A STUDY OF AGRIC HORIZONS IN QUEBEC SOILS

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ABSTRACT

M.Sc. ESAM ABDUL-SATTAR SEDDYK Soil Science

A Study of Agric Horizons in Québec Soils

A physical and chemical study was conducted on soils with hardpan layers observed in eight profiles of gleyed humo ferric podzol soils in the St. Lawrence Lowland Region (Québec province).

Studies were confined to these horizons overlying the clay stratum. The hardpans had a finer texture in cultivated than in non-cultivated soils (woodland). The chemical composition indicated translocation and accumulation of iron, aluminum and soluble organic matter (fulvic acid), thus making it possible to infer that metallo-organic matter complexes were formed, precipitated, and then consolidated with silica and other metallic cations and anions, by pedogenetic processes. The presence of lenses of silty clay indicates that migration or formation of clay particles has taken place in the hardpan.

Extraction techniques indicated more Al than Fe was removed from the amorphous aluminosilicate mineral. They also indicated the presence of goethite and/or hematite in these soils and their accumulation in the hardpan. Oxalate-extractable iron and aluminum and the dithionite-extractable iron and aluminum values helped to distinguish between Podzolic and Gleysolic soils with pronounced horizons of dithionite iron accumulation. Induration of the soil as measured by penetrometer increased from 14 to 19 kg/cm^2 from the surface to the agric horizon overlying the clay substratum in profiles of cultivated soils only.

RESUME

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Etude d'horizons agriques dans des sols du Québec

Les propriétés chimiques et physiques de couches indurées qui furent observées dans huit profils de type podzol humo ferrique gleyifié de la Plaine du St-Laurent au Québec, furent étudiées dans la présente recherche.

Les études furent confinées à l'horizon de sol qui recouvrait l'argile sous-jacente. Les couches indurées avaient une texture plus fine dans les sols cultivés que dans les sols non-cultivés (en boisé). La composition chimique indiquait qu'une translocation et une accumulation de fer, d'aluminium et de matière organique soluble (acide fulvique) avaient eu lieu, rendant possible l'hypothèse que des composés organo-métalliques se soient formés, précipités et consolidés avec de la silice et autres cations et anions métalliques au moyen de processus pédogénétiques. La présence de lentilles d'argile limoneuse indique qu'il y a eu migration ou formation de particules d'argile dans la couche indurée.

Les méthodes d'extraction ont révélé que plus d'aluminium que de fer était extrait des minéraux alumino-silicates. Elles ont indiqué la présence de goethite et/ou d'hématite dans ces sols ainsi que leur accumulation dans la couche indurée. Les quantités de fer et d'aluminium extractibles à l'oxalate et au dithionite ont aidé à distinguer les sols podzoliques des gleysoliques qui ont une accumulation prononcée de fer dithionite. L'induration du sol évaluée par le pénétromètre augmentait de 14 à 19 Kg/cm^2 depuis la surface jusqu'à l'horizon agrique située à la ligne de contact avec l'argile, dans les profils de sols cultivés seulement.

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1. INTRODUCTION

Cultivated soils are subjected to an environment which differs from that of non-cultivated soils (Morgan Arboretum soil). Hence, the equilibrium and pedological processes which prevail under cultivation tend to alter the properties of the cultivated soils which are quantitatively changed, thus forming a soil with tendency to develop an agric horizon. An agric horizon is an illuvial horizon formed under cultivation that contains significant amounts of illuvial silt, clay and humus (U.S.D.A. 1975). It was observed in field surveys that a dense layer which impeded downward movement of water and root penetration through the soil had formed unfavourable conditions for plant growth in soils made up of sandy alluvium overlying marine clay.

The object of this research was to detect the effects of 70 years of cultivation on the characteristics of St. Damase soil series profiles in Quebec by comparing them to similar profiles located nearby which were under forest cover.

All results of field observation and laboratory measurements were to be analyzed statistically in order to elaborate a hypothesis concerning some of the potential changes occurring in profiles and resulting into the possible development of an agric horizon.

2. LITERATURE REVIEW

The presence of a very compact or indurated layer in many soils has been reported for many years (Nikiforoff and Alexander, 1942; Gerard, 1961; Veen et al. 1971; U.S. Soil Survey Staff, 1975) and occurs in a wide range of climate (Litchfield, 1942; Wright, 1963), of topography (Litchfield, 1962; Bailey, 1964), of parent material (Nikiforoff and Humbert, 1942; Chang Wang, 1974) and of vegetation (Damman, 1965).

Nikiforoff and Alexander (1942) indicated that the term "hardpan" denotes either the soil horizon or the layer of the parent material which is characterized by a hard stone-like consistency and which differs in that respect from the other layers or horizons of the same profile. Nikiforoff and Humbert (1948) assumed that hardpans in soil profiles are genetic horizons irreversibly cemented by some binding material such as free silica or iron oxides. The U.S. Soil Survey Staff (1975) reported that cultivation may bring changes in soil and sub-horizons which could lead to the development of an agric horizon. In many cases, however, the hardpans, whether pedogenic or relic, are uncemented and are hard simply because of their physical make up.

These genetic horizons are developed in the profile through the slow, but long-continued action of soil genetic processes. They form groups of horizons which are further sub-divided according to the nature of the material responsible for restricting root and water penetration. The subdivisions are discussed hereinafter according to the nature of the cementing material.

2.1 Iron-pan: Pan in which an inorganic form of iron is apparently the main cementing agent.

2.2 Iron-Organic matter pan: Pan in which iron is complexed with organic matter, and particles are coated with shiny, black, to dusky red material.

2.3 Iron-Manganese pan: Pan in which an inorganic form of iron and manganese is apparently the main cementing agent.

2.4 Clay-pan: A pan in which the particle size distribution shows maximum clay accumulation in the Bt-horizon.

2.5 Silica-pan: A sub-surface pan, which is less permeable than other horizons in the same soil profile and which seems to contain some extractable silica.

2.6 Physico-Chemical pan: A sub-soil horizon (pan) that differs from the adjacent horizons by one or more distinctive morphological features such as: hardness when dry and brittleness when moist. The common terms for these pans are: plow pan (or traffic pan) and fragipan according to nature of pan formation.

a. Plow-pan or traffic pan or compacted layer: A pan layer described as an induced pan which is found just below the zone disturbed by normal tillage operations.

b. Fragipan: A genetic sub-soil horizon which is hard to extremely hard when dry, and firm to very firm when moist, and displays the property of brittleness when both dry and moist.

c. Agric horizon: Is an illuvial horizon formed under cultivation that contains significant amounts of illuvial silt, clay and humus.

2.1 IRON-PAN

2.1.1 Muir (1934), one of the first to describe iron-pans, noted that they occurred commonly just below the Ae-horizon or within the B-horizon and that they might develop either under the B-horizon of humus accumulation in normal podzol, or at the boundary located between the water-saturated, reduced upper horizon and the aerated lower horizons of a soil covered with a peaty surface horizon. Iron-pans occur in soils of many regions having cool humid climate. Crampton (1963), Damman (1965), Muir (1934) and Clark(1966) reported a marked depletion of Fe in the Ae-horizon and AB, and a striking maximum of Fe in the iron-pan. Dithionite-extractable iron in the pan exceeded oxalate iron by a factor of about 2, and pyrophosphate Fe by a factor of about 20.

Bailey (1964) reported that thicker pan occurred in the poorly drained soils developed in deep loess, than in the moderately well-drained soils.

Pan horizons tended to exhibit marked coloration, red, brown and yellow mottling which differed from the horizons above the pan. Moreover, pan had more yellow and less red hues, while values remained about the same as compared to the upper horizon. Chroma generally decreased about one unit when the first pan horizon was reached.

Pan horizons commonly showed a tendency toward compaction and brittleness when observed in the dry or moist condition, respectively.

2.1.2 Hypothesis of genesis of iron-pans:

Crampton (1956, 1963) and Damman (1965) suggested that iron is mobilized by reduction in the upper saturated part of the profile and oxidized after being translocated to the aerated lower part of the profile. In this case the pan would be expected to occur at the boundary between fine and coarse material.

Frei (1949), Duchaufour (1951) and Crampton (1963) suggested that the destruction of clay occurs in highly acid soils, while podzolization process caused the mobilization of released iron downward which precipitated within sub-surface horizons. The biological cycle (Kononova, 1961 and Aristovskaya, 1965, 1974) of iron proceeds with great intensity in soils under humid climates and influences soil morphology. Different living organisms use iron as an electron carrier in their enzymatic systems, and the change of valence of the iron is the essential part of important oxidation-reduction processes in metabolism. In accordance with the high requirement of microorganism for iron their biochemical activity is the essential factor for its mobilization in soluble form from stable compounds, including the crystalline lattices of minerals.

The mobility of iron may also be influenced by different reducing compounds (H_2, H_2S, CH_4) formed by micro-organisms under anaerobic conditions.

2.2 IRON-ORGANIC MATTER PAN

2.2.1 McKeague (1967) indicated that this pan consists of a thin, shiny, black to dusky red layer coating the particles of the indurated layer which is lower in value and in chroma than the indurated layer of the iron-pan. This pan occurs in soils of many regions having a cool humid climate. Crampton (1962) and Muir (1934) found also that soluble organic matter was markedly higher in iron-pans than in adjacent horizons. The cementing material of this pan consists mainly of an amorphous iron-fulvic acid complex (McKeague and Schnitzer, 1967; McKeague and Day, 1966; Schnitzer and Desjardins, 1961).

2.2.2 Hypothesis of genesis:

Many organic acids which are produced by microorganisms react with iron to form iron-organic matter complexes, and favour the mobility of iron by giving it the ability to migrate over a wide range of pH conditions. Moreover, the transformation of organic matter in soils of humid regions is usually accompanied by the formation of great quantities of humic and fulvic acids. These products apparently play the principal role in the weathering of the parent material and in iron mobilization in the course of podzol formation (Kononova, 1961; Schnitzer and Skinner, 1965; Crampton, 1963; McKeague, 1971).

2.3 IRON-MANGANESE PAN

2.3.1 This is a pan which contains a larger quantity of Mn and Fe than the soil in which it occurs (McKeague et al., 1968). The latter indicated also that iron-manganese pan could be distinguished from the iron-organic matter pan by the fact that the black manganese layer usually occurs at the base of iron-manganese pan, whereas a rusty layer occurs at the base of the iron-fulvic acid pan. Nikiforoff and Humbert (1948) believed that the hardness depends largely upon a rather close packing of the primary particles and, perhaps, on their interlocking orientation during deposition.

2.3.2 Hypothesis of genesis:

Collins (1970) showed that the physico-chemical behaviour of iron and manganese in natural systems is controlled, to a large extent, by fluctuations in the Eh-pH environment under acid or slightly acid conditions, the oxidation of both Fe^{++} and particularly Mn^{++} being slow. It was found that the precipitation of iron at lower Eh values (in the pH range 5.8 to 6.0) which caused the removal of some Mn^{++} from solution, may be due to sorption of Mn^{++} by the hydrated iron oxides which have evidenced a negative charge. At pH values above approximately 5.1, the major part of the Mn^{++}, however, precipitated independently of the iron in an exclusive manganese system.

Wolf (1964) indicated that Fe- and Mn-oxidizing organisms were involved in the formation of the pans, but biological oxidation would presumably occur only under pH and Eh conditions at which chemical oxidation could occur too.

2.4 CLAY-PAN

2.4.1 This is a pan which is formed by the infiltration of colloidal clay, which would clog at least the largest voids and make the pan almost impermeable (Nikiforoff and Humbert, 1948). Nikiforoff and Alexander (1942) showed that the San Juaquin and Madera soils of California were characterized by a conspicuous development of clay-pan. The topmost part of the pan usually was the hardest, and its upper boundary was abrupt, whereas the lower boundary was less distinct and could not be determined precisely in most places. Sesquioxides which were brought down from the overlying horizons accumulated in the clay-pan. The areas with clay-pan have a concave microtopography and collect more water of percolation than surrounding areas.

2.4.2 Hypothesis of genesis:

Crampton (1963), Duchaufour (1951) and Frei (1949) suggest that the translocation of clay from the eluvial to the illuvial horizon occurred in weakly acid soils, while podzolization involved the mobilization of colloidal clay, solution and precipitation.

2.5 SILICA-PAN

2.5.1 Eric Winters (1942) defined silica-pan as an indurated genetic horizon, less permeable than other horizons in the soil profile. It occurs most frequently in soils developed on smooth relief, with slopes of less than 10%, from parent materials containing predominantly silt and usually siliceous material. The silica hardpan layer shows a great range of variation in its properties from one soil to another. The range in colour is from yellow to brownish-yellow, slightly mottled with gray. Uniform red or brown colours have not been observed in silica-pans. The pan may have a coarse textured material which overlies a heavy stratum that impedes drainage. It has a brittle consistency when either wet or dry. Many soils in Tennessee and adjacent areas have a silica-hardpan at 45-60 cm below the surface.

2.5.2 Hypothesis of genesis:

Soluble SiO_2 could result from silicate hydrolysis during the moist period of the year. Restricted drainage would prevent the leaching of the silica (SiO_2) except from the upper horizons during the late summer, while an extremely dry condition throughout the entire soil profile, at such time would not only precipitate much of the silica but would dehydrate it and form a coating on the soil grains.

In the absence of the disruptive forces of shrinking and swelling of adjacent soil grains, over a period of years, the grains would become cemented and gradually be held together.

Silica-pans should develop more rapidly and hence become harder in a warm region that favours silicate hydrolysis than in a cold climate where chemical weathering is slow.

2.6 PHYSICO-CHEMICAL PANS

These pans include two kinds of indurated pans which may be differentiated as follows, according to the nature of the pan development:-

2.6.A Plow-pan or compacted layer
or (Traffic-pan)

2.6.A1 Nichols (1955) stated that a horizon or layer limiting water and root penetration is apparently the result of recently applied compacting forces such as from implement traffic or trampling upon a soil. It is more common in medium textured (loam, sandy loam, and silt loam) soils than in fine textured soils and occurs just below the soil zone disturbed by normal tillage operations.

It is similar in texture and chemical properties to the material immediately above and below it. McCracken (1963) reported that Southeastern U.S.A. soils contain sub-soil horizons which differ from the adjacent horizons in distinctive morphological features such as: "brittle when moist, hard when dry, apparent compaction and dry appearance while adjacent horizons appear moist." This pan layer occurs between 20-30 cm in depth.

Gerard (1961) defined it as an indurated or compacted soil layer with reduced permeability which developed in the first 30 cm of the soil profile and is usually from 8 to 15 cm thick. He stated that the compaction factor by tillage implements was important in the formation of this pan. This layer has the same chemical and physical properties as other layers above and below. He found only small differences in bulk density between the pan and other layers.

2.6.A2 Hypothesis of genesis:

Gerard (1961) in a laboratory investigation was able to evaluate the influence of certain factors on close-packing or orientation of soil particles in Willacy fine sandy loam soil. He postulated that frequent irrigations, followed by rapid evaporation or moisture absorption by plants which resulted in frequent wetting and drying cycles, contributed to close-packing of soil particles and subsequent hard or indurated pan formation.

The physico-chemical forces are probably instrumental in increasing coherence among soil particles. And the physico-chemical bonding of the soil particle surfaces is apparently a function of the rate of moisture loss and probably of temperature.

Nichols (1955) gave some reasons for the increase in compaction of the layer, which were as follows:

(a) The rapid adoption of new fertilizer practices, new insecticides, crop varieties, etc.

(b) An increasing number of farmers who have access to power units and tillage tools that enable them to "do something about soil compaction problems."

(c) Many soils are actually becoming compact under the continuing influence of present day systems of management.

2.6.B Fragipan:

Fragipan soils have been found and studied extensively in central and northeastern parts of U.S.A. It extends into eastern parts of Canada, and some research work has been published about these soils in Canada (McCracken, 1963; Daniels, 1966; DeKimpe, 1970 and 1974; and Chang Wagn, 1974; U.S.D.A. 1975).

2.6.B1 McCracken (1963) defined fragipan as a genetic sub-soil horizon, which differs from the adjacent horizons by one or more distinctive morphological features, is brittle when moist, hard when dry.

Daniels (1966) defined fragipan as a loamy sub-surface horizon that is low in organic matter, has a high bulk density compared to the solum above, and is seemingly cemented when dry.

Chang Wang (1974) defined the term "fragipan" as a compacted horizon rich in silt and/or sand, and relatively low in clay content.

Daniels (1966) indicated that the properties of the fragipan horizons apparently are more dependent upon drainage and topographic position than on changes in sediment or mineralogy.

The brittle parts of the fragipan horizons are dense gray loamy sands, sandy loam or silt loams. The dense material is brittle, in other words, it ruptures rather than deforms gradually under applied pressure. It does not shatter into individual grains but breaks into pieces, then to single grains.

DeKimpe (1970) described fragipan in Quebec, occurring in the Appalachian hills, which developed on glacial till deposits with podzol profiles. The particle size distribution throughout the profile showed an increase in the clay fraction of the fragipan level. The cumulative figures for the (medium + fine sand) 0.5-0.1 mm on the one hand and the (very fine sand + silt) 0.1-0.002 mm fractions on the other hand, above and in the fragipan, gave a similar total. However, the content of smaller particles 0.1-0.002 mm markedly increased in the fragipan.

Chemical analysis indicated an increase of 1.5 pH units in fragipan over the values of the horizons above. Dithionite Fe exceeded oxalate Fe in all horizons, whereas oxalate Al exceeded dithionite Al below the fragipan horizons.

DeKimpe (1974) described the properties of a podzolic soil with a fragipan, which had a thick, dark brown, highly porous podzolic B-horizon with a high content of amorphous Fe, Al-organic matter complex material and a low bulk density, underlaid abruptly by a dense gray fragipan with high bulk density of nearly 2.0 g/cc. However little is known concerning the physical properties of such soils and very few micromorphological data are available.

2.6.B2 Hypothesis of fragipan genesis:

Fragipans are common in soils developed from medium to coarse textured, and acid parent materials (Stobbe, 1936; Carlisle, 1954; Yassoglou, 1960; DeKimpe, 1970; and Chang Wang, 1972; etc.)

Yassoglou (1960) showed that the properties of the pan, which are responsible for its induration, have been developed and not inherited from the primary material. In other words, these fragipans are pedogenetic horizons and the following steps are postulated for their development:

(1) Removal of a part of the clay and, preferentially, of the expanding clay.

(2) Contraction following the removal of soluble material and clay, which results in the close packing of the sand grains.

(3) Following the contraction and the close packing of skeletal elements, the matrix substances undergo rearrangement. The close packing of the sand grains has provided the capillary intergranular spaces in which the soil suspension is confined at a moisture level below field capacity.

(4) During the course of the soil development, aluminum is released from the decomposing minerals, and a part of it is precipitated

from the soil solution in the area of the pan, possibly adding to the induration of the pan.

Cline (1963) concluded that the genesis of the fragipan consisted primarily of physical phenomena related to the development of close packing and to organization and orientation of clays in intergrain spaces as the medium through which binding material must be transmitted.

Nettleton (1968) indicated that a collapse of the soil matrix has caused the high bulk density of the fragipan horizons. The source of extractable aluminum is not known with certainty, but wetting and drying of the lower sola may be responsible for its accumulation. If ferrous hydroxide is produced by water saturation of the soil, it would neutralize exchangeable aluminum, thus precipitating aluminum hydroxide and releasing ferrous iron (Cate, 1964).

With periodic wetting and drying, aluminum could be exchanged for bases as the soil becomes dry, while the bases could be removed during the initial wetting of the soil. Some exchangeable iron could be removed and aluminum accumulated.

2.6.C Agric horizons:

2.6.C1 The U.S.Soil Survey Staff (1975) described an agric horizon as an illuvial horizon formed under cultivation that contains significant amounts of illuvial silt, clay, and humus. An agric horizon may form in several of the other diagnostic horizons, but not in a mollic or an anthropic epipedon because a soil in which an illuvial horizon has formed in the mollic epipedon is distinguished by other means.

2.6.C2 Hypothesis of genesis:

When a soil is brought under cultivation, the vegetation and the soil fauna as a rule are changed drastically. The plow layer is mixed periodically and, in effect, a new cycle of soil formation is started. Even where the cultivated crops resemble the native vegetation, stirring of the plow layer and use of amendments, especially lime, nitrogen and phosphate, normally produce significant changes in the soil structure, flora, and fauna.

After long-continued cultivation, changes in the horizon immediately below the plow layer become apparent and cannot be ignored in classifying the soil. The large pores in the plow layer and the absence of vegetation immediately after plowing permit turbulent flow of muddy water to the base of the plow layer. Here the water can enter worm holes or fine cracks between peds, and the suspended material is deposited as the water is withdrawn into capillary pores. The worm channels, root channels, or ped surfaces become coated with a dark-coloured mixture of organic matter , silt, and clay. The accumulation on the sides of worm holes becomes thick and eventually can fill them. If worms are scarce, the accumulation may take the form of thick lamellae that may range in thickness from a few millimeters to about 1 cm. The coatings on the sides of worm holes and lamellae always have lower colour value and chroma than the soil matrix.

The agric horizon has somewhat different forms in different climates because of differences in soil fauna. Coatings could not be observed in the soils under study because they had a sandy texture, but movements of silt size particles and of organic materials were detected in the laboratory.

3. FIELD CHARACTERISTICS OF THE SOILS

All profiles used for the experiment belonged to the St. Damase series and are described hereinafter.

3.1 General description of the area:

3.1.1 Location and extent:

All profiles were sampled on the Macdonald College farm and the Morgan Arboretum, which comprise some 1550 acres. Both areas are contiguous and are located at the western tip of the Island of Montreal, approximately at longitude 73°57'W and latitude 45°26'N. The area lies within the Valley of the St. Lawrence River, at elevations ranging from 38 to 46 meters above mean sea level, or 15 to 20 meters above the Lake of Two Mountains which forms the western boundary of the Island of Montreal.

3.1.2 Physiography:

The physiographic conditions of the Macdonald College farm are those of the St. Lawrence plain which extends as a large flat plain ending rather abruptly against the Laurentians on the northwest side while rising slowly through a Piedmont Zone into the Appalachians on the southeast side. The land which is mostly a clay plain, has an overall level or nearly level topography, which is broken by some undulations or gentle rolls of the glacial deposits and ridges called Monteregian Hills. On the Macdonald College farm the highest land occurs north of Ste. Marie road, on top of a clay terrace which has developed as a result of a river channel which was carved through the deep clay of marine origin.

3.1.3 Climate:

The climate of the area, which is part of the St. Lawrence lowlands, has been described as humid-temperate (Lajoie and Stobbe, 1950).

It is essentially a cool and humid climate. The summers are relatively short with hot and usually humid days. The winters are cold and relatively long with a considerable amount of snow fall. The data of temperature, rainfall and snowfall have been taken at Ste.Anne de Bellevue, Macdonald College meteorological station for over 50 years (1926-1976) (Table 1). The mean annual temperature ranges from 2°C as a minimum mean annual temperature to 10°C as a maximum mean annual temperature.

The summers are moderately hot with a maximum temperature of about 20.5°C and a minimum of about 9.9°C. The winters are cold with maximum temperature of -0.7°C and minimum of -7.5°C, moreover the length of the frost free periods can vary from a minimum of 71 days to a maximum of 214 days. The average frost free period ranges between 121 and 178 days. Normally the mean atmospheric temperature drops below the freezing point in December, January, February and March.

The average annual rainfall is 775 mm. From the middle of November to early April nearly all the precipitation falls as snow, which averages 196 cm. From May to October all the precipitation falls as rain and averages 504.35 mm.

