a low of 4.2 in the IIB_3 horizon to a high of 12.2 in the B&A. This water, assumed to be available for plant growth, is influenced largely by the organic matter, clay content (See figure 6 and Table 4) and soil compaction.

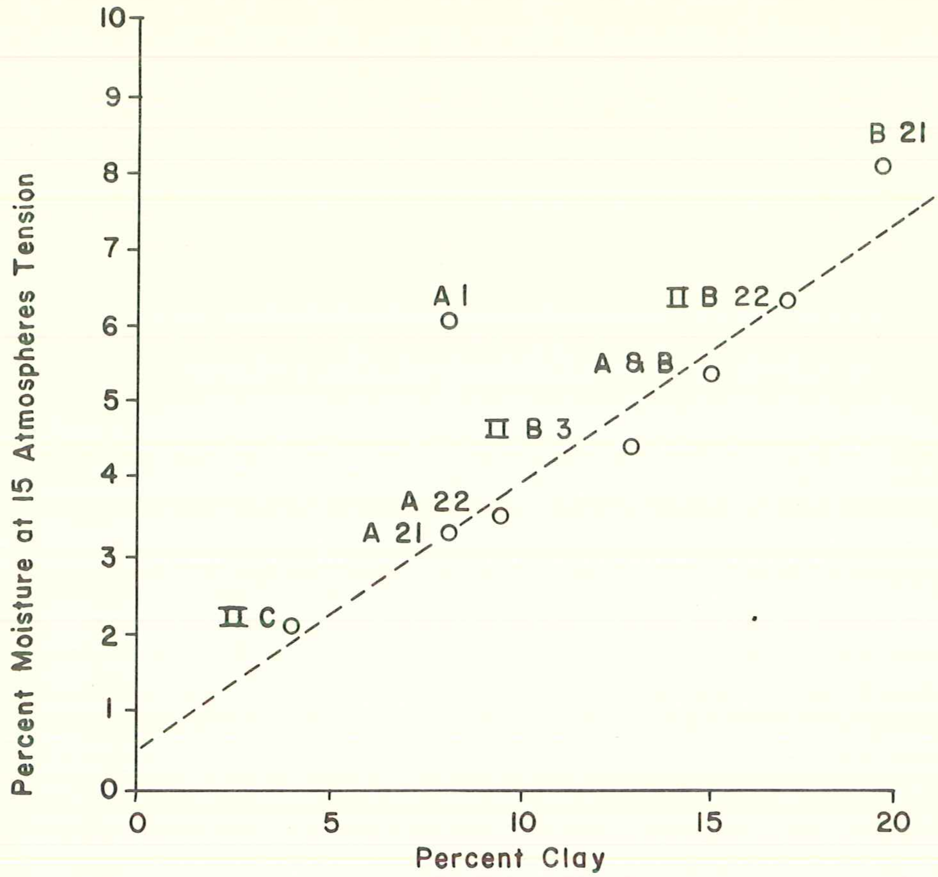


Figure 6. Percent moisture in a representative Santiago soil (22) at 15 Atmospheres in relation to percent clay. The specific data are indicated by labeled points.

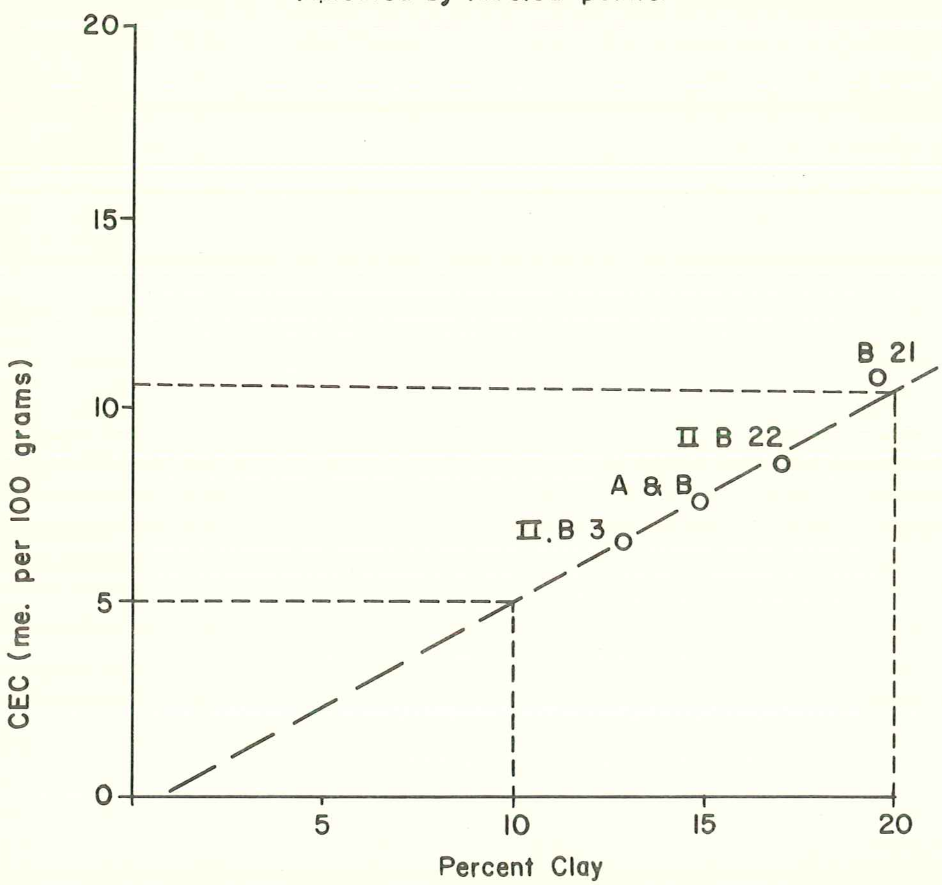


Figure 7. Cation exchange capacity (CEC) in relation to percentage of clay in the B horizons. The data for specific horizons are shown by labeled points.

The high compaction or relatively high bulk density values in this representative profile appear to be associated with smaller and fewer soil pores and, consequently, with a lower amount of water held and a slower rate of its movement in the soil.

When converted to inches of water per inch of soil material, the amount of available water ranges from a low of .08 inches in the II B_3 to a high of .18 inches in the B & A. It is estimated that the representative Santiago profile to a depth of 5 feet has a water holding capacity of approximately 11.00 inches and an available water content of 6.84 inches.

Maximum Density, Liquid and Plastic Limits, and Optimum Moisture

Maximum dry densities, optimum moisture, liquid limits and plastic limits are given in Table 5 for representative Santiago surface soil, subsoil and substratum samples. These data were obtained from engineering tests conducted by the Bureau of Public Roads (6,7) and show the range in the respective properties of Santiago soils. In these three representative profiles the mean maximum dry density of the A = 106, of B_2 = 124, and of C = 125. The mean optimum moisture of A = 16, B_2 = 11, and of C = 10. The liquid limit mean for the A = 27, B_2 = 24 and C = 23. Plastic limit mean for A = 6, B = 10, and C = 10.

Table 5. Data for representative Santiago silt loam surface, subsoil and substratum samples.

Horizon	Depth	Sample No.	Maximum Dry Density Lbs/ cu. ft.	Optimum Moisture	Liquid Limit	Plastic Limit
Ap (7)	0- 8	S-33998	99	20	32	8
B_2	20-25	S-34000	124	11	23	9
C	28-60	S-34001	129	9	18	5
Ap (8)	0- 7	S-34025	109	14	26	5
B_2	16-20	S-34026	122	11	26	11
C	23+	S-34027	122	11	26	13
Ap (8)	0- 8	S-34028	111	14	24	4
B_2	19-24	S-34029	126	10	23	10
C	37-50	S-34030	123	11	26	13

Reaction

Santiago soils apparently have followed the natural tendency of soils to become increasingly acid in humid climate and under forest cover. They have developed in an area of Wisconsin and Minnesota where rainfall has been sufficiently high to leach away much of the bases. This has resulted in an exchange capacity occupied dominantly with ions of hydrogen and in reactions that are medium to very strongly acid throughout the solum and, often, deep into the substratum.

