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CHARACTERISTIC OF SOME HAPLUDALFS WITHIN A LANDSCAPE IN SOUTHERN MICHIGAN

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CHARACTERISTIC OF SOME HAPLUDALFS WITHIN A LANDSCAPE IN SOUTHERN MICHIGAN

By

Bhairav Raj Khakural

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ABSTRACT

CHARACTERISTICS OF SOME HAPLUDALFS WITHIN A LANDSCAPE IN SOUTHERN MICHIGAN

by

Bhairav Raj Khakural

Characteristics of some Hapludalfs were studied at the Clarksville Horticultural Experiment Station in Ionia County, Michigan. Pedons representing six soil mapping units were described in the field. Samples were analyzed for particle size; hydraulic conductivity; bulk density; organic carbon; nitrate nitrogen; extractable phosphorus, potassium, calcium, magnesium; and soil pH. Representative pedons were classified according to Soil Taxonomy. Limitation Tables were developed for assessing these soils for some common horticultural and agronomic crops.

Two subgroups of Hapludalfs were encountered, Typic and Psammentic. Typic Hapludalfs found were of the coarse-loamy; coarse-loamy over sandy; fine-loamy; or fine-loamy over sandy, mixed, mesic family. The Psammentic Hapludalfs were of the sandy, mixed, mesic family.

In general, the studied soils had slight limitations for the selected crops (both horticultural and agronomic) with the following exceptions. Spinks soils (Psammentic Hapludalfs) have a low water holding capacity and had severe limitations for both horticultural and agronomic crops. The moderately well drained Riddles (Typic Hapludalfs, fine-loamy, mixed, mesic) had moderate limitations for apples, pears and peaches. All moderately sloping soils (2-6%) had moderate limitation for the selected crops.

To

My Parents

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Thanks are also extended to Dr. Hugh Price for his help in preparing limitation tables of the studied soils for selected vegetable crops, to Clarksville Horticulture Research Station Personnel for their cooperation during my field study, to the personnel of the soil testing laboratory in carrying out some of the routine chemical analysis and to Mrs. Ardell Ward for her help at various occasions throughout the completion of this work.

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INTRODUCTION

Hapludalfs in Southern Michigan are well drained reddish or brownish Alfisols with udic moisture regimes and mesic temperature regimes. They have argillic horizons and are the most common soils found on nearly level to gently sloping till plains and moraines of the area. Hapludalfs are the dominant upland soils of Indiana, Ohio and Southern Michigan. Nearly 118,000 hectares of Hapludalfs have been correlated in Michigan by 1979 during the progress of cooperative soil survey program (Soil Survey Staff, 1979).

Hapludalfs are the dominant soils of the Michigan State University Clarksville Horticultural Experiment Station. A detailed characterization of morphological, physical and chemical properties of these soils is essential for research plot designs. Horticultural crops such as fruits and vegetables respond differently to different soil properties. Differences in these soils influence the management of the studied crops.

Information on soil physical properties such as particle size distribution, water holding capacity and water movement is required in designing irrigation and drainage systems. Irrigation scheduling for maximum crop response with minimum water and energy inputs is dependent upon soils information.

Accurate extrapolation of research results obtained on the experiment station will benefit Michigan agriculture. The classification of the soils will assist researchers in understanding their data and in guiding them in making management recommendations to the general population of Michigan.

The specific objectives of this study were as follows:

1. To determine selected morphological, physical and chemical properties of representative pedons from the Clarksville Horticultural Experiment Station.

2. To classify the representative pedons.

3. To develop generalized suitability tables for the production of selected hortucultural and agricultural crops on the studied soils.

The Clarksville Horticultural Experiment Station is located in Boston Township, Ionia County including the S 1/2, Sec. 28; NE 1/4, NE 1/4, Sec. 33; and W 1/2, SW 1/4, Sec. 27; T6N, R8W (Figure 1). A soil map at a scale of 1:1066.67 ft. was prepared by Dr. Delbert Mokma and Dr. Gary Lemme of the Department of Crop and Soil Sciences after observations were made at 61 meter intervals (Figure 2).

The dominant upland soils of the experimental station were Riddles (fine-loamy, mixed, mesic Typic Hapludalfs), Bixby (fine-loamy over sandy or sandy skeletal, mixed, mesic Typic Hapludalfs), Kalamazoo (fine-loamy over sandy or sandy skeletal, mixed, mesic Typic Hapludalfs) and Spinks (sandy, mixed mesic Psammentic Hapludalfs) correlated hectares of these series in Michigan are given in Table 1. The Experiment Station is within the Charlotte moraine system which is composed of a sequence of moraines and till plains of the Wisconsin age Saginaw glacial lobe.

Ionia County is an agricultural county with a total land area of 136,728 hectares (Michigan Conservation Needs Committee, 1975) of which 57% (78,205.5 hectares) is cropland, 13.6% (18,630 hectares) pasture, 19.7% (269,730) woodland and 9.5% (12,555 hectares) in other land uses such as resorts, urban, recreational and industrial sites. U.S.D.A. capability class I-IV comprises about 95% of the total land. Ninety-nine

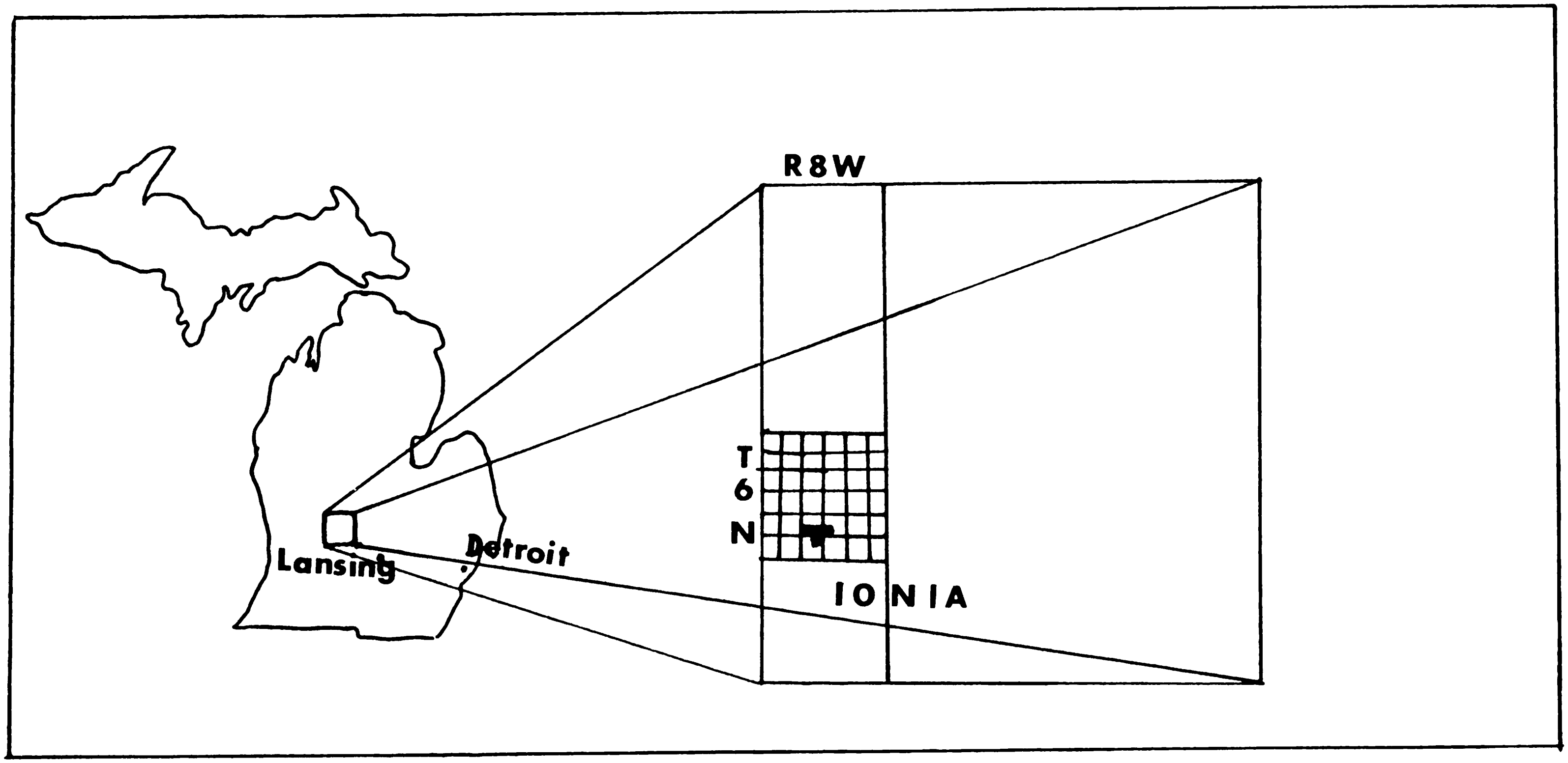
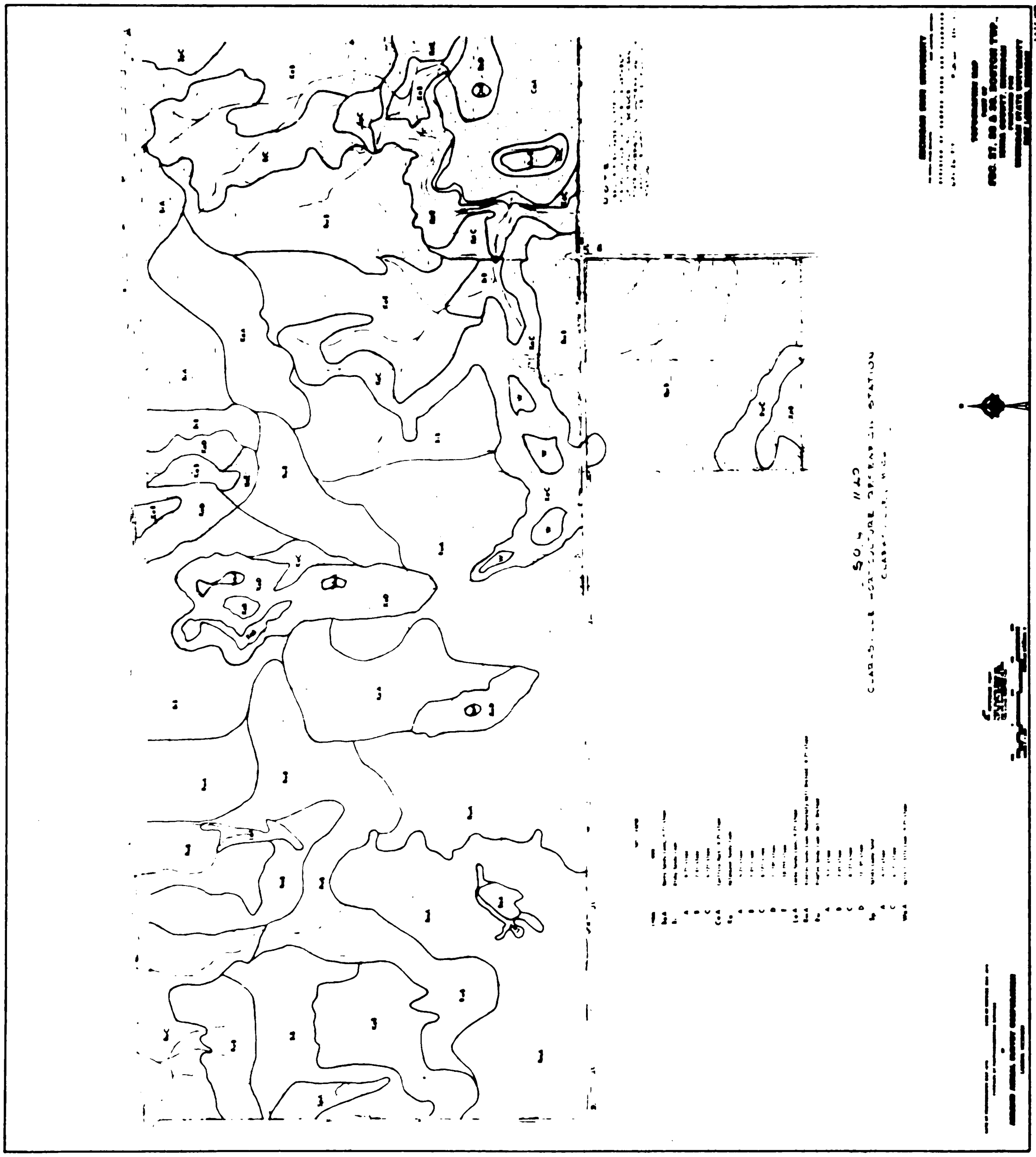


Fig. 1 Location of the Clarksville Horticultural Experiment Station.

Figure 2.



Note: Originals of this map are available at the Department of Crop and Soil Sciences, Department of Horticulture, and Clarksville Horticultural Experiment Station.

and one half percent of the cropland is found on these capability classes. Corn is the main row crop (Table 2). Wheat and oats are the important small grains. Alfalfa and clover are the main forage crops which cover 12,222.5 and 2,934.2 hectares (Threlkeld, G. and S. Alfred, 1967), respectively. Horticultural crops are also important agricultural products in the area. Potatoes are grown on 89.9 hectares, tree fruits, nuts and grapes on 1,116.6 hectares and vegetable crops on 707.9 hectares. Apples are the dominant tree fruits grown in the county. Pears, peaches and plums are other important fruits grown in this area.

Table 1

Correlated Hectares of Soils Found on the Clarksville Horticultural Experiment Station in Michigan (1979)

Soil Series	Hectares
Riddles	56,371.14
Bixby	571.1
Kalamazoo	48,621.9
Spinks	81,299.7

Table 2

Ionia County Field Crop Area, Production and Economic Value (1978)

Crop	Area (hectares)	Yield (kg/ha)	Crop Price/ kg($)	Production (1000 kg)	Product Value (1000 $)
Corn	24,340.5	876.498	0.32	38,075.511	12,213
Wheat	7,978.5	459.31	0.81	36,646.048	2,984.4
Oats	6,885	664.78	0.31	4,439.320	1,356.75
Soybeans	2,535.2	294.571	1.52	746.794	1,142.44
Dry beans	4,536	1,670.29	0.36	7,576.435	2,748.82

Source: Michigan Agricultural Statistics, July 1979.

LITERATURE REVIEW

A. Soil Forming Factors of Clarksville Horticultural Research Station

Climate

Post glacial climates since the deposition of the glacial deposits that these soils have formed in, likely have not always been exactly like the present day climate. However, in general the soils of the area have formed under a cool, moist modified continental climate. Lake Michigan modifies the climate of the area. As a result, Ionia County has a milder winter and cooler summer than areas at the same latitude west of the lake (Threlkeld, G. and S. Alfred 1967). Ionia County has an annual mean temperature of 8.92°C with an average daily maximum and minimum of 14.75°C and 3.07°C, respectively (Table 3). Eighty-three centimeters of precipitation are received on the average. The precipitation is distributed throughout the year with two-thirds of the total rainfall falling during the months of April to September. Snow covers the ground for 58 days with 104 cm. average annual snowfall (Table 3). The humidity is high throughout most of the year. There are normally 135 frost-free days (Threlkeld, G. and S. Alfred 1967) and 2751 growing degree days at base 50°F (Brink, C.V.D., et al., 1971).

Parent Material

The soils of the station are developed in the glacial drift of the late Wisconsin (Cary) glaciation. The drift is very thick and there is no direct influence of the underlying reddish sandstone bedrock on the soils of the Experiment Station (Threlkeld, G. and S. Alfred, 1967). The bedrock is of

Table 3: Temperature and Precipitation, Ionia County, Michigan*

Month	Temperature		Precipitation		
	Average Daily Maximum 0°C	Average Daily Minimum 0°C	Average Total cm	Days with Snow Cover 2.5 cm or more	Average Depth of Snow on days with Snow Cover of 2.54 cm or more
January	-0.39	-8.77	4.09	18	6.35
February	0.5	-8.94	3.20	18	9.40
March	6.5	-4.17	6.05	6	7.36
April	15.0	1.83	8.00	0	0
May	20.39	7.05	10.80	0	0
June	26.50	13.06	9.14	0	0
July	29.17	14.83	8.15	0	0
August	28.33	14.00	8.73	0	0
September	23.78	10.11	7.57	0	0
October	17.83	4.50	6.02	0	0
November	7.89	-0.89	6.10	5	7.11
December	1.44	-5.78	5.26	11	9.40
Year	14.75	3.07	83.11	58	39.62 cm

*Source: Soil Survey, Ionia County, Michigan, by Therlkeld, G. and S. Alfred 1967

the Grand River Formation and is late Pennsylvanian in age (Dorr, J. A., Jr. and D. F. Eschman, 1970). Unweathered glacial drift consists of limy residue; with fragments of shale, limestone, sandstone and smaller amounts of crystalline rocks. These materials were deposited in the form of glacial till or glacial outwash (Threlkeld, G. and S. Alfred, 1967). The area is within the Charlotte moraine system which is composed of a sequence of moraines and till plains.