3.2 Description of the soil profiles:

Two sets of profiles of the St.Damase series were described and sampled. One set, made up of four sites located on the farm, was under cultivation while the other, comprising four sites, was under forest vegetation in the Morgan Arboretum.

3.2.1 General Introduction for Description of the Series

St. Damase:

This soil type occurs from Mississquoi County near the U.S.A. border to Drummond and Terrebonne Counties, almost half way between

TABLE 1. Meteorological data for 50 years average (1926-1976) at Ste. Anne de Bellevue, Macdonald College Station.

Month	Temperature (°C)		Precipitation (mm)	
	Mean Monthly Maximum	Mean Monthly Minimum	Average Monthly Rainfall	Average Monthly Snow
November	5.0	-1.0	55.63	151.64
December	-4.3	-10.5	34.04	554.23
January	-7.0	-13.4	25.91	297.94
February	-6.0	-12.4	22.61	509.78
March	0.3	-7.0	47.75	346.20
April	8.0	-0.4	74.42	101.09
Mean, November to April	-0.7	-7.5	260.35	1960.88
May	17.0	7.0	72.9	1.48
June	23.4	14.0	76.71	-
July	25.0	16.0	107.95	-
August	25.0	15.0	91.19	-
September	13.1	5.5	103.71	-
October	17.3	1.6		-
Mean, May to October	20.1	9.9	514.35	1.48
Mean for Year (Annually)	9.7	1.2	774.7	1962.36

Montreal and Quebec cities, and covers an area of about 85,000 acres in the Province of Quebec. It occurs as many small areas scattered over the lowland, and as isolated spots on the clay plain or as transitions from the sands to the clays. It is developed from outwash sand capping marine clay as former islands, or as former bank deposits on top of clay terraces. These sandy deposits vary in thickness from approximately 40 cm to a maximum of 80 or 90 cm. When the sandy deposits over clay are thinner than 40 cm they are named Courval series, while deposits deeper than 90 cm are designated as St. Amable, St. Sophie or Upland, as the thickness of the sand increases and the drainage changes from imperfect to moderate to good or excessive. All of these soils occur on gentle sandy undulations emerging slightly above the clay flats, at elevations ranging between 15 and 75 meters.

Surface drainage is usually fairly good, but the internal drainage is moderately good to imperfect, depending upon the depth of sand over the impermeable clay and also upon the topographic features of the clay. Where the St. Damase soils are surrounded by flat clay, the drainage is moderately good at the center of the undulations and imperfect on the sides. The sides of the sand spots are also moderately well drained if the clay substratum is strongly sloping along gullies and banks.

There is considerable variation in the depth of sandy material over the clay. Generally the sand is deeper at the center of the undulations and becomes shallower on every side until it grades into St. Rosalie clay loam or Rideau clay loam.

St. Damase soils are partly cultivated and partly used as small woodlots. Where cultivated they are used for general farming and sometimes for gardening. The main crops are hay and grain, but yields are only fair. Due to the variable nature of the texture and drainage of these soils, crop yields are spotty, but more uniform than on the St. Amable sandy loam. Corn can be adapted to this soil with improvements in drainage conditions. On the better-drained areas, potatoes may be grown with considerable success and fairly large yields are obtained. The soil fertility is naturally low but it can be improved considerably and rapidly by generous use of organic matter and fertilizers. Lime is necessary for the normal growth of legumes. Good stands of alfalfa are seen where the soil has been properly prepared.

Descriptions of the selected profile of the St. Damase and of two profiles of St. Amable (non cultivated), in which the horizons were identified according to the conventions concerning horizon designations which were established by the Canada Soil Survey Committee (1970) are presented below.

The two pedons of St. Amable were located in an area of St. Damase and would have reached the thickness of 90 cm over the clay once they were cleared.

The system of colour description is that of Munsell (1970).

Profile No. 1 — Cultivated St. Damase

Location: Macdonald College farm area between highways No.20 and No.40. This profile occurs on gentle undulations, forming a micro-relief with individual slopes ranging between 0.3 - 3 %, imperfect drainage, little runoff and water erosion.

Ah	0-15 cm	7.5 YR 3/2; sod layer; sandy loam; medium angular to subangular blocky; slightly hard when dry, friable when moist; clear smooth boundary; pH 5.2.
Aheg	15-30 cm	10 YR 5/4; sandy loam; common, medium, distinct 7.5 YR 5/3 mottles; single grain; slightly hard, dry; friable, moist; clear wavy boundary; pH 4.8.
Bfjg	30-45 cm	10 YR 5/6; sandy loam; common, medium, distinct 7.5 YR 5/3 mottles; weakly cemented; single grain; loose moist; clear smooth boundary; pH 5.1.
Cg	45-60 cm	10 YR 6/3; sandy loam; many, medium, distinct 7.5 YR 5/3 mottles; firm; structureless; abrupt smooth boundary; pH 5.1.
C II	60+ cm	2.5Y 6/2; clay; many, coarse, prominent 7.5 YR 6/6 mottles; sticky, wet; very hard, dry; strong blocky to subangular blocky.

Profile No. 2 Cultivated St. Damase

Location: Macdonald College farm, field located between highways 20 and 40. This profile occurs on gentle undulations forming a micro relief with individual slopes ranging between 0.5 and 2%. The moisture regime is imperfect, erosion is minimal.

Ap	0-15 cm	Sod layer; 7.5 YR 4/3; sandy loam, fibrous; friable, moist; soft, dry; abundant, fine roots; distinct patches 10 YR 5/8; clear boundary; pH 4.9.
Aeg	15-26 cm	10 YR 5/6; sandy loam; distinct patches 7.5 YR 5/3 mottles; plentiful, medium to fine roots; firm, single grain; amorphous; clear wavy boundary; pH 4.9.
Bfg	26-45 cm	10 YR 5/3; loamy sand; many, distinct 7.5 YR 5/3 mottles; firm, moist; amorphous; abrupt smooth boundary; pH 5.1.
C	45+ cm	2.5Y 6/2; clay; many, coarse, faint 5 YR 5/6 mottles; sticky, wet; very hard, dry; strong blocky to sub-angular blocky.

Profile No. 3 Cultivated St. Damase

Location: Macdonald College highest land, north of highway 40. This profile occurs on the nearly level topography 0-0.5 % slope; parent material as in previous profiles; very little erosion; moisture regime imperfect to moderate.

Ah	0-20 cm	Sod layer; 7.5 YR 4/3; loamy sand; soft, dry; very friable, moist; abundant, fine roots; abrupt, smooth boundary; pH 5.2.
Ahe	20-40 cm	10 YR 5/6; loamy sand; amorphous; single grain; loose, dry; few, fine roots; clear wavy boundary; pH 5.3.
Bfg	40-50 cm	10 YR 5/3; loamy sand; common, distinct, 7.5 YR 5/3 mottles; firm, moist; hard, dry; abrupt smooth boundary; pH 5.2.
C	50+ cm	2.5 Y 5/2; clay; common, coarse to medium, prominent 7.5 YR 6/6 mottles; sticky, wet; hard, dry; strong blocky to subangular blocky.

Profile No.4 Cultivated St. Damase

Location: Macdonald College farm highest land, north of highway 40. This profile occurs on the nearly level topography to slightly undulating, 0.5-1 % slope; the same parent material as previous profiles; very little erosion, a moisture regime imperfect to moderate.

Ah	0-15 cm	sod layer; 10 YR 3/4; loamy sand; loose, dry; friable, moist; abundant, fine roots; abrupt, smooth boundary; pH 5.1.
Ae	15-40 cm	10 YR 5/8; loamy sand; single grain; loose; plentiful; clear, wavy boundary; pH 5.1.
Bfjg	40-50 cm	10 YR 5/3; loamy sand; common, distinct, 7.5 YR 5/3 mottles; amorphous single grain; friable, moist; diffuse boundary; pH 5.0.
Cg	50-65 cm	10 YR 5/3; loamy sand; common, medium, distinct 7.5 YR 5/3 mottles; clear wavy boundary; slightly sticky, wet; firm, moist; pH 5.3.
C II	65+ cm	2.5 Y 6/2; clay, many, medium to fine, prominent 7.5 YR 5/6 mottles; sticky, wet; very hard, dry; strong blocky to subangular coarse blocky.

3.2.2 Non-Cultivated Soil Profiles (Morgan Arboretum Area)

Profile No.5 Non-cultivated St. Damase (woodland)

This profile occurs on wooded land, on the slope of a single long undulation having a 1-3 % slope; drainage, moderate; little runoff; the water percolates rapidly through the sandy material until it reaches the clay substratum.

L-H	0-7 cm	10 YR 2/1; sandy loam; semi-decomposed organic matter layer; fibrous; abundant, fine to medium roots; abrupt, smooth boundary; pH 3.8.
Ah_1	7-25 cm	7.5 YR 4/6; sandy loam; single grain, dry; loose; friable; plentiful, moderate roots; clear wavy boundary; pH 4.4.
Ah_2	25-50 cm	5 YR 4/4; sandy loam; common, fine to medium, distinct 7.5 YR 5/6 mottles; amorphous single grain; friable, moist; diffuse boundary; single grain pH 4.4.
Bfhgj	50-70 cm	5 YR 5/6; sandy loam; common, medium, distinct 7.5 YR 5/6 mottles; amorphous single grain; firm; clear smooth boundary; pH 4.8.
Bg	70-82 cm	7.5 YR 5/6; loamy sand; many, medium, faint 7.5 YR 5/6 mottles; amorphous single grain; firm, moist; clear smooth boundary; pH 5.1.
Cg	82-92 cm	10 YR 5/1; loamy sand; many, medium, distinct 7.5 YR 5/3 mottles; amorphous single grain; firm, moist; clear smooth boundary; pH 5.5.
C II	92+ cm	2.5 Y 6/1; clay, many, medium to fine, prominent 7.5 YR 5/6 mottles; sticky, wet; strong coarse blocky to subangular blocky.

Profile No.6 Non-cultivated (Morgan Arboretum area) St.Damase

Location: This profile occurs on a slope which is undulating in one direction 1-3%; the parent material is medium to fine sand deposited over marine clay in depth about 80cm; the natural drainage is imperfect.

L-H	0-7 cm	10 YR 2/1; semi-decomposed organic matter; fibrous; sandy loam; abundant, fine and medium roots; abrupt, smooth boundary; pH 4.1.
Ahg	7-15 cm	7.5 YR 4/6; loamy sand; single grain; loose; friable, wet; common to few distinct 7.5 YR 5/6 mottles; clear wavy boundary; pH 4.4.
Bfg	15-25 cm	7.5 YR 4/6; sandy loam; common to many distinct 7.5 YR 5/6 mottles; amorphous; single grain; clear wavy boundary; pH 4.5.
Bfgj	25-55 cm	10 YR 5/4; loamy sand; many distinct 7.5 YR 5/6 mottles; amorphous; single grain; diffuse boundary; friable, moist; pH 5.3.
Bhjg	55-75 cm	10 YR 5/4; sand; many distinct 7.5 YR 5/6 mottles, friable, moist; amorphous single grain; clear wavy boundary; pH 5.7.
Cg	75-80 cm	10 YR 5/1; loamy sand; many distinct 7.5 YR 5/3 mottles; amorphous single grain; firm; diffuse boundary pH 5.8.
C II	80+ cm	2.5 Y 6/1; clay; many, fine, prominent 7.5 YR 5/6 mottles; sticky, wet; strong coarse blocky to subangular blocky.

Profile No.7 — Non-cultivated (Morgan Arboretum area) St. Amable

Location: This profile occurs on a gently undulating to undulating landscape with considerable micro-relief. The parent material is medium to fine sand deposited over the marine clay in depth of about 120 cm; slope 0.5 - 2%; imperfectly drained.

L-H	0-7 cm	10 YR 2/1; semi-decomposed organic matter layer; fibrous; sandy loam; abundant fine and medium roots; abrupt, smooth boundary; pH 3.2.
Ah	7-20 cm	10 YR 3/4; loamy sand; friable, moist; plentiful, fine to medium roots; wavy clear boundary; pH 4.1.
Aheg	20-65 cm	10 YR 5/6; loamy sand; common distinct 7.5 YR 5/6 mottles; loose; amorphous single grain; diffuse boundary; pH 4.5.
Bhjg	65-80 cm	10 YR 5/4; loamy sand; common distinct 7.5 YR 5/6 mottles; firm, moist; amorphous single grain; clear wavy boundary; pH 4.9.
Bhfg	80-90 cm	10 YR 5/1; sand; many distinct 7.5 YR 5/3 mottles; firm, moist; diffuse boundary; pH 5.0.
Cg	90-120 cm	10 YR 5/3; sand; many distinct 7.5 YR 5/6 mottles; hard, dry; firm, moist; amorphous single grain; diffuse boundary; pH 5.2.
C II	120+ cm	2.5 Y 6/1; clay; many, medium, prominent 7.5 YR 5/6 mottles; sticky, wet; hard, dry; strong coarse blocky to subangular blocky.

Profile No.8 Non-cultivated (Morgan Arboretum area) St. Amable

Location: This profile occurs on gently undulating topography; moderately well drained; the parent material is a fine sand which has a thickness of about 120 cm over clay.

L-H	0-7 cm	10 YR 2/1; semi-decomposed organic matter layer; sandy loam; fibrous; abundant fine to medium roots; abrupt, smooth boundary; pH 3.7.
Ah	7-20 cm	10 YR 5/6; loamy sand; friable, moist; plentiful roots; single grain; wavy clear boundary; pH 4.7.
Aheg	20-60 cm	10 YR 5/6; sand; common distinct 7.5 YR 5/6 mottles; loose; amorphous single grain; diffuse boundary; pH 4.5.
Bhjg	60-85 cm	10 YR 5/3; sand; many distinct 7.5 YR 5/6 mottles; massive; amorphous single grain; clear wavy boundary; pH 4.8.
Bfhjg	85-100 cm	10 YR 5/1; sand; many distinct 7.5 YR 5/3 mottles; firm, moist; hard, dry; amorphous single grain; diffuse boundary; pH 5.1.
Cg	100-120 cm	10 YR 5/3; sand; many distinct 7.5 YR 5/6 mottles; slightly sticky, wet; firm, dry; amorphous single grain; diffuse boundary; pH 5.11.
C II	120+ cm	2.5 Y 6/1; clay; many, medium, prominent 7.5 YR 5/6 mottles; sticky, wet; hard, dry; strong coarse blocky to subangular blocky.

4. METHODS OF ANALYSIS

4.1 Field Work

4.1.1 Sampling

The field work was carried out in the summer of 1975. Sample sites were selected by preliminary auger tests to ascertain the relative homogeneity of the parent material and to allow an investigation of changes occurring in the physical and chemical properties of soil horizons among profiles which originated from similar parent material.

4.1.2 Measurements made in the field

While sampling each horizon with core samplers, field measurements were conducted by means of a Troxler Density Moisture Gauge Meter, and a Proving Ring Penetrometer for quick field checks of bulk density values in the field. Eight sites, four each of representative cultivated and non-cultivated soils were sampled, respectively.

The cultivated soil consisted of pastured fields which had been under cultivation for approximately 70 years. The non-cultivated soil (Morgan Arboretum woodland) consisted of natural hardwood stands.

4.2 Physical Determinations

4.2.1 Bulk Density

Bulk density was determined at the saturation point by the core method as outlined by Blake (1965).

Bulk density at the saturation point was desired in order to obtain comparable results between the profiles, usually at different natural water contents at the time of sampling. Over three core samples for each horizon were taken and brought to saturation by allowing them to absorb water for about 72 hours. The soil exceeding the edges of the cores due to the swelling effect was trimmed off. The water-saturated soil cores were weighed then dried, and their oven-dry weight (Ws) measured. The bulk density (Bd) expressed in g/cc was obtained by dividing the oven-dry weight by the known core volume.

4.2.2 Total porosity

It was determined at the same time as bulk density. The water of saturation was calculated on a weight basis from the oven-dry weight of soil and converted to volume to express total porosity.

4.2.3 Particle density (specific gravity)

This represented the weight of the solid which occupied the volume of the core which was not pore volume.

4.2.4 Particle size distribution

4.2.4.1 Preparation of samples

The three core samples were air-dried, mixed, and gravel and root fibers removed by passing the soil through a 2.0 mm sieve.

4.2.4.2 Determination of particle size distribution

A representative portion of approximately 12 grams of air-dried soil was obtained from each horizon sample by the quartering procedure. This sample was treated for the removal of organic matter by the Kunze and Rich's method as quoted in Black (1965). Free iron oxides were then removed as outlined by Mehra and Jackson (1960), as quoted by Kunze in Black (1965). The pipette method of Kilmer and Alexander (1949), as cited by Day (1965) in Black (1965), with the modifications introduced by Toogood and Peters (1953) was followed for the separation of particle size separates. Dispersion of the soil particles was achieved by using 10 ml of 5% sodium metaphosphate (Calgon) solution per sample. The sand particles were separated from the silt and clay by wet sieving through a 53 micron (0.053 mm) sieve. Both fractions were then oven-dried at 80°C and weighed. The sand fraction was further split into five size sub-fractions using the following nest of sieves of the U.S.Bureau of Standards:-

Sieve number	Opening
18	1.0 mm
35	0.5 mm
60	0.25 mm
140	0.105 mm
270	0.053 mm

shaken on a reciprocal shaker for 10 minutes.

4.2.5 Penetration Resistance

The penetration resistance of soils was assessed in the field by means of a cone-type Proving Ring Penetrometer, Soil Test Co. Model CN-970. The tests were done by pressing the cone penetrometer into the soil in a vertical position at a steady uniform rate of 5 seconds to reach a depth of 15 cm and by recording the proving ring dial indicator reading. The test was repeated three times at each location, in order to determine the maximum penetration load in kilograms/cm^2 using the proving ring calibration chart.

4.2.6 Consistency

4.2.6.1 Liquid-Limit determination

Liquid limit characteristics of the soil samples for each horizon were determined by means of the Atterberg liquid-limit apparatus (Black, 1965). The test was carried out in triplicate and results expressed as percent of moisture on an oven-dry weight basis.

4.2.6.2 Plastic Limit (plasticity)

Plastic limit characteristics for the soils were determined by Sower's method (Black, 1965), and expressed as percent of moisture on an oven-dry weight basis.

4.3 Chemical Determination

4.3.1 Soil Reaction (pH)

Soil reaction was determined in 0.01 M $CaCl_2$ solution, using a digital Model 801 pH-meter with glass calomel electrode (Black, 1965).

4.3.2 Extractable Phosphorous

Elemental extractable phosphorous was determined by the method of Bray and Kurtz (1945), modified as follows: a 2.5 gram air-dried soil specimen was shaken for 5 minutes in 25 ml of approximately 0.03N acidified ammonium fluoride extracting solution, and measured by the "Technicon" auto-analyser.

4.3.3 Extractable Cations

Elemental extractable potassium, calcium and magnesium were assessed by the method of Smith and Matthews (1957). Potassium and calcium were measured by the Technicon auto-analyser and magnesium by a Perkin-Elmer Model 290B Atomic Absorption Spectrophotometer.

4.3.4 Organic Matter

Organic matter in all samples was determined by the method of Walkley-Black (Black, 1965).

4.3.5 Fulvic Acid

Fulvic acid was extracted by a 0.5N NaOH solution under N_2, at room temperature and determined by the method of Stevenson (Black, 1965), as modified by Schnitzer (1970).

The fulvic acid in the solution was measured by means of the Beckman quartz prism absorption spectrophotometer, model DU according to the procedure outlined by Graham (1948), modified by Carolan (1948) and by Sims and Haby (1971).

4.3.6 Dithionite-Extractable Iron, Manganese, Aluminum, Silicon

Dithionite-extractable free oxides of iron, aluminum and manganese as well as silica, were extracted according to the method of Coffin (1963). A Perkin-Elmer model 303 atomic absorption spectrophotometer was used to measure iron, manganese and aluminum. For the determination of silica by atomic absorption, a Beckman quartz prism absorption spectrophotometer, Model DU was used (Jackson, 1957).

4.3.7 Oxalate-Extractable Iron, Manganese, Aluminum, Silicon

The extraction method outlined by McKeague and Day (1966) was modified according to Raad and Thomas (1969). Iron, manganese, aluminum and silica were determined by the same methods that were used for the dithionite-extracted elements.

4.3.8 Pyrophosphate-Extractable Iron, Aluminum, Manganese, Silicon

The extraction method was as outlined by Bascomb (1968).

Iron, manganese, aluminum and silica were determined according to the procedures outlined for the dithionite-extracted elements.

4.3.9 Total Nitrogen

Total nitrogen was determined by means of a semimicro-Kjeldahl apparatus according to Bremner's method (1965).

4.3.10 pH-Dependent Cation Exchange Capacity

The pH-dependent cation exchange capacity was measured in NaCl 2N solution by the method developed by Singh (1976) based upon

Clark's method (1965). Exchangeable Ca and K were measured in the "Technicon" autoanalyser, exchangeable Mg in an atomic absorption spectrometer Model 290B, and exchangeable aluminum in an atomic absorption spectrometer, Model 303 Perkin-Elmer.

4.3.11 Cation Exchange Capacity

The cation exchange capacity of each horizon was determined by neutral ammonium acetate 1N at pH 7. Cations were measured in the "Technicon" autoanalyser by the method of Marshall (1958) modified by Pratt and Bradford (1960).

5. RESULTS AND DISCUSSION

5.1 Physical Analyses

5.1.1 Testing homogeneity of soil material

Because mineralogical analyses were not performed on the sand fractions in this investigation, two systems were used to check the homogeneity of the soil material, so that changes that might be observed in soil profiles could be ascertained as resulting from cultivation.

The approach described by Rim (1955) was tested. The relative parallelism observed among cumulative particle size distribution curves (see figures 8 to 15) of similar horizons indicate that the original material was homogeneous.

A second test based on statistical analyses (F test) summarized in Table 2a and illustrated in Appendix 3, of the percentages of specific size fractions observed in the surface and one sub-horizon of all profiles sampled, indicated that there were no significant differences within groups, while significant differences occurred between groups of cultivated vs non-cultivated profiles. Thus indicating that differences observed in particles distribution between cultivated and non-cultivated profiles were due to causes other than deposition.

5.1.2 Particle size distribution

In all soil survey reports of Eastern Canada, and in most of the detailed analyses of orthic podzol profiles reported in academic journals, results of particle size analyses are given on a weight basis, and so are values reported in the present study.