Data from the three virgin profiles analyzed (22, 38) show medium to very strongly acid surface layers, very strongly acid subsoils and medium to strongly acid upper substrata. At depths of 70 to 100 inches, the reaction becomes slightly acid but at no time displays alkaline or even neutral reaction.

The amount of grade A limestone (89 to 95 percent $CaCO_3$) needed to raise the pH of a highly organic top 7-inch layer of Santiago silt loam from 4.5 to 6.5 within three years is approximately 9 tons per acre (49). Under cultivation and subsequent organic matter depletion, the same soils may require only 7 or 8 tons per acre.

Reactions of a typical virgin profile of Santiago silt loam (22) is given in Table 6.

Table 6. Soil reaction in a Santiago silt loam profile (22).

Horizon	Depth Inches	pH	Reaction
A_1	0- 2	5.2	Strongly acid
A_{21}	2- 5	4.8	Strongly acid
A_{22}	5- 9	4.9	Strongly acid
B & A	9-15	4.8	Strongly acid
B_{21}	15-19	4.8	Strongly acid
II B_{22}	19-25	4.9	Strongly acid
II B_3	25-36	5.0	Very strongly acid
II C	36-53	5.1	Strongly acid

Exchangeable Cations and Exchange Capacity

The dominant cation in Santiago soils is hydrogen. It ranges in the representative profile (Table 7) from a low of 1.4 milliquivalents per 100 grams in the C horizon to a high of 8.9 in the surface soil. Surface horizons of some Santiago soils may exceed 20 (37). The hydrogen cations occupy from 35 to 80 percent of the exchange capacity.

Calcium in the representative profile, as well as in other observed Santiago soils, (38) occupies as little as 35 percent of the exchange capacity in the B horizon but rarely exceeds 65 percent. Sodium and potassium generally are low, the two ranging from 0.1 to 0.3 meq. per 100 grams.

The calcium to magnesium ratios in the B horizons of several Santiago soils (22, 38) range from .6 to 1.8.

Cation exchange capacities are low in all Santiago soils. In the representative solum in Table 7 they range from a low of 5.0 meq. per 100 grams in the A_{22} to a high of 10.9 in the B_{21}. Some Santiago soils may exceed 20 meq. in their organi-mineral surface horizons and approach 15 in their horizons of maximum clay illuvation.

The value for exchange capacity per 100 grams of clay for the A_1 horizon is higher than that for underlying horizons and is due in large part to organic matter. Assuming the same exchange capacity per unit of clay for the A_1 as for the underlying horizons, the clay content may account for approximately 5.0 meq. of the 10.5 meq. exchange capacity of 100 grams of the A_1 horizon. Thus about 5.5 meq. exchange capacity of the A_1 horizon of this soil can be attributed to the difference between the 3.15 percent organic carbon or 5.42 percent organic matter of the A_1 as compared to that of the A_2. On this basis, the exchange capacity per 100 grams of organic matter can be calculated as about 126 me. This value appears quite low until one considers that the total organic matter in the A_1 is, in large part, composed of inactive fibrous roots and partially decomposed organic debris.

Other horizons of the solum show a moderately high average exchange capacity of 53 meq. per 100 grams of clay. A different conclusion is reached, however, if exchange capacity is plotted against percent clay (Figure 7). By inspection, a straight line is drawn among the points representing the specific B horizons. Then one may read the exchange capacity off the vertical axis for two values of clay, say 10 percent and 20 percent, to get the value for a 10 percent increase in clay. In the B horizon of the Santiago soil, this value is about 6.3. Multiplying by 10 we have 63 for the approximate exchange capacity (CEC) for 100 grams of clay--suggesting the possibility of some expanding lattice clay. Exchange capacity in this order of magnitude is more nearly representative of hydrous mica and montmorillonite clay minerals.

Table 7. Exchangeable cations and exchange capacity of a representative Santiago silt loam profile from St. Croix County, Wisconsin (22).

Horizon	Depth	Cation Exchange Capacity NH4OAc	C.E.C. per 100 g. clay a/	Extractable Cations Ca	Mg	H	Na	K	Base Saturation % NH4OAc Exchange	Base Saturation. % on sum cations	Sum extractable Bases	Sum extractable Cations	Ratio of Ca to mg.
		←meq. per 100 grams→											
A_1	0-2	10.5	126	4.0	1.4	8.9	< 0.1	0.4	55	39	5.8	14.7	2.8
A_{21}	2-5	6.2	75	0.8	0.8	7.5	< 0.1	0.2	29	19	1.8	9.3	1.0
A_{22}	5-9	5.0	53	0.7	0.8	5.8	< 0.1	0.2	34	23	1.7	7.5	0.9
B & A	9-15	7.6	51	1.3	2.0	6.8	< 0.1	0.2	46	34	3.5	10.3	0.6
B_{21}	15-19	10.9	56	3.8	3.0	6.9	< 0.1	0.2	64	50	7.0	13.9	1.3
II B_{22}	19-25	9.2	54	3.8	2.4	5.2	< 0.1	0.2	70	55	6.4	11.6	1.6
II B_3	25-36	6.6	51	3.0	1.7	3.0	< 0.1	0.1	73	62	4.8	7.8	1.8
II C_1	36-53	5.9	57	3.0	1.8	2.3	< 0.1	0.1	83	68	4.9	7.2	1.7
II C_2	53-65	3.7	92	2.3	1.2	1.4	< 0.1	0.1	94	71	3.5	4.9	1.9

a/ Obtained from formula $x = \frac{y}{z} 100$, where

x = CEC per 100 g. clay
y = CEC per 100 g. of all fractions of the soil below 2 mm
z = Percent clay

Organic Carbon, Organic Matter and Carbon-Nitrogen Ratio

Total organic carbon and, accordingly, organic matter content (percent organic carbon times 1.72) are quite high and the carbon-nitrogen ratio relatively wide in the surface few inches of Santiago soils. See Table 8. This may be attributed in large part to depressed microbiological activity and subsequent organic matter accumulation in the cool, acid soil environment of the western and northwestern part of Wisconsin. The rather abrupt change in percentage of organic matter below the surface few inches, with an accompanying drop in the carbon-nitrogen ratio, is more or less consistent with the soil's tree vegetation and with Gray-Brown Podzolic soils in general.

Table 8. Organic carbon, organic matter and C/N ratio of major horizons in a representative Santiago profile in St. Croix County, Wisconsin (22).

Horizon	Depth (inches)	Organic Carbon (%)	Organic Matter (%)	C/N Ratio [a]
A_1	0- 2	3.15	5.42	17
A_{21}	2- 5	0.94	1.62	13
A_{22}	5- 9	0.39	0.69	10
B & A	9-15	0.30	0.52	10
B_{21}	15-19	0.27	0.46	9
II B_{22}	19-25	0.13	0.22	8
II B_3	25-36	0.08	0.14	
II C_1	36-53	0.06	0.10	
II C_2	53-65	0.02	0.03	

[a] See also Table 9 in which the percentage of total nitrogen is shown.

Soil profiles from St. Croix and Barron counties, Wisconsin (22,38) have average organic matter percentages in the A_1, A_2, B, IIB and C of 4.23, 1.28, .45, .15 and .09, respectively. They have carbon-nitrogen ratios in the first four of these horizons of 22, 11, 9 and 7, respectively. Figure 8 shows the distribution of organic matter with depth on both a histogram and smoothed curve for the horizons of a representative Santiago profile.