Biological Organisms

The soils of the station have formed under forest vegetation. Prior to settlement the area was under a dense forest of oaks, hickory, and sugar maple. The dominant species were elm (Ulmus sp.), basswood (Tilia americana L.), ash (Fraxinus sp.), shagbark hickory (carya ovata (Mill.) K Koch), swamp white oak (Quercus bicolor Willd.), sugar maple (Acer saccharum Marsh), and beech (Fagus grandifolia Ehrh) (Veatch, J. O. 1959, U.S.D.A., 1949).

Earthworms, arthropods and rotifers are the major soil forming animals of the area (Threlkeld, G. and S. Alfred, 1967, Pritchett, W. L., 1979). These animals help in the fragmentation of the plant litter and the incorporation of the fragmentations with the mineral soils; which can later on be acted upon by decomposing micro-organisms. Bacteria, actinomycetes and fungi are the major decomposers, with bacteria being the dominant one. The foliage of hardwood species is generally high in pH, bases, and protein content which are more favorable for bacterial decomposition (Whitkamp, M. 1963). In addition to fragmentation and mixing of plant litters, soil animals such as earthworm burrow into the soil and cause soil

mixing. They also modify soil structure, aeration and drainage (Hole, F.D., 1981). Presence of worm casts in the studied profiles indicate that earthworm activities are common in these soils.

Relief

The study area has slight micro relief with 0 (nearly level) to 12 percent (moderately sloping) slope. The upland soils of the Station are mostly well drained, with some moderately well drained soils on level plains, and depressions where the sub-soil permeability is slow (Figure 1).

Time

The soils of the station are geologically relatively young. They have developed in the late Wisconsin (Cary) aged glacial drift (Threlkeld, G. and S. Alfred, 1967) which dates back 16,000 to 13,500 years before present (Dorr, J. A., Jr. and D. F. Eschman, 1970).

B. Formation and Classification of Soils of the Clarksville Horticultural Research Station

A good knowledge of soil formation is essential for the proper understanding of certain soil properties and their implications in management planning. A lot of new terms are encountered at various category levels in the new classification system (Soil Survey Staff, 1975). Therefore, formation of some diagnostic horizons and terms that would be used in classifying studied soils are reviewed in this section.

Alfisol

Alfisols are those soils which have an ochric or umbric epipedon, an argillic horizon, a medium to high supply of bases and water available to the mesophytic plants more than half of the year or more than three consecutive months during the warm season of the year (Soil Survey Staff, 1975).

Ochric Epipedon

Ochric epipedons are those surface soils that are too high in value or chroma, are too dry, have too little organic matter, have an N value too high, or are too thin to meet the criteria of a mollic, umbric, anthropic, plaggen or histic epipedon, or it is both hard and massive when dry (Soil Survey Staff, 1975).

Argillic Horizon

An argillic horizon is one that contains illuvial layer-lattice clays. This horizon forms below an eluvial horizon but it can be at the surface if the soil has been partially truncated by erosion. The following properties can be used for identifying an argillic horizon (Soil Survey Staff, 1975).

1. If there is no lithologic discontinuity the argillic horizon contains more total and fine clay than the eluvial horizon as follows.

    a. If the eluvial horizon has <15% clay in the fine earth fraction, the argillic horizon must contain 3% more clay.

    b. If the eluvial horizon has 15-40% total clay, the argillic horizon must have at least 1.2 times more clay.

    c. If the eluvial horizon has >40% clay, the argillic horizon must contain at least 8% more clay.

2. The argillic horizon should be at least one-tenth as thick as the sum of the thickness of overlying horizons. If the argillic horizon is composed entirely of lamellae $\geq$ 1 cm. thick, it should have a combined thickness of 15 cm.

3. If the peds are present,

    a. An argillic horizon should have clay skins on both vertical and horizontal ped surfaces.

    b. The clay skin requirement may be waived if there are evidences of pressure caused by swelling, uncoated grains of sand and silt in overlying horizon; and if the ratio of fine to total clay in the argillic horizon is at least one-third more than in the eluvial horizon.

4. If the soil has a lithologic discontinuity between the eluvial horizon and argillic horizon, or if only the plow layer overlies the argillic horizon needs to have clay skins only in some part.

<u>Formation of Argillic Horizon</u>

Argillic horizons are formed by the eluviation of clay from an overlying A horizon and its accumulation in a B horizon (McKeague, J. A., et al., 1959). In this process more fine clay is moved than coarse clay. Four requirements are recognized for the formation of an argillic horizon (Soil Survey Staff, 1975).

1. Sufficient fine clay content in the parent material and/or sufficient production by weathering.
2. Disruption of the fabric and dispersion of the clay particles.
3. Clay translocation through the soil.
4. Some mechanism for deposition.

Wetting and drying soils can disrupt the fabric and disperse clays. Sodium ions increase the dispersion of clays. Organic matter also has some indirect effects on clay dispersion. Dispersed clay moves with percolating water until it is flocculated (Soil Survey Staff, 1975). Deposition of clay in the argillic horizon may be brought about by the depletion of percolating water through absorption into the peds; constriction of voids by the swelling of clays which prevent the continued percolation of water; clogging of finer pores with clay particles from the percolation water; and flocculation of negatively charged clays by iron oxide or other cations such as calcium ions in B horizons (Boul, S. W., et al., 1980, Throp, J., et al., 1959). Clays can be translocated either in suspension or as weathering products (silica, alumina) in solution (Birkeland, W. P., 1974). Weathering products such as silica and alumina later precipitate as clay minerals in the illuvial horizon. Clay carried in suspension could account for the formation of clay skins (Throp, J., et al., 1957, Buol, S. W., et al., 1961). Therefore, the presence of clay cutans in the B horizon is considered as evidence of illuvation (Grossman, R. B., et al., 1959). Such strongly expressed illuviation features are attributed to a higher frequency of wetting and drying cycles (Smith, H., et al., 1972). In many Udalfs, maximum clay films were observed in the lower B horizons (Buol, S. W., et al., 1959, 1961). However, a maximum accumulation of fine clay was observed in the upper B2 horizon of the same soils (Smith, H., et al., 1972).

Argillic horizons generally are more strongly developed under forest vegetation than under grass vegetation probably because of a more extensive use of subsurface water by trees. Moisture regimes also influence the formation

of argillic horizons. No evidences of clay illuviation are found in the soil with perhumid climate. It might be because of the lack of wetting drying cycles in those soils (Soil Survey Staff, 1975). The distribution of clay in the solum is influenced by the depth of leaching, amount and distribution of rainfall, and the natural drainage class of the soil (Goddard, T.M., et al., 1973). Argillic horizon formation requires at least a few thousand years and a stabilized condition. There should be minimum or no mixing of horizons by animals, frost or by shrink-swell action of the soil (Soil Survey Staff, 1975).

Formation of Lamellae

Some sandy soils of the humid temperate regions have thin subsoil bands which contain more silicate clays, free iron oxide and/or organic matter complexes than the layers above or below. The genesis of these bands is not well understood. Many of these bands are pedogenic (Folks, et al., 1956; Wurman, et al., 1959; and Dijkerman, et al., 1967) while others are geologic in origin (Robinson, et al., 1960). Some kind of periodic precipitation mechanism is involved in the formation of iron enriched clay bands in the soil (Folks, et al., 1956). Iron oxides, silicate clays, and organic complexes can move simultaneously or at different times in the soil (Wurman, et al., 1959). The deposition of suspended material takes place by flocculation, sieving or simple drying where the wetting front ceases (Wurman, et al., 1959, Dijkerman, et al., 1967).

In many cases lamellae have formed by clay translocation. It was concluded from the study of lamellae in Psammentic Haploxeralfs that clay illuviation is the most important factor in their formation (Torrent, J., et al., 1980). Clay illuviation can be confirmed by observing well-oriented argillans. If a

B horizon has lamellae $\geq$ 1 cm. thick and has a combined thickness of 15 cm., it qualifies for an argillic horizon (Soil Survey Staff, 1975). Textural stratification of the parent material may initiate clay accumulation in certain lamellae (Bartelli, 1960) due to its influence in the downward movement of water (Miller and Gardner, 1962). Larger soil pores in the coarse textured layers cause the water to be concentrated in the finer pores above in the lamellae. When this water is withdrawn by evapotranspiration, the suspended clay is deposited. Once an incipient lamella is formed, it grows further due to increased pore size differences between the two layers (Soil Survey Staff, 1975).

Udalfs

Udalfs are the Alfisols (Soil Survey Staff, 1975) that have:

1. A mesic or isomesic or warmer temperature regime.
2. A udic moisture regime or, if marginal to an ustic or a xeric moisture regime, do not have a calcic horizon and do not have soft powdery lime in spheroidal forms or as coatings on peds or disseminated in clay-size particles.
3. A chroma too high for aqualfs or do not have either an aquic moisture regime or artificial drainage.

Hapludalfs

Hapludalfs are the udalfs (Soil Survey Staff, 1975) that:

1. Do not have tongues of albic materials in the argillic horizon that constitute as much as 15 percent of the volume in any subhorizon;
2. Have mean summer and mean winter soil temperatures at a depth of 50 cm. that differ by 5°C or more and have a mean annual soil temperature of 8°C or higher;
3. Do not have a fragipan, a natric horizon, or an agric horizon; and

4. Have an argillic horizon in which the clay distribution is such that the amount of clay decreases by 20 percent or more of the maximum clay content within a depth of 1.5 m. from the surface if,

   a. The hue is redder than 10 YR and the chroma is more than 4.

   b. The hue is 2.5 YR or redder, the value, moist, is less than four and the value, dry, is less than five throughout the major part of the argillic horizon; or

   c. There are many coarse mottles that have a hue redder than 7.5 YR or chroma of more than five; and in addition,

   d. There is $\leq$ 5 percent plinthite (by volume) in the horizon in which the amount of clay decreases.

C. Soil Properties in Relation to Crop Production

Soil Texture

Soil texture can be associated with the nutrient status of most soils. Clay particles have a large surface area compared to silt and sand particles. In addition to large surface area, clay particles are also negatively charged. The electrical charge helps to absorb positively charged nutrient ions. Therefore, soils which are high in clay content are also high in cation exchange capacity (Thomson and Troeh, 1978). Moderately fine textured soils tend to contain higher amounts of available water (Black, 1968). The coarse textured soils on the other hand are droughty with rapid infiltration and percolation rates (U.S.D.A., 1957). Properties that present management problems in clayey soils are their stickiness and slow permeability. They become very sticky when wet and hard when dry; they require greater power for tillage and are difficult to drain. Therefore, medium textured soils (Loams and Silt Loams) are preferred for most crop production (U.S.D.A., 1957, Thomson and Troeh, 1978).

Decidious fruits such as apples, pears and peaches can grow in a wide variety of soils but deep sandy loam soils are best suited. Pears are more tolerant of more clayey soils than the other two species (Childers, 1976). Sandy loam soils are well suited for early crops such as cabbage and cauliflower where as medium loams and heavy loams are preferred for later crops. Tomato yields are usually greatest on deep loam, silt loam and clay loam soils (U.S.D.A., 1957). It was concluded from a three-year field survey including field and greenhouse crops that sandy loam soils yield 20-30 percent more tomatoes than sandy soils (Vandamme, J., 1978). Field crops (corn, wheat, soybeans) do very well on sandy loam to clay loam soils. However, wheat can yield equally well in finer soils (U.S.D.A., 1957).

Natural Drainage

Most crops (including fruits, vegetables and field crops) require a well aerated soil. Oxygen exchange is required for root respiration. Energy released during respiration is used for plant growth; and for the uptake of water and nutrients. Poor drainage causes oxygen deficiency. A short term oxygen deficiency can reduce root respiration, increase resistance to water movement through roots, reduce nutrient uptake, and product toxic substances in the plants. Continued poor aeration results in death of cells, increased cell permeability, and finally death of roots (Williamson, R. E., et al., 1970).

Drainage is more critical for fruit orchards than for other crops because fruit trees have a long life and deep rooting pattern. Decidious

fruit trees (apples, pears, peaches) can tolerate some submergence during the winter dormant period but water logging during the growing season is detrimental (Makeriev, Z. 1976; Rom, C., et al., 1979). Most of the root hairs are lost during winter dormancy. These must be replaced during the spring to supply sufficient water and nutrients for the new growing plant tissue (Hoffman, M. B., 1966). Oxygen is essential for the production of root hairs. Waterlogging becomes more detrimental when the temperatures are high (Rowe, R. N., et al., 1971). Therefore, a soil with a water table within 15 cm. of the surface more than a week after a heavy rain or irrigation is considered unfit for fruit production (Childers, 1976). Some plant diseases and physiological disorders such as Pithium infection of the peach roots; bitter pit, summer leaf fall and withering of leaf buds of apples have been associated with poor drainage (Segeren, W. A., et al., 1969; Taylor, J., et al., 1970).

A reduction in the yield of tomatoes and cabbage was observed in a soil with a water table 15 cm. below the surface. Tomato yields increased with increasing depth to water table from 15 cm. to 81 cm. (Williamson, R. E., et al., 1964, Goins, T., et al., 1966). Diseases such as club root in cauliflower and mud wilt in tomatoes have been associated with poor drainage (Lopatin, V. M., et al., 1972; Young, P. A., 1963).

Field crops such as corn, soybean and wheat are also sensitive to poor drainage (U.S.D.A., 1957). Winter wheat is most sensitive to water logging between germination and emergence (Cannel, R. Q., et al., 1980). Water logging of wheat reduced root growth and penetration and was responsible for the decreased production of tillers and fertile heads (Watson, E. R., et al., 1976). Major reduction of dry matter yield of corn was evident after flooding for four days. This reduction increased as the period of flooding increased (Sheard, R. W., et al., 1976). Greater yield reductions were observed with a single submergence than repeated submergences of equal total duration (Chaudhary, T. N., et al., 1975). Soybean plants cannot tolerate water logged conditions even for a short period (Williams, C. N., et al., 1978).

Soil Reaction

Soil reaction affects the availability of nutrients. Strongly acid soils are generally low in plant available calcium and phosphorus but potentially may contain aluminum and manganese in toxic amounts. Strongly alkaline soils on the other hand are commonly deficient in iron and phosphorus (Tisdale and Nelson, 1975). Soil microbial activity is also influenced by soil acidity. The optimum soil reaction for crop production differs among species. Apple and pear trees do very well at slightly acid reaction (Lebedev, V. M., 1972). It was concluded by growing a wild apple seeding in a nutrient solution that roots are the most sensitive organs and began to die at strongly alkaline (PH > 8.5) and extremely acid (< 3.5) ranges. Internal bark necrosis of apple is associated with low PH's and high leaf manganese concentration (Fisher, A. G., et al., 1977). Slight to medium acid reactions (5.5-6.5) tends to prevent specific apple replant disorder (Jonkers, H., et al., 1978).

The highest tomato yields were obtained at slightly acid to neutral (6.1 to 6.9) soil reactions (Worley, R. E., 1976). However, optimum growth of the crop was observed at medium to slightly acid reactions; in the solution culture experiment (Islam, A.K.M.S., et al., 1980). Tomato yields are also found to be influenced by subsoil acidity (Doss, B. D., et al., 1977). Lucedale sandy loam (Rhodic Paleudult) with a medium acid (6.0) surface reaction produced a maximum yield when the subsoil pH was also within the medium acid range (5.6 to 5.8). Maximum yields of Chinese cabbage are generally obtained at neutral reactions (6.5 to 6.8) (Oh, W. K., et al., 1975). Fusarium wilt in tomatoes (Fusarium oxysporum f. sp. Lycopersici) is reduced by adjusting the soil reaction from medium acid to neutral (Jones, J. P., et al., 1971).