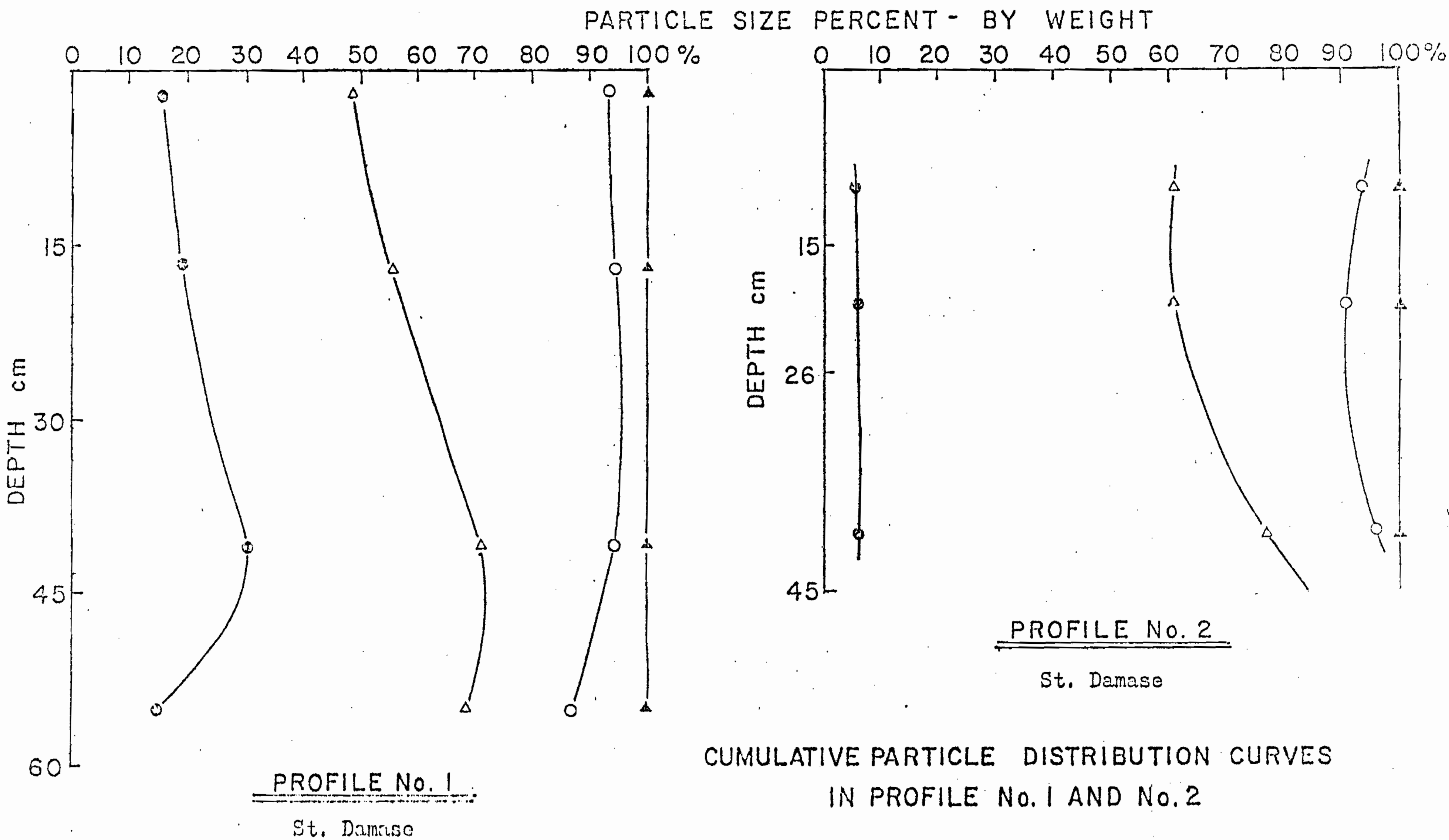
All the values of physical properties for the individual profiles are listed in Appendix 1, which also includes particle size distributions values.

Figures 1, 2, 3, 4, 5 present cumulative average particle size distribution for the individual horizons of the profiles and show the changes in texture with depth in soil profiles. Particle (< 0.2 mm, < 0.5 mm and < 0.005 mm) accumulation with depth in soil profiles show a relative increase in proportion in the cultivated profiles when compared against the corresponding non-cultivated soil profiles, particularly within the hardpan layer (Bg horizons). Moreover, the accumulation of coarse particles (0.1-2.0 mm) increases more with depth in non-cultivated than in cultivated soil profiles, especially in the agric horizons (figures 6 and 7).

Paired t tests in Table 2 indicate that contents of particles with < 0.05 mm in diameter increase significantly at the 0.01 probability level, in the C and B horizons of cultivated profiles, compared to the uncultivated sites, while in the non-cultivated profiles the weight of particle sizes more than 0.2 mm increases significantly at the 0.05 probability level.

The particle size distribution curves for cultivated and non-cultivated soil profiles are presented in figures 8 through 15, illustrating the distribution of fine particles in cultivated soil horizons and coarse particles in non-cultivated soil horizons. Moreover, it was found that there was a greater accumulation of fine particles in the agric horizon than in the above horizons.

In soils with contents of particles > 0.02 mm ranging between 30 and 60 percent, paired t-test analyses indicate significant (0.05 probability) decreases in particle size in profiles of cultivated soils with an agric horizon and significant increases in profiles of non-cultivated soils with an agripan.



CUMULATIVE PARTICLE DISTRIBUTION CURVES
IN PROFILE No. 1 AND No. 2

PARTICLES GREATER THAN 0.002 mm ▲——▲

PARTICLES GREATER THAN 0.005 mm ○——○

PARTICLES GREATER THAN 0.05 mm △——△

PARTICLES GREATER THAN 0.2 mm ⊕——⊕

FIGURE 1.

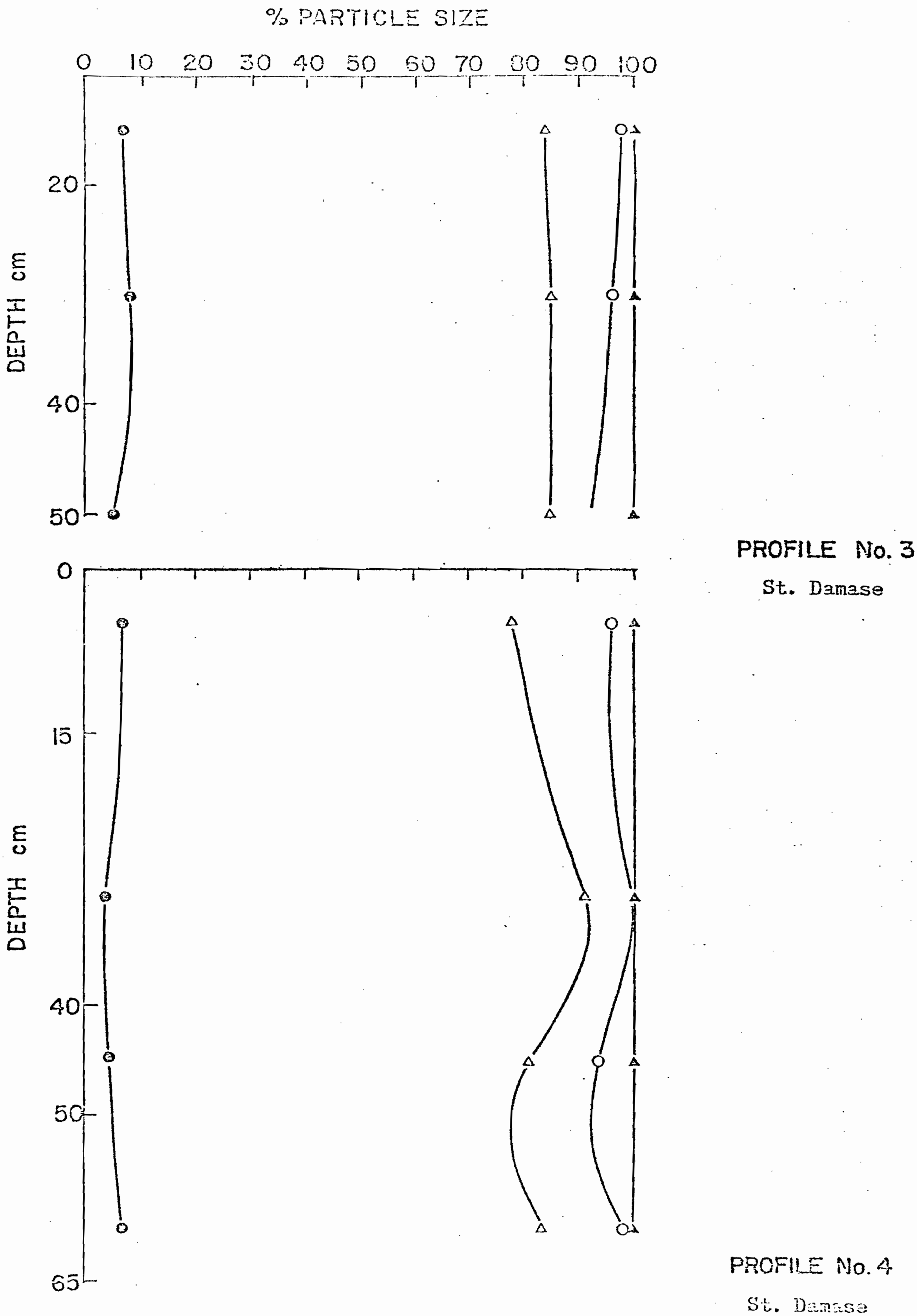

% PARTICLE SIZE
0
10
20
30
40
50
60
70
80
90
100
DEPTH cm
20
40
50
0
15
40
50
65
PROFILE No. 3
St. Damase
PROFILE No. 4
St. Damase

FIGURE 2.

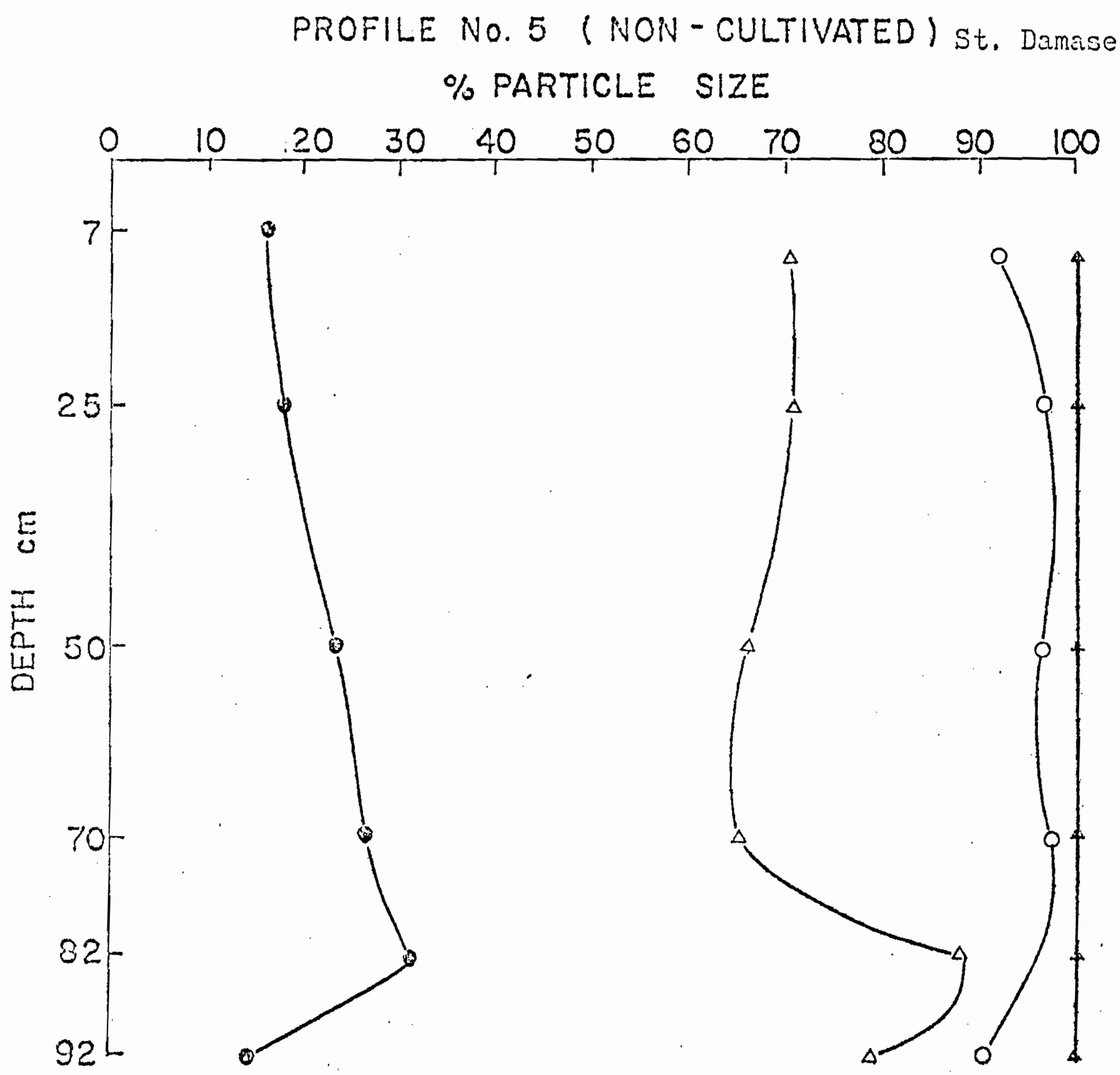

PROFILE No. 5 (NON - CULTIVATED) St. Damase
% PARTICLE SIZE
0
10
20
30
40
50
60
70
80
90
100
DEPTH cm
7
25
50
70
82
92

FIGURE 3.

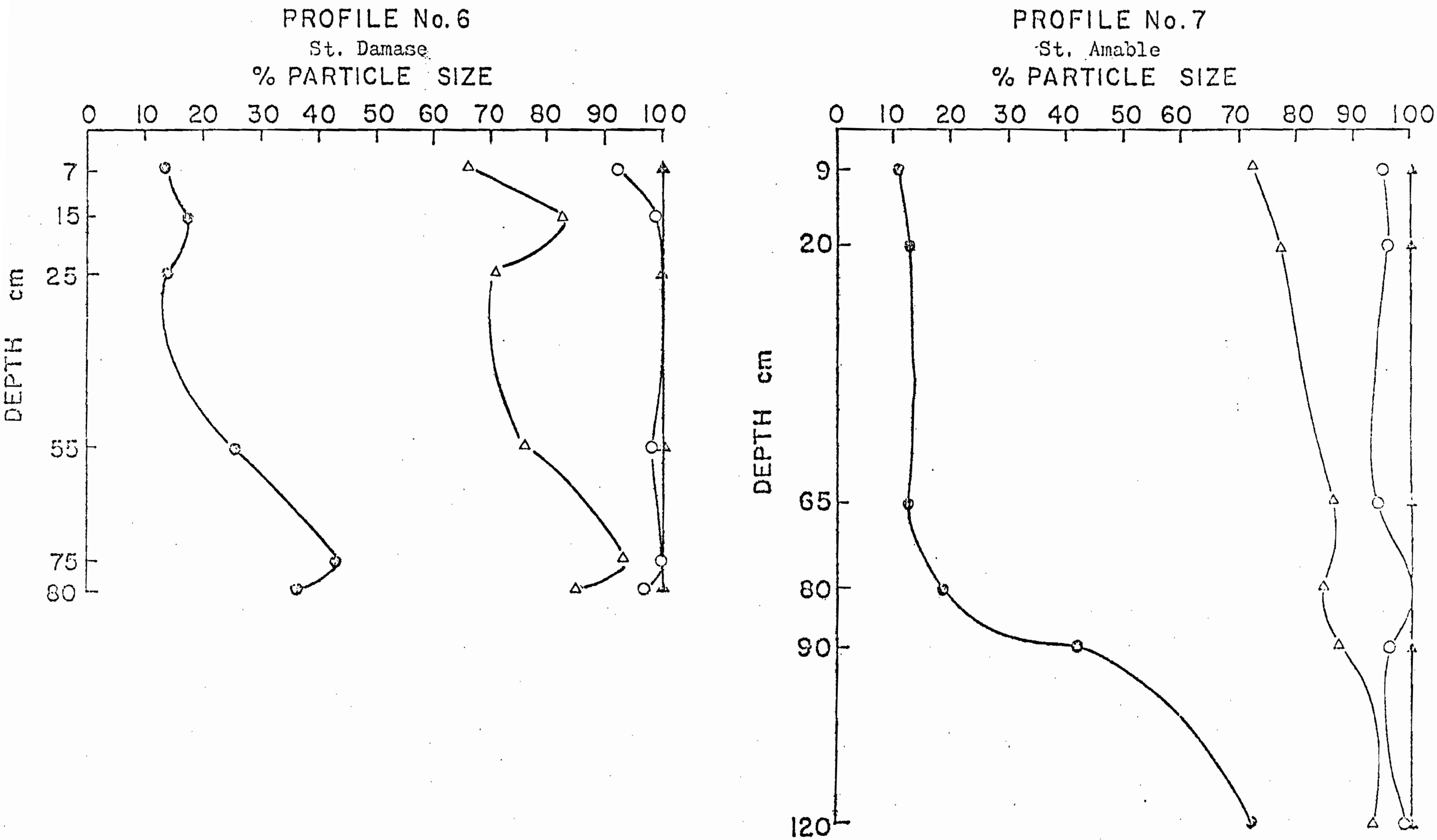

PROFILE No. 6
St. Damase
% PARTICLE SIZE
0 10 20 30 40 50 60 70 80 90 100
DEPTH cm
7
15
25
55
75
80
PROFILE No. 7
St. Amable
% PARTICLE SIZE
0 10 20 30 40 50 60 70 80 90 100
DEPTH cm
9
20
65
80
90
120

FIGURE 4.

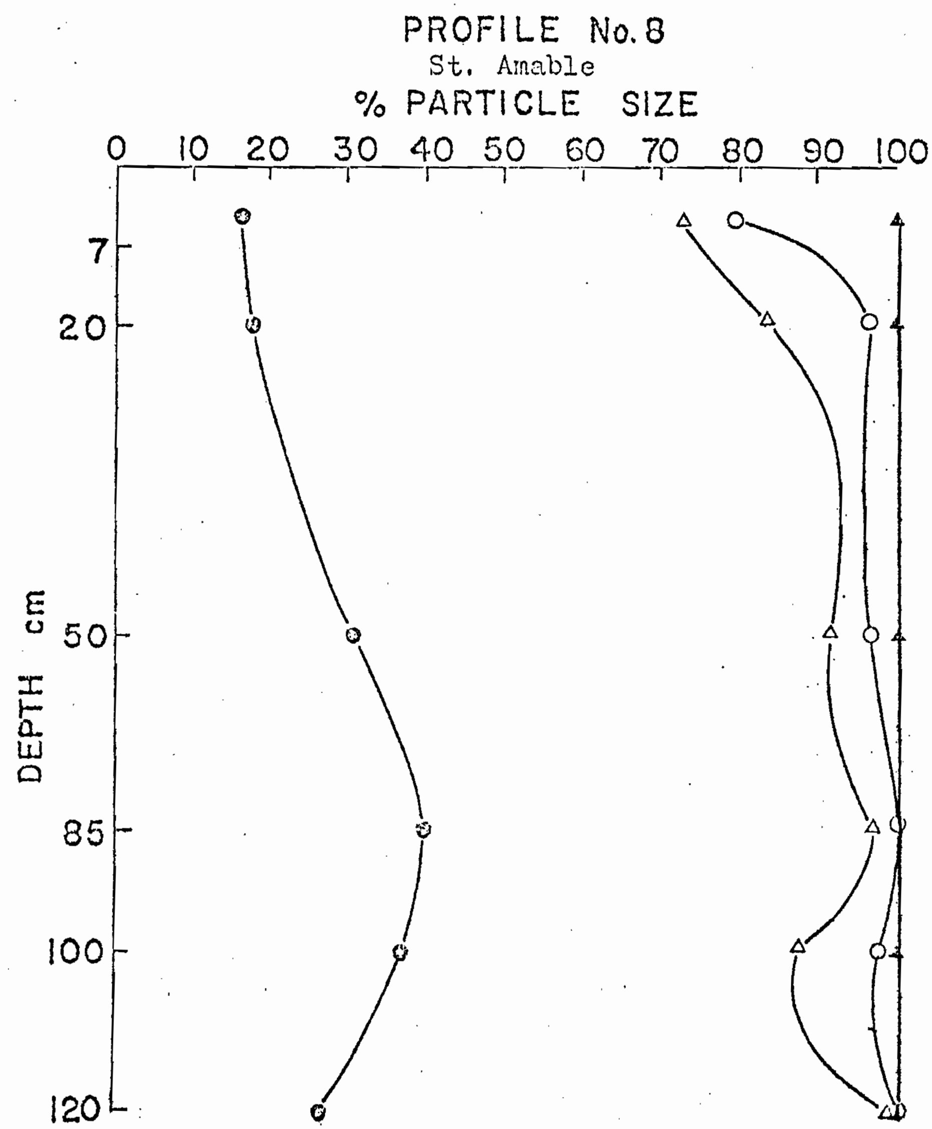

PROFILE No.8
St. Amable
% PARTICLE SIZE
0
10
20
30
40
50
60
70
80
90
100
DEPTH cm
7
20
50
85
100
120

FIGURE 5.

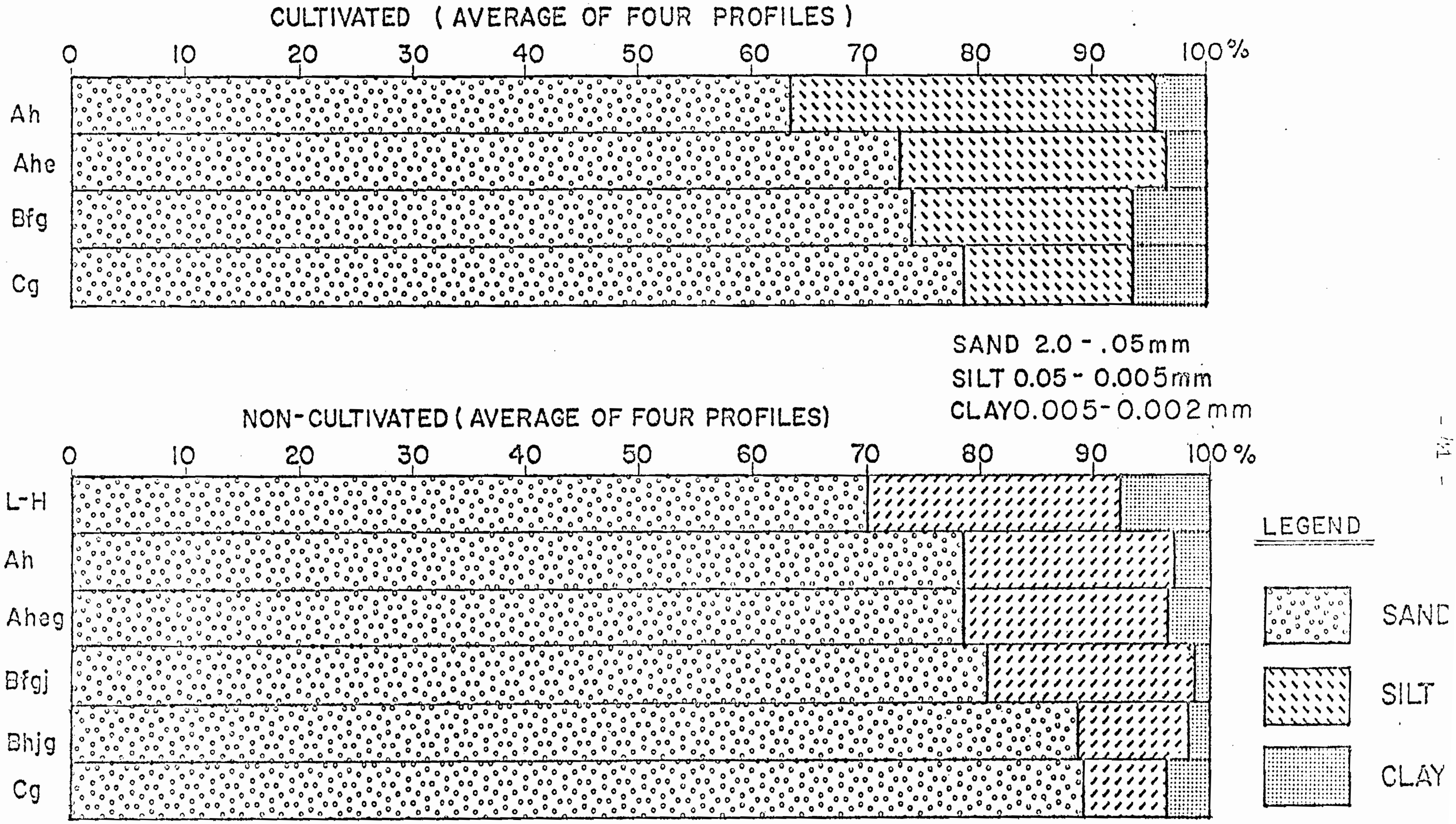
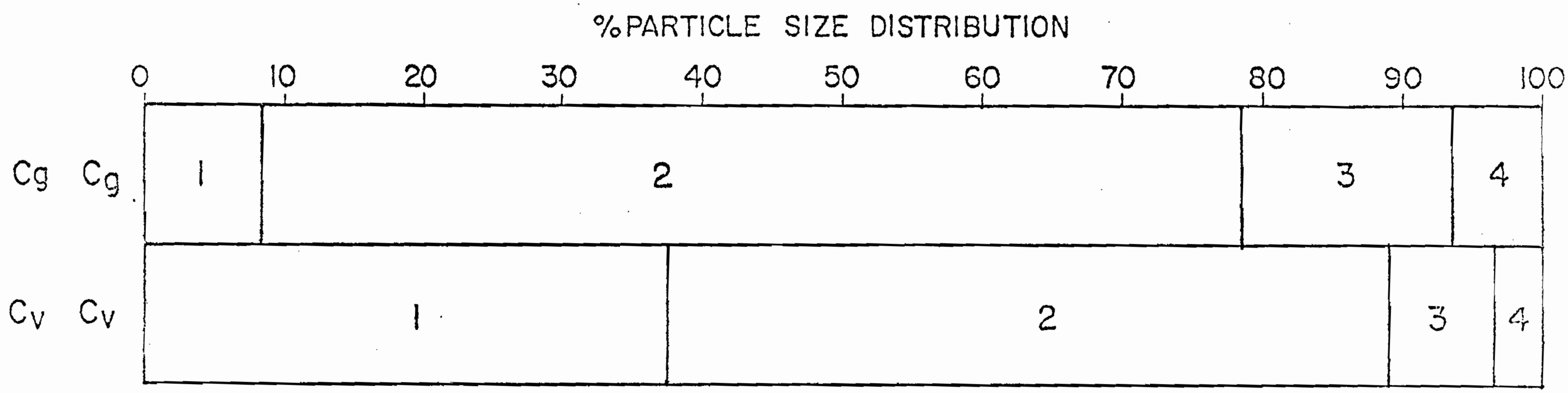


FIGURE 6: Average particle size distribution for the individual horizons of the cultivated and non-cultivated profiles. gms/100 gms of soil.