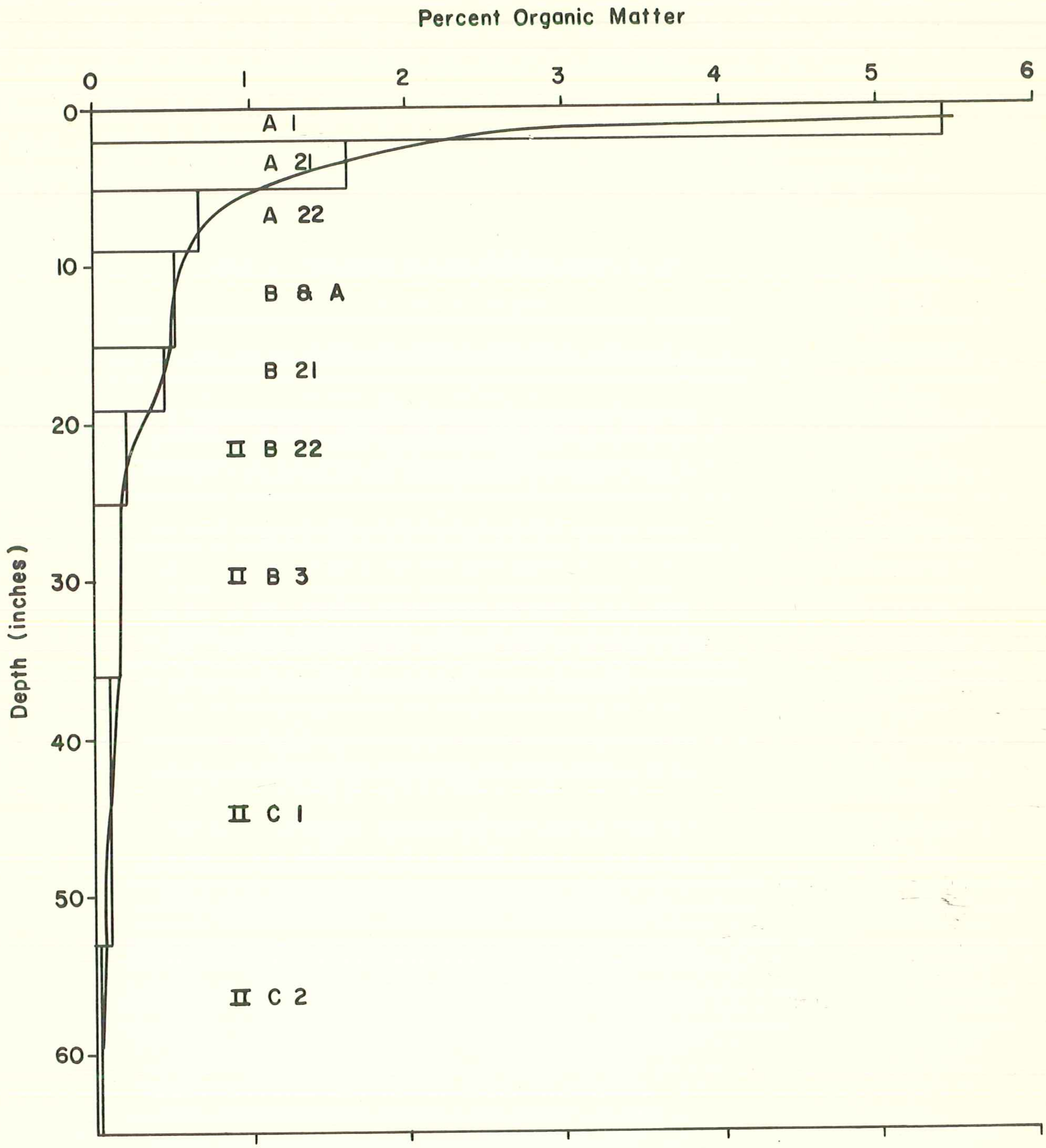


Figure 8. Distribution of organic matter with depth in a representative profile of Santiago silt loam (22).

Available Nutrients

Subsoil fertility studies conducted by Beatty and Corey (14) on Santiago soils of Chippewa, St. Croix and Dunn counties, Wisconsin show these soils to be low in both phosphorous and potassium. They are somewhat lower in these nutrients, particularly potassium, than other Gray-Brown Podzolic soils sampled farther south in the State*. The subsoils (B horizons) of Santiago soils are medium to low in available phosphorous and low to very low in available potassium.

For purposes of making fertilizer recommendations to farmers and on the basis of soil tests, Walsh, et. al. (49) and Beatty and Corey (14,3) have combined the soils of Wisconsin into groups that have similar subsoil fertility. For example, the available phosphorous in soils northward in the "tension" belt of Wisconsin is considered "low" if soil tests show 0-20 lbs/acre, "medium" if tests show 21-40 lbs/acre and "high" if over 40 lbs/acre. Soils having 0-90 lbs/acre available potassium qualify as "very low" in content, 91-120 lbs/acre as "low" and 121-160 lbs/acre as "medium". More than 160 lbs/acre is considered "high".

Using the above available P and K levels for the plow layer as points of reference, one is made aware of the low nutrient supply in a representative Santiago silt loam from St. Croix County, Wisconsin (See Table 9). Though the soil has a relatively high phosphorous content in its surface 3 inches, it drops off abruptly to a low content at 6 inches. The available phosphorous remains low throughout the upper B horizon, rising again into the medium range in that portion of the B horizon below the loess-till boundary.

Available potassium by analysis of field-moist samples shows the entire profile below the A_1 to be very low in this nutrient. Though there is appreciable potassium released on drying at 55°C, analyses show the amounts as still generally within the low potassium test level.

The subsoil of Santiago soils is never really air dry; therefore, the levels of available K in the field moist samples are most nearly representative of conditions in nature. Santiago soils with incipient podzol development in their upper solum release less potassium upon drying than do the typical Santiago soils. The reason for this is unknown but is likely related to the greater intensity of weathering associated with podzolization processes.

The nitrogen content of the representative Santiago profile in Table 9 is average. The 9-inch surface layer averages slightly more than 0.1 percent. This may be compared to the 0.1 to 0.2 percent said by Waksman and Starkey (48) to be the average nitrogen content of surface layers in most field soils. The nitrogen content drops off rapidly in the upper B horizon to approximately 0.03 percent and in the lower B to less than 0.015 percent.

*Statement by M.T. Beatty, Extension Specialist for University of Wisconsin, in personal correspondence with the author.

Table 9. Available phosphorous, potassium and nitrogen in a representative Santiago silt loam (14).

Horizon	Depth	Lbs/Acre Available				Percent
		Phosphorous		Potassium		
		SSTL[a]	Bray [b]	Wet [c]	Dry [d]	Nitrogen
A_1	0- 3"	34	47	290	280	.170
A_{21}	3- 6"	16	40	51	80	.099
A_{22}	6- 9"	2	16	23	65	.050
B_1	9-15"	-	--	--	--	.036
B_{21}	15-19"	0	8	14	120	.029
B_{22}	19-23"	2	10	10	130	.025
II B_{23}	23-27"	8	26	16	125	.014
II B_3	27-36"	10	26	11	130	--
II C_1	36-48"	29	30	6	130	--
II C_2	48-70"	60	36	14	140	--

[a] State Soil Testing Laboratory. Determines lbs/acre available phosphorous extracted by .3N HCl.

[b] Refers to Bray Test No. 1 (5).

[c] Lbs/acre available potassium extracted from moist samples.

[d] Drying of Santiago soil samples is shown to favor the release of non-exchangeable potassium from all horizons below the A1.

Free Iron Oxides

The percentage of free iron (Fe_2O_3) in Santiago silt loam does not vary greatly from that in other Gray-Brown Podzolic soils of northwestern Wisconsin.

The percent free iron oxide in the whole soil is shown in the representative profile of Table 10 to be highest in the B_2 horizon. However, in calculating the free iron oxide on a per-unit-of-clay basis, the free iron is higher in the A_1 horizon than in the B_2, and the value increases with depth below the B_2.

Table 10. Free iron content in a representative Santiago silt loam profile (22).