Maximum yields of corn and wheat are generally obtained at slightly acid reactions (Walker, W. M., et al., 1979). Whereas soybeans performed well within medium to slightly acid ranges (Chen, T. T., et al., 1974). Nodulation depressed at extremely acid reactions while nodulation and nitrogen fixation were optimum in strongly acid to neutral (5.2-7.0) soils (Harper, J. E., et al., 1976).

Soil Slope

Nearly level to gently sloping sites are preferred for the production of fruits, vegetables and field crops. Soil erosion is a serious problem in steeper slopes. The problem becomes more serious for producing clear tilled crops such as corn (Shrader, W. D., et al., 1964). The use of equipment and other management practices also becomes difficult on steeper slopes. In fruit production, many orchard operations such as pruning, thinning, harvesting and hauling fruits are much more difficult on strongly sloping ground (Childers, 1976). A flat valley floor, a river bottom or a depressional area should be avoided for fruit orchards because of the possible

frost damage from the cold air draining into it. The slope should be uniform with well defined air and water drainage ways. There should not be any obstructions to the cold air drainage (Childers, 1976, Soil Conservation Service, 1970).

MATERIALS AND METHODS

Site Selection

Six representative pedons from four dominant upland soil series of the Clarksville Horticultural Experiment Station were selected after the soils were sampled on a 61 meter grid. Six pedons represent the following mapping units.

RWA (Riddles Sandy Loam, well drained, 0-2% slope)
RMA (Riddles Sandy Loam, moderately well drained, 0-2% slope)
KaA (Kalamazoo Sandy Loam, well drained, 0-2% slope)
BiA (Bixby Sandy Loam, 0-2% slope)
BiC (Bixby Sandy Loam, 6-12% slope)
SpC (Spinks, Loamy Sand, 6-12% slope)

Field Study

The soil profiles were described in the field (Soil Survey Staff 1975). Descriptions included the following morphological properties: depth of horizon, color, texture, structure, consistence, root distribution, clay films, horizon boundary, reaction to 10% HCL and other important observed features.

Sample Collection and Preparation

Representative bulk samples were collected from each horizon for laboratory analysis. Five core samples from each horizon were also taken for saturated hydraulic conductivity, bulk density and moisture retention studies. Soil samples were air dried, crushed with a wooden rolling pin and passed through a 2 mm sieve. Greater than 2 mm fractions were weighed and discarded. Sub-samples were taken with a sample splitter, which were later on used for various physical and chemical determination.

MATERIALS AND METHODS

Site Selection

Six representative pedons from four dominant upland soil series of the Clarksville Horticultural Experiment Station were selected after the soils were sampled on a 61 meter grid. Six pedons represent the following mapping units.

RWA (Riddles Sandy Loam, well drained, 0-2% slope)
RMA (Riddles Sandy Loam, moderately well drained, 0-2% slope)
KaA (Kalamazoo Sandy Loam, well drained, 0-2% slope)
BiA (Bixby Sandy Loam, 0-2% slope)
BiC (Bixby Sandy Loam, 6-12% slope)
SpC (Spinks, Loamy Sand, 6-12% slope)

Field Study

The soil profiles were described in the field (Soil Survey Staff 1975). Descriptions included the following morphological properties: depth of horizon, color, texture, structure, consistence, root distribution, clay films, horizon boundary, reaction to 10% HCL and other important observed features.

Sample Collection and Preparation

Representative bulk samples were collected from each horizon for laboratory analysis. Five core samples from each horizon were also taken for saturated hydraulic conductivity, bulk density and moisture retention studies. Soil samples were air dried, crushed with a wooden rolling pin and passed through a 2 mm sieve. Greater than 2 mm fractions were weighed and discarded. Sub-samples were taken with a sample splitter, which were later on used for various physical and chemical determination.

Analysis of Selected Physical Properties

Particle size analysis was performed by the pipette method of Kilmer and Alexander (1949) with modifications as described by Day (1965). Carbonates were removed by using 1N sodium acetate solution buffered at pH 5. Undisturbed core samples were used for saturated hydraulic conductivity measurements (Klute 1965). The same core samples were used for measuring 1/3 bar moisture retention and bulk density on a 1/3 bar and oven dry basis (Procedure 4Ale, 4Bla, Soil Survey Staff 1972). A pressure membrane apparatus was used for determining 15 bar moisture (Procedure 4B2, Soil Survey Staff 1972).

Analysis of Selected Chemical Properties

Organic carbon determination was performed by the Walkley-Black Method as described by Allison (1965). A glass electrode pH meter was used to measure the pH of a 1:1 soil to water suspension. The Shoemaker, McLean and Pratt (SMP) Method (McLean 1980) was used for lime requirements. Phosphorous extracted with Bray P1 solution was measured with a colorimeter (Knudsen 1980). Extractable bases (Ca, Mg, K) were extracted with 1N NH_4OAC at pH 7. The concentration of bases was determined on a Perkin-Elmer 290, Atomic Absorption Spectrophotometer. The Nitrate-Nitrogen Electrode Method was used for determining nitrate nitrogen (Carson 1980). Cation exchange capacity values were estimated from the equation developed from Ohio State University: CEC = (lb K/A ÷ 780) + (lb Ca/A ÷ 400) + (lb Mg/A ÷ 240) + 12 (7.0 - SMP Buffer pH) which correlated well with CEC values determined with 1N Nh_4OAC method (Warncke, et al., 1980). Percent base saturation was determined.

Soils were classified on the basis of studied soil properties (Soil Survey Staff, 1975). Generalized limitation tables were prepared for selected field crops, vegetables and fruits on the basis of soil properties by consultation with university staff with experience in these crops and by reviewing existing information.

RESULT AND DISCUSSION

A. Morphology

Profile descriptions of the six representative pedons are given in Appendix A.

B. Physical Properties

Particle Size Distribution

Particle size distribution data for the six pedons studied are shown in Table 4. Total sand, silt, and clay distribution for each pedon is shown in Figure 3(a-f). Percent total sand values varied from 32.41 to 98.06. The Ap horizon in Pedon 2 had the lowest sand content while horizon II A&B in Pedon 5 had the highest percent total sand. In general, percent total sand increased with depth in the profile. However, the Ap horizon in Pedon 5 and B21t horizon in Pedon 3 had higher percent total sand than the lower horizons within the profile (Table 4). Sand fractions in Pedons 1, 2 and 5 were mostly fine, whereas Pedons 3 and 4 contained dominantly medium sand fractions. Pedon 6 had greater than 87.85% total sand throughout the profile. Percent total sand increased abruptly at 203, 142, 65 and 75 cm. depths in Pedons 1, 3, 4 and 5, respectively. The abrupt increase in percent total sand occurred as the soil parent material changed from glacial till to glacial outwash. This agreed with field descriptions where soil horizons developed in the second parent material were designated with a Roman numeral two (Appendix A). No change in percent total sand and hence in parent material was observed to a depth of 197 cm in Pedon 2.

TABLE 4
Particle Size Distribution

Pedon	Horizon	% Size Fraction											Tex. Class *
		V.C. Sand 2-1 mm	C. Sand 1-.5 mm	M. Sand .5-.25 mm	F. Sand .25-.1 mm	V.F. Sand .1-.05 mm	Total Sand 2-.05 mm	C. Silt .05-.02 mm	M. Silt .02-.005 mm	F. Silt .005-.002 mm	Total Silt .05-.002 mm	Clay <.002 mm	
1	Ap	0.88	2.10	9.91	16.59	8.14	38.07	38.70	10.16	3.52	52.38	9.56	Sil
	B1	1.20	2.92	11.91	22.24	9.96	48.94	20.75	7.06	3.84	31.65	19.40	L
	B21t	1.51	3.04	13.84	25.18	11.14	55.62	18.15	4.89	2.44	25.47	18.91	FSal
	B22t	2.26	3.87	14.74	24.64	11.21	57.58	14.88	9.18	3.94	28.14	14.10	FSal
	B3t	3.47	4.16	13.82	23.54	11.07	55.71	21.47	7.87	2.96	32.03	12.21	FSal
	C1	3.40	4.99	14.37	23.32	10.59	57.82	18.09	9.21	4.14	31.45	10.73	FSal
	IIB3	1.42	1.92	23.41	48.24	11.38	87.15	7.43	1.42	1.42	10.28	2.64	Sa
2	Ap	0.86	1.84	7.89	13.39	8.43	32.41	40.62	10.99	4.77	56.39	11.20	Sil
	A&B	1.11	3.30	13.39	22.48	12.67	52.97	23.88	4.21	3.11	31.20	15.83	FSal
	B21t	1.31	3.37	13.73	25.23	11.00	57.97	10.39	10.68	4.02	25.10	16.93	FSal
	B22t	1.94	2.39	15.09	27.68	8.87	58.78	16.94	4.34	5.56	26.84	14.38	FSal
	B3t	1.47	3.96	16.73	27.72	11.70	61.62	20.83	3.22	1.00	25.05	13.33	FSal
	C	3.28	4.84	16.80	29.38	8.87	63.27	15.15	9.62	3.93	28.64	8.19	FSal
3	Ap	0.88	3.54	15.77	21.25	4.08	47.27	32.76	6.85	4.47	44.07	8.66	L
	B1	1.16	4.21	23.23	25.56	5.07	59.09	22.43	5.88	4.17	32.47	8.44	FSal
	B21t	1.30	6.18	34.99	27.00	4.66	73.56	8.35	0.59	0.59	9.53	16.91	Sal
	B22t	0.5	4.66	28.10	27.00	6.57	67.67	6.65	8.29	4.23	19.17	12.95	Sal
	IIA&B	0.50	5.24	69.66	20.14	1.00	96.95	0.85	0.40	0.41	1.66	1.38	Sa
4	Ap	1.21	9.88	25.72	14.84	5.59	58.15	21.72	13.24	4.08	39.04	6.93	Sal
	B21t	1.18	6.81	32.81	19.90	5.09	65.79	13.34	10.52	2.44	26.29	7.92	Sal
	B22t	1.10	7.99	40.37	21.16	3.76	75.48	7.72	3.20	3.20	14.13	10.40	Sal
	IIC1	0.00	5.14	66.12	23.90	1.92	97.05	0.83	0.20	0.66	1.69	1.26	Sa
	IIC2	0.10	6.20	65.75	22.11	2.49	96.67	0.94	0.00	0.00	0.94	2.89	Sa

TABLE 4
Particle Size Distribution

Pedon	Horizon	% Size Fraction											Tex. Class *
		V.C. Sand 2-1 mm	C. Sand 1-.5 mm	M. Sand .5-.25 mm	F. Sand .25-.1 mm	V.F. Sand .1-.05 mm	Total Sand 2-.05 mm	C. Silt .05-.02 mm	M. Silt .02-.005 mm	F. Silt .005-.002 mm	Total Silt .05-.002 mm	Clay <.002 mm	
1	Ap	0.88	2.10	9.91	16.59	8.14	38.07	38.70	10.16	3.52	52.38	9.56	Sil
	B1	1.20	2.92	11.91	22.24	9.96	48.94	20.75	7.06	3.84	31.65	19.40	L
	B21t	1.51	3.04	13.84	25.18	11.14	55.62	18.15	4.89	2.44	25.47	18.91	FSal
	B22t	2.26	3.87	14.74	24.64	11.21	57.58	14.88	9.18	3.94	28.14	14.10	FSal
	B3t	3.47	4.16	13.82	23.54	11.07	55.71	21.47	7.87	2.96	32.03	12.21	FSal
	C1	3.40	4.99	14.37	23.32	10.59	57.82	18.09	9.21	4.14	31.45	10.73	FSal
	IIB3	1.42	1.92	23.41	48.24	11.38	87.15	7.43	1.42	1.42	10.28	2.64	Sa
2	Ap	0.86	1.84	7.89	13.39	8.43	32.41	40.62	10.99	4.77	56.39	11.20	Sil
	A&B	1.11	3.30	13.39	22.48	12.67	52.97	23.88	4.21	3.11	31.20	15.83	FSal
	B21t	1.31	3.37	13.73	25.23	11.00	57.97	10.39	10.68	4.02	25.10	16.93	FSal
	B22t	1.94	2.39	15.09	27.68	8.87	58.78	16.94	4.34	5.56	26.84	14.38	FSal
	B3t	1.47	3.96	16.73	27.72	11.70	61.62	20.83	3.22	1.00	25.05	13.33	FSal
	C	3.28	4.84	16.80	29.38	8.87	63.27	15.15	9.62	3.93	28.64	8.19	FSal
3	Ap	0.88	3.54	15.77	21.25	4.08	47.27	32.76	6.85	4.47	44.07	8.66	L
	B1	1.16	4.21	23.23	25.56	5.07	59.09	22.43	5.88	4.17	32.47	8.44	FSal
	B21t	1.30	6.18	34.99	27.00	4.66	73.56	8.35	0.59	0.59	9.53	16.91	Sal
	B22t	0.5	4.66	28.10	27.00	6.57	67.67	6.65	8.29	4.23	19.17	12.95	Sal
	IIA&B	0.50	5.24	69.66	20.14	1.00	96.95	0.85	0.40	0.41	1.66	1.38	Sa
4	Ap	1.21	9.88	25.72	14.84	5.59	58.15	21.72	13.24	4.08	39.04	6.93	Sal
	B21t	1.18	6.81	32.81	19.90	5.09	65.79	13.34	10.52	2.44	26.29	7.92	Sal
	B22t	1.10	7.99	40.37	21.16	3.76	75.43	7.72	3.20	3.20	14.13	10.40	Sal
	IIC1	0.00	5.14	66.12	23.90	1.92	97.05	0.83	0.20	0.66	1.69	1.26	Sa
	IIC2	0.10	6.20	65.75	22.11	2.49	96.67	0.94	0.00	0.00	0.94	2.89	Sa

TABLE 4 (continued)

Pedon	Horizon	% Size Fraction											Tex. Class *
		V.C. Sand 2-1 mm	C. Sand 1-.5 mm	M. Sand .5-.25 mm	F. Sand .25-.1 mm	V.F. Sand .1-.05 mm	Total Sand 2-.05 mm	C. Silt .05-.02 mm	M. Silt .02-.005 mm	F. Silt .005-.002 mm	Total Silt .05-.002 mm	Clay <.002 mm	
5	Ap	0.20	2.60	21.50	30.20	9.65	64.25	19.08	7.75	2.85	29.65	6.09	FSal
	Bl	0.08	1.13	18.30	18.44	16.85	55.70	13.38	10.07	4.56	33.07	11.90	FSal
	B2t	0.14	0.71	9.64	26.68	18.37	55.70	13.60	9.35	3.46	26.41	17.89	FSal
	IIA&B	0.26	8.13	55.85	31.63	2.14	98.06	0.37	0.60	0.00	0.96	0.98	Sa
6	Ap	1.35	3.92	33.99	44.69	3.91	87.85	4.05	2.57	1.57	8.19	3.96	LSa
	B&A	1.20	3.64	31.48	50.22	4.29	90.89	2.15	2.66	0.41	5.22	3.89	FSa
	A&B	0.69	1.98	30.56	51.71	5.24	90.39	3.65	1.20	0.80	6.04	3.57	FSa
		0.04	0.36	66.31	30.69	0.56	97.91	0.50	0.40	0.40	1.29	0.76	Sa

* L = Loam
Sil = Silt Loam
Sa = Sand
Sal = Sandy Loam
FSal = Fine Sandy Loam
FSa = Fine Sand
LSa = Loamy Sand