Cg = CULTIVATED C-HORIZON
Cv = NONCULTIVATED C-HORIZON

1. 2.0 mm - 0.2 mm
2. 0.2 - 0.05 mm
3. 0.05 - 0.005 mm
4. 0.005 - 0.001 mm

FIGURE 7 : Average particle size distribution within hardpan layer of the soils.

TABLE 2. Paired "t" analysis values comparing the effect of particle size distribution on agric formation.

Horizon		2.0 - 0.25	0.25 - 0.05	0.05 - 0.005	0.005 - 0.001
C	c	8.32	70.16	14.9^{T}	6.62^{*}
	v	37.50^{*}	51.5	7.65	3.35
B_2	c	12.20	61.61	19.44^{*}	6.43^{*}
B_2	v	37.96^{**}	50.67	8.68	2.72
B_1	c	8.88	64.24	23.17	3.72^{**}
B_1	v	27.07^{T}	53.89	18.74	0.81
B_o	c	11.5	51.18	31.22	5.25
B_o	v	19.84	58.74	17.82	3.6
C-B_2	c	8.32 : 12.2	70.16^{*}: 61.61	14.9 : 19.44^{T}	6.62 : 6.43
	v	37.50 : 37.96	51.5 : 50.67	7.65 : 8.68	3.35 : 2.72
C-B_1	c	8.32 : 8.88	70.16^{*}64.24	14.9 : 23.17^{T}	6.62^{*}: 3.72
	v	37.50 : 27.07	51.5 : 53.89	7.65 : 18.74^{*}	3.35^{**}: 0.81

c = cultivated soil

v = noncultivated soil

C = Indicates overlaying clay horizon

B_2 = Indicates overlaying C-horizon

B_1 = Indicates overlaying B_2-horizon

B_o = Indicates overlaying B_1-horizon

A_o = Indicates overlaying B_o-horizon

T = Indicates significant at 0.1 level (10%)

* = Indicates significant at 0.05 level (5%)

** = Indicates significant at 0.01 level (1%)

TABLE 2a. Summary of results of F test on particle size percentages of Ap and C horizons

	1.0-0.5 mm	0.5-0.25 mm	0.25-0.1 mm	0.1-0.05 mm	0.05-0.02 mm	0.02-0.05 mm	0.05-0.005 mm
Comparison for C-horizons between groups (cultivated and non-cultivated soil profiles)	N.S.	N.S.	N.S.	N.S.	N.S.	**	*
Comparison for C-horizons within groups (cultivated and non-cultivated soil profiles)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Comparison for Ap horizon between groups (cultivated and non-cultivated soil profiles)	*	N.S.	*	N.S.	*	*	N.S.
Comparison for Ap horizon within groups (cultivated and non-cultivated soil profiles)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

N.S. = non-significant at 0.05 (5%) level

* = significant at 0.05 (5%) level

** = significant at 0.01 (1%) level

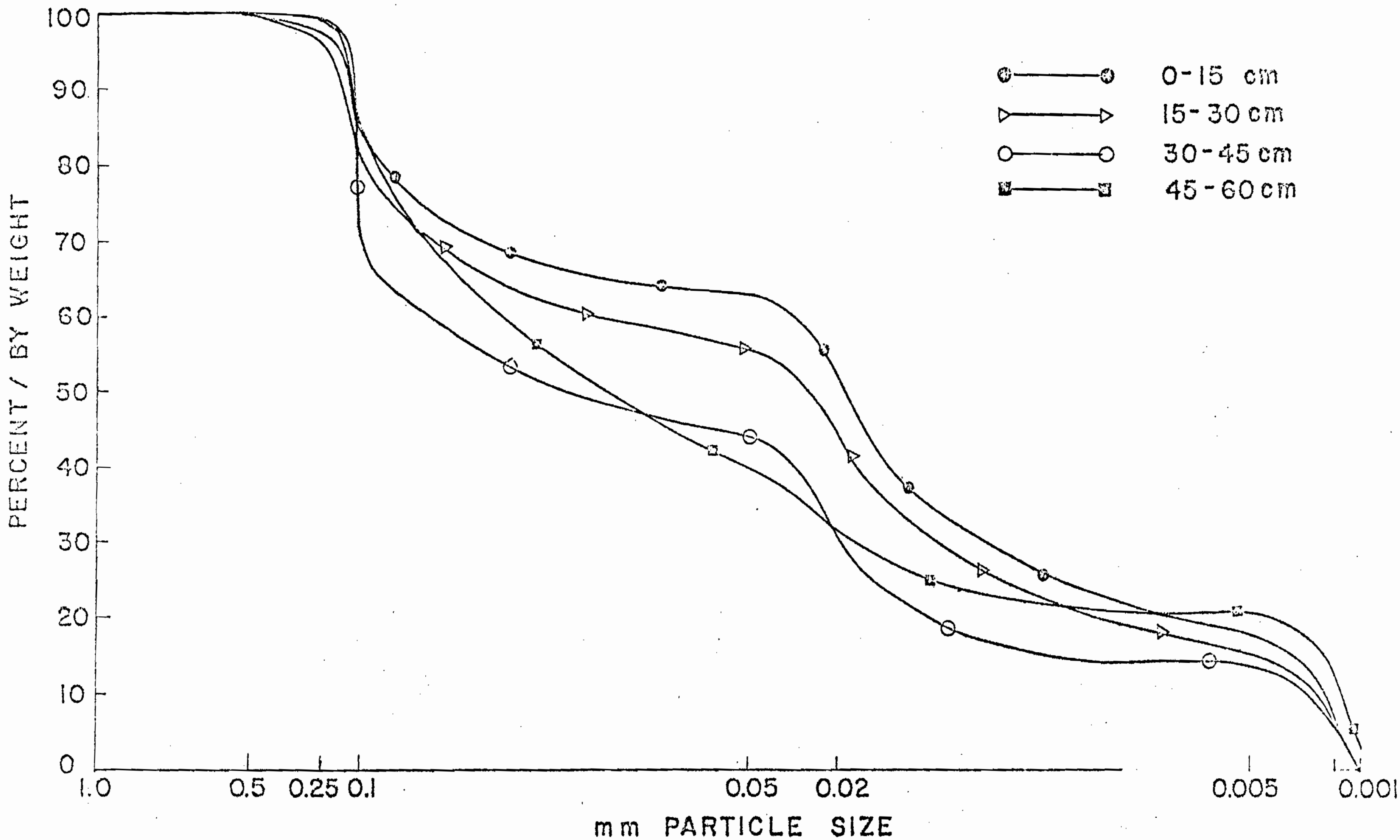


FIGURE 8 : Particle size distribution curves. St. Damase soil. Profile No.1.

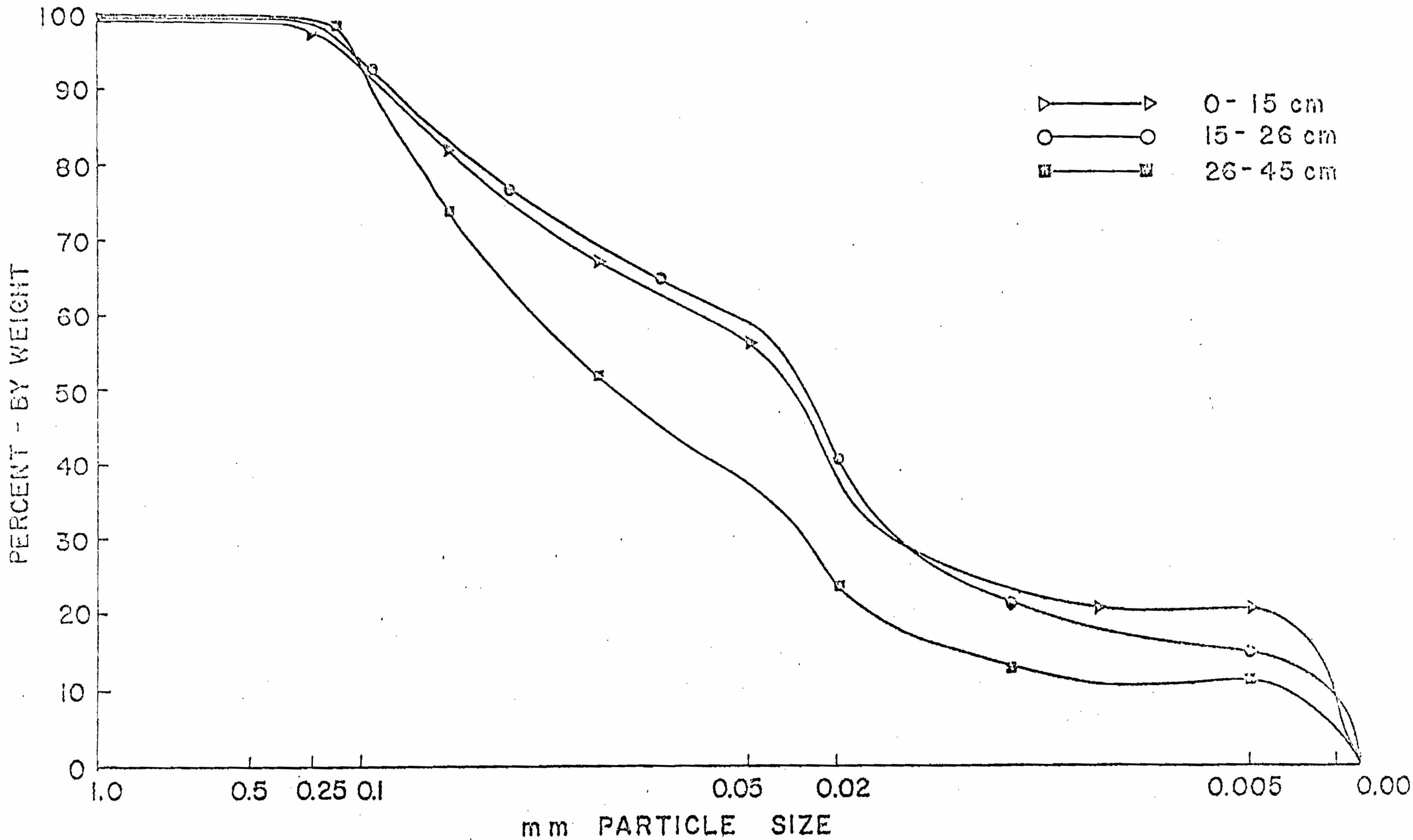


FIGURE 9 : Particle size distribution curves. St. Damase soil. Profile No.2.

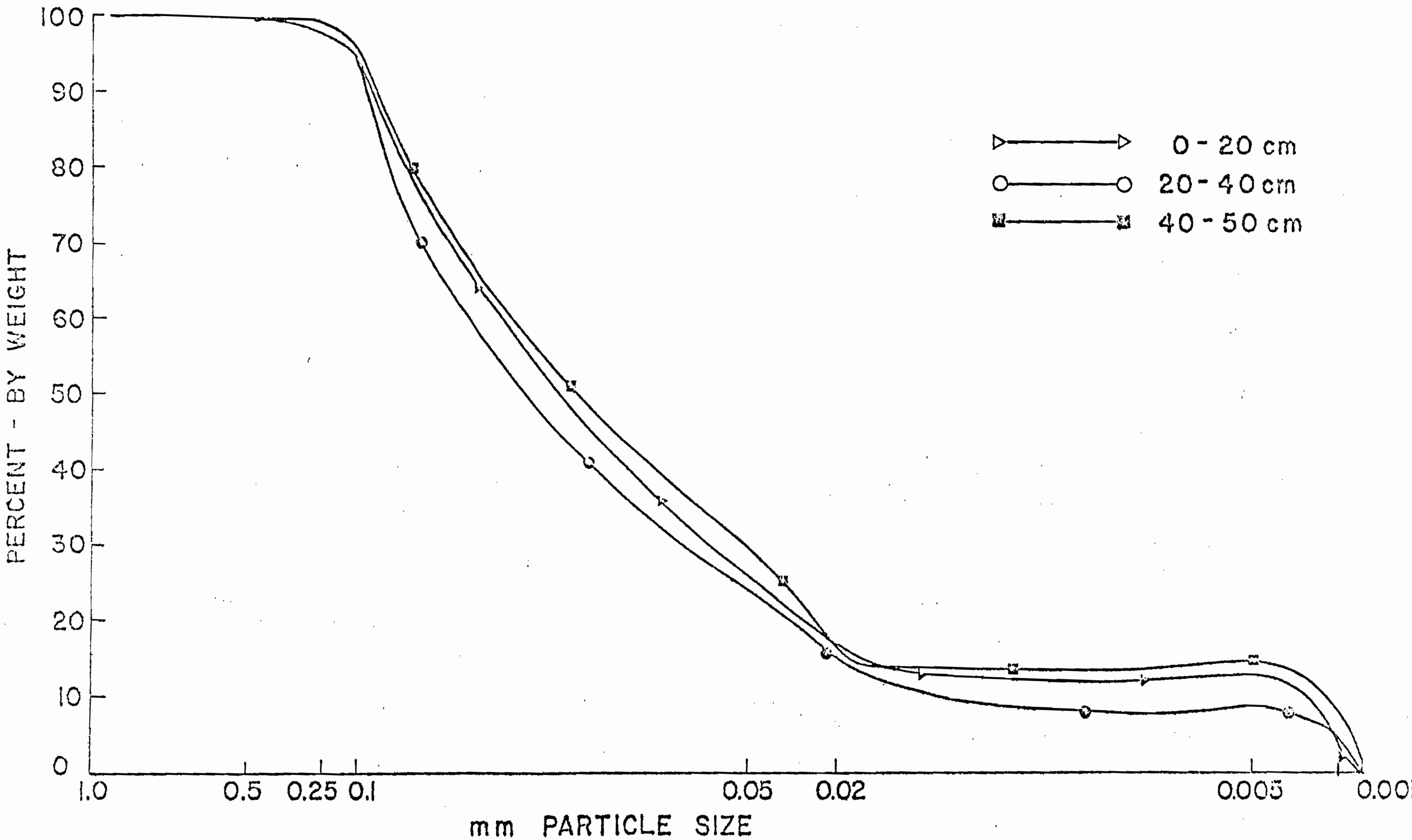


FIGURE 10: Particle size distribution curves. St. Damase soil. Profile No.3.

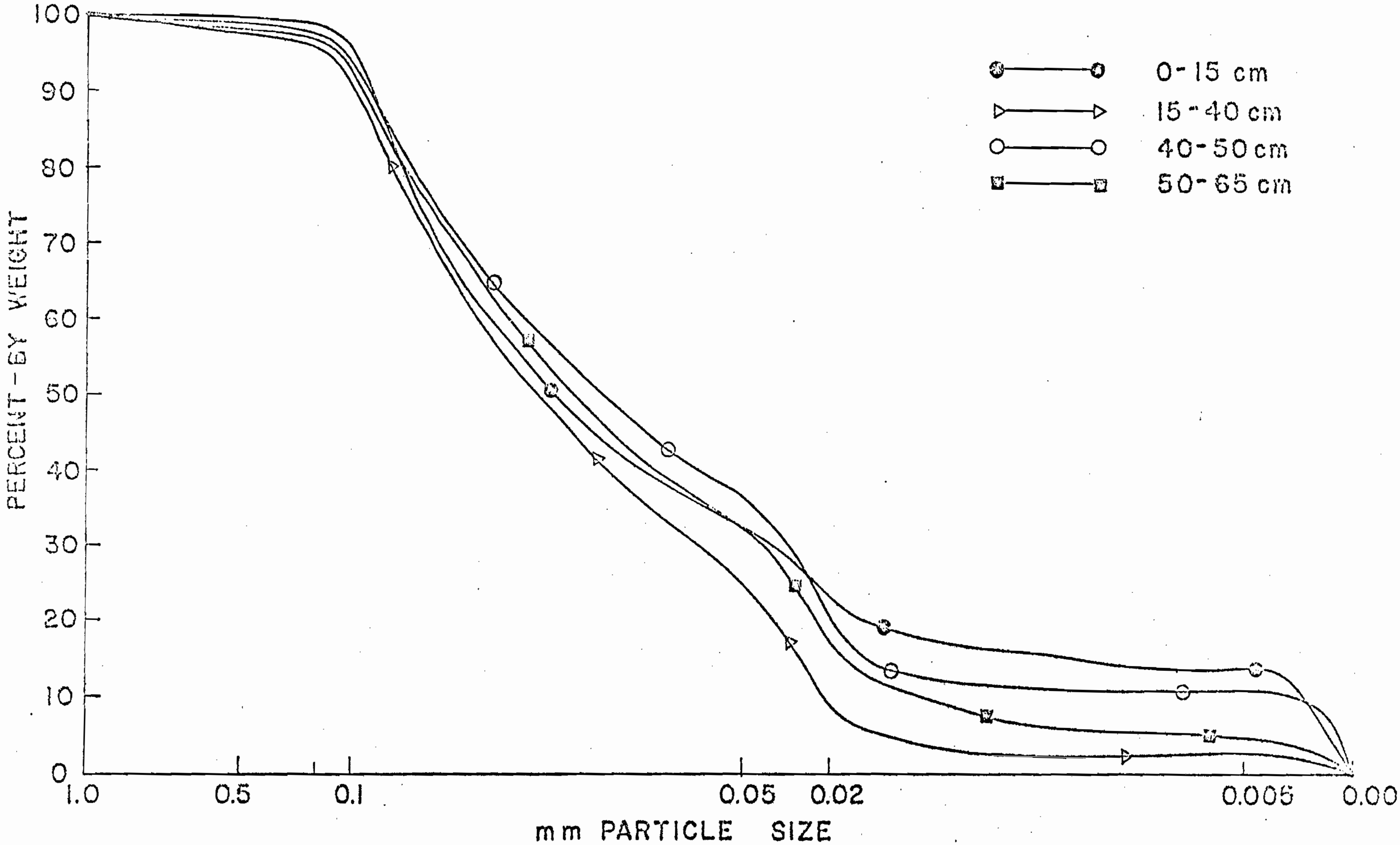


FIGURE 11 : Particle size distribution curves. St. Damase soil. Profile No. 4.

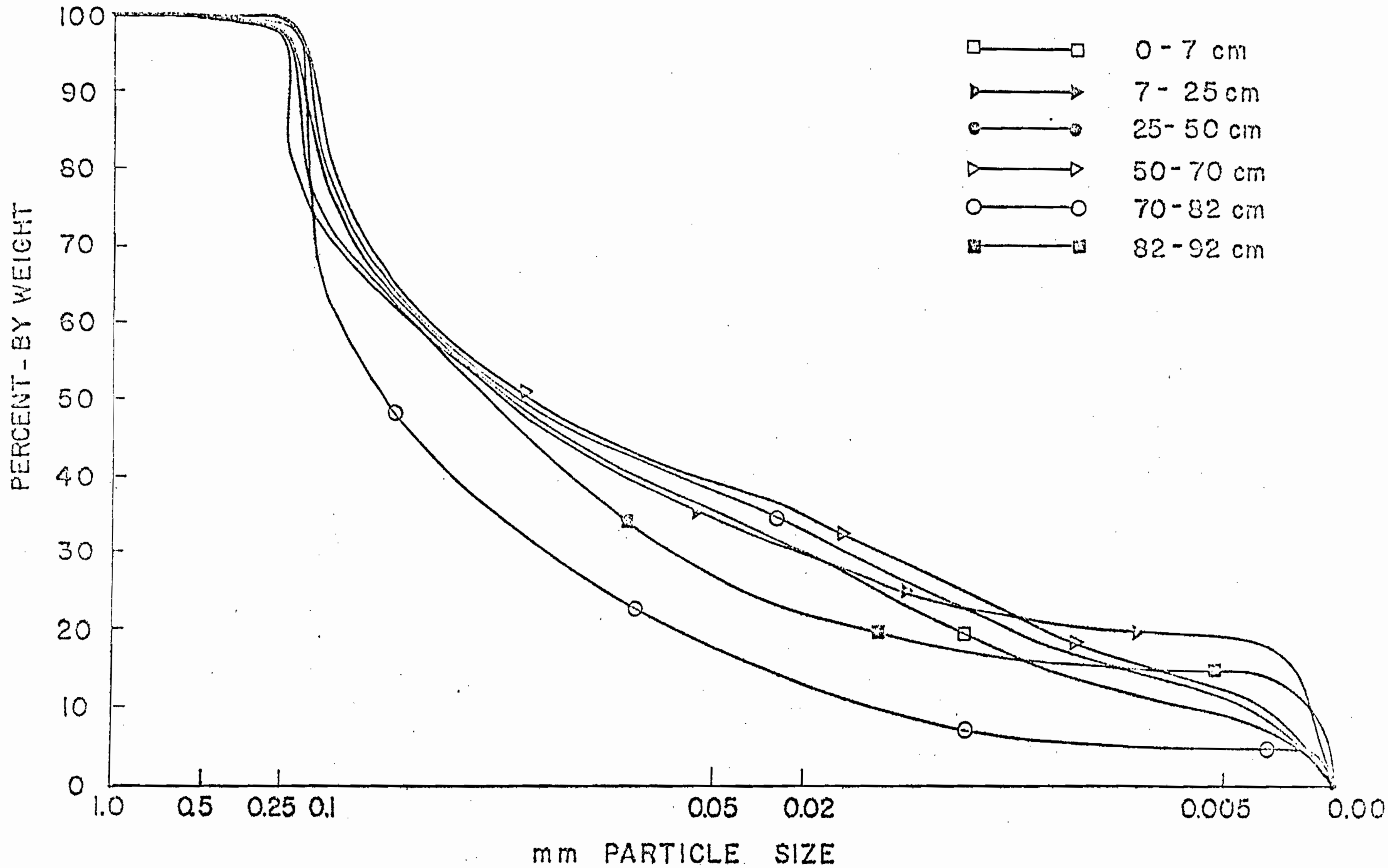


FIGURE 12 : Particle size distribution curves. St. Damase soil from Morgan Arboretum, Profile No. 5.