Horizon	Depth	Fe_2O_3 (Whole soil)	Fe_2O_3 (per unit of clay)
		%	%
A_1	0- 2"	0.9	11
A_{21}	2- 5"	0.9	11
A_{22}	5- 9"	0.9	9
B_1	9-15"	1.2	8
B_{21}	15-19"	1.5	8
II B_{22}	19-25"	1.5	9
II B_3	25-36"	1.3	10
II C_1	36-53"	1.2	12
II C_2	53-65"	1.1	28

The percentage of free iron in the whole soil of A_1 horizons in two Santiago profiles from St. Croix County, Wisconsin (22) ranges from .9 to 1.0, in the A_2 horizon from .9 to 1.1, in the B_2 horizon from 1.5 to 1.6 and in the C horizon from 1.1 to 1.5. The percentage free iron per unit of clay of the same horizons shows ranges of 8.0 to 8.3, 7.0 to 11.0, 5 to 10, and 11 to 28, respectively.

SECTION V

SOIL QUALITIES

Fertility Status

Santiago soils have a moderately low level of natural fertility and require fertilizer applications for the growth of most crops. They usually are medium to low in available phosphorous and low to very low in available potassium. The more strongly leached Santiago soils; that is, those displaying incipient Podzol upper sequa, usually have less available phosphorous and potassium than do the typical Santiago soils.

The strong to very strong acidity of these soils lowers their nitrogen fertility by depressing activity of the nitrogen-fixing bacteria. This condition may be remedied, first by liming, then by heavy applications of nitrogen fertilizers and followed by a program of organic matter incorporation. Santiago soils placed under cultivation without such a program will suffer an even further drop in humus content and a subsequent drop not only in nitrogen but in phosphorous and potassium as well.

There also exists a linear relationship between the pH value of these soils and their relatively low degree of base saturation. Depressed growth of plants on some acid Santiago soils perhaps is not due to a calcium or magnesium nutrient deficiency but rather to the indirect influence of low pH on the availability of other nutrients. For example, increased pH brought about through liming provides a more favorable soil habitat for nitrogen-fixing bacteria, possibly increases the uptake of phosphorous and potassium and the minor element molybdenum and decreases possible toxic uptakes of manganese, iron and aluminum.

Nitrogen applications in the form of commercial fertilizers and manures are required for maximum yields of corn and small grains. Potassium and phosphorous applications are especially beneficial for the production of alfalfa and other legumes. Minor elements, with the possible exception of boron, for alfalfa nutrition, generally are present in sufficient amounts for favorable crop production.

Erodibility

The erodibility of Santiago soils has not been measured directly. Rather, it is inferred from characteristics and closely related evidence observed in the field. Factors that affect the erosion of these soils include structure, texture and clay mineralogy; permeability to water; degree, length, and shape of slope; and amount, intensity and seasonal distribution of rainfall.

No direct relation exists between erodibility and any one of these factors where the others vary. For example, the unstable structure in Santiago silt loam contributes to high erodibility on steep, bare slopes that are subject to excessive water runoff but the soil remains relatively safe from erosion on gentle, sodded slopes. It is when an unbalance between the resisting power of the soil and the eroding power of water is created that erosion begins.

The formation of water-stable and erosion-resistant aggregates in Santiago soils is hindered by the uniformity in size of soil particles in the loess mantle and by the small quantity of clay and organic binder. The low plasticity index (See Section IX) shows the soil's cohesion to be little more than that of a sandy soil. It also indicates a limited moisture range separating the plastic condition from the liquid condition. When wet, this soil material may change quickly to a very unstable condition and flow as a viscous fluid.

Permeability of the entire solum, with the possible exception of the friable surface layer, is limited somewhat by a rather high bulk density (See Section IV). This contributes to a low total porosity in the soil. Consequently, water that is impeded in its downward movement may tend to move across the soil surface, creating an erosion hazard.

The steepness of slope and slope length on Santiago soils affects the rapidity and extent of erosion under varied conditions of land cover and use. For example, the soil's undulating to gently rolling topography, even with slope lengths that rarely exceed 200 feet, might contribute materially to accelerated erosion under conditions of bareness and infrequent summer storms.

The approximately 30-inch rainfall of the Santiago soil area, of itself, rarely initiates accelerated erosion. Rainfall is quite evenly distributed, arriving mostly in the form of snow and slow rains.

Air and Moisture Regimes

The total pore space and percentage pores of capillary size in Santiago soils are favorable for the storage of moderate quantities of available moisture and for the movement of air and water.

Individual soil particles occupy about 60 percent or more of the total volume of Santiago silt loam. The remaining space, consisting of voids between the particles, is occupied by water and air.

In a representative profile of a Santiago silt loam from St. Croix County, Wisconsin (22), the highest void ratio is in the well granulated, highly organic A_1 horizon, and the lowest is in the underlying glacial till. Among the five horizons samples (A_{22}, B&A, B_{21}, IIB_{22} and IIB_3), the B&A and the A_{22} have the highest percentage total pore space, approximately 43 percent (Figure 9 and Table 11). Of this amount, between one-half and one-third consists of capillary pores that store water at field capacity. This is the only important reservoir of water storage for cultivated plants.

The lowest percentage total pore space, approximately 29 percent, is in the IIB_3 horizon. Here, approximately 9 percent of the porosity is of capillary size.

The representative Santiago profile, to a depth of 40 inches, has an average total pore space of 36 percent. Its capillary porosity is approximately 13 percent or slightly more than one-third of the total void space.

Water-holding capacity and available water measured in percent, inches per inch and inches per horizon are shown in Table 4.

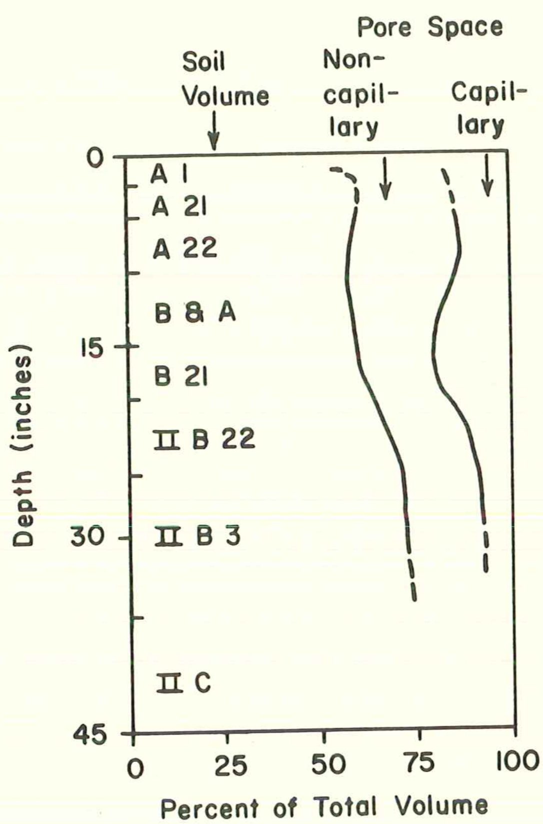


Figure 9. Capillary and non-capillary pore-space relationship in a representative Santiago silt loam profile.

(See Table II)

Table 11. Air and Moisture Relationships in a Representative Santiago Soil Profile.

Horizon	Depth in Inches	Texture	Bulk Density (at 30 cm. tension)[1/]	Moisture (at 30 cm. tension)[1/]	Moisture at 15 atmos. tension (22)	Pore Space[2/]	Water Filled Volume[3/]	Air Filled Volume[4/]	Volume in Excess of 15 atm.[5/]	Volume at 15 atm.[6/]
				%	%	%	%	%	%	%
A_{22}	5- 9	sil	1.52	14.6	3.6	43	22.2	20.8	37.5	5.5
B & A	9-15	sil	1.50	17.6	5.4	43	26.4	16.6	34.9	8.1
B_{21}	15-19	l	1.55	18.7	8.1	42	29.0	13.0	29.5	12.5
II B_{22}	19-25	fsl	1.78	11.9	6.1	33	21.2	11.8	22.2	10.8
II B_3	25-36	fsl	1.88	8.6	4.4	29	16.2	12.8	20.7	8.3

1/ See Table 3.

2/ Percent pore space = $\frac{100 - \text{bulk density (at 30 cm tension)} \times 100}{2.65 \text{ (grain density)}}$

3/ Percent water filled volume = percent moisture x bulk density at 30 cm tension.