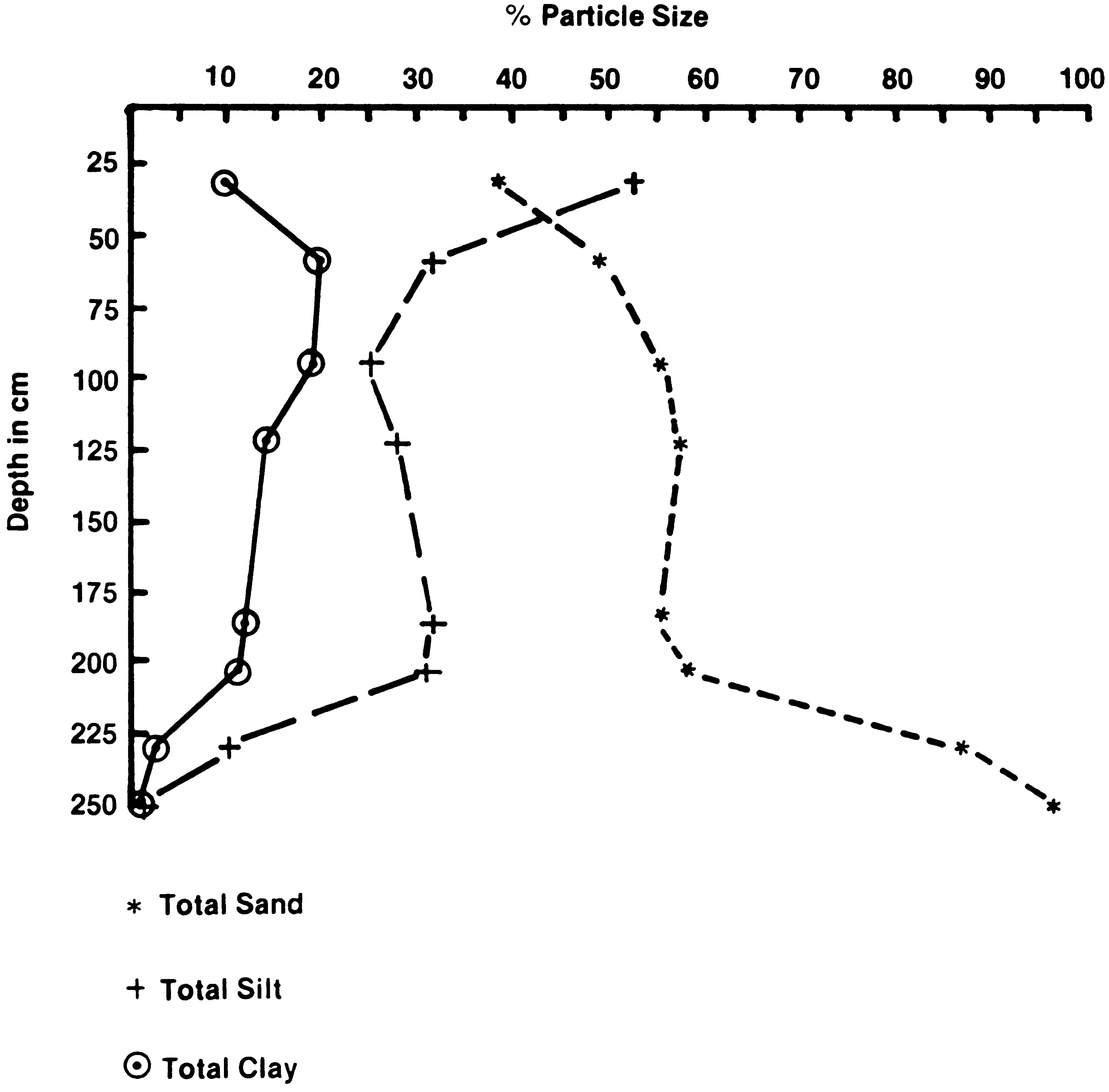


Figure 3(a). Particle Size Distribution for Pedon 1
(Riddles Well Drained).

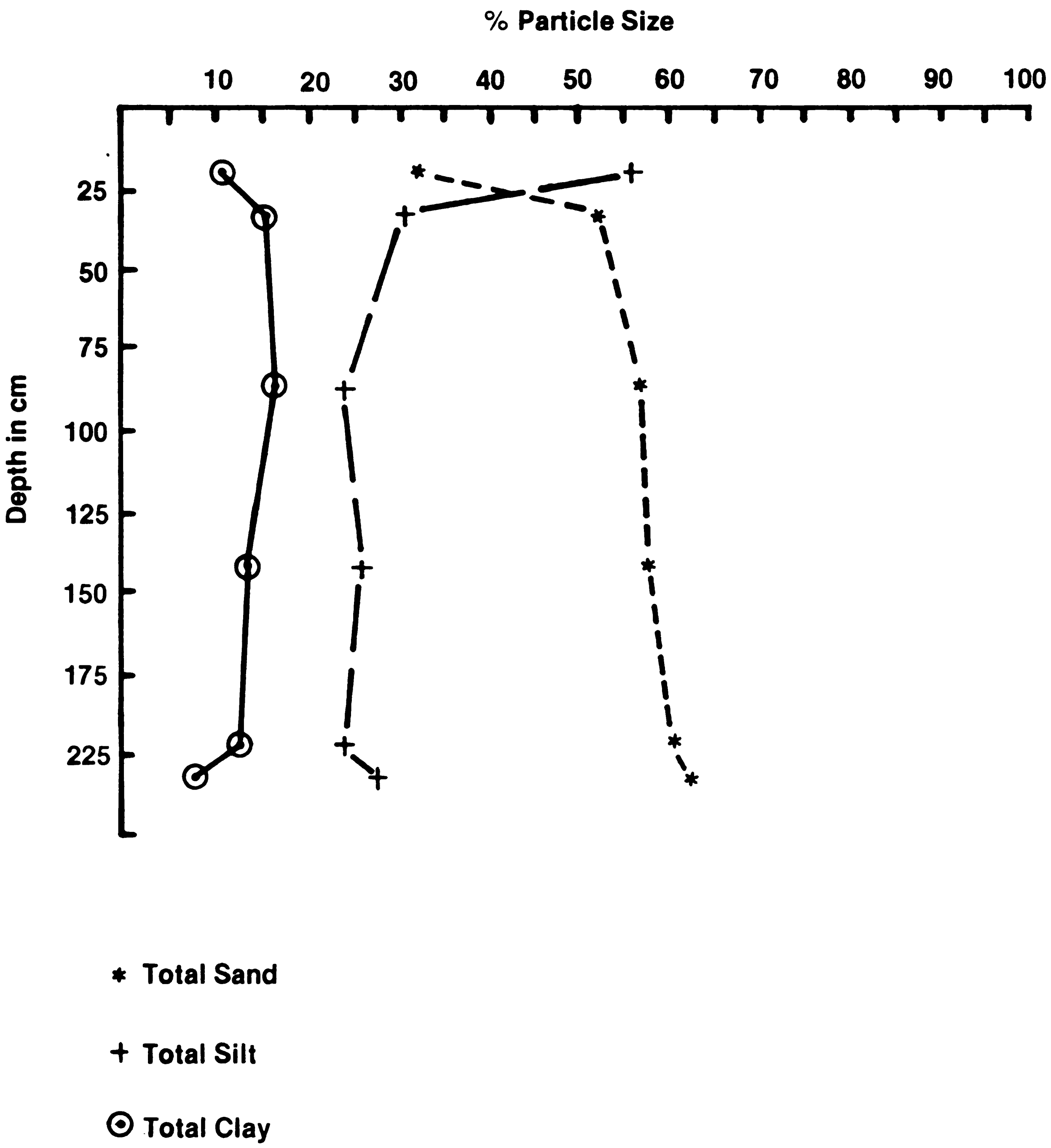


Figure 3(b). Particle Size Distribution for Pedon 2
(Riddles Moderately Well Drained).

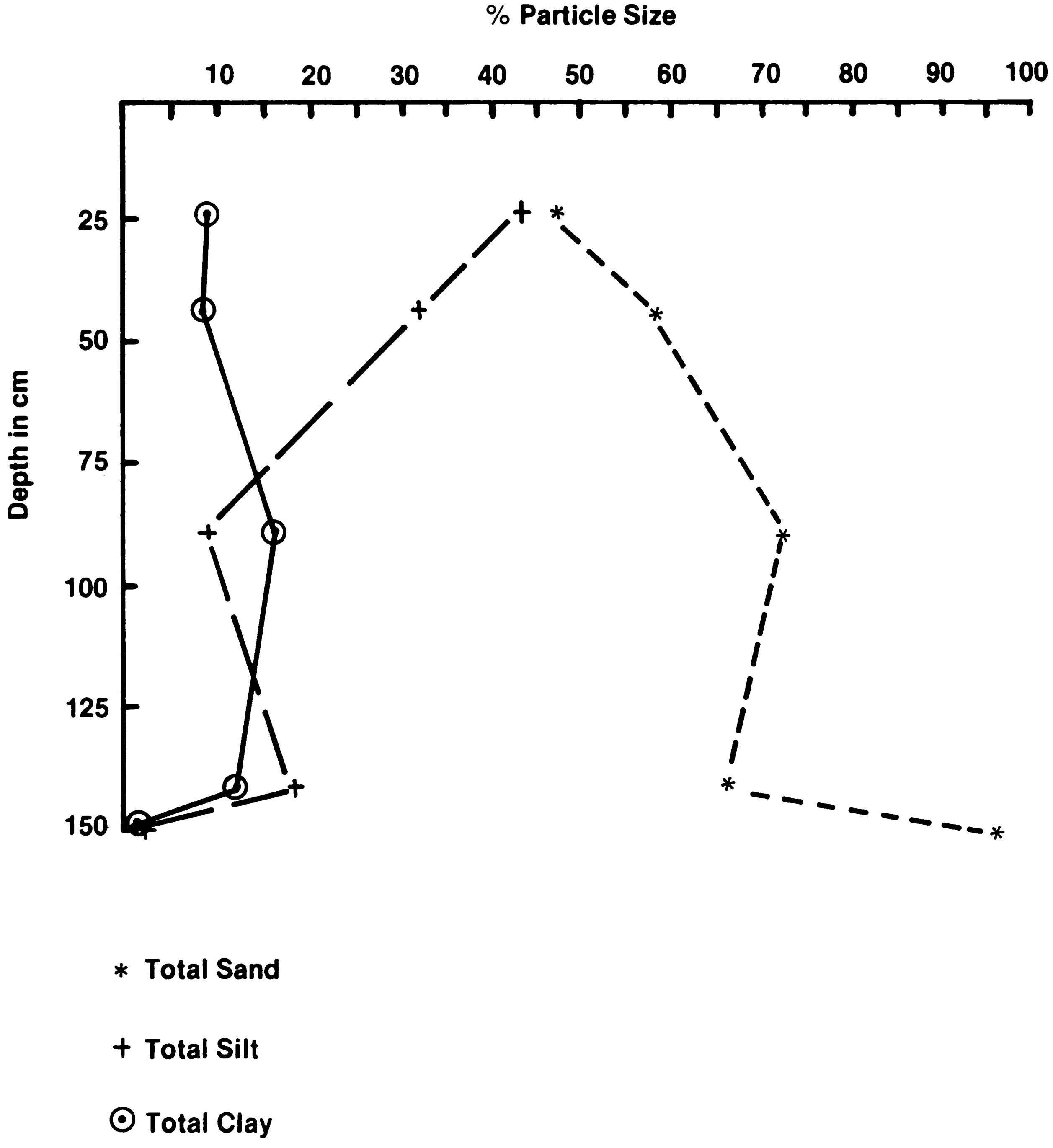


Figure 3(c). Particle Size Distribution for Pedon 3 (Kalamazoo).

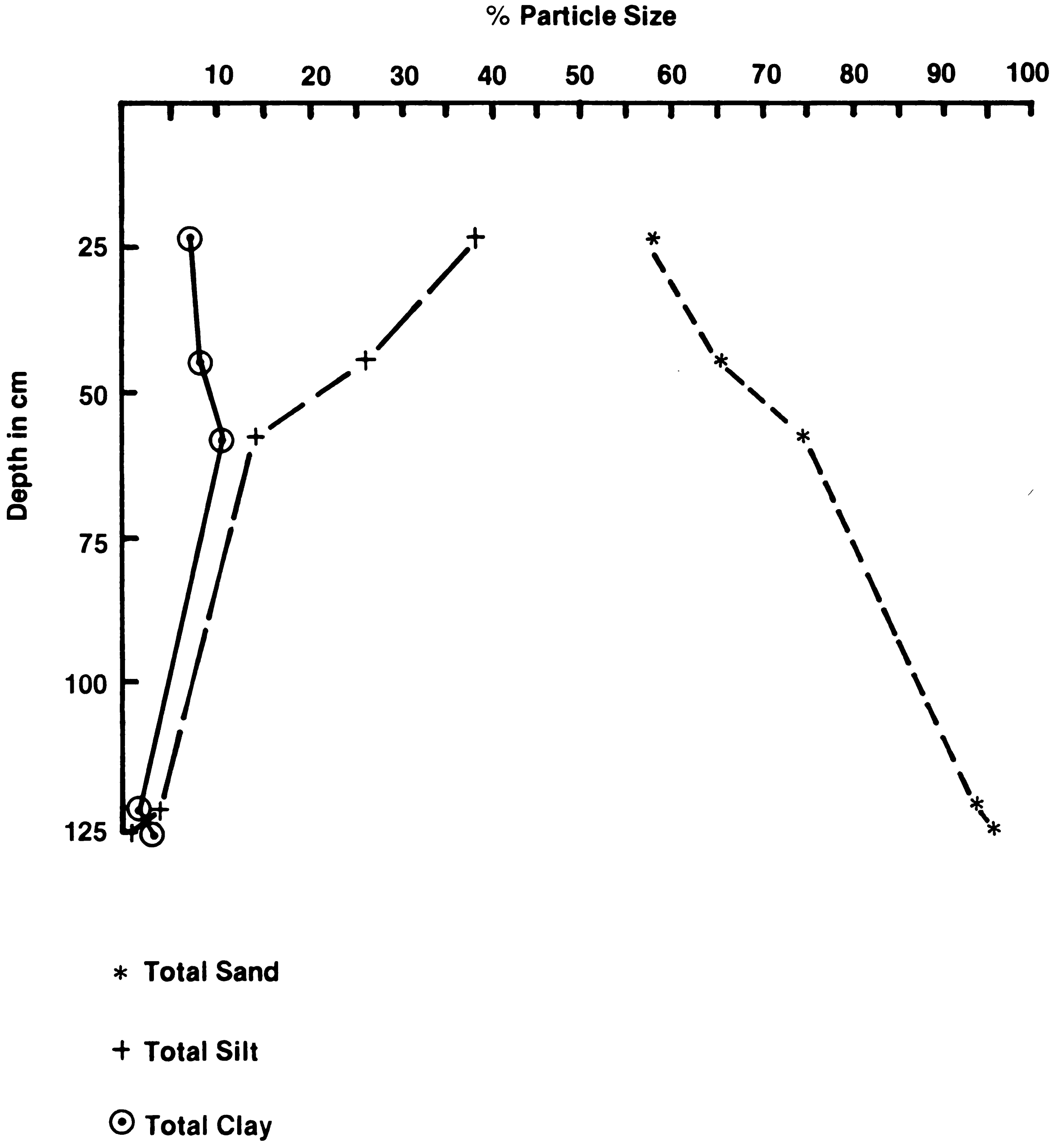


Figure 3(d). Particle Size Distribution for Pedon 4
(Bixby, 0-2%).