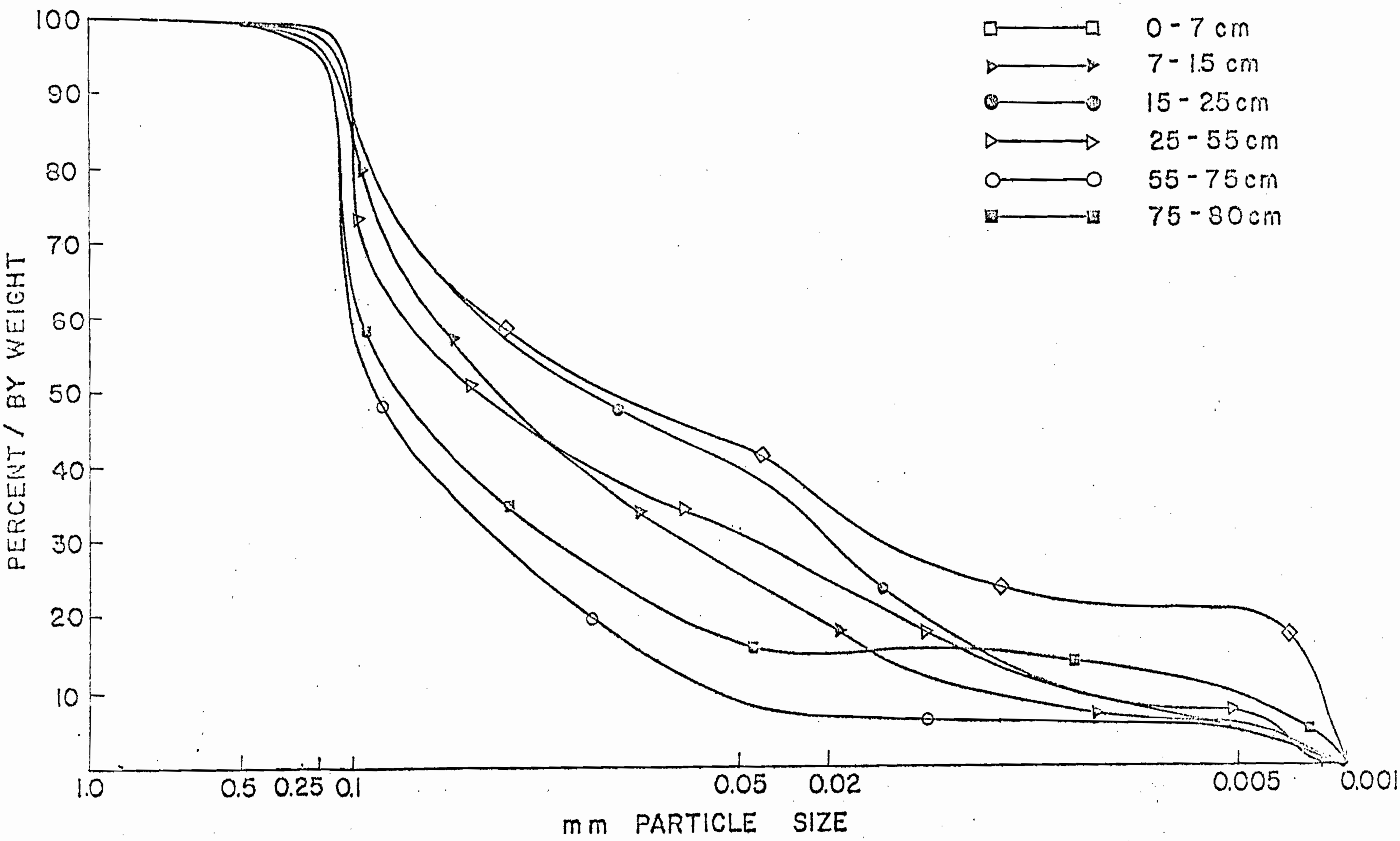


FIGURE 13: Particle size distribution curves, St. Damase soil from Morgan Arboretum. Profile No.6.

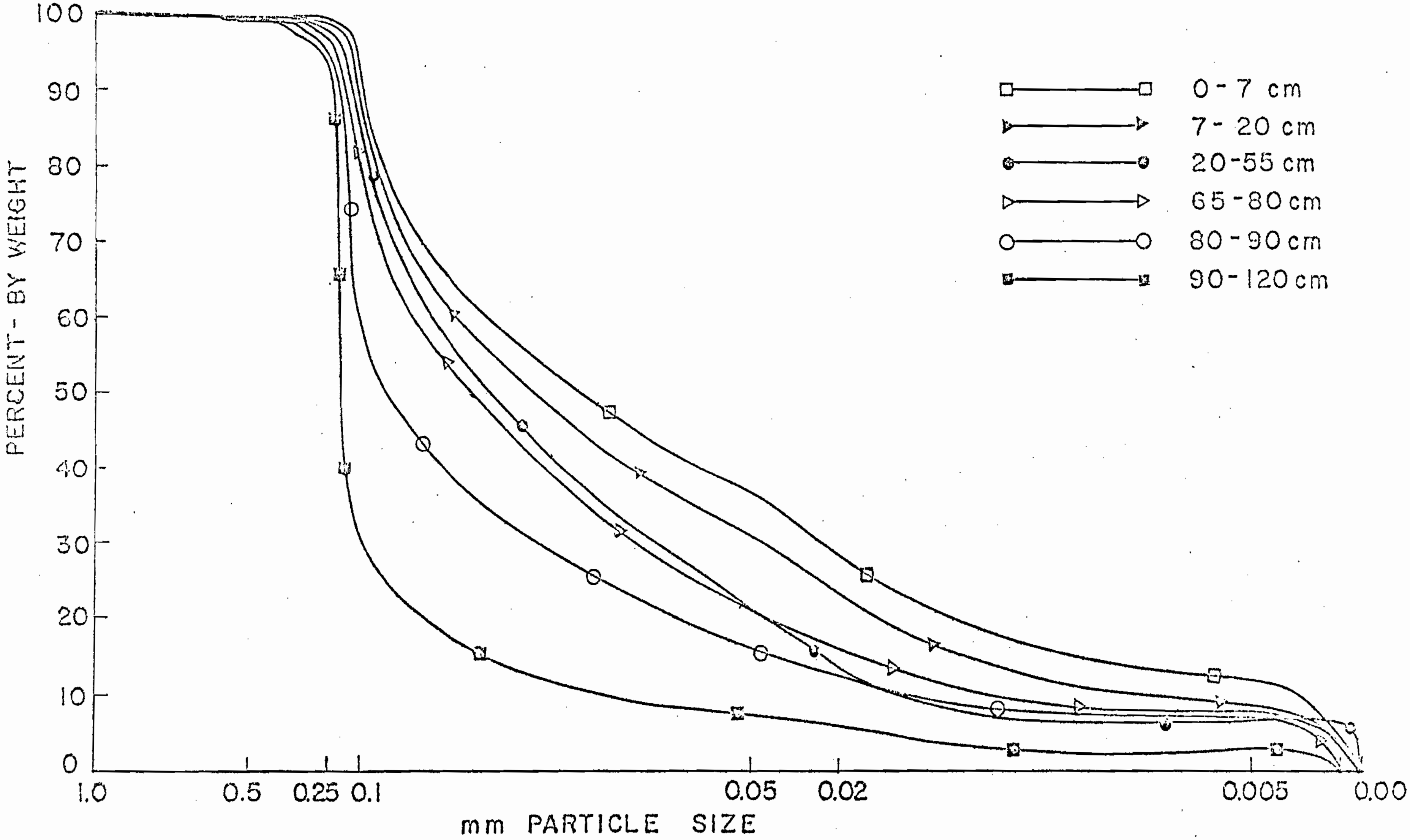


FIGURE 14: Particle size distribution curves. St. Amable soil from Morgan Arboretum. Profile No.7.

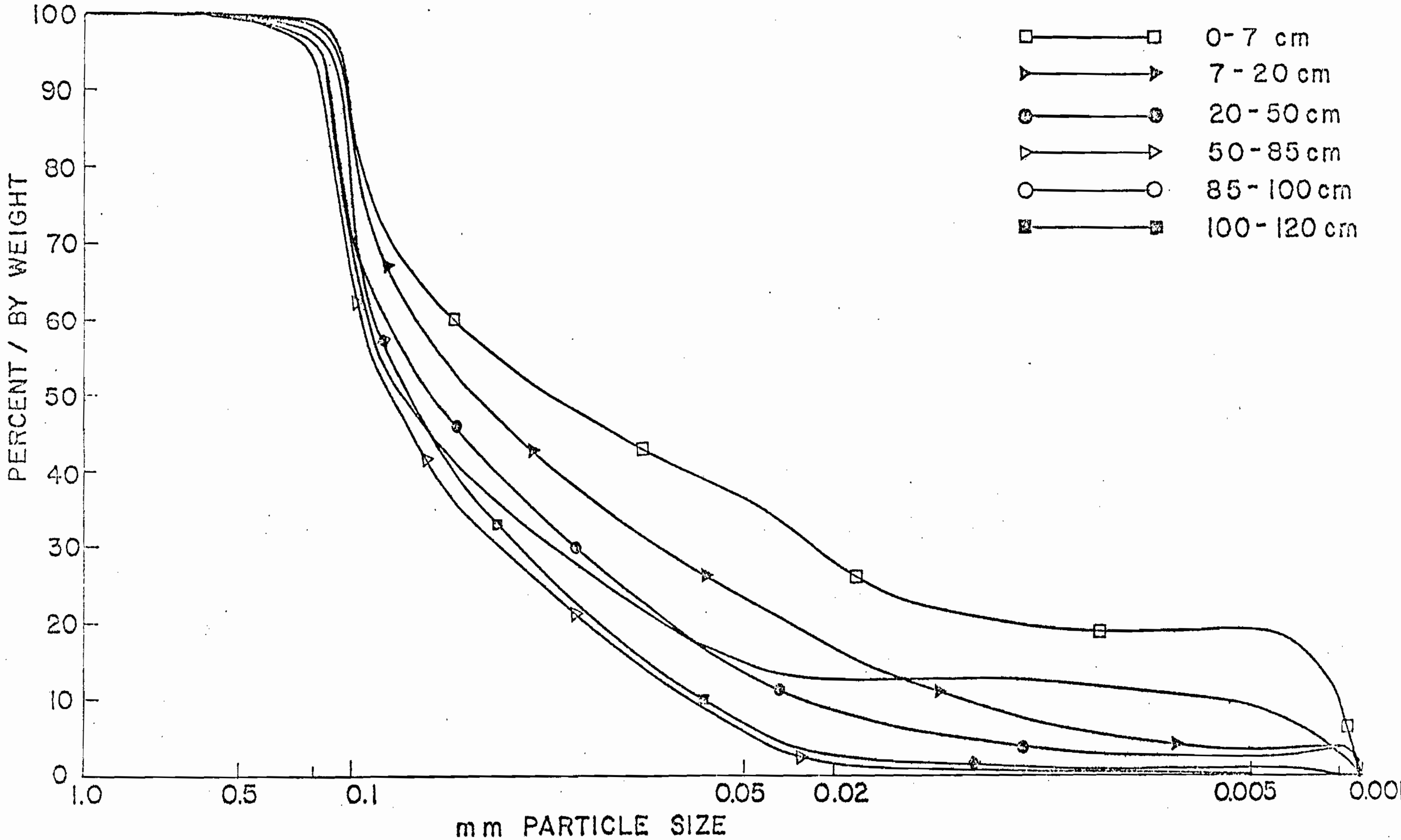


FIGURE 15: Particle size distribution curves. St. Amable soil from Morgan Arboretum, Profile No.8.

Conversely, paired t-test analyses conducted on results of cultivated profiles indicate significant decreases (0.05 probability) in the soils having 34 to 50% of particle size range ($>$ 0.05 mm); whereas those with particle sizes $<$0.05 mm there is a significant increase in the Cg horizon.

These phenomena of particle size distribution could be explained by one or all of the following phenomena:-

(1) fine particles could be moved from the surface horizon to the lower horizons, and

(2) this process could have been accelerated by cultivation. The reasons for the accelerated rate of movement in the cultivated profile could be associated with:

(a) an increase in the volume of water percolating through the cultivated profiles;

(b) an accelerated breakdown of aggregates and coarse particles in the surface soil as a result of cultivation which, according to Baver (1965), results in the release of fine and very fine particles. The particles could then be carried by gravity water to the lower horizons.

The increase in the breakdown of soil aggregates as a result of cultivation could be attributed to:

i. Exposure of surface aggregates, by removing the protective humus layer, to the direct impact of raindrops.

ii. Increased risk of rapid freezing, thawing, drying and wetting, which tend to break down soil aggregates (Marshall, 1959).

iii. Shearing of aggregates by humans, animals, and machinery.

iv. Accelerated rate of weathering due to increase in surface soil temperature, resulting from land clearing.

The concentration of clay or the appearance of clay particles in the B and/or C horizons has been attributed to the presence of chemical components such as Al, Fe, Si, etc. (Blume, 1969; Kodama, 1973; and Guitian, 1974), and its magnitude in the soil surface.

Two actions, other than leaching and weathering, could bring differences between agric (Cg-horizon) and upper horizons without any gains or losses actually taking place. These are the artificial increase or decrease in the percentage of one or more size separates resulting from changes in other size separates within a horizon, and an artificial decrease of all size separates due to an expansion of the soil lattice during profile development. This could occur especially in the Bfh horizons which show a very loose and open structure.

5.1.3 Bulk density and total porosity

Bulk density and total porosity values for the individual layers of each profile appear in Appendix 1, while Table 3 lists the mean bulk density and total porosity values for cultivated and non-cultivated soil profiles.

It is noteworthy that two cultivated profiles, No.2 and No.3 (in Appendix 1) show a trend toward a definite increase in bulk density in an agric layer. This characteristic was also evident in all non-cultivated profiles.

In cultivated profiles 1 and 4 (Appendix 1) the rate of change in bulk density was constant throughout the profile. Paired t-test analyses, comparing the indurated horizon (C) with all upper horizons, indicates that there is no significant increase in bulk density except with the surface layer (Table 3). The mean of bulk density values of the agric was significantly (0.05 probability level)

TABLE 3. "t" test of significance of mean values indicating changes in the profile associated with induration in cultivated and non-cultivated soils

Horizon		Bulk Density gram/cc	Particle Density gram/cc	Total Porosity % volume
C	c	1.47	2.52	41.42
C	v	1.51	2.54	40.69
B_2	c	1.38	2.47	42.89
B_2	v	1.44	2.42	40.16
B_1	c	1.29	2.43	46.98
B_1	v	1.37	2.35	41.71
B_o	c	1.21	2.37	48.75
B_o	v	1.28	2.35	45.58
C-B_2	c	1.47 : 1.38	2.52 : 2.47	41.42 : 42.89
C-B_2	v	1.51 : 1.44	2.54* : 2.42	40.69 : 40.16
C-B_1	c	1.47 : 1.29	2.52 : 2.43	41.42 : 46.98
C-B_1	v	1.51 : 1.37	2.54T : 2.35	40.69 : 41.71
C-B_o	c	1.47* : 1.21	2.52 : 2.37	41.42T : 48.75
C-B_o	v	1.51* : 1.28	2.54T : 2.35	40.69 : 45.58

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C = Indicates layer overlaying clay layer

B_2 = Indicates layer overlaying C-horizon

B_1 = Indicates layer overlaying B_2-horizon

B_o = Indicates layer overlaying B_1-horizon

A = Indicates layer overlaying B_o-horizon greater than the bulk density of the A-horizon.

The above data indicate that bulk density may vary through the profile, due to either a varying particle size distribution among different layers, or a different arrangement of the soil particles (i.e. due to differential soil compaction), or to a combination of both effects (Baver, 1965).

Consequently, any increase in bulk density should be accompanied by a corresponding decrease in total porosity, and vice versa.

The occurrence of a hard B-layer in the cultivated soils could be due to the mode of deposition of materials or to the effect of cultivation of the soil. This coincides with the occurrence of a firm layer which could be due to differential induration of similar material, and not due to differences in bulk density and/or total porosity.

5.1.4 Particle density

The values of the change in particle density with depth for each horizon of each profile are given in Appendix 1.

The data (Table 3) indicate that the rate of change in particle density with depth was constant throughout all cultivated profiles; i.e. all increases or decreases in particle density were non-significant (0.05 probability level), but paired t-test analysis indicates a significant increase (0.10 probability level) in particle density of the C horizon with respect to the B_2 horizon, and a significant increase (0.05 probability level) in the particle density of the C horizon with respect to the B_1 horizon, in all non-cultivated profiles. This is most likely associated with the particle sorting throughout the profile, discussed previously in section 5.1.1.

5.1.5 Penetration resistance

Maximum values of penetration resistance, or penetration load, in kilogram/cm^2 for all profiles appear in Appendix 1. Table 4 lists the mean of penetration resistance values for cultivated and non-cultivated soil profiles.

Paired t-test analyses indicate a significant increase (0.10 probability level) between B_2 and C horizons of cultivated soil, but show no significance between the C and other upper horizons. This could be due to dryness of soil surface during the measurements.

On the other hand, t-test analyses show a significant increase (0.05 probability level) in resistance in the C horizons of cultivated soils when compared against the non-cultivated soils. The same relationship was evident when comparing the B_2 horizons of these soils. The bearing capacity tests indicate the formation of a hard agric horizon overlaying the clay layer in the soil profile, associated with an accumulation of, and compaction of, fine particles. Hence, penetration resistance of the sub-surface material can be correlated, in a general way, with physical properties. It is possible, however, that it could be caused by deposition of mineral or chemical materials.

5.1.6 Liquid limit and plastic limit

Values of liquid limit and plastic limit (Atterberg Limits) for all profile horizons are given in Appendix 1, and illustrate marked changes throughout the profile. Table 5 gives the t-test of significance of mean values for Atterberg Limits in cultivated and non-cultivated soil profiles.

Paired t-test analyses (Table 5) indicate that cultivation significantly decreased (0.05 probability level) the liquid limit of the

TABLE 4. "t"-test of significance of mean values indicating changes in the profile associated with induration in cultivated and non-cultivated soils

Horizon		Penetration Resistance (Bearing Capacity) (Kg/cm^2)
C	c	18.92*
C	v	16.73
B_2	c	17.63T
B_2	v	16.08
B_1	c	13.74
B_1	v	15.27
$C-B_2$	c	18.92T - 17.63
$C-B_1$	c	18.92 - 13.74
$C-B_2$	v	16.73* - 16.08
$C-B_1$	v	16.73 - 15.27
B_2-B_1	c	17.63 - 13.74

T = Significant at 0.1 (10%)level

* = Significant at 0.05 (5%) level

** - Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C = Indicates layer overlaying clay layer

B_2 = Indicates layer overlaying C-horizon

B_1 = Indicates layer overlaying B_2-horizon

B_o = Indicates layer overlaying B_1-horizon

TABLE 5. "t"-test of significance of mean values of Atterberg Limits, indicating changes in the profile associated with induration in cultivated and non-cultivated soils.

Horizon		Liquid Limit %	Plastic Limit %
C	c	19.9	19.1
C	v	23.15*	22.29*
B_2	c	18.53	15.5
B_2	v	23.58	22.29
B_1	c	23.32	22.71
B_1	v	22.15	21.41
B_o	c	27.0	26.75
B_o	v	15.53	11.99
$C-B_2$	c	19.9 : 18.53	19.1 : 15.5
$C-B_1$	c	19.9 : 23.32	19.1 : 22.71
$C-B_2$	v	23.15 : 23.58	22.29 : 21.41
$C-B_1$	v	23.15 : 22.15	22.29 : 11.99
B_2-B_1	c	18.53 : 23.32	15.5 : 22.29

T = Significant at 0.1 (10%) level
* = Significant at 0.05 (5%) level
** = Significant at 0.01 (1%) level
c = cultivated soil
v = non-cultivated soil
C = Indicates layer overlaying clay layer
B_2 = Indicates layer overlaying C-horizon
B_1 = Indicates layer overlaying B_2-horizon
B_o = Indicates layer overlaying B_1-horizon
A = Indicates layer overlaying B_o-horizon

C-horizons when compared with the non-cultivated soils. Moreover, the lack of significant decrease (0.05 probability level) in liquid limit among the C and all other horizons of cultivated soils, indicates the uniformity of this characteristic throughout the cultivated soil profiles. This is related to the adequate amount of fine fractions contained in these horizons and to the degree of soil compaction within cultivated soils.

Exchangeable ions (i.e. Na, Al, Fe, SiO_2, etc.) can play an important role in water adsorption, and hence increase both the liquid and plastic limit to some extent (Bear, 1965; Warkentin, 1975). The increase in Atterberg characteristics for sandy soils, which is approximately 16%, could be due to the increase in fine particles, to chemical components, and/or to fibrous organic particles which have the same effect as porous grains.

5.2 CHEMICAL ANALYSIS

5.2.1 Soil reaction (pH)

Values of soil pH for all profiles are presented in Appendix 2. pH values, which change with depth in the soils, indicate acidity in all profiles. Table 6 lists t-test of significance for mean values of pH and Cation Exchange Capacity in cultivated and non-cultivated soil profiles. Paired t-test values indicate that pH values increase with soil profile depth in both cultivated and non-cultivated profiles. pH differences between the B and C horizons of cultivated soils were non-significant, but a significant (0.05 probability level) increase in pH occurred between the A and C horizons. pH differences between C horizons of cultivated and non-cultivated soil were non-significant.

TABLE 6. "t"-test of significance of mean values indicating changes in pH and exchangeable properties of the soils

Horizon		C. E. C. meq/100 gm soil	pH	pH-dependent C.E.C. meq/100 gm soil
C	c	22.27*	5.17	24.1*
C	v	5.18	5.39	10.3
B_2	c	16.10*	4.99	23.43
B_2	v	4.25	5.22	16.93
B_1	c	38.21T	4.97	27.61
B_1	v	11.35	4.95	18.39
B_o	c	57.1	5.15**	32.2T
B_o	v	23.20	4.47	20.65
$C-B_2$	c	22.27 : 16.10	5.17 : 4.99	24.1 : 23.43
$C-B_1$	c	22.27 : 38.21	5.17 : 4.97T	24.1 : 27.61
$C-B_2$	v	5.18 : 4.25	5.39 : 5.22	10.3 : 16.93
$C-B_1$	v	5.18 : 11.35	5.39 : 4.95T	10.3 : 18.39
B_2-B_1	c	16.10 : 38.21	4.99 : 4.97	23.43 : 27.61

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level)

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

A Indicates layer overlaying B_o-horizon

C.E.C. = Cation exchange capacity

This increase in soil pH values in the sub-surface horizons, particularly in overlaying clay layers (strata) could be due to the leaching and mobilization of soil surface components and their segregation and precipitation within these horizons.

5.2.2 Cation exchange capacity

Values of cation exchange capacity (CEC) for individual profiles on a meq/100 gram soil basis, are shown in Appendix 2. Table 6 lists the t-tests of significances for mean values of CEC measurements in cultivated and non-cultivated soil profiles.