4/ Percent air filled volume = percent pore space - percent water filled volume.

5/ Percent volume in excess of 15 atm. moisture volume =
Percent porosity - (15 atm. tension x bulk density).

6/ Percent volume at 15 atm. = bulk density (at 30 cm. tension) x 15 atm. moisture tension.

SECTION VI

CROP YIELD DATA

Crop yield data for Santiago soils in Table ~~10~~ 12 are obtained from the examination of 43 farm business records on 22 farms in northwestern Wisconsin. Yields are based on a three-year period; 1953, 1954 and 1955. This relatively short time period does not reflect all possible changes in weather and other variables. The data are sufficiently representative, however, to permit a close approximation of yields under actual cropping practices. The level of management on the farms studied is regarded as above average for farms in the general area as well as for the State as a whole.

Table 12. Crop yields on Santiago soils for the three-year period of 1953, 1954, and 1955 (41).

Hay-Tons per acre	Grass Silage-tons per acre [a]	Oats-Bu. per acre	Corn Grain-bu. per acre	Corn Silage-Tons per acre
2.60	5.3	50.2	65.4	8.72

[a] Grass silage production data obtained for 1955 only.

SECTION VII

YIELD PREDICTIONS

Yield Estimates

Expected average acre yields for principal crops under past and present levels of management are given in this section for the Santiago soils of Wisconsin. The comparison emphasizes the high production potential of these soils under modern methods of treatment. Table 13 presents the expected average crop yields under average and high levels of management for these two periods.

TABLE 13

Expected long time average yields per acre of principal field and pasture crops on Santiago silt loam under average and high levels of management a/

	CORN				Oats Grain Bushels		Alfalfa-Brome Hay Tons e/		Red Clover Timothy Hay Tons f/		Native Bluegrass Pasture Tons g/		Cropland and Renovated Pasture-Tons
	Grain Bushels		Silage Tons										
	Average	High	Average	High	Average	High	Average	High	Average	High	Unimproved	Improved	
Expected production under past levels of management b/	30	48	5.0	8.5	40	58	1.8	3.3	1.10	2.00			
Expected production under present recommended levels of management c/	50	80	9-12	12-15	55	75 d/	2.5	4.0	2.25	3.25	1.00	h/	i/

a/ All field and pasture crop estimates are for Santiago silt loam, 6 to 12 percent slopes, moderately eroded. This is the dominant cultivated Santiago soils.

b/ Estimated in 1947 and recorded in the Soil Survey Report for Barron County, Wisconsin (38).

c/ Estimated in 1961 and recorded in the Univ. Wis. Special Circular 65, "What Yields from Wisconsin Soils" (28).

d/ This yield is for oats with legume-grass seeding. Higher yields may be obtained, but a poorer stand of legume-grass seeding usually results.

e/ Average of first and second year hay after adequate stands are established, 15% moisture basis.

f/ Yield of first and second cuttings first year after adequate stands are established, 15% moisture basis.

g/ Yields are based on grass with about 15% moisture.

h/ Approximately double the production of total dry matter can be obtained with proper fertilization. Recovering of dry matter depends on grazing management.

i/ Yields of total dry matter from cropland and renovated pasture are approximately the same as from alfalfa-brome. Recovery of dry matter depends on grazing management.

Management Levels

Average management is the level of treatment most commonly practiced by Wisconsin farmers. It usually will not achieve the highest yield potential of the soil. The recommended high level of management, however, will achieve maximum crop yields, being the best management possible under existing agricultural knowledge, technology and equipment. Both levels of management, under past and present criteria, are defined below.

Ordinary or average crop management on Santiago soils twelve to fifteen years ago included little more than the use of manure, starter fertilizer for corn, and little or no fertilizer for oats or hay.

High levels of management during this same period included the addition of lime where needed, heavier applications of fertilizer for corn, the use of fertilizer for both oats and hay and other practices designed to control weeds and maintain good surface mulch.

General practices under modern levels of management are more intense than in past years. Therefore, crop yields under both average and high levels of management have shown increases of 30 to 50 percent within the past two decades.

Average Management, Field Crops

The following is the present average level of management for field crops:

General:

1. Soil is limed to pH 6.0 or less.
2. Weeds frequently are not controlled adequately; thereby, causing some yield reduction.
3. Seedbed preparation sometimes is carried out when soil is too wet or too dry or seedbed is not prepared adequately.
4. Erosion control practices may be inadequate.
5. Only limited insect control is practiced.

Corn:

1. Soil fertility is not adequate to produce yields possible with high management.
2. Corn of improper relative maturity frequently is used.
3. Seeding rates and resultant plant populations commonly are too low.

Oats: (with legume-grass seeding)

1. Soil fertility usually is inadequate. Many oats are not fertilized and most fertilized fields do not receive adequate amounts.
2. Poor seed commonly is used and often is planted too thick and too deep.

Legume-Grass hay:

1. The most desirable varieties of legumes are not always used in seeding mixtures.
2. Stand of legumes and grass may be thin due to lodged oats or oat straw which were not removed.

3. Little or no fertilizer is applied.
4. Hay is cut usually at later than optimum dates and some is lost due to poor harvesting methods.
5. Hay fields frequently are grazed throughout the fall.

Though average management today is far superior to that of past decades, it still falls short of unlocking the full yield potential of the Santiago soils. A high level of management such as that outlined below still is recommended.

General:

1. Lime soil to about pH 6.5 according to soil test recommendations.
2. Provide adequate surface drainage where needed.
3. Use timely and adequate seedbed preparation.
4. Use timely and careful harvesting methods.
5. Install and maintain needed erosion control practices.
6. Use a rotation adapted to soil and slope conditions.
7. Control annual and perennial weeds by timely use of needed chemical and mechanical control practices.
8. Control insects that damage crops.

Corn:

1. Fertilize according to soil test recommendations for the yield a particular soil can be expected to produce over a period of years.
2. Supply adequate organic matter to soil from barnyard and green manure and crop residue.
3. Maintain good soil structure by keeping tillage operations to a minimum during seedbed preparation and cultivation.
4. Grow hybrid corn of proper relative maturity.
5. Adjust seeding rate to get a population adequate to produce the expected yield. Allow for 10% seedling mortality.
   a. Plant enough seed to get 16,000 to 18,000 mature plants per acre when about 100-bushel yields per acre are expected.
   b. Plant sufficient seed to get 14,000 to 16,000 plants per acre for 50 to 70 bushel yields.

Oats: (with legume-grass seeding)

1. Fertilize according to soil test recommendations.
2. Plant clean, viable seed of adapted varieties at recommended rate.
3. Plant only short, stiff-strawed varieties on fertile soils.
4. Plant oats early and at the right depth.

Legume-grass hay:

1. Use sufficient quantity of recommended seeding mixtures.
2. Plant only clean, viable seed of recommended varieties.
3. If seeding is threatened by lodged oats or by drouth, remove oats for silage or hay.
4. Cut twice each year in early bloom stage.
5. Eliminate or restrict fall cutting and grazing to allow plants to build up necessary root reserves to prevent winter killing.

Management Levels for Pasture

Yields of dry matter for cropland and renovated pastures on Santiago soils are given for high levels of management only.

The number of acres needed per cow per season is not given because it is so greatly affected by grazing management.

For cropland pastures, the high level of management is the same as for legume-grass hay, with the additional requirement of grazing management that will not destroy the legumes in the stand. Intensive grazing management such as stripgrazing will, of course, recover the greatest amount of dry matter produced. For renovated pastures, the cultural, fertility, and grazing practices given above should be applied, and, in addition, an adequate job of destroying the old sod before reseeding is assumed.

Yields from improved native pastures are based on treatment that includes topdressing with Nitrogen and complete fertilization with 10-10-10 in early spring.

Management Levels for Woodland

Much of the forested area of Santiago soils in the State presently is producing below its potential. This results in part from such factors as low tree density due to destructive logging, fires, and overgrazing by livestock. In addition, selective cutting has not been practiced and inferior species and stands have resulted. Such a wide variance in yields, depending on past management, has resulted that adequate figures cannot be obtained for an average management level.