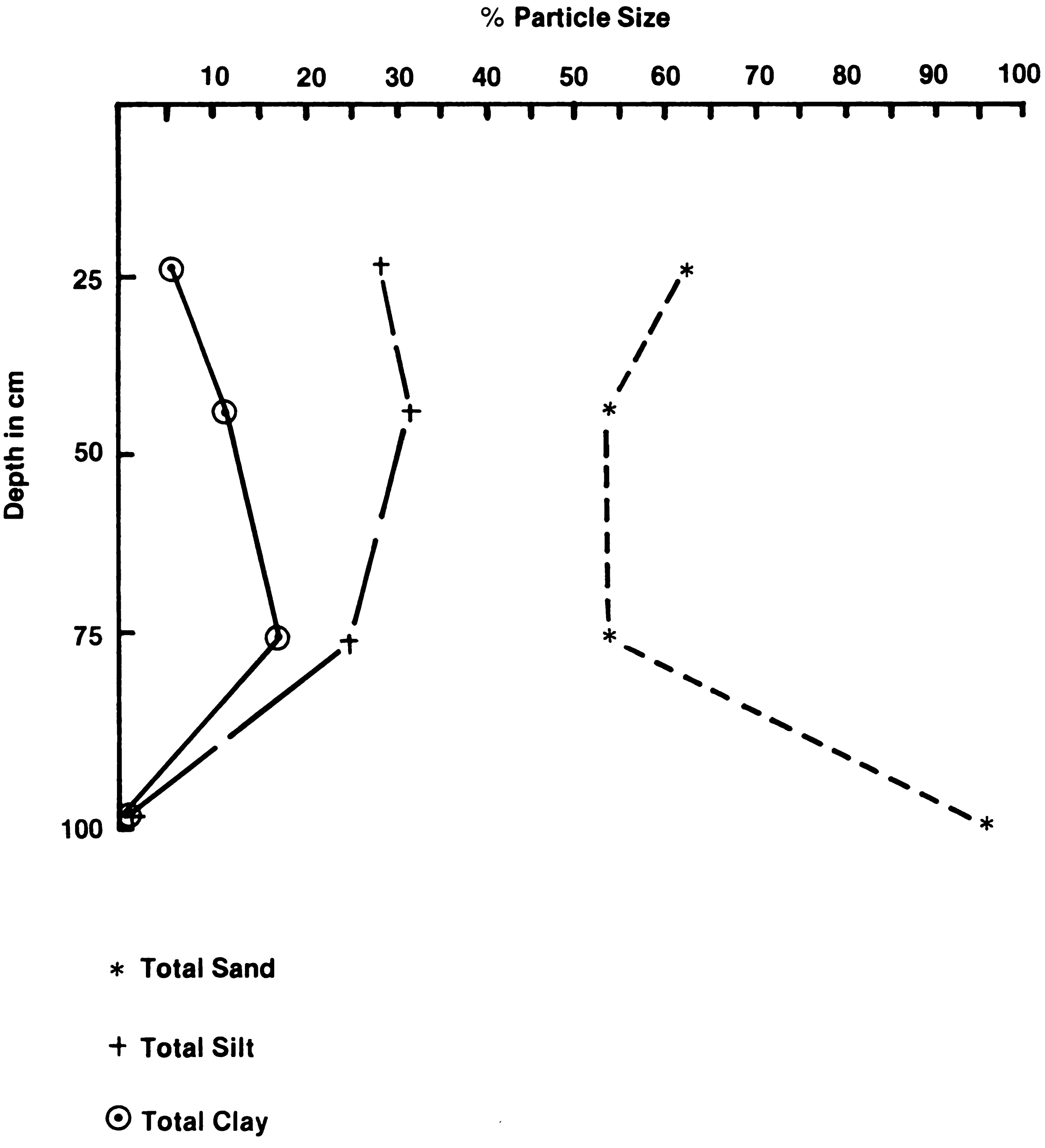


Figure 3(e). Particle size Distribution for Pedon 5 (Bixby, 6-12%).

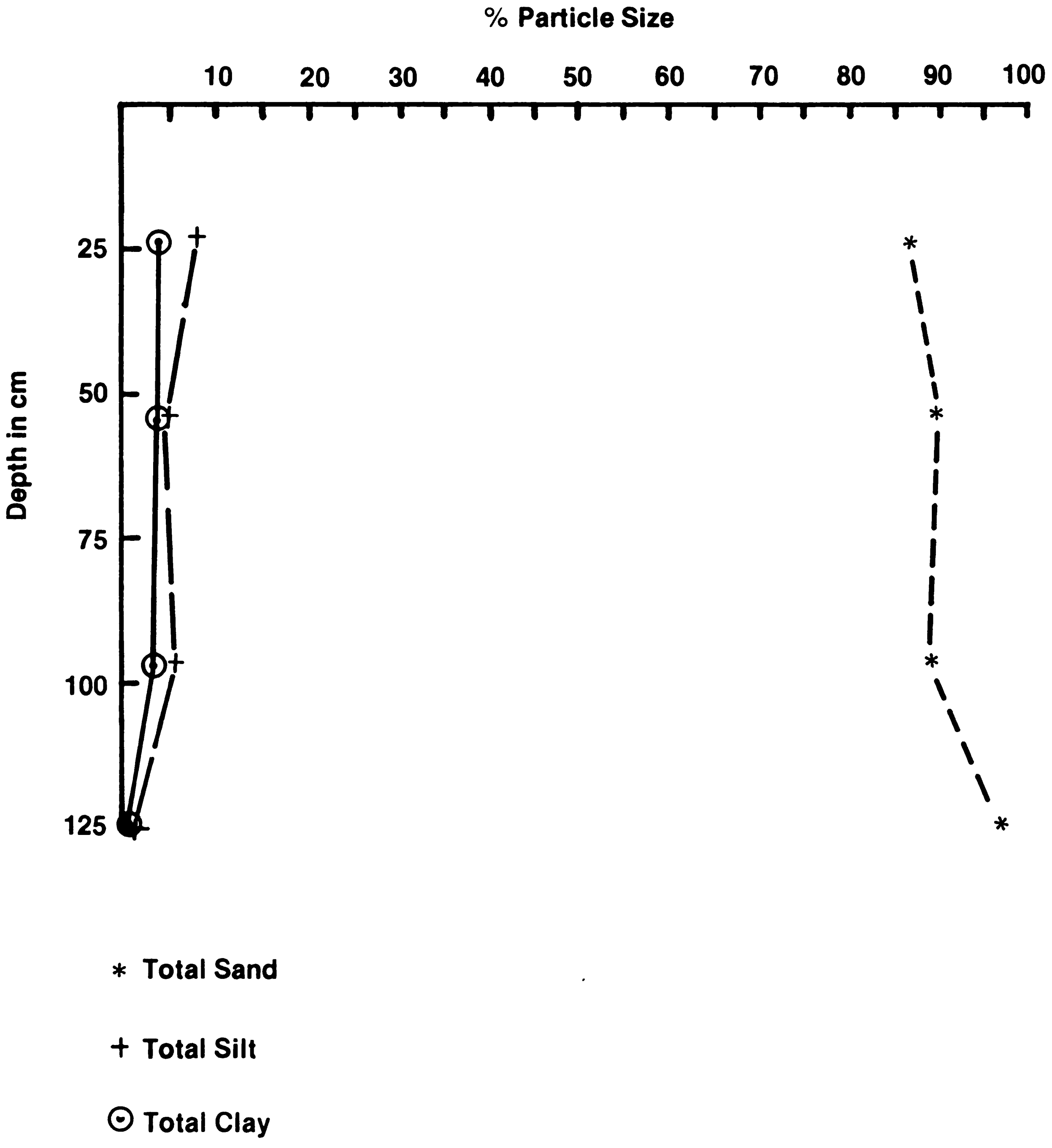


Figure 3(f). Particle Size Distribution for Pedon 6 (Spinks).

In general, percent total silt also decreased with depth (Table 4, Fig. 3(a-f)). Surface horizons had higher percent total silt than subsoil horizons except in Pedon 5 where the AP horizon contained slightly less total silt than the B1 horizon (Table 4). Surface horizons of Pedons 1 and 2 contained greater than 50% total silt which fall within the silt loam textural class. Even Pedon 3 and 4 contained greater than 40% total silt in their surface horizon. Coarse silt was the most dominating silt fraction in all studied pedons with lesser amounts of medium and fine silts. The silt accumulation on the surface of some of the pedons studied might have taken place either by the deposition of wind blown silt particles or by the deposition of silt particles carried by flowing water from the surrounding area. Pedon 5 which is situated in moderately sloping position contained less silt in its surface horizon. Silt particles from the surface might have been lost by runoff water during rains.

Pedons 1 through 5 follow the same trend in total clay distribution (Figure 3a-f). In general, clay content was low in the surface horizon (6.1 to 11.2%). It increased with depth, maximized in the B2 horizon (10.4-19.4). A decreasing trend occurred deeper into the profile beyond this point. However, maximum clay accumulation occurred at different depths. This trend of clay distribution might be the result of clay translocation, which was further confirmed by the presence of clay skins in the B horizon of these profiles (Appendix A; Grossman, R. B., et al., 1959). Pedon 6 does not show much change in its total clay distribution (Figure 3f). Percent total clay also decreased abruptly in Pedons 1, 3, 4 and 5 as parent material changed from glacial till to glacial outwash (Table 4). Percent

total clay dropped from 17.89% in the B2t horizon to 0.98% in the IIA&B horizon in Pedon 5.

Parent Material Homogeneity

Particle size distribution of non-clay fractions on a clay free basis, $\frac{si}{s}$ $(\frac{\text{Total silt}}{\text{Total sand}})$ ratio; $\frac{\text{si/s in upper horizon}}{\text{si/s in lower horizon}}$ and its deviation from 1 are shown in Table 5. The criteria of comparing the silt/sand ratio of one horizon with the ratio of another horizon seems to be the best test of initial uniformity of materials (Asady, G. H., 1980). If the two soil horizons are originally formed from a uniform parent material, $\frac{\text{si/s in Horizon 1}}{\text{si/s in Horizon 2}}$ should be 1 or close to 1. The greater the deviation from 1 the greater are the chances for the parent materials not being uniform. The largest deviations of $\frac{\text{si/s Hi}}{\text{si/s Hj}}$ ratio from 1 were observed between the following horizons: C1 and IIB3 in Pedon 1; B22t and IIA&B in Pedon 3; B22t and IIC in Pedon 4; and B2t and IIA&B in Pedon 5. Lithological discontinuities between these horizons were also confirmed by field observations (Appendix A). There was a change in parent material from sandy loam glacial till to sandy glacial outwash in all of the above horizons.

Bulk Density

Distribution of 1/3 bar and oven dry bulk density values are shown in Table 6 and Figure 4(a-f). One-third bar bulk density values were always higher than the respective oven dry bulk density values. Both 1/3 bar and oven dry bulk density distributions showed a similar trend in every soil (Figure 3a-f). Highest oven dry bulk density values were observed in the C horizons of Pedons 1 and 2. Pedons 3 and 4 had their highest bulk density

TABLE 5
Particle Size Distribution of Non-Clay Fractions on Clay Free Basis

Pedon	Horizon	% V.C. Sand	% C Sand	% Med. Sand	% F Sand	% V.F. Sand	% C Silt	% Med. Silt	% F. Silt	Si/S	$\frac{Si/S\ Hi}{Si/S\ Hj}$	$\frac{Si/S\ Hi}{Si/S\ Hj} - 1$
1	Ap	0.97	2.32	10.96	18.34	9.00	42.78	11.23	3.89	1.38		
	B1	1.49	3.62	14.78	27.59	12.36	25.74	8.76	4.77	0.65	2.07	1.07
	B21t	1.86	3.73	17.07	31.05	13.74	22.38	6.02	3.01	0.46	2.42	0.42
	B22t	2.63	4.51	17.15	28.67	13.05	17.31	10.68	4.59	0.49	0.96	-0.04
	B3t	4.26	4.74	15.74	26.81	12.61	24.46	8.96	3.37	0.57	0.86	-0.01
	C1	3.81	5.59	16.09	26.12	11.76	20.27	10.32	4.64	0.54	1.02	0.02
	IIB3	1.46	1.97	24.04	49.55	11.68	7.63	1.46	1.46	0.12	4.50	3.50
	IIC2	0.37	0.96	42.51	47.71	1.70	0.99	0.41	0.41	0.02	6.00	5.00
2	Ap	0.97	2.06	8.87	15.05	9.47	45.65	12.35	5.36	1.73		
	A&B	1.31	3.93	15.91	26.71	15.05	28.36	14.67	3.69	0.59	2.93	1.93
	B21t	1.18	4.06	16.53	30.37	13.24	12.51	12.86	4.84	0.43	1.37	0.37
	B22t	2.27	2.79	17.62	32.32	10.36	19.78	5.07	6.49	0.46	0.93	-0.07
	B3t	1.69	4.46	19.26	31.91	13.47	23.98	3.70	1.16	0.41	1.12	0.12
	C	3.57	5.27	18.30	32.00	9.66	16.50	10.48	4.27	0.45	0.91	-0.09
3	Ap	0.96	3.87	17.27	23.26	4.46	35.88	7.49	4.90	0.93		
	B1	1.26	4.60	25.36	27.91	5.53	24.49	6.42	4.55	0.55	1.69	0.69
	B21t	1.56	7.43	42.10	32.49	5.61	10.04	0.71	0.71	0.13	4.23	3.23
	B22t	0.58	5.34	32.28	31.01	7.54	7.64	9.50	4.85	0.28	0.46	0.54
	IIA&B	0.51	5.31	70.64	20.42	1.01	0.86	0.40	0.41	0.017	16.47	15.47
4	Ap	1.30	10.61	27.63	15.94	6.01	23.34	14.23	4.38	0.93		
	B21t	1.28	7.40	35.63	21.61	5.52	14.48	11.43	2.64	0.40	2.32	1.32
	B22t	1.23	8.92	45.06	22.98	4.19	8.62	3.58	3.57	0.19	2.11	1.11
	IIC1	0.00	5.20	66.96	24.20	1.95	0.84	0.20	0.67	0.017	11.18	10.18
	IIC2	0.10	6.38	67.71	22.76	2.57	0.96	0.00	0.00	0.010	1.70	0.70

TABLE 5 (Continued)

Pedon	Horizon	% V.C. Sand	% C Sand	% Med. Sand	% F Sand	% V.F. Sand	% C Silt	% Med. Silt	% F. Silt	Si/S	$\frac{Si/S\ Hi}{Si/S\ Hj}$	$\frac{Si/S\ Hi}{Si/S\ Hj} - 1$
5	Ap	0.21	2.77	22.90	32.16	10.27	20.32	8.22	3.03	0.46		
	B1	0.09	1.29	20.77	20.93	15.57	15.18	11.43	5.17	0.59	0.78	-0.22
	B2t	0.17	0.86	11.74	32.49	22.37	16.58	11.38	4.22	0.47	1.26	0.26
	IIA&B	0.26	8.21	56.40	31.99	2.16	0.37	0.60	0.00	0.01	47.0	46.0
6	Ap	1.41	4.08	35.39	46.53	4.07	4.22	2.67	1.64	0.093		
	B&A	1.25	3.79	32.75	52.25	4.07	4.21	2.67	0.43	0.057	1.63	0.63
	A&B	0.71	2.06	31.70	53.62	5.43	3.78	1.24	0.83	0.067	0.85	0.15
	A&B	0.04	0.37	66.81	30.93	0.58	0.50	0.40	0.40	0.013	5.15	4.15

Note: Si/S = Total Silt over Total Sand Ratio
Hi = Upper Horizon
Hj = Lower Horizon

Table 6
Mean Values of Selected Physical Properties from Representative Pedons

Pedon	Horizon	Sat. Hydraulic Conductivity Cm/hr	Bulk Density (gm/cm^3) 1/3 bar	Bulk Density (gm/cm^3) Oven Dry	% Moisture by Weight 1/3 bar	% Moisture by Weight 15 bar	% Available Moisture by Weight	% Available Moisture by Volume	cm of Plant Available Water
1	AP	1.02	1.59	1.35	18.11	9.54	8.57	11.57	3.59
	B1	0.74	1.84	1.60	14.84	10.43	4.41	7.06	1.98
	B21t	1.74	1.73	1.39	13.34	10.17	3.37	4.68	1.68
	B22t	0.71	1.76	1.56	13.16	8.65	4.51	7.04	1.97
	B3t	0.74	1.90	1.72	10.67	7.41	3.56	6.12	3.86
	C_1	0.44	1.91	1.73	10.56	7.33	3.23	5.59	0.95
2	AP	3.60	1.64	1.37	17.42	8.93	8.54	11.70	2.46
	A&B	3.56	1.69	1.45	16.27	8.91	7.36	10.67	1.28
	B21t	0.29	1.89	1.64	15.09	8.81	6.28	10.30	5.46
	B22t	0.33	1.83	1.62	12.54	8.87	3.67	5.95	3.33
	B3t	0.22	1.77	1.59	11.49	8.33	3.16	5.02	2.76
	C	0.44	2.02	1.84	9.68	5.85	3.83	7.05	--
3	AP	6.42	1.54	1.26	23.30	7.06	15.24	19.20	4.42
	B_1	2.83	1.73	1.52	12.89	5.89	7.00	10.64	2.13
	B21t	0.66	1.93	1.73	11.38	5.39	5.99	10.36	4.77
	B22t	0.68	1.88	1.69	10.68	6.80	3.88	6.56	3.48
	IIA&B	17.65	1.60	1.55	3.39	1.20	2.19	3.39	--
4	AP	5.03	1.58	1.32	19.25	6.65	12.60	16.63	3.99
	B21t	7.26	1.69	1.55	10.27	6.17	4.10	6.36	1.27
	B22t	1.89	1.86	1.70	10.23	6.17	4.06	6.90	0.90
	B3t	18.53	1.73	1.60	7.81	1.05	6.76	10.82	0.76
	IIC_1	54.79	1.45	1.42	2.55	1.71	0.84	1.19	0.86
5	AP	13.00	1.70	1.49	13.87	6.15	7.72	15.50	2.65
	B_1	0.82	1.87	1.64	13.78	7.85	5.93	9.73	1.95
	B2t	0.90	1.85	1.58	17.08	9.20	7.88	12.45	3.98
	IIA&B	19.79	1.62	1.54	4.01	2.25	1.76	2.71	3.05
6	AP	19.95	1.63	1.56	4.61	2.58	2.03	3.17	0.76
	B&A	12.93	1.68	1.60	5.02	2.74	2.38	3.80	1.14
	A&B	19.79	1.62	1.54	4.01	2.25	1.76	2.71	--
	A&B	36.20	1.61	1.59	2.29	0.89	1.40	2.23	--