The paired t-tests indicate marked increases (but non-significant at the 0.10 probability level) in CEC values of C-horizons compared with B-horizons of cultivated soils, however decreases (also non-significant at the 0.10 probability level) occurred in the C-horizon when compared to the A-horizon. On the other hand, B- and C-horizons of cultivated soils have CEC values significantly (0.05 probability level) higher than the corresponding horizons in non-cultivated soils.

This characteristic of the soil is associated with organic matter contents and fine particle deposition in the C-horizon (hardpan layer) overlying the clay strata.

5.2.3 pH-dependent CEC (ΔCEC)

Values of pH-dependent CEC (Δ CEC) for the individual profiles, on a meq/100 gram soil basis, appear in Appendix 2, while Table 6 lists "t"-test of significance of mean values of Δ CEC (pH-dependent CEC) in cultivated and non-cultivated soil profiles. Paired t-test analyses indicate a marked increase in value (but statistically non-significant at the 0.10 probability level) in the C-horizon (agric horizon) compared with the upper layers in cultivated soils. In the case of non-cultivated soils, a marked decrease (but statistically non-significant at the 0.10 probability level) was observed in the C horizon. On the other hand pH-dependent cation exchange capacity values in cultivated C-horizons show significant increases (0.05 probability level) when compared to C-horizons of non-cultivated soils.

5.2.4 Extractable potassium

Values of extractable potassium appear in Appendix 2, while Table 7 lists the "t"-test of significance of mean values of extractable potassium in cultivated and non-cultivated soil profiles. Paired t-tests indicate significant (0.05 probability level) increases in exchangeable K in the cultivated C-horizons compared with non-cultivated C-horizons. This increase in exchangeable potassium may be due to fertilizer practices and/or to the presence of the crystalline structure of primary and secondary minerals such as micas, feldspar, and the micaceous minerals of the clay fraction.

5.2.5 Extractable calcium

Values of extractable calcium for individual profiles appear in Appendix 2, while Table 7 lists the "t"-test of significance of mean values of extractable calcium in cultivated and non-cultivated soil profiles. Paired t-test analyses indicate marked increased in calcium in the C-horizons of both cultivated and non-cultivated soils. Differences in extractable Ca levels in all horizons of cultivated soils were non-significant, whereas C-horizons in non-cultivated profiles showed a significant (0.05 probability level) increase in calcium content compared to all other horizons.

This increase could play an important role in increasing the Atterberg Limits for horizons of non-cultivated profiles compared with

TABLE 7. "t"-test of significance of mean values indicating changes in alkali and alkaline earth cations content of the soils

Horizon		K ppm	Ca ppm	Mg ppm
C	c	12.25^{*}	32.0	5.8
C	v	3.05	21.00	3.7
B_2	c	8.2^{*}	21.33^{T}	3.85
B_2	v	2.21	8.55	0.87
B_1	c	11.95^{**}	43.38^{***}	4.8^{*}
B_1	v	2.45	5.88	0.69
B_o	c	14.15^{***}	83.75^{***}	10.95^{**}
B_o	v	1.862	3.8	0.60
$C\text{-}B_2$	c	12.25 : 8.2	32.0 : 21.33	5.8 : 3.85
$C\text{-}B_1$	c	12.25 : 11.95	32.0 : 43.38	5.8 : 4.8
$C\text{-}B_2$	v	3.05 : 2.21	21.0^{T}: 8.55	3.7 : 0.84
$C\text{-}B_1$	v	3.05 : 2.45	21.0^{*}: 5.88	3.7 : 0.69
$B_2\text{-}B_1$	c	8.2 : 11.95	21.33 : 43.38	3.85 : 4.8

T = Significant at 0.1 (10% level)

* = Significant at 0.05 (5% level)

**= Significant at 0.01 (1%) level)

*** = Significant at 0.001 (.1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

A Indicates layer overlaying B_o-horizon similar ones in cultivated profiles.

5.2.6 Extractable magnesium

Values of extractable magnesium for individual profiles are listed in Appendix 2. Extractable magnesium changes with depth of soil profiles. Table 7 lists the "t"-test of significance of mean values of extractable magnesium in cultivated and non-cultivated soil profiles. A marked increase in levels of extractable Mg occurs in the C-horizon of both soils, which was not statistically significant (0.10 probability level). A comparison of the C-horizons of cultivated and non-cultivated soils indicates that differences in the levels of extractable Mg were non-significant statistically (0.10 probability level).

5.2.7 Extractable phosphorous

Values of extractable phosphorous for individual profiles appear in Appendix 2. Extractable phosphorous was found to decrease with depth. Table 8 lists the "t"-test of significance of mean values of extractable phosphorous in cultivated and non-cultivated soil profiles. Paired t-tests indicate no statistically significant differences (0.10 probability level) between C-horizons of cultivated and non-cultivated soils. Extractable phosphorous in the C-horizons of cultivated soils was significantly (0.05 probability level) decreased when compared to the upper horizons, however this phenomenon was not evident in non-cultivated soils.

5.2.8 Total nitrogen

Values of total nitrogen (in percent) for individual profiles are given in Appendix 2. Table 8 lists the "t"-test of significance of mean values of total nitrogen in cultivated and non-cultivated soil profiles. Paired t-tests indicate a marked but statistically non-significant

TABLE 8. "t"-test of significance of mean values indicating changes in phosphorous and total nitrogen content in the soils

Horizon		P_2O_5 ppm	Total Nitrogen %
C	c	5.51	0.023
C	v	4.18	0.005
B_2	c	8.05	0.017*
B_2	v	5.54	0.007
B_1	c	13.33T	0.002
B_1	v	6.73	0.02
B_o	c	18.5 *	0.16T
B_o	v	5.19	0.05
$C-B_2$	c	5.51 : 8.05	0.023 : 0.017
$C-B_1$	c	5.51 : 13.33*	0.023 : 0.02
$C-B_2$	v	4.18 : 5.54	0.005 : 0.007
$C-B_1$	v	4.18 : 6.73	0.005 : 0.02
B_2-B_1	c	8.05 : 13.33	0.007 : 0.02

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

increase in the content of total nitrogen in C-horizon of cultivated soils when compared with non-cultivated C-horizons. Marked increases (non-significant at the 0.10 probability level) were observed in the percent total nitrogen of the C-horizon when compared to the B_1- and B_2-horizons of cultivated soils. However, in non-cultivated soils, a marked decrease (non-significant at the 0.10 probability level) was evident when comparing the C- to the B_1- and B_2-horizons.

5.2.9 Organic matter content

Values of percent organic matter in the individual profiles are given in Appendix 2, while Table 9 lists the "t"-test of significance of mean values of fulvic acid in cultivated and non-cultivated soil profiles. Paired t-tests indicate that the content of organic matter decreases with depth. A marked increase in percent organic matter in the cultivated C-horizon was evident when compared to the non-cultivated C-horizon, however this increase was statistically non-significant (0.10 probability level).

5.2.10 Fulvic acid

Values of percent fulvic acid in the individual profiles are given in Appendix 2, while Table 9 lists the "t"-test of significance of mean values of fulvic acid in cultivated and non-cultivated soil profiles. Paired t-tests indicate a significant increase in the content of fulvic acid in the C-horizons of cultivated soils when compared to the A- and B-horizons (0.05 and 0.10 probability levels), respectively. It also indicates a highly significant (0.01 probability level) increase in the contents of C-horizons of non-cultivated soils when compared to the A- and B-horizons. Comparison of the fulvic acid levels in the C-horizons of cultivated and non-cultivated soils indicates that significant (0.1 probability) level differences do not exist between the two groups.

TABLE 9. "t"-test of significance of mean values indicating changes in organic compounds of the soils.

Horizon		Fulvic Acid %	Total Organic Matter %
C	c	1.003	0.907
C	v	1.004	1.185
B_2	c	0.714	1.44
B_2	v	1.040	1.46
B_1	c	0.512	3.75*
B_1	v	0.660	1.66
B_o	c	0.418	5.23
B_o	v	0.417	3.35
C-B_2	c	1.003 : 0.714	1.907 : 1.44
C-B_1	c	1.003^{T}: 0.512	1.907 : 3.75*
C-B_2	v	1.004 : 1.04	1.185 : 1.46
C-B_1	v	1.004 : 0.660	1.185 : 1.66
B_2-B_1	c	0.714 : 0.512	1.44 : 3.75*

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%)level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

This portion of organic matter (fulvic acid) is very soluble in water, acid, and alkali, and tends to form organo-metallic complexes in combination with iron, aluminum, calcium, and magnesium salts. Adsorption complexes of fulvic acid with clay minerals, and non-siliceous forms of sesquioxides may also have been formed, all phenomena which might be instrumental in the development of an agric horizon.

5.2.11 Extractable iron, aluminum, manganese, and silicon

5.2.11.1 Dithionite-extractable iron, aluminum, manganese and silicon

Values of dithionite-extractable elements for individual profiles are shown in Appendix 2. Table 10 lists the "t"-test of significance of mean values of free iron, aluminum, and manganese oxides and silica, in cultivated and non-cultivated soil profiles. Paired t-tests of mean values for free iron in cultivated soils, indicate a marked increase (but non-significant at the 0.10 probability level) in C-horizon (agric horizon) when compared with the upper horizon (B_2-horizon). This increase was not as pronounced in non-cultivated soils. The accumulation of free iron oxides in the C-horizon of cultivated soils was significantly (0.01 probability level) higher than in the corresponding horizon of non-cultivated soils.

Cultivated soils showed a marked increase (but non-significant at the 0.10 probability level) in free aluminum content of the C-horizon when compared with the B_2-horizon, however non-cultivated soils showed a marked decrease (but non-significant at the 0.10 probability level) in the free aluminum content of the C-horizon when compared with both the B_1- and B_2-horizons. A marked (non-significant at the 0.10 probability level) increase in the free aluminum content of C-horizons of cultivated soils compared with C-horizons of non-cultivated soils was evident. A

TABLE 10. "t"-test of significance of mean values indicating changes in the dithionite-extractable elements of the soils.

Horizon		Fe_2O_3 % by Dithionite	Al_2O_3 % by Dithionite	MnO % by Dithionite	SiO_2 % by Dithionite
C	c	0.47**	0.18	0.024	0.08*
C	v	0.25	0.03	0.023	0.03
B_2	c	0.39	0.13*	0.016	0.09
B_2	v	0.23	0.05	0.016	0.03
B_1	c	0.56*	0.28*	0.012	0.05*
B_1	v	0.36	0.06	0.007	0.04
B_o	c	0.65	0.32	0.014	0.09
B_o	v	0.65	0.14	0.005	0.04
$C-B_2$	c	0.47 : 0.39	0.18 : 0.13	0.024 : 0.016	0.08 : 0.09
$C-B_1$	c	0.47 : 0.56	0.18 : 0.28	0.024 : 0.012	0.08* : 0.05
$C-B_2$	v	0.25 : 0.23	0.03 : 0.05	0.023 : 0.016	0.03 : 0.03
$C-B_1$	v	0.25 : 0.2	0.03 : 0.06	0.023* : 0.007	0.03 : 0.04
B_2-B_1	c	0.39 : 0.56	0.13 : 0.28T	0.016 : 0.012	0.09* : 0.05

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

significant (0.05 probability level) increase was found in the free Al content of the B_1- and B_2-horizons of cultivated soils when compared with the corresponding horizons of non-cultivated soils. Free manganese oxide content showed marked increases with profile depth, but its accumulation in cultivated C-horizons shows non-significant increase at the 0.10 probability level, when compared to C-horizons of non-cultivated soils. However C-horizons of non-cultivated soils showed significant (0.05 probability level) increases when compared with the upper horizons.

Silica content data indicate marked increases with depth throughout cultivated profiles, whereas non-cultivated profiles show decreases in silica content. Moreover, accumulation of silica in B_1- and C-horizons of cultivated soils was significantly (0.05 probability level) higher than the corresponding non-cultivated horizons. C-horizons of cultivated soils show significant (0.05 probability level) increases when compared against the upper horizon (B_1).

From the above observations, it appears that the crystalline form of free iron oxides, aluminum oxides, silica were increased in the C-horizon (agric horizon) layers of cultivated soils when compared with C-horizons (agric horizon) of non-cultivated soils. This could be due to genetic and surface weathering processes which might occur more intensively in cultivated than in non-cultivated soil profiles.

5.2.11.2 Oxalate-extractable iron, aluminum, manganese, silicon

Values of oxalate-extractable elements mentioned above for individual profiles are given in Appendix 2. Table 11 lists "t"-test of significance of mean values of oxalate-extractable iron, aluminum, manganese and silica in cultivated and non-cultivated soil profiles. Paired t-tests indicate a significant (0.05 probability level) increase in the B_o-, B_2- and C-horizons of cultivated soils when compared with the corresponding non-cultivated horizons. Paired t-tests indicate that iron

TABLE 11. "t"-test of significance of mean values indicating changes in the oxalate-extractable elements of the soils.

Horizon		Fe_2O_3 % by Oxalate	Al_2O_3 % by Oxalate	MnO % by Oxalate	SiO_2 % by Oxalate
C	c	0.16*	0.27*	0.03	0.06
C	v	0.04	0.04	0.02	0.06
B_2	c	0.13 *	0.20^T	0.02	0.09
B_2	v	0.04	0.1	0.01	0.09
B_1	c	0.23	0.42	0.01	0.22
B_1	v	0.13	0.28	0.004	0.11
B_o	c	0.24*	0.45	0.01	0.12
B_o	v	0.04	0.48	0.002	0.14
$C-B_2$	c	0.16 : 0.13	0.27 : 0.2	0.03 : 0.02	0.06 : 0.09
$C-B_1$	c	0.16 : 0.23	0.27 : 0.42	0.03^T: 0.01	0.06 : 0.22
$C-B_2$	v	0.04 : 0.04	0.04 : 0.1^T	0.02 : 0.01	0.06 : 0.09^T
$C-B_1$	v	0.04 : 0.13	0.04 : 0.28*	0.02*: 0.004	0.06 : 0.11^T
B_2-B_1	c	0.13 : 0.23	0.2 : 0.42	0.02 : 0.01	0.09 : 0.22

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

accumulation was markedly increased (non-significantly) in the C-horizon (agric horizon) compared with the B_2-horizons of cultivated soils, whereas a marked decrease was found in the C-horizons compared with the B_2-horizons of non-cultivated soils.

Paired t-tests indicate significant increases, at the 0.10 probability level in B_2- and at the 0.05 level in the C-horizon of cultivated soils when compared with equivalent horizons in non-cultivated profiles.

In cultivated soils, a marked increase (non-significant) in extractable Al (aluminum) accumulation with depth was evident, whereas in non-cultivated soils a significant decrease was found when comparing the C-horizon with the B_1- and B_2-horizons (0.05 and 0.10 probability level, respectively).

Extractable manganese content in cultivated soils was markedly increased with depth, and showed significant (0.1 probability level) increases in C-horizon when compared to the B_1-horizon. Non-cultivated soils also showed a marked increase with depth and indicated significant (0.05 probability level) increase in the C-horizons compared with the B_o- and B_1-horizons.

Silica content in cultivated soil profiles showed a marked decrease with depth, and paired t-tests indicate a significant (0.10 probability level) decrease in the C-horizon compared to all upper horizons. In non-cultivated soils, silica also sharply decreased with depth. Paired t-test analyses indicated a significant (0.10 probability level) decrease in silica in the C-horizon compared to that in all upper horizons.

5.2.11.3 Pyrophosphate-extractable iron, aluminum, manganese, silicon

Values for the pyrophosphate-extractable elements mentioned above for individual profiles are shown in Appendix 2. Table 12 lists the "t"-test of significance of mean values of pyrophosphate-extractable iron, aluminum, manganese and silica in cultivated and non-cultivated soil profiles. t-tests indicate highly significant increases in the B_2- and C-horizons of cultivated soils compared with the corresponding horizons of non-cultivated soils (0.05 and 0.01 probability level, respectively). Paired t-tests indicate an accumulation (non-significant) of iron in the C-horizon compared with the B_2-horizon.

Paired t-tests indicate a significant (0.05 probability level) increase in aluminum content in the C-horizons of cultivated soils compared with those of corresponding non-cultivated horizons.

Measurement of pyrophosphate-extractable aluminum in cultivated soils shows a decided increase (non-significant) in accumulation in the C-horizon with respect to the B_2-horizon. Extractable aluminum did not accumulate in the C-horizon of non-cultivated soils, as a matter of fact it decreased significantly (0.05 probability level) with depth in these profiles.

Only trace amounts of manganese were found in both the cultivated and non-cultivated profiles by this method. This is attributed to the complimentary increase in pH and organic matter of the extracting solution (Adam, in Black, C.A., 1965). There was a significant trend only between silica content of the B_o-horizon in cultivated compared with that of the non-cultivated soils. Extractable silica contents in both cultivated and non-cultivated C-horizons show a non-significant accumulation with respect to the B_1- and B_2-horizons. Pyrophosphate extracts have

TABLE 12. "t"-test of significance of mean values indicating changes in the pyrophosphate-extractable elements of the soils.

Horizon		Fe % by Pyrophosphate	Al % by Pyrophosphate	Mn % by Pyrophosphate	SiO_2 % by Pyrophosphate
C	c	0.26**	0.23*	0.01	3.16
C	v	0.05	0.044	0.008	3.15
B_2	c	0.16*	0.11	0.008	2.29
B_2	v	0.05	0.06	0.007	2.33
B_1	c	0.3	0.25	0.01T	2.11
B_1	v	0.12	0.12	0.005	2.72
B_o	c	0.33	0.25	0.015	4.28T
B_o	v	0.29	0.29	0.004	2.51
$C-B_2$	c	0.26 : 0.16	0.23 : 0.11	0.01 : 0.008	3.16 : 2.29
$C-B_1$	c	0.26 : 0.3	0.23 : 0.25	0.01 : 0.01	3.16 : 2.11
$C-B_2$	v	0.05 : 0.05	0.044 : 0.06	0.008 : 0.007	3.15 : 2.33
$C-B_1$	v	0.05 : 0.12	0.044 : 0.12*	0.008* : 0.005	3.15 : 2.72
B_2-B_1	c	0.16 : 0.3	0.11 : 0.25	0.008 : 0.01	2.29 : 2.11

T = Significant at 0.1 (10%) level

* = Significant at 0.05 (5%) level

** = Significant at 0.01 (1%) level

c = cultivated soil

v = non-cultivated soil

C Indicates layer overlaying clay layer

B_2 Indicates layer overlaying C-horizon

B_1 Indicates layer overlaying B_2-horizon

B_o Indicates layer overlaying B_1-horizon

been reported to be the most specific for the removal of hydrous oxides of iron and aluminum (sesquioxide) complexed with organic material which accumulate in the soil (Bear, 1965). Therefore it appears here that iron and aluminum hydrous oxides complexed (sesquioxides) with organic material (presumably fulvic acids), moved into and accumulated in the agric horizon as soluble complexes.

5.3 CORRELATION COEFFICIENTS AND REGRESSION EQUATIONS

Table 13 lists only simple correlation coefficients and regression equations for selected pairs of variables which are statistically related. The correlations are based on separate analyses of data from horizons of the four cultivated and of the four non-cultivated soils. Multiple regression and correlation analyses were carried out but no meaningful relationships were obtained.

High correlation coefficients between texture and (1) dithionite-extractable iron and (2) pyrophosphate-extractable silica in profiles of cultivated soils were obtained, whereas in profiles of non-cultivated soils the high correlation was obtained between texture and both C.E.C. and oxalate-extractable aluminum. Likewise the high correlation between C.E.C. and dithionite-and oxalate-extractable iron and aluminum in cultivated soils while C.E.C. of non-cultivated soils correlated highly with oxalate-extractable aluminum, indicate that the explanations advanced in 5.1.1. concerning the occurrence of increases in fine particles and in some extractable elements into a potential agric horizon are related to an increase in weathering and leaching in cultivated profiles. "The concentration of fine particles or appearance of clay particles in the B- and/or C-horizons have been attributed to the presence of chemical components such as Al, Fe, Si, etc. Sec. 5.1.1."

Bulk density correlates well with fulvic acid in non-cultivated profiles, with oxalate-extractable silica in cultivated ones. This indicates that the explanation given in section 5.1.2 for the possible formation of an agric horizon in cultivated soils, may be valid. "The occurrence of a hard B-layer in cultivated soils could be due to the mode of deposition of material or to the effect of cultivation of the soil. Sec. 5.1.2."

The high correlation coefficients between penetrometer resistance and oxalate-extractable iron in profiles of non-cultivated soils indicate that the explanation given in section 5.1.4 concerning the significant accumulation of oxalate-extractable iron (amorphous iron) may be related to a slow rate of weathering in profiles of non-cultivated soils. "Penetration resistance of the sub-surface material can be correlated, in a general way, with physical properties. It is possible, however, that it could be caused by deposition of mineral or chemical materials. Sec. 5.1.4."

The high correlation coefficients between pH and pyrophosphate-extractable silica in profiles of cultivated soils indicate that increase in pH with depth and pyrophosphate-extractable silica might be related to the intensity of weathering of the surface profiles of cultivated soils. "Increase in soil pH values in the sub-surface horizons, particularly in overlaying clay layers (strata), could be due to the leaching and mobilization of soil surface components and their segregation and precipitation within these horizons. Sec. 5.2.1."

Extractable phosphorous was highly correlated with dithionite- and oxalate-extractable manganese in profiles of cultivated soils. This confirms findings in the literature that various kinds of complexes accumulate to form indurated horizons in profiles of cultivated soils, which are associated with the leaching and weathering taking place in the upper horizons.

High correlation coefficients occur between fulvic acid and dithionite- and oxalate-extractable manganese in profiles of cultivated soils, while in profiles of non-cultivated soils this correlation appears between fulvic acid and oxalate-extractable silica. This agrees with the theory (Wright and Schnitzer, 1963, and others) that fulvic acid is capable of chelating these elements after their release through weathering of surface minerals in profiles of cultivated soils.

The following correlations were obtained in profiles of cultivated soils: (1) between oxalate-extractable iron and (oxalate- and pyrophosphate-extractable aluminum); (2) between oxalate-extractable aluminum and (pyrophosphate-extractable aluminum and dithionite-extractable-silica); (3) between dithionite-extractable aluminum and (dithionite- and oxalate-extractable manganese); (4) between pyrophosphate-extractable aluminum, dithionite-extractable manganese and (dithionite-extractable manganese and oxalate-extractable manganese), respectively.

The following correlations were obtained in profiles of non-cultivated soils: (1) between oxalate-extractable iron and pyrophosphate-extractable manganese; (2) between dithionite-extractable manganese and (oxalate- and pyrophosphate-extractable manganese and silica); (3) between oxalate- and pyrophosphate-extractable manganese and (oxalate and pyrophosphate-extractable silica).

A comparison between these groups of correlation indicates that the explanations advanced in Section 5.2.11 to explain the significant accumulation of these compounds may be related to weathering in profiles of cultivated soils. "Dithionite-extractable (crystalline form) of free iron oxides, aluminum oxides, silica were increased in the agric horizons of non-cultivated soils. Sec. 5.2.11.1." Oxalate-extractable (amorphous form) of iron, aluminum and manganese were increased in the agric horizons of cultivated soils when compared with agric horizon of non-cultivated ones. Section 5.2.11.2. "Pyrophosphate-extractable iron and aluminum indicate here that iron and aluminum hydrous oxides complexed (sesquioxides) with organic material (presumably fulvic acids), moved and accumulated into the agric horizon as soluble complexes. Sec. 5.2.11.3." This could support the idea that formation of various kinds of complexes within C-horizon in profiles of cultivated soils have been developed and not inherited from the original material.