Table 14 a/. Estimated yields of wood products from Santiago soils (28).

HARDWOODS		CONIFERS	
Bd. Feet b/	Cords	Bd. Feet b/	Cords
200-250	0.4 - 0.5	Over 300	Over 0.6

a/ Estimated yield of wood products is computed from timber growth on cool sites, assuming no hot sites to be found in the area of Santiago soils.

b/ Board feet (Scrib. Dec. C) per acre per year to be expected from Santiago soils. For the purpose of interpretation, it may be assumed that 1000 board feet of sawlogs are approximately equal to 2 standard 4' x 9' x 8' cords of pulpwood. This relationship will vary considerably depending on the size and quality of the pulpwood.

A high level of woodland management assumes the following:

1. Stands are fully stocked but not overstocked.
2. Stands are maintained in good growing condition with a minimum of cull trees.
3. Selective cutting is practiced to favor the more desirable species.
4. Merchantable products removed in improvement cutting, thinning, salvage and harvest cuts are fully utilized.
5. Losses from mortality are kept at a minimum.
6. Where natural reproduction of desirable tree species does not occur in open areas, adapted species are planted.
7. Areas are protected from livestock grazing and fires.
8. Serious insect infestations and diseases are absent.

The yield figures in Table 12 are from mean annual growth. The rate of annual growth is not the same throughout the life of the stand. Annual growth increases with the age of the stand to a maximum and, subsequently, declines.

According to 5 individual plot measurements on level to gently sloping Santiago soils in Polk and Burnett counties, Wisconsin, the average site indices a/ for aspen, red oak and Norway pine are 68, 61, and 72, respectively. Although no northern hardwood or white pine are now growing on the plots, there are good indications that both of these were major species of the original timber stands. White pine probably approached its best development on these soils, occurring as scattered overstory to the hardwood. This observation b/ is based on the size and distribution of white pine stumps in the study plots.

Trees on the lower slopes generally have a higher site index than do trees on the middle or upper slopes. Aspect or direction of slopes, however, appears to have little bearing on site index on gentler slopes.

Hardwoods growing on these soils have long, clear boles suitable for veneer and sawlogs.

a/ "Site" is a term that includes all the factors influencing the growth of trees at any given location. Site is most commonly measured by the height to which the dominant trees of a given species will grow in a specific number of years (generally 50). Thus a site index of 70 for red oak simply means that on a particular site dominant red oak will grow to a height of 70 feet in 50 years. Obviously this is a better site for red oak than one with a site index of 60.

b/ Observation by A. William Jipson, Woodland Conservationist, Soil Conservation Service, USDA, Wisconsin.

Regenerative Ability:

Seedling mortality on these soils is moderate to severe, particularly for the oaks. Seed crops are greatly reduced by rodents and insects. Diseases, frost heaving, and intermittent droughts take a heavy toll of established seedlings. Highly skilled management is needed to overcome these hazards. Where mature stands are harvested, group selection or shelterwood cutting frequently is employed. This opens up limited areas close to seed sources so that desirable species can become established.

The high rate of mortality is somewhat offset by the large amount of seed produced by native hardwoods. Thus, a good stand of reproduction frequently is obtainable if enough seed-producing individuals are present.

Plant Competition:

Encroachment by species of low desirability is a common hazard. This is particularly true in oak stands, where the more valuable red oak may be replaced by the more tolerant but less desirable ironwood, hickory and elm. Periodic improvement is necessary to reduce these species.

Establishment of desirable stands on understocked areas is frequently hindered by thick growths of grass, weeds and brush. Competing vegetation should be controlled if satisfactory stocking is to be attained in the shortest time.

On open land that has not been clean-tilled, trees should be planted in furrows or scalps, to insure best survival.

Equipment Limitations:

Limitations for the use of mechanized equipment are slight for level soils to moderate on strongly sloping soils. Roads on strongly sloping soils usually must be laid out along ridge tops or in draws, with skidding done up or down the slopes. Logging equipment generally can be operated in all seasons, except during spring thaws. Prolonged rains occasionally will make logging roads temporarily unserviceable.

These soils are damaged by compaction of heavy equipment; therefore, it is unwise to operate trucks and tractors needlessly while the surface is spongy. Winter logging will avoid damage to the soil by equipment.

Machine planting can be used on the nearly level to sloping soils. On the moderately steep soils, planting is done by hand, as mechanical tree planting generally will not operate well on slopes steeper than 12 percent. Gullied areas present special problems in traffic and planting. The most practical approach is to plan these operations so that the need for crossing gullies is kept to a minimum.

Erosion:

Erosion hazards are moderate to severe on the sloping soils. This can be minimized by logging in the winter when ground cover and soils are less likely to be damaged.

Disease, Insect or Pest Problems:

Aside from hazards to seedling survival, there appear to be no special pest problems associated with these soils.

Windthrow:

Windthrow is not a special problem. Harvesting and thinning may be done without special precautions for windthrow.

Erosion:

Erosion hazards are slight to moderate. Greatest danger occurs when runoff from surrounding fields concentrates in waterways and forms gullies. Control of the runoff on the adjacent non-forested areas usually is the only practical remedy for this problem. On steeper slopes, erosion may occur in roads and skid trails. Water should be diverted from the problem area. When furrows are used for planting, they should be laid out approximately on the contour.

Species Priority:

Native hardwoods, especially red oak, sugar maple, basswood, white ash and other quality hardwoods are the preferred species for these soils. These should be favored when present in a stand.

When planting is necessary to obtain a stand of trees, these species may be used if the soil is undisturbed. On land that has been altered by tillage, grazing or erosion, it usually is preferable to plant white spruce, red pine, white cedar, Norway spruce or green ash.

SECTION VIII

USE AND MANAGEMENT

Land Capability Classification

The Santiago soils have been grouped into six land classes, according to the Land Capability Classification system used by the Soil Conservation Service. This grouping is based on the use that can be made of each mapping unit, its management needs, and the risk of erosion or other hazards. Class I soils are moderately deep to deep, nearly level, productive soils. Classes II, III, IV, VI and VII soils have varying degrees of hazards and have been further subdivided into subclasses to show the kind of limitations. Erosion and stoniness in the root zone indicated by the letters "e" and "s", respectively, are shown for the Santiago soils. For example, IIe, VIs, etc. Soils that have similar uses, management needs, and responses make up a capability unit. All of the mapping units of Santiago soils are included in eight land capability units. A brief description of these units and their use and management are given below:

Land Capability Unit I

Santiago silt loam, 0 to 2 percent slopes.

This level to nearly level, deep, friable, loamy soil needs only good management to maintain a high level of productivity. It has no serious erosion hazard when cultivated. To maintain good structure and tilth, a rotation with two years of row crop and one year each of small grain and hay or pasture is recommended. This soil is suitable for continuous row crops, providing a high level of management is used that included minimum tillage, return of all crop residues to the soil, maintenance of a high level of fertility, and use of cover crops.

Land Capability Unit IIel

Santiago silt loam, 2 to 6 percent slopes.

Santiago silt loam, 2 to 6 percent slopes, moderately eroded.

These gently sloping, friable soils are subject to water erosion hazard. They need easily applied conservation practices such as contour stripcropping, terracing and diversions to prevent sheet and rill erosion or hold it within the permissible soil loss. Grassed waterways to dispose of runoff from adjacent areas also may be needed. A suggested rotation under contour cropping consists of two years of row crops followed by one year of small grain and two or three years of hay or pasture.

Land Capability Unit IIIe1

Santiago silt loam, 6 to 12 percent slopes.

Santiago silt loam, 6 to 12 percent slopes, moderately eroded.

These sloping, friable soils need good management and intensive soil conserving practices. They have a moderate water erosion hazard, especially if planted to row crops. However, if they are well managed, soil losses can be kept to a minimum. Contour stripcropping, terracing, diversions and grassed waterways are necessary for water disposal. Under contour strip cropping, a rotation with one year each of row crop and small grains followed by three or more years of legumes and grasses is suggested.