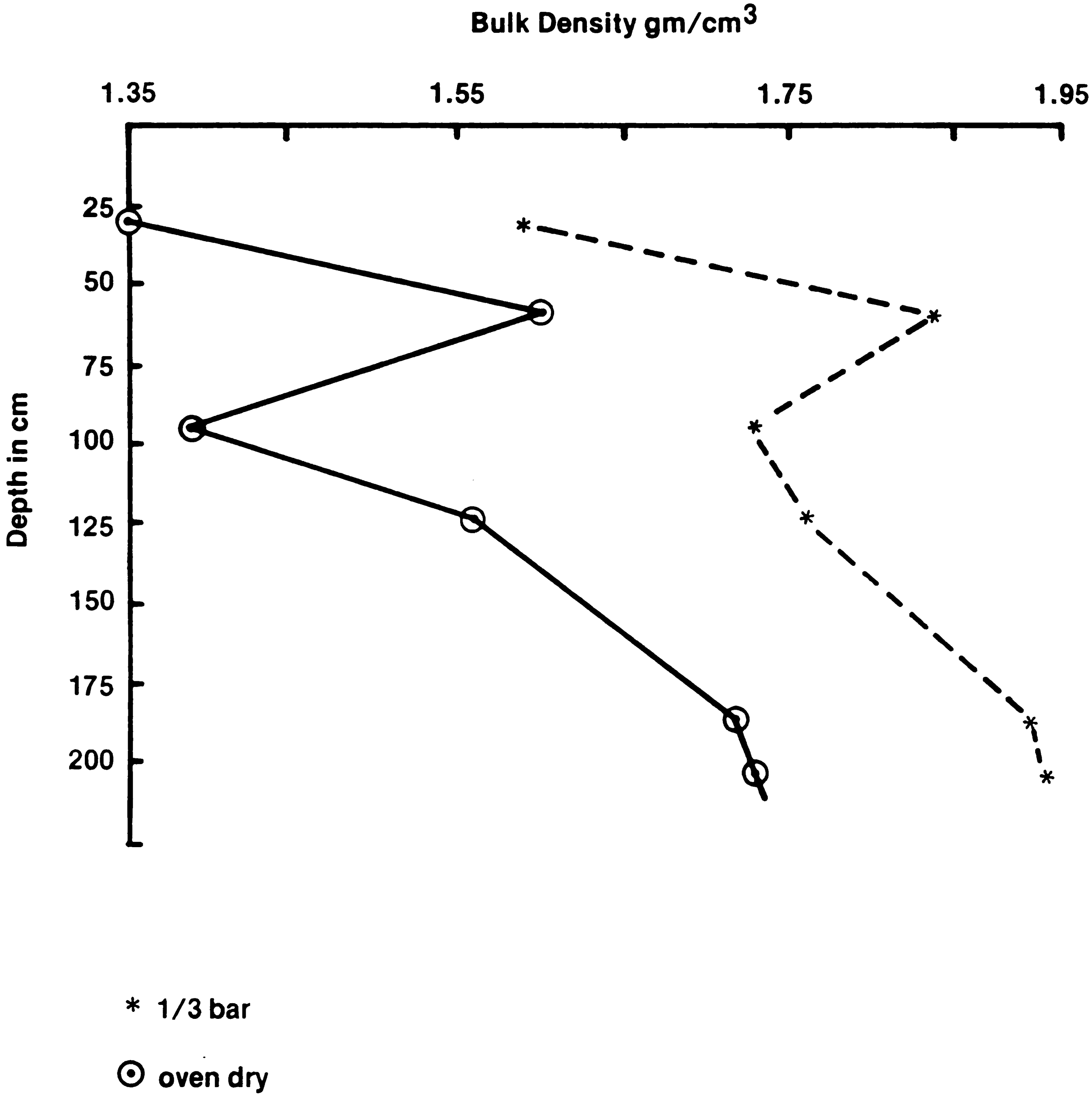


Figure 4(a). Bulk Density Distribution for Pedon 1 (Riddles Well Drained).

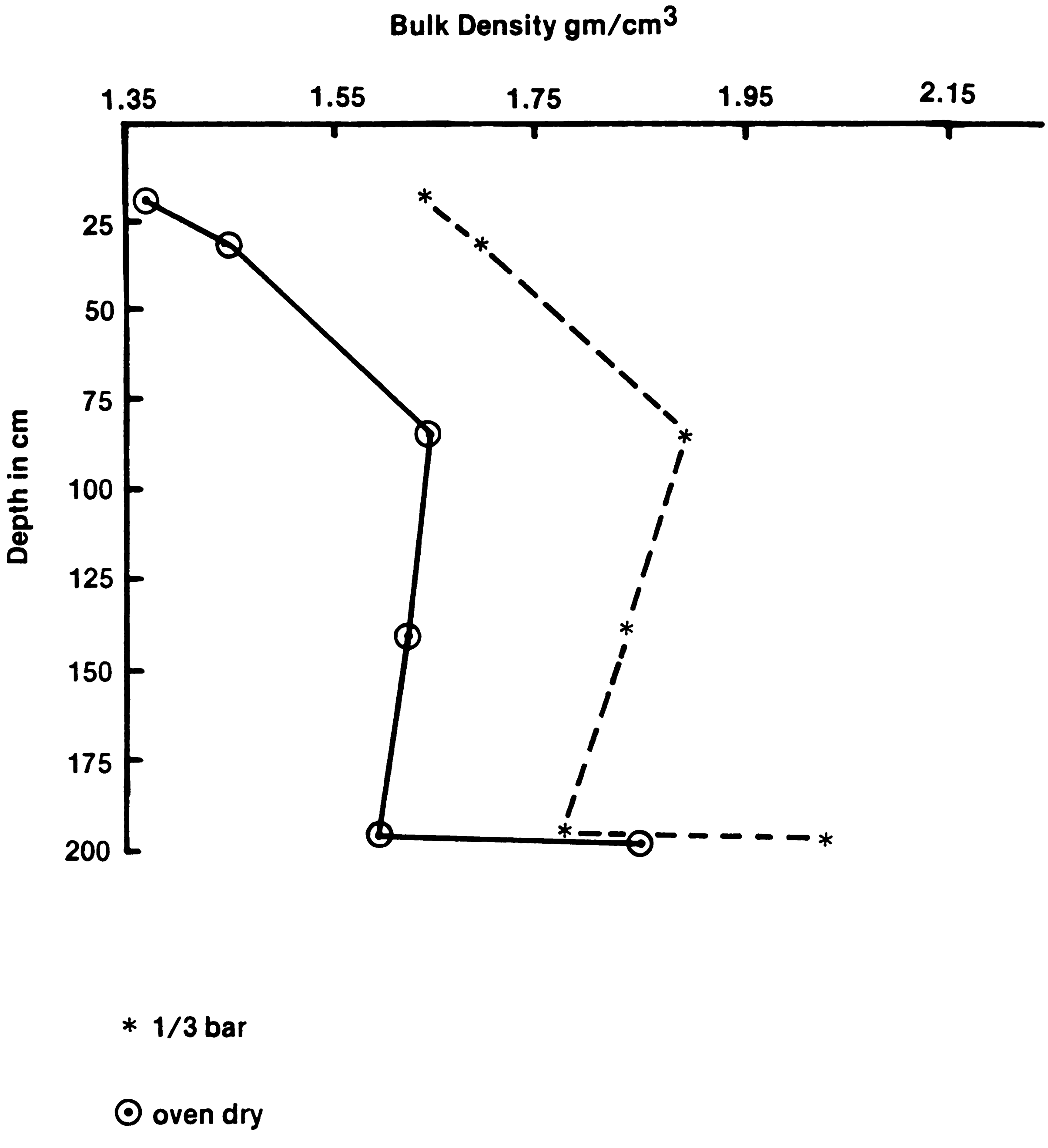


Figure 4(b). Bulk Density Distribution for Pedon 2
(Riddles Moderately Well Drained)

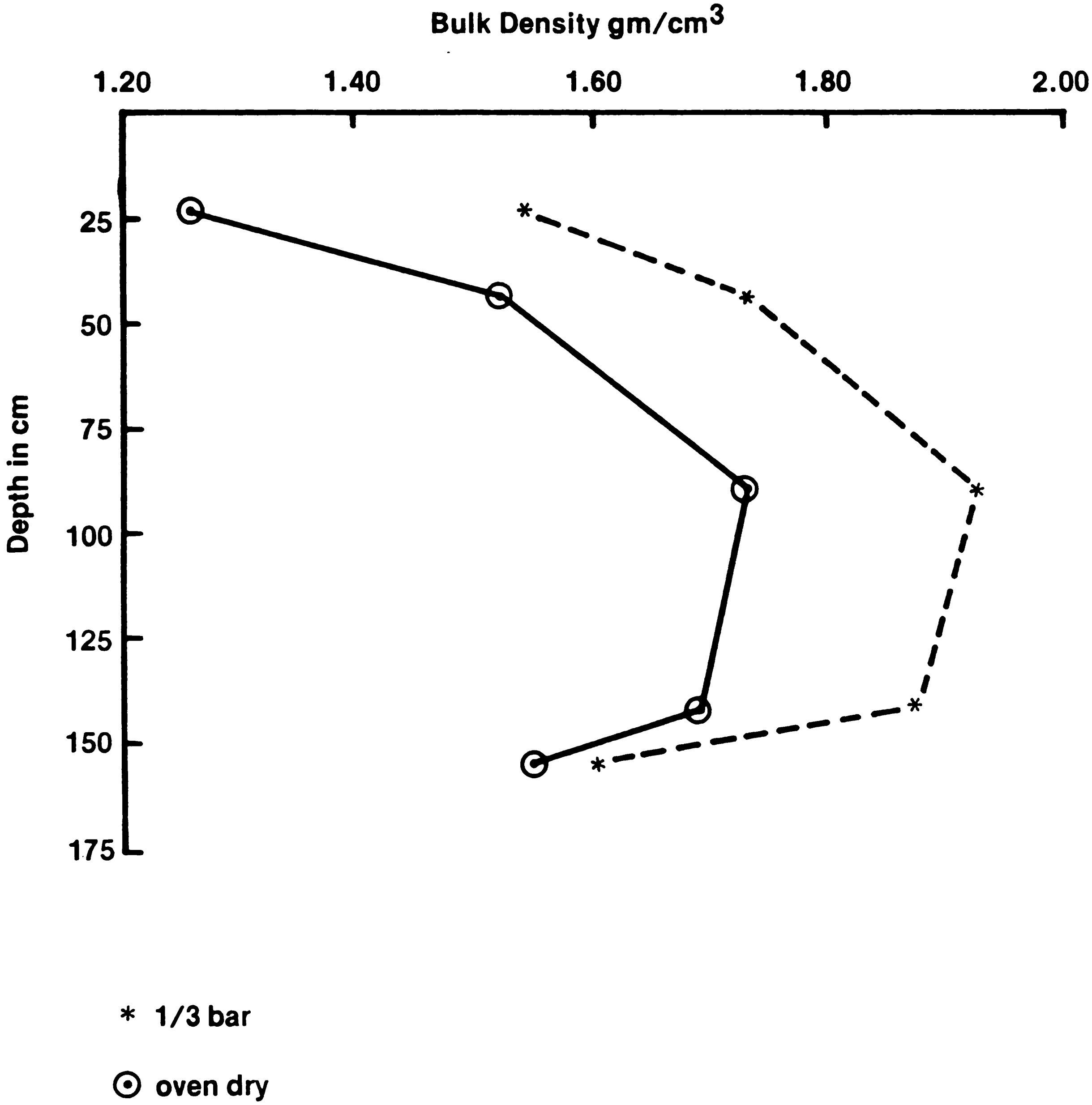
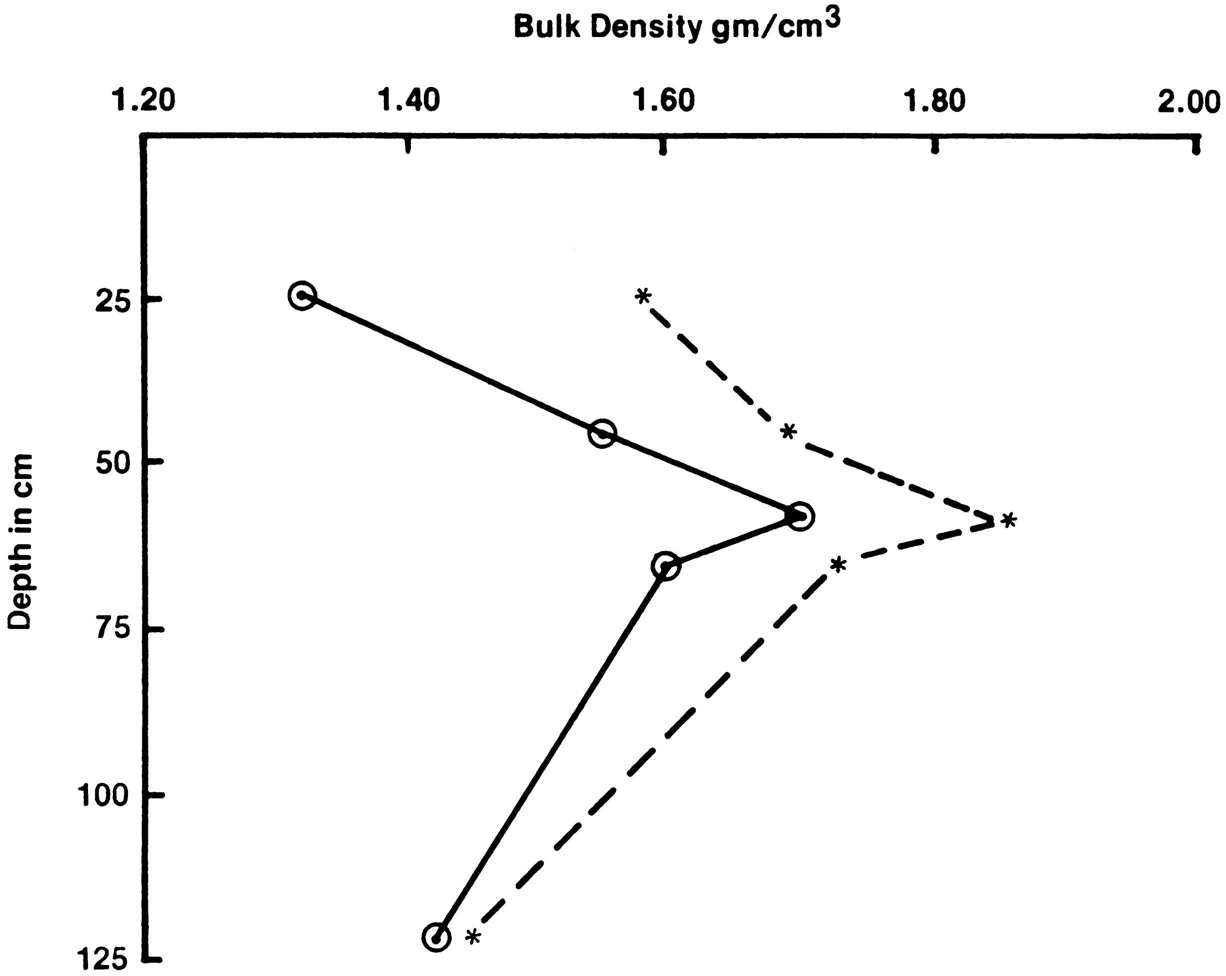


Figure 4(c). Bulk Density Distribution (Kalamazoo, 0-2%).