Finally the correlation between pH-dependent cation exchange capacity (ΔC.E.C.) and dithionite-extractable silica in profiles of cultivated soils, whereas in non-cultivated soils it is between pH-dependent C.E.C. and extractable potassium, indicates that the formation of genetic horizons in profiles of cultivated soils may result from the accumulation of weathered components in a material conducive to cementation by agents which tend to plug the interparticle spaces.

TABLE 13. Simple correlation coefficient and regression equations for selected pair of variables

Variable Pair		degree of freedom	Cultivated Profile	Simple Correlation Coefficient	Degree of Freedom	Non-cultivated Profile	Simple Correlation Coefficient
C.E.C.	vs Texture	6	Y = 7.1 + 1.01 X	0.40	6	Y = 0.748 + 0.696 X	0.917**
Fe_{dith}[1]	vs Texture	"	Y = 43.003-63.93 X	-0.96**	"	Y = -8.13 + 50.43 X	0.515
Al_{oxa}[2]	vs Texture	"	Y = 12.92 - 3.32 X	-0.13	"	Y = -2.52 + 88.42 X	0.997**
$SiO_{2\ pyr}$[3]	vs Texture	"	Y = 21.86 - 3.12 X	-0.95**	"	Y = 2.73 + 0.52 X	0.24
Fe_{oxa}	vs C.E.C.	"	Y = -4.52 + 169.53 X	-0.959**	"	Y = -9.39 + 393.71 X	0.517
Fe_{dith}	vs C.E.C.	"	Y = -32.04+ 114.53 X	0.85*	"	Y = -18.73+ 95.62 X	0.75
Al_{dith}	vs C.E.C.	"	Y = 10.86 + 62.86 X	0.811*	"	Y = -1.31 + 188.11 X	0.675
Al_{oxa}	vs C.E.C.	"	Y = 11.23 + 40.78 X	0.82*	"	Y = -3.19 + 229.2 X	0.921**
Fulvic acid	vs Bulk Density	"	Y = 1.48 - 0.01 X	-0.1	"	Y = 5.97 - 3.29 X	-0.855*
$SiO_{2\ oxa}$	vs Bulk Density	"	Y = 1.39 + 1.43 X	0.796*	"	Y = 1.58 - 1.23 X	-0.49
Fe_{oxa}	vs Penetration Resistance	"	Y = 19.43 - 3.23 X	-0.431	"	Y = 2.5 + 0.74 X	0.868*
Ca	vs pH	"	Y = 5.073 + 0.003 X	0.977**	"	Y = 4.67 + 0.023 X	0.747
Mg	vs pH	"	Y = 5.06 + 0.02 X	0.933**	"	Y = 5.08 + 0.074 X	0.904**
$SiO_{2\ pyr}$	vs pH	"	Y = 5.043 + 0.04 X	0.888**	"	Y = 5.37 + 0.007 X	0.05
Phosphorous	vs Mn_{dith}	"	Y = -0.01 + 0.01 X	0.896**	"	Y = 45.07 - 8.84 X	-0.56
Phosphorous	vs Mn_{oxa}	"	Y = -0.01 + 0.01 X	0.83*	"	Y = 0.038 - 0.004 X	-0.633
Mn_{dith}	vs Fulvic Acid	"	Y = 0.21 + 32.53 X	0.908**	"	Y = 1.16 - 6.8 X	-0.33
Mn_{oxa}	vs Fulvic Acid	"	Y = 0.314 + 27.43 X	0.904**	"	Y = 1.14 - 6.83 X	-0.36
$SiO_{2\ oxa}$	vs Fulvic Acid	"	Y = 0.66 + 5.71 X	0.296	"	Y = 0.55 + 7.6 X	-0.798*

TABLE 13 Continued.

Fe_{oxa}	vs Al_{oxa}	6	Y = -0.224 + 3.113 X	0.883*	6	Y = -0.043 + 216.0 X	0.71
Fe_{oxa}	vs Al_{pyr}	"	Y = -0.21 + 2.74 X	0.897**	"	Y = -0.035 + 2.18 X	0.97**
Al_{dith}	vs Mn_{dith}	"	Y = 0.037 - 0.07 X	-0.966**	"	Y = 0.033 - 0.295 X	-0.515
Al_{dith}	vs Mn_{oxa}	"	Y = 0.04 - 0.084 X	-0.931**	"	Y = 0.03 + 0.286 X	-0.469
Al_{oxa}	vs Al_{pyr}	"	Y = 0.836 X	0.971**	"	Y = 0.023 + 0.58 X	0.781
Al_{oxa}	vs $SiO_{2\ dith}$	"	Y = 0.06 + 0.09 X	0.91**	"	Y = 0.026 + 0.2 X	0.18
Al_{pyr}	vs $SiO_{2\ dith}$	"	Y = 0.06 - 0.095 X	0.869**	"	Y = 0.038 - 0.12 X	-0.1
Mn_{dith}	vs Mn_{oxa}	"	Y = -0.003+ 1.17 X	0.99**	"	Y = -0.003 + 1.06 X	0.997**
Mn_{dith}	vs Mn_{pyr}	"	Y = 0.007 + 0.15 X	0.537	"	Y = 0.003 + 0.184 X	0.887**
Mn_{dith}	vs $SiO_{2\ oxa}$	"	Y = 0.043 + 0.68 X	0.37	"	Y = 0.099 - 1.72 X	-0.802*
Mn_{dith}	vs $SiO_{2\ pyr}$	"	Y = 1.85 + 53.98 X	0.35	"	Y = 6.55 - 148.04 X	-0.864*
Mn_{oxa}	vs Mn_{pyr}	"	Y = 0.008 + 0.106 X	0.46	"	Y = 0.004 + 0.17 X	0.877*
Mn_{oxa}	vs $SiO_{2\ oxa}$	"	Y = 0.05 + 0.37 X	0.237	"	Y = 0.09 - 1.614 X	-0.80*
Mn_{oxa}	vs $SiO_{2\ pyr}$	"	Y = 1.9 + 50.26 X	0.383	"	Y = 6.07 - 142.54 X	-0.887**
Mn_{pyr}	vs $SiO_{2\ oxa}$	"	Y = 0.007 + 4.8 X	0.711	"	Y = 0.137 - 10.03 X	-0.973**
Mn_{pyr}	vs $SiO_{2\ pyr}$	"	Y = 6.42 - 297.0 X	-0.529	"	Y = 8.66 - 711.19 X	-0.862*
$SiO_{2\ oxa}$	vs $SiO_{2\ pyr}$	"	Y = 3.73 - 9.41 X	-0.11	"	Y = -1.16 + 71.81 X	-0.898**
K	vs Δ C.E.C. 4	"	Y = 28.3 - 0.34 X	-0.59	"	Y = -19.19 + 9.68 X	0.974**
Al_{oxa}	vs Δ C.E.C.	"	Y = 25.91 - 6.68 X	-0.59	"	Y = -7.94 + 499.7 X	0.904**
$SiO_{2\ dith}$	vs Δ C.E.C.	"	Y = 32.52 - 102.42 X	-0.849*	"	Y = 1.17 + 274.6X	0.54

Legenda:

(1) dith = Dithionite-extractable
(2) oxa = Oxalate-extractable
(3) pyr = Pyrophosphate-extractable
(4) Δ C.E.C. = pH dependent C.E.C.
* = indicates significance at the 5% level
** = indicates significance at the 1% level

6. SUMMARY AND CONCLUSIONS

The formation of agric horizons in gleyed humo ferric podzol soils has been investigated by comparing physical and chemical analyses of four cultivated soil profiles representing St. Damase soil series and four non-cultivated ones (woodland) which included two of the St. Damase and two of the St. Amable soil series. Both cultivated and non-cultivated soils were developed on similar parent materials, which were outwash sands. Each group, due to their nature and deposition in the region, had been subjected to similar weathering and development processes since their time of deposition. The climate of this area is considered to be a cool, humid temperate region with an average annual rainfall of about 775 mm and a maximum mean annual temperature of 9.7°C and a minimum mean annual temperature of 1.2°C.

The morphology of the soils was studied and described in the field, and major properties were measured by laboratory analysis. Results showed that indurated agric horizons occurred more frequently in cultivated profiles than in non-cultivated (woodland) ones. This could be due to the fact that cultivated soils have been subjected to more intensive weathering and development processes, which resulted from more than 70 years of cultivation and implement traffic. The following properties of the soils which were investigated agree with the properties of hardpan layers (referred to by American workers as Fragipan) reviewed in the literature:-

6.1 Soil Colour

The agric layers had a reddish-brown colour which is either darker or brighter than the above horizons, depending upon the nature of the deposited material. The horizons which preceded the agric horizon had a lighter colour, which could be associated with the loss of di-, tri-valent cations and organic components, particularly under an imperfectly drained system.

It was concluded that the agric horizons tended to exhibit more marked colour differences than horizons above the pan. This colour variation was related to the accumulation of mobilized compounds which characterized the formation of variegated colours in an agric horizon within the soil profile.

6.2 Particle Size Distribution

The cumulative figures for the fine and very fine sand fractions (0.2-0.05 mm) and the coarse and fine silt fractions (0.5-0.002 mm) increased in the agric horizon compared with the upper horizon in cultivated soil profiles.

In agric horizons of non-cultivated soils the cumulative figures for the medium and very coarse sand fractions (0.2-2.0 mm) increased. This indicates that agric horizons in cultivated profiles have a medium to fine texture, whereas horizons in non-cultivated conditions have a medium to coarse texture. This coarse texture is uncommon for agric development. Fragipan concepts quoted or reviewed in the literature have a narrow range of particle sizes, concentrating in very fine sand and coarse silt fractions. Agric horizons commonly showed a tendency toward induration and brittleness when observed in the dry or moist condition. Consistency was generally hard to very hard when dry and firm to very firm when moist.

6.3 Density and Porosity of the Soil Profiles

Increases in bulk density and particle density vary directly with increases in the depth of the soil profile, whereas porosity and depth have a reverse relationship. However, in agreement with the agric concept reviewed in the literature, comparison between agric horizon density and porosity, and the density and porosity of the preceding layers in the profile, showed no significant differences resulting from pan formation. These characteristics are considered as a function of the close packing of particles. The reason for non-significant differences in density in the agric horizons is possibly due to the formation of plow or traffic pan layer or layers. These layers occur commonly at the 20-30 cm depth in the Ap-Ae transition horizon due to sustained use of moderately heavy field machinery.

6.4 Penetration Resistance of the Profiles and Agric Horizons

The compaction of a soil, as measured by a penetrometer throughout the profiles, increased downward from 14 to 19 kg/cm^2. This indicates significant differences in induration of the agric horizon in cultivated profiles when compared to the above horizons. This results from the close packing of particles by binding material or by impregnation of the originally loose material with some binding substances. This agrees with the results reported by Pohjakas (1966).

6.5 Organic Matter (Fulvic Acid) Content of both the Agripan and the Profile

The soluble portion of organic matter (fulvic acid) content increased sharply with an increase in depth. Its maximum values appeared in the agric horizons rather than in the above horizons. This indicates the accumulation or precipitation of a portion of organic substances which have the ability to form organo-metal complexes during their interaction with di- and tri-valent metallic cations.

A high correlation between fulvic acid and these metals supports this hypothesis, in agreement with the results reported by Wright and Schnitzer (1963).

6.6 Extractable Di- and Tri-Valent Metallic Cations Content of the Agric Horizon and the Solum

6.7 pH Values of the Agric Horizon and the Profile

Extractable iron, aluminum, manganese and silicon by means of three chemical reagents (i.e. dithionite, oxalate and pyrophosphate) showed the nature and forms of these metal cations which have been redistributed through a soil profile as a result of weathering and development processes. Statistical t-test values indicate a significant loss of these elements from the upper horizons and a resulting accumulation in agric horizons due to a translocation from the bleached upper horizons of iron, aluminum and manganese oxides, and silica.

Data from the hardpan layer led to the following conclusions:-

Lower levels of oxalate-extractable iron than aluminum, and lower levels of dithionite-extractable aluminum than iron in the pan layer indicated relatively high amounts of crystalline iron oxides compared to crystalline aluminum oxides. Less amorphous iron-organic matter complexes than amorphous aluminum-organic matter complexes occurred in the agric, due to the increased susceptibility of aluminum to form organo-metal complexes. The observations are in agreement with those reviewed in the literature. Pyrophosphate extracts indicate a significant increase in content of amorphous hydrous oxides of iron and aluminum.

Moreover, the activity ratio of Blume and Schwertmann (1969) for Fe_o/Fe_d (oxalate-extractable iron and dithionite-extractable iron ratio) which decreases with an increase in depth within the profile, indicates a higher proportion of free iron oxides than amorphous iron oxides, hydroxides, Fe-salts and Fe-organic matter complexes, occur in crystalline forms in the agric horizon. This is in agreement with the results reported by McKeague (1971).

Under acid or slightly acid conditions, the oxidation or precipitation of iron, aluminum and manganese was low. Moreover, under these conditions any movement of free silica is hardly feasible. However, the presence of a fine textured stratum which impedes the downward percolation of water has caused the accumulation of the above elements in the overlying horizon to form an agric horizon. This agrees with the results reported by Collins and Buol (1970).

Moreover the precipitation of iron in an agric horizon, resulting in the removal of some Mn^{++} from solution, is due to Mn^{++} sorption by the hydrated oxides which show a negative charge at pH values above approximately 5.0. Therefore it is concluded that the presence of hydrated iron oxides (oxalate-extractable iron) caused a decrease in the amount of Mn^{++} in solution.

Since dithionite-extractable iron exceeded oxalate-extractable iron in all horizons, and oxalate-extractable aluminum exceeded dithionite-extractable aluminum in all horizons, it is concluded that the cementing or binding material between the particles may consist of free iron oxides and amorphous aluminum- and iron-organic matter complexes in the agric. To a lesser extent, manganese oxide and its amorphous form, and finally free silicon and its amorphous organic complexes, also influence cementing of particles. This hypothesis is based on the observation that pyrophosphate-extractable aluminum, iron, and manganese values were a little lower than oxalate-and/or dithionite-extractable values, whereas pyrophosphate-extractable silica values were much greater than oxalate and/or dithionite-extractable values. This indicates adequate proportions of iron, aluminum and silica and, to a lesser extent, manganese accumulated in the agric horizon was complexed as organo-metal complexes, particularly fulvic acid complexes (according to section 6.5).

6.8 Extractable Base Elements and Phosphorous Content in the Solum and within the Agric Horizon

Extractable base elements such as calcium, potassium and magnesium increased sharply in the agric horizon with respect to horizons above, but extractable phosphorous showed no significant increases within the profile.

High correlation between calcium, magnesium, oxalate-extractable iron and aluminum, and pyrophosphate-extractable iron and aluminum indicates the flocculation of iron- and aluminum-organic matter complexes by calcium and magnesium. Moreover, iron is considerably more susceptible to flocculation than aluminum in the agric horizon. This is in agreement with results reported by Wright and Schnitzer (1963).

The high correlation between phosphorous and each of dithionite- and oxalate-extractable manganese may indicate the formation of precipitated phosphorous salts in the presence of aluminum hydroxide. Moreover, iron oxides react much more slowly than aluminum hydroxides and have much less effect on the precipitation of phosphate. This agrees with results reported by Taylor (1965).

However, high correlation between basic metals such as calcium, magnesium and manganese and, to a lesser extent, potassium with heavy metals such as iron, aluminum and silica (different forms and natures) indicate the formation of different types of complex compounds, particularly some genetic clay particles representative of clay minerals which can play an important role as binding agent within agric horizons. This agrees with the results reported by Hunsaker and Pratt (1970).

6.9 Permanent Cation Exchange Capacity and pH-Dependent CEC Content in Agric Horizon and a Solum of the Soils

Paired t-test analyses indicated a marked increase in permanent cation exchange capacity values within the agripan compared with the overlying layer. It also indicated a marked increase in pH-dependent CEC (ΔCEC) values within the agripan in the case of cultivated profiles. A decrease in the pH-dependent CEC values in the agric horizon was found in the case of non-cultivated profiles.

A high correlation existed between pH-dependent cation exchange capacity and dithionite-extractable silica in cultivated profiles, while this correlation occurred between pH-dependent CEC and each of potassium and oxalate-extractable aluminum in non-cultivated soil profiles. It can be concluded that these horizons with high CEC and pH-dependent CEC contained significant quantities of amorphous sesquioxides-organic matter complexes and crystalline colloidal material, as shown by their relatively high organic matter (fulvic acid) and free sesquioxide contents, and by their exchange properties (isomorphous ion substitutions, ionization of hydroxyl groups attached to silicon of broken tetrahedron planes and humic substances, -COOH, -OH).

Thus this characteristic provided a simple and definitive aid for determining whether or not the layer had indurated or brittle properties resulting from the accumulation of colloidal metallic (sesquioxides)-organic matter complexes which have little effective charge but a high pH-dependent CEC. Finally, a high correlation between CEC and various forms of Al, Fe, and Mn supports this hypothesis. Generally it is concluded that the agric horizon in the soil profiles under study are genetic horizons irreversibly cemented by chemical binding material, and that the induration of the agric horizon is a function of the length of time during which the process has operated and has formed as an integral part of the podzol profile. However, agric horizons which are developed in cultivated soil profiles could be due to the following environmental conditions and soil nature:-

(1) The rate of infiltration of precipitation is higher in plowed soil than in forest soil because of the large amount of precipitation reaching the surface of a field and also because of the greater porosity of the upper part of the plow layer.

(2) More mineral salts are leached from plowed soil than from forest soil, because of the migration of cations and anions from applied fertilizers.

(3) The eluvial processes responsible for the removal of substances without the destruction of minerals are more pronounced in the plowed soil and podzolization is less intense than in non-cultivated soils.

(4) Less organic matter migrates in the plowed than in the forest soil, agreeing with the results reported by Suvorov (1974). Moreover,

observations which provide evidence indicating the breakdown and weathering processes of primary minerals, particularly clay minerals in the upper horizons of the soils under study are:-

(i) Oxalate-extractable iron and aluminum contents were generally highest on the surface horizons, probably due to the more intensive weathering of the minerals of the surface.

(ii) Iron oxides distribution through the profiles shows a relative rate of weathering in these profiles which can be tentatively determined, and which was generally related to the organic matter distribution.

(iii) The active forces of soil weathering were indicated by a loss of Ca and Mg in the A-horizon and accumulation in the agric horizon.

(iv) Appreciable weathering of primary minerals must have occurred to produce the iron and aluminum rich amorphous material in the agric horizon.

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A P P E N D I C E S

Results of Laboratory Analyses

Appendix 1

Values of Physical Measurements

Complete averaged results of physical analyses for 8 cultivated and non-cultivated profiles

Particle size distribution, percent

Depth cm	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05&0.02	0.05-0.02	0.02-0.005	0.005-0.002	0.002-0.001
Profile No.1. St. Damase										
0-15	0.41	2.32	13.44	19.98	12.63	29.72	3.56	11.51	6.43	-
15-30	0.01	1.45	17.84	24.46	12.26	20.17	6.61	11.56	5.64	-
30-45	-	0.22	30.85	24.73	14.91	7.89	6.91	7.91	6.4	-
45-60	0.08	0.44	14.19	45.15	9.31	2.54	7.50	8.34	8.94	3.51
Profile No.2. St. Damase										
0-15	0.13	2.00	4.00	36.58	18.56	7.64	10.72	13.91	6.46	-
15-26	0.11	0.56	5.17	34.76	19.93	22.19	5.04	3.33	8.91	-
26-45	-	0.45	5.44	55.59	15.03	10.15	2.71	6.32	4.32	-
Profile No.3. St. Damase										
0-20	-	0.45	6.40	67.22	9.84	0.85	2.33	10.14	2.77	-
20-40	-	0.70	7.58	67.75	8.84	2.10	4.11	4.79	4.12	-
40-50	0.04	0.57	5.12	64.25	15.15	0.06	2.58	4.41	7.82	-
Profile No.4. St. Damase										
0-15	0.11	0.66	6.05	61.61	9.85	0.17	7.41	10.07	4.07	-
15-40	0.07	0.24	2.94	71.58	16.44	4.12	2.30	2.31	-	-
40-50	1.23	1.18	2.20	58.50	17.07	-	8.78	4.69	6.30	-
50-65	1.89	1.73	3.33	60.42	15.75	8.49	3.98	2.52	1.89	-

Continued

Depth cm	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05&0.02	0.05-0.02	0.02-0.005	0.005-0.002	0.002-0.001
					Profile No.5. St. Damase					
0-7	0.15	1.36	14.63	48.42	5.76	2.23	8.11	11.00	8.34	-
7-25	0.04	1.25	16.33	47.62	5.36	16.63	4.54	4.96	3.27	-
25-50	0.11	2.18	21.29	38.10	4.63	16.17	6.03	7.90	3.59	-
50-70	0.08	1.84	24.00	35.64	3.33	18.27	4.34	9.58	2.92	-
70-82	-	1.34	30.02	50.75	4.82	4.65	3.40	1.11	3.92	-
82-92	0.03	0.73	13.8	59.2	5.33	0.07	5.94	5.4	9.5	-
					Profile No.6. St. Amable					
0-7	0.15	1.83	11.67	43.28	8.91	1.83	11.8	12.38	8.06	-
7-15	0.36	2.24	14.7	56.94	8.68	13.16	-	2.99	0.93	-
15-25	-	1.25	11.53	47.82	9.78	21.23	2.76	4.81	0.72	-
25-55	0.04	2.12	22.61	44.30	6.73	17.19	-	5.58	1.12	0.30
55-75	0.22	2.63	40.21	48.33	1.61	2.39	0.30	4.31	-	-
75-80	0.31	3.99	32.04	47.71	1.02	-	5.54	5.8	3.59	-
					Profile No.7. St. Amable					
0-7	0.12	0.79	9.87	52.72	8.44	12.70	2.87	7.87	4.62	-
7-20	-	0.78	11.82	56.46	8.16	7.54	6.20	4.94	4.10	-
20-65	0.08	0.96	11.24	65.86	8.06	5.33	2.04	-	6.43	-
65-80	0.02	1.59	16.53	60.92	4.99	5.05	4.00	6.90	-	-
80-90	0.02	2.77	38.65	43.00	2.86	-	4.24	4.30	4.26	-
90-120	-	3.80	68.14	20.26	1.40	-	3.40	2.70	0.30	-

Continued

Depth cm	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05&0.02	0.05-0.02	0.02-0.005	0.005-0.002	0.002-0.001
					Profile No.8. St. Amable					
0-7	-	0.88	15.74	46.01	9.64	2.38	5.08	10.46	8.98	-
7-20	-	1.15	16.90	58.31	7.33	11.32	1.35	-	3.64	-
20-60	-	1.78	28.94	56.32	4.40	3.57	1.35	-	3.64	-
60-85	0.25	2.34	36.87	54.40	3.23	1.05	0.36	1.50	-	-
85-100	-	1.29	34.69	49.48	1.84	-	4.46	5.54	2.70	-
100-120	0.20	3.85	23.12	67.53	3.55	0.85	0.90	-	-	-

Depth cm	Bulk Density gram/cc	Particle Density gram/cc	Total Porosity % on vol.basis	Penetration Resistance (Bearing Capacity) kg/cm^2	Atterberg Characteristic	
					Liquid Limit	Plastic Limit
			Profile No.1 - St. Damase			
0-15	1.14	2.33	51.00	10.0	30.8	30.49
15-30	1.35	2.5	45.9	16.69	20.5	21.10
30-45	1.46	2.52	41.82	17.93	22.5	22.0
45-60	1.44	2.48	42.0	19.23	19.9	19.11
			Profille No.2 - St. Damase			
0-15	0.96	2.26	57.36	5.06	30.08	28.56
15-26	1.06	2.32	49.71	15.90	11.11	-
26-45	1.46	2.42	39.74	18.77	17.3	16.55
			Profile No.3 - St. Damase			
0-20	1.38	2.46	43.36	15.21	20.5	20.02
20-40	1.52	2.51	39.32	18.26	20.5	20.00
40-50	1.54	2.64	38.82	19.48	21.4	19.7
			Profile No.4 - St. Damase			
0-15	1.28	2.4	46.55	15.57	23.2	23.0
15-40	1.48	2.51	41.3	17.99	22.2	22.17
40-50	1.49	2.51	40.71	18.42	20.0	20.0
50-65	1.46	2.52	42.12	18.19	21.0	20.91