Land Capability Unit IVe1

Santiago silt loam, 6 to 12 percent slopes, severely eroded.

Santiago silt loam, 12 to 20 percent slopes.

Santiago silt loam, 12 to 20 percent slopes, moderately eroded.

These sloping, friable soils are suited only for limited cultivation. Intensive soil conserving practices are needed to maintain these soils when cultivated. They have a severe water erosion hazard; therefore, use should be made of contour stripcropping and diversions where the slopes are not too steep. Surface water may be disposed of by grassed waterways. Heavy applications of manure and fertilizers are needed to improve tilth, infiltration rate of water and productivity on these soils. A suggested rotation under contour stripcropping is one year each of row crop and grain followed by three years of grasses and legumes.

Land Capability Unit VIe1

Santiago silt loam, 12 to 20 percent slopes, severely eroded.

Santiago silt loam, 20 to 30 percent slopes.

Santiago silt loam, 20 to 30 percent slopes, moderately eroded.

These soils are too steep and eroded for cultivation and have a very severe water erosion hazard. They may be suited best for the production of hay and pasture or for forestry and wildlife. If used for hay or pasture, renovation not more than one year out of five, will be beneficial in obtaining maximum yields without deterioration of the soil. Controlled grazing is necessary to maintain a good protective sod cover. Fertilization of permanent bluegrass pasture also is recommended. Woodlots should be protected from fires and fenced to keep out livestock. Selective cutting is recommended.

Land Capability Unit VIIe1

Santiago silt loam, 20 to 30 percent slopes, severely eroded.

Steep slopes, eroded condition and continued severe water erosion hazard make these soils best suited for limited forage production or for woodland or wildlife use. If used for forage production, topdressing and heavy fertilization generally will be needed to establish satisfactory seedings. Controlled grazing is necessary to maintain a good protective sod cover. These areas should not be renovated more often than one year out of five. Protection against livestock grazing and fires in woodlots is recommended.

Land Capability Unit VIs6

Santiago stony silt loam, 6 to 20 percent slopes, slight to no apparent erosion.

The stony nature of these soils restricts their use to meadow, pasture, woodland or wildlife. There is a moderate to severe water erosion hazard if vegetative cover is removed. Some areas may be cleared of surface rocks so that pasture renovation for increased production may be practiced. Renovation, however, should not be done more often than one year out of five. Topdressing each year may be substituted for renovation.

Land Capability Unit VIIs6

Santiago stony silt loam, 20 to 30 percent slopes.

The stony nature, severe water erosion hazard and steep slopes of these soils limits their use to pasture, woodland and wildlife. It is seldom feasible to remove surface rocks for pasture improvement. Topdressing permanent pasture is practical for increasing production, but renovation generally is not. These areas are best suited for pasture, woodland and wildlife.

Conservation Practices and Rotations by Capability Units

From the experimental runoff and erosion data available, combinations of the most intensive rotations and soil conserving practices which will control erosion were calculated for each capability unit. These data are given in Table 15.

Shorter rotations may be used safely where more intensive management is practiced. Such intensive management may include such practices as minimum tillage, returning all crop residues to the soil and wheel track planting.

The rotations in this table are based on calculations using a K factor* of .37 and a permissible annual soil loss of 3 tons per acre.

*The factor K in the universal soil loss prediction equation is tons of soil loss per acre per unit of rainfall erosion index for a slope of specified dimensions. It may vary with soil type, series, and degree of erosion. It expresses the loss from continuous cultivated fallow without the influence of crop cover.

Table 15. Medium intensity cropping systems suitable for Santiago soils with different conservation practices on varying slope lengths (29,45). (With average management).

Capability	No Special Practices	Contour Only		Contour Stripcropping		Terracing
		200' slope	300' slope	200' slope	300' slope	200' slope
I	RROM	-	-	-	-	-
IIe1		RROMM	RROMMM	RROMM	RROMM	RROM
IIIe1		ROMMMM	OOMMM	ROMM	ROMMM	RROMM
					100' slopes	
IVe1		-	-	ROMMM	ROMM	
VIe1		Pasture or hayland				
VIIe1		Woodland or permanent pasture				
VIs6		Pasture or hayland				
VIIs6		Woodland or permanent pasture				

R - Row crop; O - Spring grain; M - Meadow

SECTION IX
Data Related to Other Uses
Engineering Properties

Engineering properties were determined for three Santiago silt loam profiles in St. Croix and Dunn counties, Wisconsin (6,7). Because their properties are so nearly similar, one profile from Dunn County was chosen as representative and its engineering test data are shown in Table 16.

The grain-size data in the upper solum of the representative profile, including the A_1, A_2, B&A and, to a lesser extent the B_{21}, shows a high percentage of silt size grains and indicates at once that the characteristics of silt predominate. The B_{21} which is slightly more clayey than other horizons in the upper story has an AASHO classification of A-4 with a within-group evaluation of 8. It has a Unified classification of ML-CL. Its textural class is silt loam.

The liquid limit of 25 indicates of itself that there is a relatively low percentage of clay in the B_{21} or that it is relatively inactive. This is verified by the low plasticity index of 7 which also shows that the soil's cohesion is little more than that of the sandy loam texture shown in the underlying IIC horizon. The low plasticity index also points to a limited moisture range separating the plastic condition from the liquid condition. When this soil becomes wet, it changes quickly to a very unstable condition above the liquid limit, particularly when it is subjected to manipulation or vibration. Not only does the silty upper story of Santiago soils liquefy easily if saturated and flow as a viscous fluid, it also remains relatively unstable at all moisture contents. Its stability and bearing strength vary inversely as the moisture content.

The material also is fairly impervious. It is difficult to compact because of its narrow range of moisture content. The relatively high moisture content retained at field capacity shows this soil to be highly susceptible to frost heaving and to subsequent loss of bearing strength on thawing. Though the silty upper story has a high bulk density for its texture, it is relatively low when compared to the underlying story of sandy loam glacial till. This is due probably to the higher percentage of voids in the silt produced by poor gradation and inadequate binder material.

The grain size data in the lower story (IIB_{22} and IIC horizons in Table 16) of the representative profile shows a high percentage of sand grains and indicates that characteristics of sand predominate.

The IIC horizon has an AASHO classification of A-2-4 with a within-group evaluation of 0. It has a Unified classification of SM that grades to SC in the uppermost part of the horizon. Its textural classification is sandy loam. The liquid limit of 18 indicates either a low percentage of clay or the presence of relatively inactive clay. This is verified by a low plasticity index of 5 which implies low cohesion. The low plasticity index points to a very limited moisture range between the plastic and liquid conditions. If below the water table and loose, the soil may become "quick" and flow during excavation operations and may result in lost ground in the surrounding area if proper drainage techniques are not utilized. Though this soil material may soften during wet weather, it may be highly stable when fairly dry.

The IIB_{22} horizon exhibits engineering properties somewhat intermediate between the two previously discussed horizons.