* 1/3 bar

⊙ oven dry

Figure 4(d). Bulk Density Distribution for Pedon 4 (Bixby 0-2%).

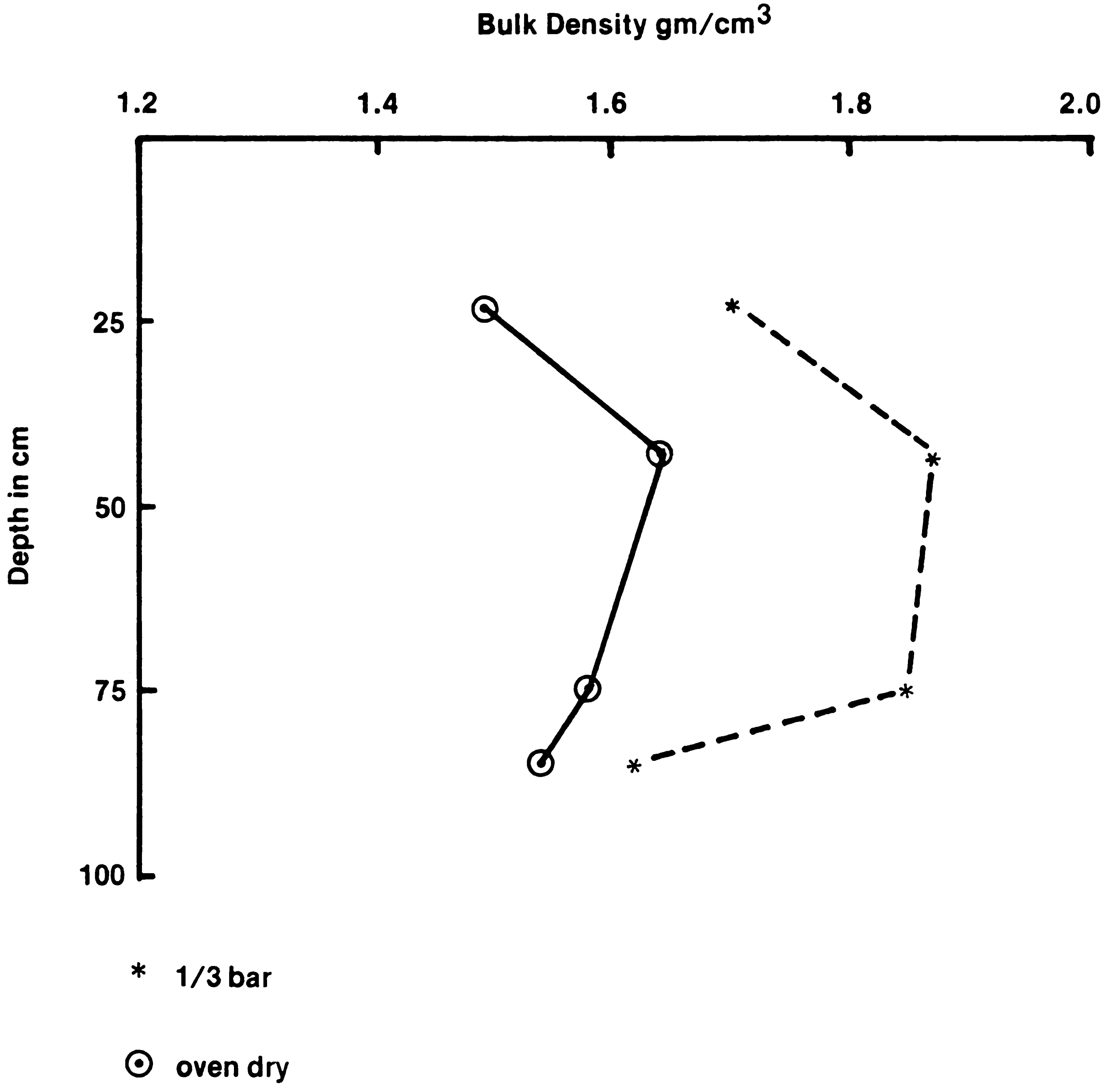


Figure 4(e). Bulk Density Distribution for Pedon 5 (Bixby, 6-12%).

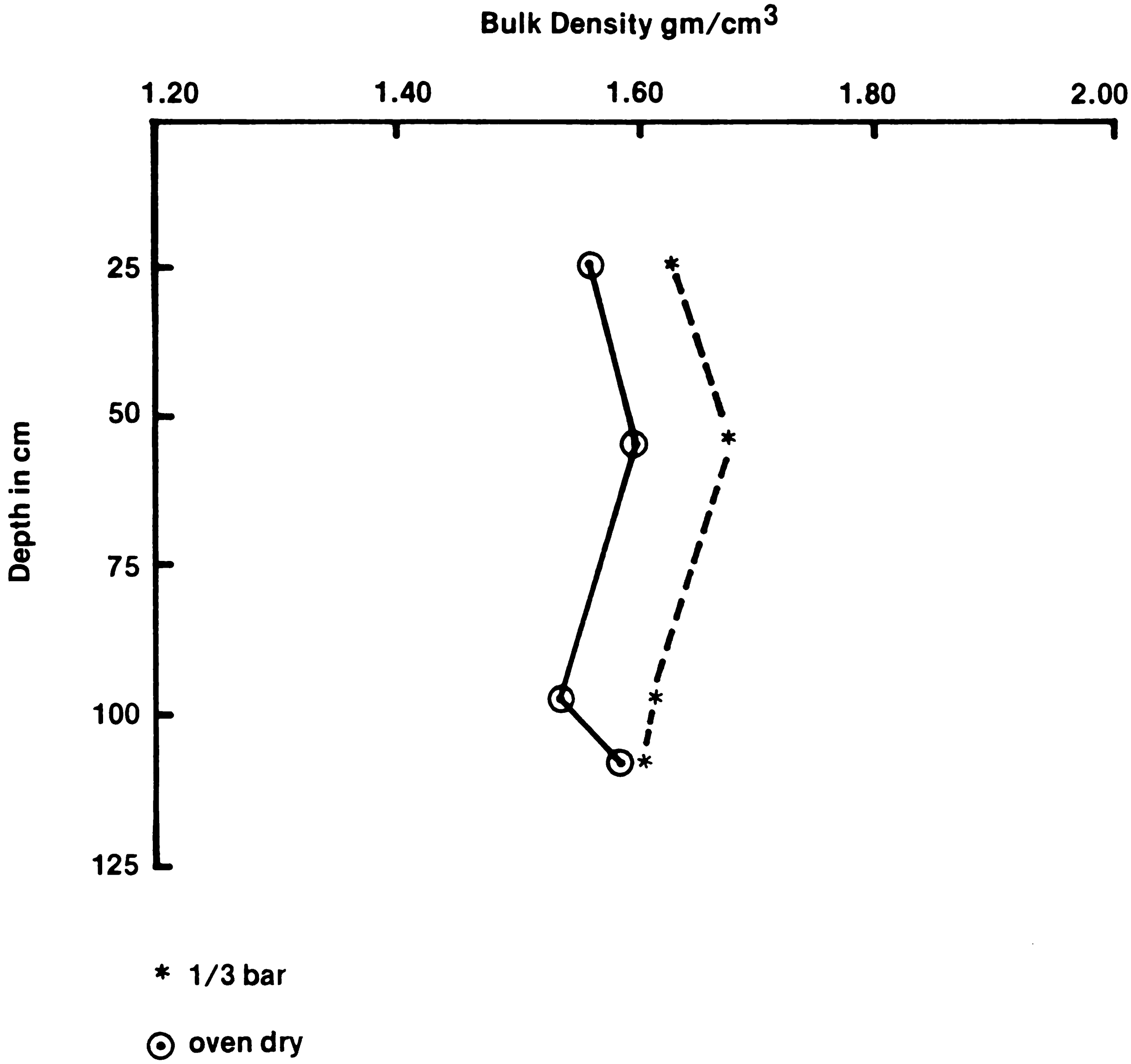


Figure 4(f). Bulk Density Distribution for Pedon 6 (Spinks, 6-12%).

values in their argillic horizons (B21t in Pedon 3 and B22t in Pedon 4). However, Pedon 5 had its highest bulk density value in the B1 horizon. The B1 horizon of Pedon 1 also had a higher bulk density than the lower two horizons. There was no particular trend in the bulk density distribution of Pedon 6.

Pedons 1 and 2 had coarse platy structure in their C horizons (Appendix A). This might have been the result of compaction caused by overlying materials when the glacial till was deposited. The reason for the argillic horizons having higher bulk density values is the filling of pore spaces by translocated clays. Higher bulk density values in B1 horizons might be the result of compaction from farm implements.

Hydraulic Conductivity

Table 6 and Figure 5(a,b) show saturated hydraulic conductivity distribution. Pedons 1 and 2 had slowly permeable subsoil layers. The B3t horizon in Pedon 2 had the slowest permeability with a saturated conductivity value of 0.216 cm/hr. Surface horizons of Pedons 1 and 2, respectively, had moderately slow and moderate permeability. The rate of water percolation into the soil is controlled by the least permeable layer in the solum or immediate substratum (Soil Survey Staff, 1951). The slowest permeable layer in Pedon 2 might have caused a temporary pearched water table. All other soils had moderately slow or higher permeability in their slowest permeable horizons. Hydraulic conductivity values increased abruptly in the lower horizons (IIA&B, IIc, and IIA&B) of Pedons 3, 4 and 5 as soil texture changed from sandy loam to sand. All the horizons in Pedon 6 had rapid to very rapid permeability. In general, lower conductivity values were associated with

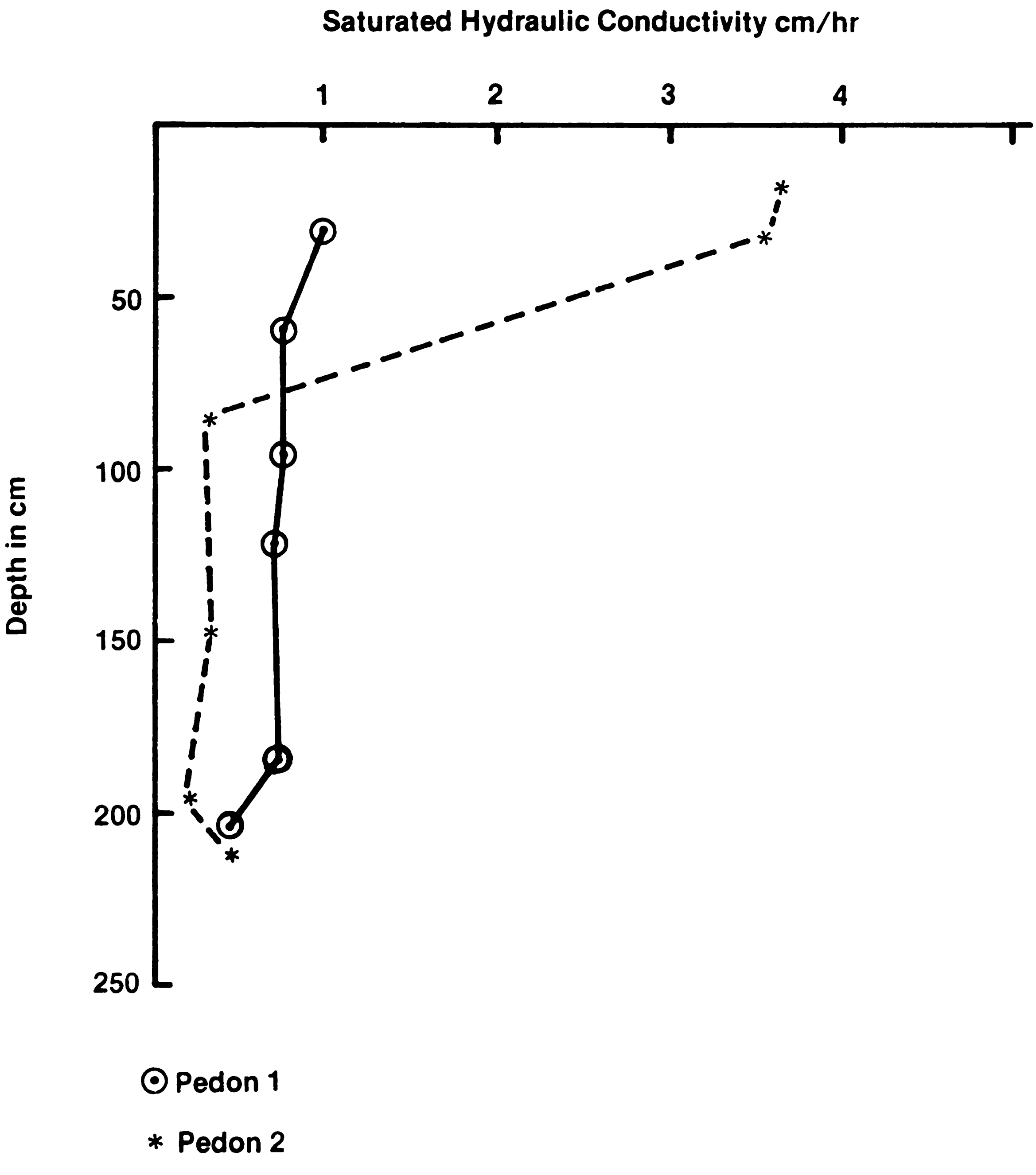


Figure 5(a). Hydraulic Conductivity Distribution for Pedon 1 and 2 (Well and Moderately Well Drained Riddles).

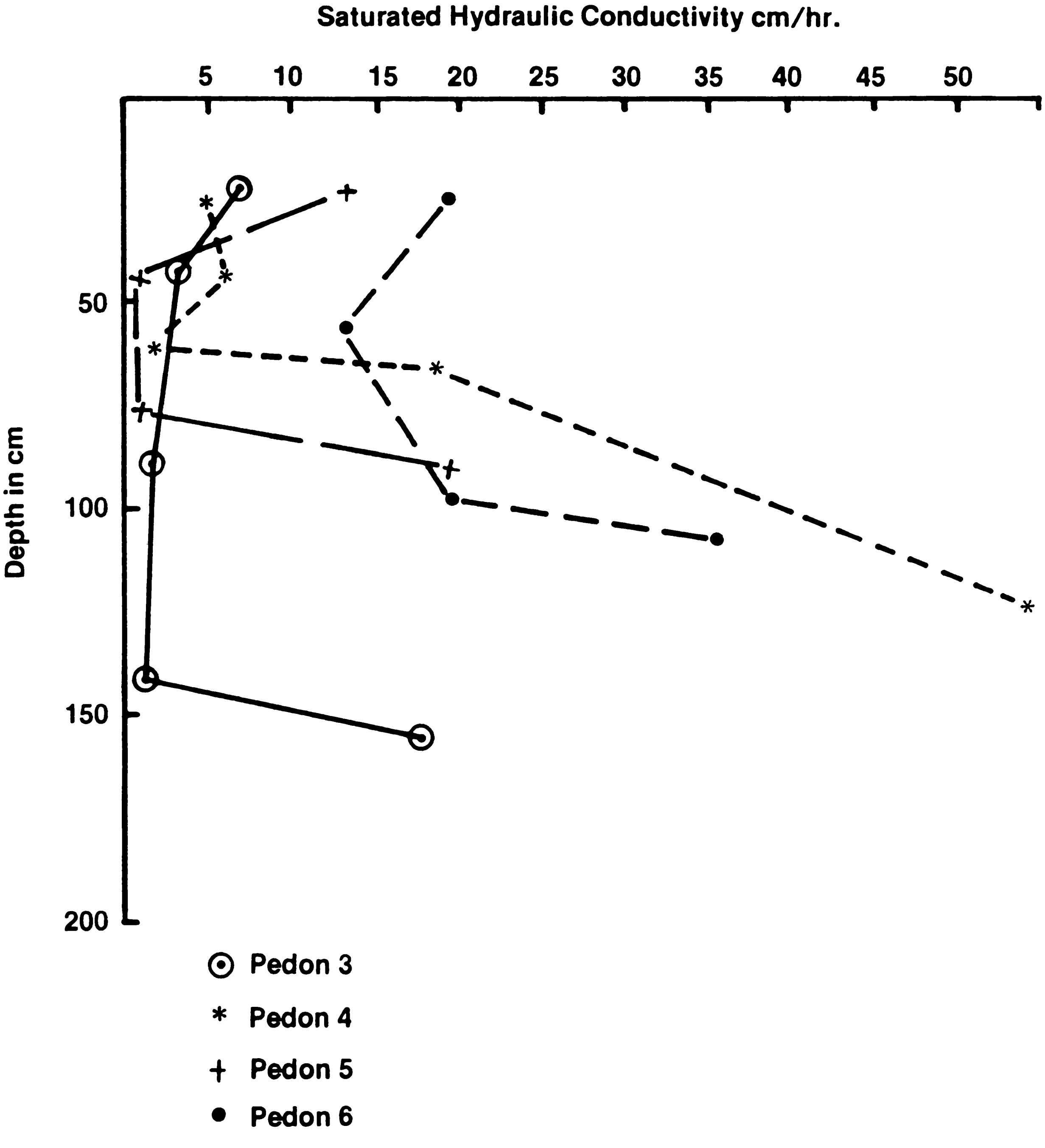


Figure 5(b). Hydraulic Conductivity Distribution for Pedons 3, 4, 5 and 6 [Kalamazoo (0-2%), Bixby (0-2%), Bixby (6-12%), Spinks (6-12%)].

soil horizons which had either high bulk density values or high clay content or both.