Continued

Depth cm	Bulk Density gram/cc	Particle Density gram/cc	Total Porosity % on vol.basis	Penetration Resistance (Bearing Capacity) kg/cm2	Atterberg Characteristic Liquid Limit	Atterberg Characteristic Plastic Limit
			Profile No.5 - St. Damase			
0-7	0.88	2.16	59.17	7.73	30.2	30.13
7-25	1.02	2.3	55.51	8.54	9.8	-
25-50	1.31	2.37	45.18	12.75	6.9	-
50-70	1.30	2.32	45.66	16.10	21.7	20.9
70-82	1.48	2.50	40.77	17.58	25.5	25.0
82-92	1.56	2.71	38.67	18.63	21.8	21.00
			Profile No.6 - St. Amable			
0-7	0.85	2.02	57.54	8.56	37.2	37.0
7-15	1.07	2.18	50.89	9.01	26.0	25.0
15-25	1.25	2.32	46.18	14.20	25.2	25.0
25-55	1.21	2.17	47.00	14.27	23.6	23.1
55-75	1.41	2.42	41.78	15.50	22.4	22.15
75-80	1.43	2.45	41.73	15.65	24.0	23.89
			Profile No.7 - St. Amable			
0-7	0.51	1.16	56.09	6.5	42.2	41.99
7-20	1.05	2.29	54.39	9.25	26.2	25.94
20-65	1.25	2.44	48.89	11.67	5.0	-
65-80	1.53	2.55	39.98	15.99	20.9	20.65
80-90	1.47	2.51	41.57	16.17	21.0	20.51
90-120	1.51	2.54	40.57	16.80	23.2	22.5

Continued

Depth cm	Bulk Density gram/cc	Particle Density gram/cc	Total Porosity % on vol. basis	Penetration Resistance (Bearing Capacity) kg/cm^2	Atterberg Characteristic	
					Liquid Limit	Plastic Limit
			Profile No.8 - St. Amable			
0-7	0.82	2.01	55.58	6.36	28.3	27.54
7-20	1.08	2.27	52.57	9.77	30.5	26.05
20-60	1.33	2.3	42.07	13.64	25.0	22.99
60-85	1.43	2.35	39.18	14.72	22.4	21.0
85-100	1.41	2.23	39.50	15.05	25.4	21.5
100-120	1.54	2.47	37.69	15.85	23.6	21.75

Depth cm	Moisture % Based on Dry wt.	Dry Bulk Density gram/cc
Profile No.1 - St. Amable		
0-10	36.25	0.951
10-20	38.94	1.038
20-30	92.92	0.637
30-40	16.74	1.247
40-50	21.52	1.284
Profile No.2 - Ste. Sophie		
0-10	36.72	1.024
10-20	31.48	1.056
20-30	22.49	1.004
30-40	13.46	1.211
40-50	6.54	1.406
50-60	7.45	1.430
60-70	16.97	1.213
Profile No.3 - St. Damase		
0-10	37.09	0.868
10-20	45.02	0.902
20-30	45.72	1.009
30-40	14.32	1.464
40-50	15.64	1.397
Profile No.4 - St. Amable		
0-10	39.36	1.065
10-20	39.28	1.083
20-30	24.31	1.207
30-40	11.87	1.366
40-50	10.52	1.216
50-60	18.42	1.39
Profile No.5 - St. Damase		
0-10	33.46	1.084
10-20	33.36	1.128
20-30	36.09	0.925
30-40	10.70	0.908
40-50	9.23	1.161
50-60	16.57	0.804
60-70	14.85	1.431
Profile No.6 - St. Damase		
0-10	14.40	1.312
10-20	14.49	1.330
20-30	8.91	1.403
30-40	12.43	1.456
40-50	16.47	1.337
Profile No.7 - St. Damase		
0-10	15.73	1.094
10-20	17.61	1.152
20-30	17.42	2.000
30-40	17.95	1.298
40-50	17.61	1.362

Depth cm	Moisture % Based on Dry wt.	Dry Bulk Density gram/cc
Profile No.8 - St. Damase		
0-10	24.34	1.197
10-20	24.50	1.287
20-30	24.98	1.152
30-40	22.99	1.204
40-50	16.14	1.464
50-60	21.82	1.430
60-70	21.77	1.177
Profile No.9 - St. Amable		
0-10	23.11	1.276
10-20	23.85	1.295
20-30	24.53	1.231
30-40	23.53	1.333
40-50	21.56	1.143
50-60	22.36	0.719
60-70	23.12	1.818
Profile No.10 - St. Amable		
0-10	11.21	1.308
10-20	17.90	1.295
20-30	17.15	1.360
30-40	18.76	1.455
40-50	21.29	1.480
Profile No.11 - Upland		
0-10	19.79	1.294
10-20	17.87	1.376
20-30	21.21	1.410
30-40	22.84	1.452
40-50	24.25	1.458
50-60	29.95	1.402
60-70	30.99	1.273
Profile No.12 - St. Damase		
0-10	13.76	1.352
10-20	15.78	1.342
20-30	11.32	1.326
30-40	11.98	1.371
40-50	17.54	1.350
Profile No.13 - St. Damase		
0-10	16.97	1.107
10-20	23.46	1.176
20-30	27.65	1.007
30-40	19.26	1.254
40-50	15.45	0.917
50-60	19.51	1.322

Continued

Depth cm	Moisture % Based on Dry Wt.	Dry Bulk Density gram/cc
Profile No.14 - St. Amable		
0-10	15.82	1.323
10-20	15.53	1.388
20-30	16.35	1.191
30-40	11.91	1.355
40-50	15.05	1.525
50-60	16.83	1.555
60-70	20.85	1.988
Profile No.15 - Ste.Sophie		
0-10	6.61	1.286
10-20	11.31	1.323
20-30	10.74	1.407
30-40	16.75	1.412
40-50	17.92	1.331
50-60	22.11	1.403
60-70	27.34	1.141
70-80	30.45	1.320
Profile No.16 - Ste. Sophie		
0-10	15.16	1.260
10-20	24.58	1.245
20-30	27.80	1.267
30-40	24.81	1.337
40-50	27.74	1.303
50-60	24.42	1.340
60-70	29.13	1.343
70-80	30.21	1.361
80-100	31.08	1.238
Profile No.17 - Ste. Sophie		
0-10	39.45	0.831
10-20	30.09	0.944
20-30	27.17	0.989
30-40	24.10	1.081
40-50	26.96	1.132
50-60	26.64	1.251
60-70	22.26	1.298
70-80	23.68	1.341
80-90	32.62	1.393
Profile No.18 - St. Amable		
0-10	123.91	0.498
10-20	44.34	0.891
20-30	39.82	1.036
30-40	26.43	1.245
40-50	25.46	1.352
50-60	32.06	1.342
60-70	34.86	1.249
70-80	28.14	1.404
Profile No.19 - St. Amable		
0-10	220.53	0.281
10-20	67.47	0.601
20-30	40.96	1.080
30-40	24.85	1.305
40-50	32.09	1.393
50-60	38.58	1.314
60-70	43.51	1.242
Profile No.20 - Ste. Sophie		
0-10	324.98	0.237
10-20	46.64	0.736
20-30	48.62	0.791
30-40	46.98	0.856
40-50	32.48	1.157
50-60	22.65	1.380
60-70	24.17	1.167
70-80	24.18	1.488

Appendix 2

Values of Chemical Measurements

Depth cm	C.E.C. Meq/100 gm soil	pH	pH-Dependent C.E.C. Meq/100 gm soil	K ppm	Ca ppm	Mg ppm	Phosphorous (P_2O_5) ppm
			Profile No.1 - St. Damase				
0-15	88.58	5.2	38.13	21.1	120.0	19.8	28.6
15-30	28.69	4.8	25.42	22.15	32.0	6.40	6.55
30-45	15.47	5.1	20.81	12.9	17.5	2.65	3.7
45-60	8.98	5.1	22.4	19.8	17.0	4.00	5.55
			Profile No.2 - St. Damase				
0-15	101.05	4.9	36.82	16.35	98.5	10.20	19.75
15-26	27.45	4.6	30.39	9.85	39.0	10.6	7.2
26-45	38.42	5.1	21.32	11.85	12.5	2.20	2.5
			Profile No.3 - St. Damase				
0-20	8.11	5.2	25.82	5.25	42.5	1.80	16.65
20-40	7.24	5.27	20.58	5.9	15.0	0.9	12.2
40-50	13.97	5.2	24.45	8.85	31.0	4.8	7.75
			Profile No.4 - St. Damase				
0-15	25.58	5.1	26.26	7.0	47.5	2.09	8.4
15-40	14.97	5.0	22.38	4.05	15.0	0.80	10.35
40-50	14.22	5.0	21.93	4.15	13.8	1.23	9.1
50-65	27.69	5.3	28.23	8.5	67.5	12.20	6.22

Continued

Depth cm	C.E.C. Meq/100 gm soil	pH	pH-Dependent C.E.C. Meq/100 gm soil	K ppm	Ca ppm	Mg ppm	Phosphorous (P_2O_5) ppm
			Profile No.5 - St. Damase				
0-7	94.81	3.8	26.48	9.8	42.0	4.8	10.0
7-25	15.60	4.4	20.13	3.6	4.0	0.40	4.3
25-50	28.44	4.4	22.87	2.1	4.0	0.80	7.9
50-70	23.95	4.8	19.89	3.35	10.5	0.90	6.3
70-82	11.98	5.1	30.12	2.3	15.0	1.1	7.8
82-92	5.24	5.45	5.92	3.0	22.0	3.30	6.15
			Profile No.6 - St. Amable				
0-7	52.4	4.1	25.95	4.9	5.5	7.53	2.85
7-15	21.21	4.4	21.13	2.25	4.5	2.10	2.3
15-25	29.94	4.5	22.17	1.85	1.0	0.5	2.2
25-55	14.97	5.3	31.64	2.45	9.0	0.92	8.45
55-75	2.5	5.7	30.4	1.9	7.0	1.06	6.7
75-80	12.48	5.80	27.54	4.7	34.0	7.6	4.55
			Profile No.7 - St. Amable				
0-7	128.5	3.2	35.8	6.75	38.0	5.06	2.15
7-20	42.42	4.1	19.87	2.2	2.8	0.67	1.53
20-65	23.95	4.5	20.05	1.9	4.7	0.61	0.9
65-80	4.49	4.9	18.73	2.1	7.0	0.78	3.77
80-90	1.5	5.0	3.9	2.8	7.2	0.60	4.5
90-120	1.0	5.2	3.8	2.25	6.0	0.90	3.68

Continued

Depth cm	C.E.C. Meq/100 gm soil	pH	pH-Dependent C.E.C. Meq/100 gm soil	K ppm	Ca ppm	Mg ppm	Phosphorous (P_2O_5) ppm
			Profile No.8 - St. Amable				
0-7	45.54	3.7	19.84	4.7	17.5	2.30	2.2
7-20	14.35	4.7	17.47	1.85	4.0	0.57	1.5
20-60	10.48	4.5	17.5	1.6	5.5	0.50	9.75
60-85	2.0	4.8	3.28	1.9	3.0	0.58	8.4
85-100	1.0	5.1	3.3	1.85	5.0	0.70	3.14
100-120	2.0	5.11	3.93	2.25	22.0	2.88	2.32

Depth cm	Total Nitrogen % based on wt.	Fulvic Acid % based on total organic matter	Organic Matter %	Fe_2O_3 % by Dithionite	Al_2O_3 % by Dithionite	MnO % by Dithionite	SiO_2 % by Dithionite
			Profile No.1 - St. Damase				
0-15	0.22	0.41	6.65	0.81	0.38	0.013	0.12
15-30	0.03	0.74	2.19	0.48	0.24	0.007	0.05
30-45	0.02	0.94	1.39	0.32	0.19	0.009	0.2
45-60	0.013	1.38	1.240	0.34	0.1	0.03	0.09
			Profile No.2 - St. Damase				
0-15	0.25	0.29	7.75	0.9	0.45	0.02	0.04
15-26	0.01	0.81	1.17	0.39	0.08	0.03	0.07
26-45	0.06	0.32	3.87	0.53	0.44	0.01	0.12
			Profile No.3 - St. Damase				
0-20	0.002	0.56	2.78	0.37	0.21	0.02	0.05
20-40	0.02	0.51	1.68	0.25	0.09	0.02	0.03
40-50	0.013	1.04	1.31	0.45	0.09	0.03	0.07
			Profile No.4 - St. Damase				
0-15	0.1	0.43	3.8	0.48	0.25	0.02	0.05
15-40	0.04	0.47	2.27	0.50	0.2	0.01	0.07
40-50	0.02	0.6	1.53	0.61	0.16	0.01	0.07
50-65	0.01	1.26	1.21	0.56	0.1	0.04	0.06

Continued

Depth cm	Total Nitrogen % based on wt.	Fulvic Acid % based on total organic matter	Organic Matter %	Fe_2O_3 % by Dithionite	Al_2O_3 % by Dithionite	MnO % by Dithionite	SiO_2 % by Dithionite
			Profile No.5 - St. Damase				
0-7	0.25	0.5	1.68	0.55	0.11	0.01	0.11
7-25	0.07	0.26	3.58	0.43	0.18	0.01	0.09
25-50	0.06	0.54	2.56	0.47	0.2	0.01	0.001
50-70	0.03	0.47	2.26	0.56	0.16	0.01	0.04
70-82	0.01	0.65	1.39	0.45	0.08	0.03	0.05
82-92	0.01	0.82	1.17	0.27	0.05	0.02	0.02
			Profile No.6 - St. Amable				
0-7	0.15	0.39	6.18	0.65	0.13	0.004	0.1
7-15	0.08	0.27	4.75	0.91	0.15	0.01	0.07
15-25	0.09	0.19	6.25	0.83	0.22	0.004	0.08
25-55	0.02	0.66	1.75	0.47	0.09	0.01	0.05
55-75	0.01	0.86	1.32	0.19	0.05	0.01	0.02
75-80	0.01	1.22	1.24	0.28	0.05	0.03	0.05
			Profile No.7 - St. Amable				
0-7	0.6	0.67	7.82	0.45	0.07	0.01	0.03
7-20	0.1	0.36	5.33	0.62	0.11	0.004	0.02
20-65	0.04	0.5	2.67	0.94	0.09	0.01	0.07
65-80	0.01	0.28	1.46	0.26	0.05	0.01	0.03
80-90	0.01	0.72	1.13	0.16	0.04	0.02	0.05
90-120	0.003	1.17	1.24	0.19	0.03	0.01	0.01

Continued

Depth cm	Total Nitrogen % based on wt.	Fulvic Acid % based on total organic matter	Organic Matter %	Fe_2O_3 % by Dithionite	Al_2O_3 % by Dithionite	MnO % by Dithionite	SiO_2 % by Dithionite
			Profile No.8 - St. Amable				
0-7	0.13	0.43	6.79	0.18	0.32	0.003	0.07
7-20	0.05	0.43	3.29	0.15	0.53	0.001	0.11
20-60	0.02	0.44	1.9	0.11	0.32	0.002	0.10
60-85	0.01	1.23	1.17	0.03	0.1	0.002	0.11
85-100	0.004	1.91	1.13	0.02	0.03	0.001	0.07
100-120	0.003	0.81	1.09	0.03	0.02	0.03	0.03

Depth cm	Fe_2O_3 % by Oxalate	Al_2O_3 % by Oxalate	MnO % by Oxalate	SiO_2 % by Oxalate	Fe_2O_3 % by Pyrophosphate	Al_2O_3 % by Pyrophosphate	MnO % by Pyrophosphate	SiO_2 % by Pyrophosphate
				Profile No.1 - St. Damase				
0-15	0.26	0.4	0.01	0.15	0.41	0.27	0.02	5.81
15-30	0.21	0.31	0.004	0.5	0.25	0.18	0.01	3.63
30-45	0.10	0.29	0.01	0.11	0.13	0.12	0.01	3.84
45-60	0.08	0.16	0.03	0.06	0.13	0.1	0.02	0.53
				Profile No.2 - St. Damase				
0-15	0.42	0.68	0.01	0.18	0.6	0.53	0.01	1.31
15-26	0.16	0.1	0.03	0.09	0.1	0.06	0.01	0.56
26-45	0.26	0.67	0.003	0.04	0.49	0.57	0.01	2.78
				Profile No.3 - St. Damase				
0-20	0.12	0.31	0.02	0.13	0.15	0.14	0.01	1.91
20-40	0.07	0.14	0.02	0.05	0.14	0.1	0.01	2.06
40-50	0.13	0.09	0.03	0.09	0.27	0.15	0.01	3.94
				Profile No.4 - St. Damase				
0-15	0.22	0.5	0.01	0.1	0.25	0.23	0.01	2.75
15-40	0.16	0.37	0.004	0.09	0.20	0.14	0.01	1.59
40-50	0.18	0.29	0.01	0.14	0.27	0.16	0.01	2.69
50-65	0.16	0.16	0.04	0.04	0.13	0.09	0.01	5.38

Continued

Depth cm	Fe_2O_3 % by Oxalate	Al_2O_3 % by Oxalate	MnO % by Oxalate	SiO_2% by Oxalage	Fe_2O_3 % by Pyrophosphate	Al_2O_3 % by Pyrophosphate	MnO % by Pyrophosphate	SiO_2 % by Pyrophosphate
				Profile No.5 - St. Damase				
0-7	0.24	0.13	0.01	0.14	0.26	0.11	0.01	3.31
7-25	0.24	0.49	0.01	0.1	0.13	0.3	0.01	3.41
25-50	0.16	0.39	0.003	0.1	0.29	0.23	0.004	2.94
50-70	0.26	0.47	0.01	0.16	0.22	0.18	0.01	3.94
70-82	0.09	0.14	0.02	0.09	0.10	0.09	0.01	3.41
82-92	0.04	0.04	0.02	0.06	0.05	0.06	0.01	2.78
				Profile No.6 - St. Amable				
0-7	0.34	0.36	0.003	0.09	0.46	0.22	0.01	3.97
7-15	0.36	0.45	0.002	0.09	0.53	0.34	0.01	4.69
15-25	0.49	0.75	0.002	0.24	0.54	0.61	0.004	4.28
25-55	0.18	0.39	0.01	0.12	0.15	0.15	0.01	4.69
55-75	0.03	0.15	0.003	0.09	0.04	0.07	0.004	3.66
75-80	0.04	0.06	0.03	0.07	0.05	0.06	0.01	3.13
				Profile No.7 - St. Amable				
0-7	0.15	0.14	0.004	0.1	0.30	0.12	0.01	3.38
7-20	0.19	0.46	0.002	0.1	0.32	0.3	0.004	4.22
20-65	0.19	0.46	0.002	0.14	0.18	0.2	0.004	0.91
65-80	0.04	0.17	0.003	0.06	0.08	0.09	0.01	0.67
80-90	0.03	0.08	0.02	0.09	0.04	0.05	0.01	0.34
90-120	0.04	0.03	0.01	0.08	0.05	0.04	0.01	5.56

Continued

Depth cm	Fe_2O_3 % by Oxalate	Al_2O_3 % by Oxalate	MnO % by Oxalate	SiO_2 % by Oxalate	Fe_2O_3 % by Pyrophosphate	Al_2O_3 % by Pyrophosphate	MnO % by Pyrophosphate	SiO_2 % by Pyrophosphate
				Profile No.8 - St. Amable				
0-7	0.18	0.32	0.003	0.07	0.27	0.14	0.01	1.84
7-20	0.15	0.53	0.001	0.11	0.21	0.26	0.003	2.09
20-60	0.11	0.32	0.002	0.10	0.14	0.11	0.01	1.91
60-85	0.03	0.1	0.002	0.11	0.05	0.06	0.004	1.56
85-100	0.02	0.03	0.001	0.07	0.03	0.05	0.004	1.91
100-120	0.03	0.02	0.03	0.03	0.05	0.03	0.01	1.13

Appendix 3

Analysis of Variance Tables

Analysis of variance tables for particle sizes in the Ap-Horizon

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Level of Significance
1.0-0.5 mm					
Total	7	3.546			
Group	1	2.910	2.910	13.952*	5%
Profiles (replicates)	3	0.010	0.0034	0.0163	N.S.
Error	3	0.625	0.2085		
0.5-0.25 mm					
Total	7	185.573			
Group	1	53.991	53.991	4.585	N.S.
Profiles (replicates)	3	96.258	32.090	2.7253	N.S.
Error	3	35.324	11.775		
0.25-0.1 mm					
Total	7	1140.179			
Group	1	921.389	921.389	16.136*	5%
Profiles (replicates	3	47.483	15.828	0.277	N.S.
Error	3	171.308	57.10		
0.1-0.05 mm					
Total	7	106.079			
Group	1	31.292	31.292	3.5997	N.S.
Profiles (replicates)	3	48.709	16.236	1.868	N.S.
Error	3	26.079	8.693		
0.05-0.02 mm					
Total	7	86.89			
Group	1	71.25	71.250	14.05*	5%
Profiles (replicates)	3	0.43	0.143	0.028	N.S.
Error	3	15.21	5.070		
0.02-0.005 mm					
Total	7	22.272			
Group	1	18.318	18.318	27.022*	5%
Profiles (replicates)	3	1.920	0.640	0.944	N.S.
Error	3	2.033	0.678		
0.005-0.002 mm					
Total	7	13.057			
Group	1	7.236	7.236	3.847	N.S.
Profiles (replicates)	3	0.177	0.059	0.0314	N.S.
Error	3	5.644	1.881		

Analysis of variance tables for particle sizes in the C-horizon

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Level of Significance
1.0-0.5 mm					
Total	7	19.165			
Group	1	5.394	5.394	4.999	N.S.
Profiles (replicates)	3	10.534	3.511	3.000	N.S.
Error	3	3.237	1.079		
0.5-0.25 mm					
Total	7	3252.295			
Group	1	716.856	716.856	2.0486	N.S.
Profiles (replicates)	3	1485.670	495.233	1.452	N.S.
Error	3	1049.764	349.923		
0.25-0.1 mm					
Total	7	1597.510			
Group	1	474.923	474.923	0.1173	N.S.
Profiles (replicates)	3	117.8875	39.295	1.4181	N.S.
Error	3	1004.699	334.899		
0.1-0.05 mm					
Total	7	281.267			
Group	1	5.715	5.715	0.501	N.S.
Profiles (replicates)	3	241.339	80.447	7.057	N.S.
Error	3	34.212	11.40		
0.05-0.02 mm					
Total	7	31.998			
Group	1	21.698	21.698	6.395	N.S.
Profiles (replicates)	3	0.122	0.041	0.0121	N.S.
Error	3	10.178	3.393		
0.02-0.005 mm					
Total	7	47.944			
Group	1	38.849	38.849	68.396**	1%
Profiles (replicates)	3	7.392	2.464	4.338	N.S.
Error	3	1.703	0.568		
0.005-0.002 mm					
Total	7	101.2824			
Group	1	70.798	70.798	11.17*	5%
Profiles (replicates)	3	11.472	3.824	0.603	N.S.
Error	3	19.012	6.337		