Table 16. Engineering Test Data a/ For Soil Samples Taken From a Santiago Soil Profile in Dunn County, Wisconsin

Soil Name and Location				Moisture-Density b/		Mechanical Analysis c/												Classification	
	Horizon	Depth (inches)	Texture	Maximum Dry Density (Pounds per cubic ft.)	Optimum moisture (percent)	Gravel (2" to No. 10 sieve)	Coarse sands No. 10 to No. 40 sieve	Medium sand No. 40 to No. 60 sieve	Fine sands No. 60 to No. 270 sieve	Silt (0.05 to 0.002mm)	Clay (< 0.002 mm)	Passing No. 10 sieve	Passing No. 40 sieve	Passing No. 60 sieve	Passing No. 200 sieve	Liquid Limit	Plasticity Index	A.A.S.H.O. d/	Unified e/
Santiago silt loam SE¼, SW¼, Section 33, T28N, R14W Dunn County, Wisconsin	B_{21}	15-20	Silt loam	114	14	3	5	5	15	56	16	97	92	87	78	25	7	A-4(8)	ML-CL
	IIB_{22}	20-28	Sandy loam	124	11	7	11	14	29	25	14	93	82	68	47	23	9	A-4(2)	SC
	IIC	28-60	Sandy loam	129	9	11	15	15	33	16	10	89	74	59	29	18	5	A-2-4(0)	SM-SC

a/ Tests performed by the Bureau of Public Roads in accordance with standard procedures of the American Association of State Highway Officials (A.A.S.H.O.) (6).

b/ Based on the Moisture-density Relations of Soils, using 5.5-lb. Rammer and 12-in. Drop. AASHO Designation T 99-57, (Method A was used when the sample contained no particles retained on No. 4 sieve and Method C was used for other samples.

c/ Mechanical analyses according to the American Association of State Highway Officials Designation T 88. Results by this procedure frequently may differ somewhat from results that would have been obtained by the soil survey procedure of the Soil Conservation Service (SCS). In the A.A.S.H.O. procedure, the fine material is analyzed by the hydrometer method and the various grain-size fractions are calculated on the basis of all the material, including that coarser than 2 mm. in diameter. In the SCS soil survey procedure, the fine material is analyzed by the pipette method and the material coarser than 2 mm. in diameter is excluded from calculations of grain-size fractions. The mechanical analyses used in this table are not suitable for use in naming texture classes for soils.

d/ Based on Standard Specifications for Highway Materials and Methods of Sampling & Testing (Pt. 1, Ed.7): The Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes, AASHO Designation M 145-49.

e/ Based on the Unified Soil Classification System, Technical Memorandum No. 3-357, Volume 1, Waterways Experiment Station, Corps of Engineers, March 1953.

Interpretations of Engineering Properties

Limitations as source of sand and gravel - the substrata of the Santiago soils often contain pockets of well graded sand and gravel.

Limitations as source of topsoil - The term "topsoil" as used here refers specifically to soil material, preferably rich in organic matter, that is used to topdress road banks, parks, gardens and lawns. Evaluation of Santiago series as a source of topsoil considers both texture and organic matter content and is applied to both the surface and the subsoil.

The silty upper story of Santiago silt loam provides a fair to good source of topsoil. Though limited slightly by a medium to low organic matter content, the limitation is easily overcome in the otherwise favorably textured soil material by treating with fertilizers and organic amendments. The lower story of the profile is a poor source of topsoil, being low in organic matter, drouthy and often gravelly.

Limitations in use for highway subgrade - The silt loam upper story of Santiago soils has severe limitations for subgrade. Its surface absorbs moisture readily and easily exceeds the liquid limit. In this condition, flexible base material may be driven into the soil under wheel traffic and the liquefied soil permitted to enter any pores in the base material. Hence, flexible base materials must be protected by an extra layer of well graded sand, stone chips or similar material to prevent infiltration of the soil under traffic.

Subbase requirements to prevent frost heave in this silty soil is at a minimum under rigid (concrete) pavement and infiltration of the soil into the pavement is impossible. However, this soil material is subject to pumping on the more heavily traveled concrete main roads used by heavy traffic. Therefore, a subbase of soil-cement or well graded granular material is needed to blanket the subgrade. This subbase also proves adequate, under the prevailing climate, to control problems of frost heave. It is not required in the less traveled concrete roads since an occasional truck will not produce mud pumping.

The sandy loam lower story of Santiago soils has few limitations for subgrade use. It is subject to only small volume changes and does not produce severe pavement distortion even though compacted dry. It provides good subgrade for flexible pavements as shown by its grain size distribution and low liquid limit. Since the material lacks cohesion, especially at depths below five feet, it may need to be confined to give good supporting value. Otherwise, the material may form ruts under traffic. As a road surface, the soil may be highly stable when fairly dry. During wet weather, however, it may soften and, in dry periods, become loose and dusty.

Limitations in use for foundation of low buildings - Foundations for low buildings as defined here, is that part of the structure that serves exclusively to transmit the weight of the structure (up to and including three stories) onto the natural, undisturbed ground. The first requirement is that the base of every part of the foundation be located, if possible, below the depth to which the soil is subject to seasonal volume change and below the depth to which the soil structure is significantly weakened by root holes and animal burrows. In the cool, humid climate of Wisconsin and Minnesota, the depth of the foundation is determined further by the level to which frost may cause a perceptible heave. This often may reach 5 feet. It is the substratum of Santiago series, then, that most often provides the base for buildings constructed on these soils.

The moderate to high density of the Santiago substratum provides sufficient strength to carry any load from structures ordinarily built in residential areas. If there is a limit on loads, usually it is imposed by an allowable limited settlement.

If wetted while loose, the substratum material may become "quick" and flow during excavation operations. This may result in lost ground in the surrounding area if proper dewatering techniques are not utilized.

Limitations in use for water storage reservoirs and sewage lagoons - Santiago silt loam has few limitations when used for unlined water reservoirs or unlined sewage disposal lagoons, provided deep, oft-present, sandy-gravelly substrata materials are not exposed within the storage area. Should this rapidly permeable substrata material be exposed, care should be taken to reduce the resultant seepage. This may be accomplished through the use of liners or sealers of less pervious material. The upper part of the Santiago profile; that is, the material from the A and upper B horizons serves quite adequately in this respect. However, these same materials erode quite easily. Where reduction in seepage quantities and protection from erosion are of equal consequence, a soil material consisting of a favorable mixture of sand, silt and clay and, possibly, gravel should be sought. These qualities are found in the Santiago's lower B horizon, or that portion of the B developed in the glacial till. The necessary water-tight integrity and soil stability of shallow lagoons and reservoirs is achieved during excavation by exposing but not removing the lower B. In deeper excavations where drouthy substrata are exposed, the same material transferred from borrow areas may serve as a sealer or liner.

Low berms or embankments (usually less than 6' in height) for sewage lagoons or water reservoirs may be constructed from any portion of a Santiago profile, provided the embankment is made wide enough. The silty portion of a Santiago profile, however, may be found lacking in stability and, thereby, subject to erosion. Consequently, it may require excessive maintenance. Compaction of the embankment may assist in its stabilization. The silty upper portion of the Santiago profile which has a maximum laboratory dry weight of 114 pounds per cubic foot, requires a minimum field compaction of 95 percent of that weight or 108 pounds on embankments less than 10 feet in height. The lower portion of the profile, including the II B_{22} and C horizons, requires a minimum compaction of 90 percent of the laboratory maximum dry weight or 111 and 116 pounds, respectively. (Abstract of 1946 Construction and Material Specifications of the Department of Highways, State of Ohio).

Limitations in use for domestic sewage disposal area - Percolation and coefficients of permeability are the paramount characteristics considered in selecting soils for the absorption phase in domestic sewage disposal systems.

The silty upper profile of Santiago soils (0 to approximately 20") has a moderate permeability. It is underlain by approximately 10 inches of sandy loam B that is somewhat slowly permeable. The deep substrata generally has medium to moderately slow permeability but may be rapid in areas of loose gravel and sand pockets. Cementation in the lower horizons is not unusual and, where present, impairs the soil's use for sewage disposal purposes. On-site percolation tests may be needed to verify its presence.

The absence of strongly developed, water-stable structure in the silty portion of the Santiago profile lowers the soil's suitability for tile trench filter fields and seepage beds. The instability of the silty material on wetting may prove troublesome from a trench construction point of view. It also may result in infiltration of the silty material into the tile pipes or the gravelly seepage beds. Where soil horizons vary considerably in texture, structure and cementation, they may range equally as much in their suitability for use in filter fields and seepage beds.

Seepage pits may be the only satisfactory way to remove effluents in certain areas of Santiago soils. Where the soil sola provide impediments to percolation of effluents, disposal pits may need to be used, and dug sufficiently deep to tap the more pervious substrata. The use of pits, however, must be with the approval of the local health inspectors.

SECTION X

Additional Data Needed

Additional laboratory data are needed to understand fully the genesis and morphology of Santiago soils. Foremost among the analyses needed are clay mineralogy and aggregate stability in water. There also is a need for additional measured yield data for field crops, pastures, and wood products under various levels of management.

SECTION XI

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