A linear regression analysis was run to investigate the effect of different particle size fractions and bulk density on saturated hydraulic conductivity. Correlation Coefficient, Coefficient of Determination and Linear Regression Equations are shown in Table 7. Total clay, coarse silt, medium silt, total silt and very fine sand all negatively correlated with hydraulic conductivity. Medium sand and total sand however showed a positive correlation. There was no statistically significant correlation between either fine sand or oven dry bulk density and hydraulic conductivity. However, there was a significant negative correlation with $R^2 = 0.43$ when data only from Pedons 1 and 2 were plotted (Figure 6). Both Pedon 1 and 2 have dominantly sandy loam textures up to a depth of about 200 cm. An increase in bulk density in a given soil textural class means a reduction in the soil porosity and therefore a low hydraulic conductivity reading. The effect of bulk density was masked by the extreme difference in soil texture when data from all the pedons were considered.

Moisture Retention

Distributions of 1/3 bar, 15 bar, and available moisture percentages are shown in Table 6 and Figure 7(a-f). In general, percent 1/3 bar moisture decreased with depth except for Pedon 5 where B2t horizon had the highest 1/3 bar moisture retention. The surface horizon of Pedon 3 contained the highest (23.3%) 1/3 bar moisture value while the lower part of A&B horizon in Pedon 6 has the lowest (2.29%). Percent 15 bar moisture was almost constant throughout the whole solum in Pedon 2. However, it decreased

TABLE 7
Correlation Coefficients, Coefficient of Determination and Regression Equations for Effects of Textural Subclass and Oven Dry Bulk Density on Saturated Hydraulic Conductivity for the Studied Soils

Independent Variable	Correlation Coefficient	Coefficient of Determination	Regression Equation
X_1***	-0.72	0.52	$Y = 23.93 - 1.59\ X_1$
X_2***	-0.54	0.29	$Y = 17.51 - 0.63\ X_2$
X_3***	-0.60	0.35	$Y = 19.61 - 1.91\ X_3$
X_4***	-0.63	0.39	$Y = 20.75 - 0.52\ X_4$
X_5***	0.80	0.63	$Y = -6.79 + 0.56\ X_5$
X_6	N/S		
X_7***	-0.61	0.37	$Y = 21.38 - 1.73\ X_7$
X_8***	0.74	0.55	$Y = -25.84 + 0.51\ X_8$
X_9	N/S		

*** Significant at .01 level.
N/S Not statistically significant.

X_1 = Total Clay
X_2 = Coarse Silt
X_3 = Medium Silt
X_4 = Total Silt
X_5 = Medium Sand
X_6 = Fine Sand
X_7 = Very Fine Sand
X_8 = Total Sand
X_9 = Oven Dry Bulk Density

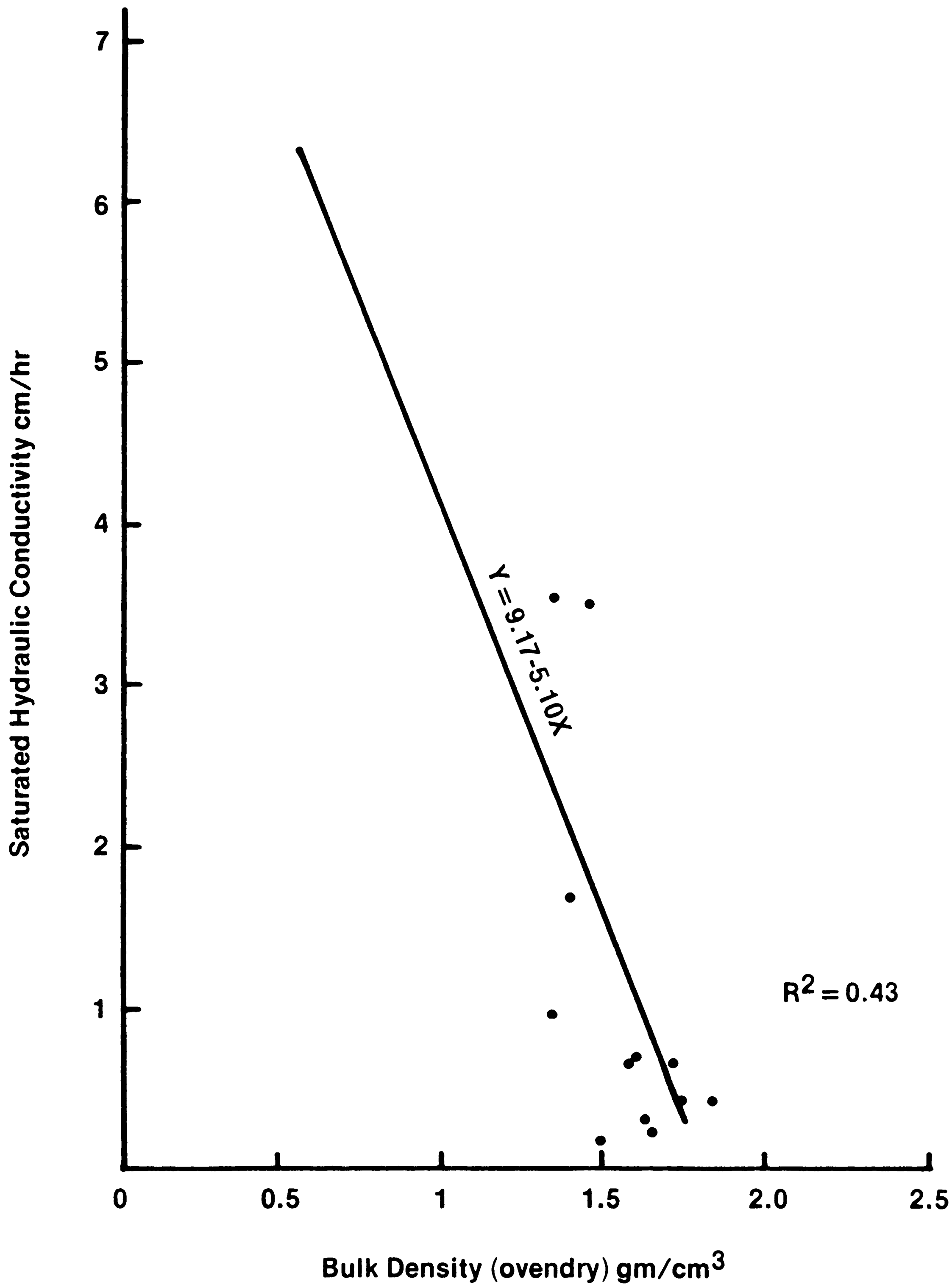


Fig. 6: Relationship between bulk density and saturated Hydraulic Conductivity in Pedon 1 and 2 (Well and Moderately Well Drained Riddles).

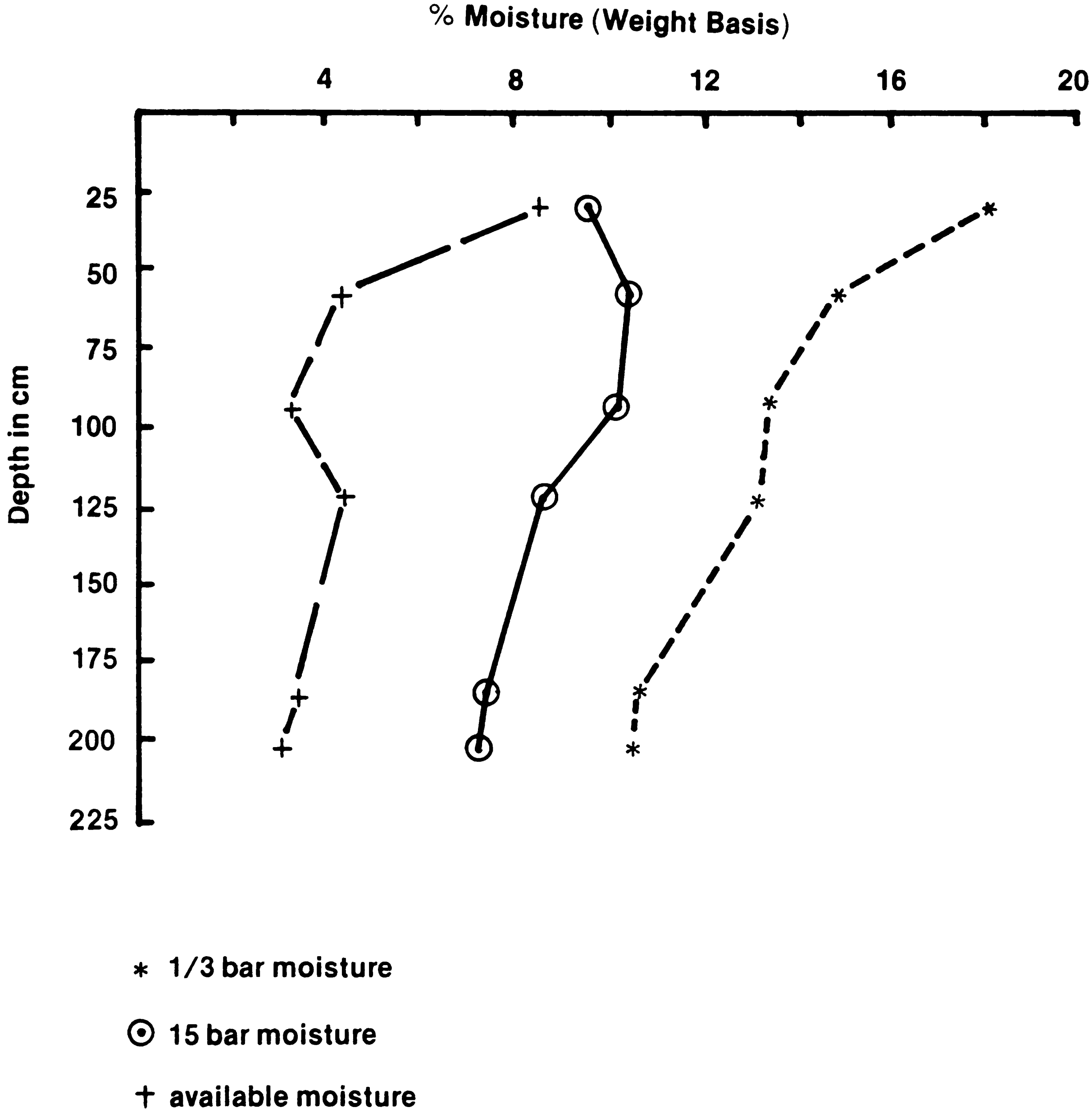


Figure 7(a). Moisture Distribution for Pedon 1 (Riddles Well Drained, 0-2%).

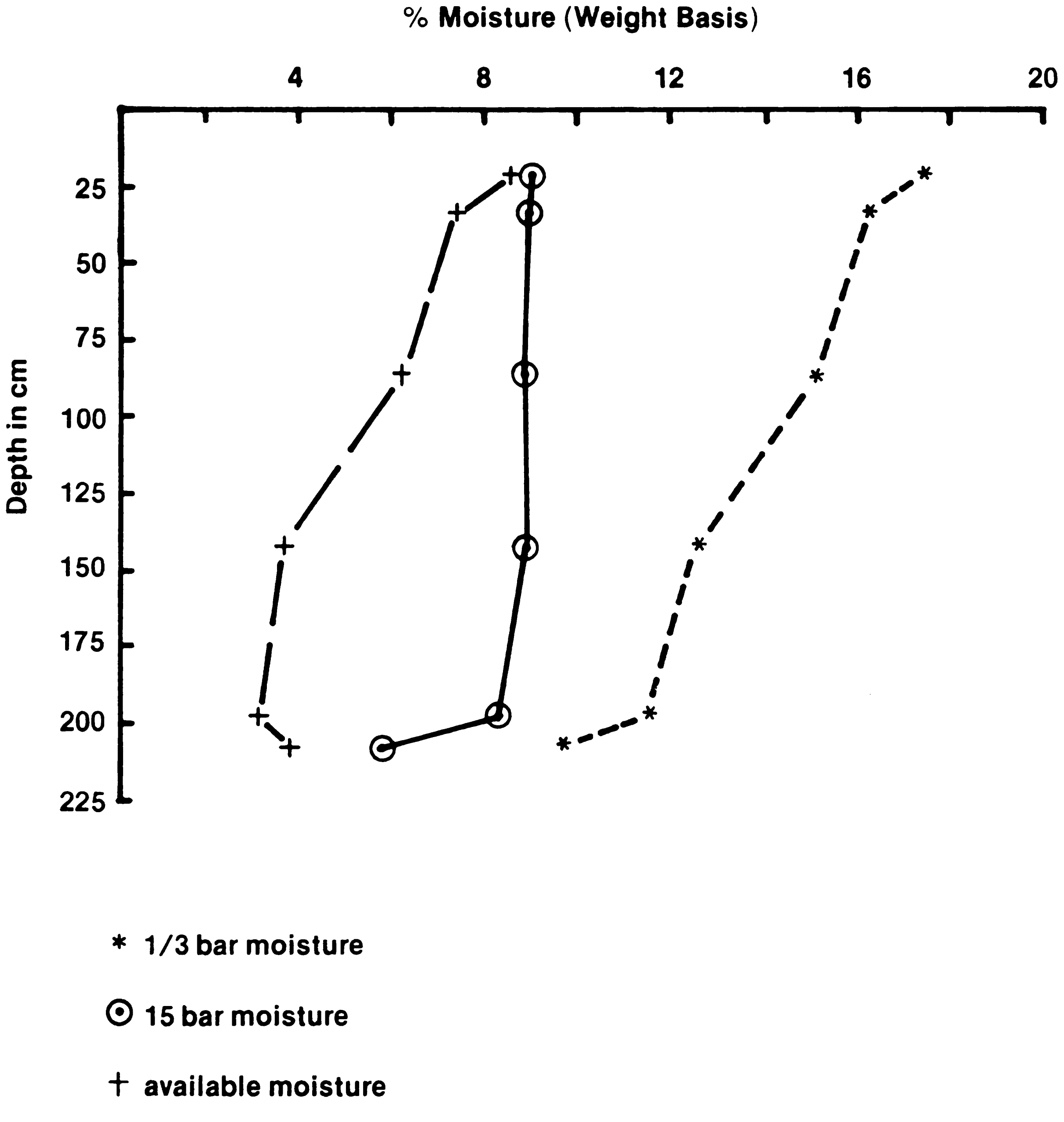


Figure 7(b). Moisture Distribution for Pedon 2 (Riddles Moderately Well Drained, 0-2%).

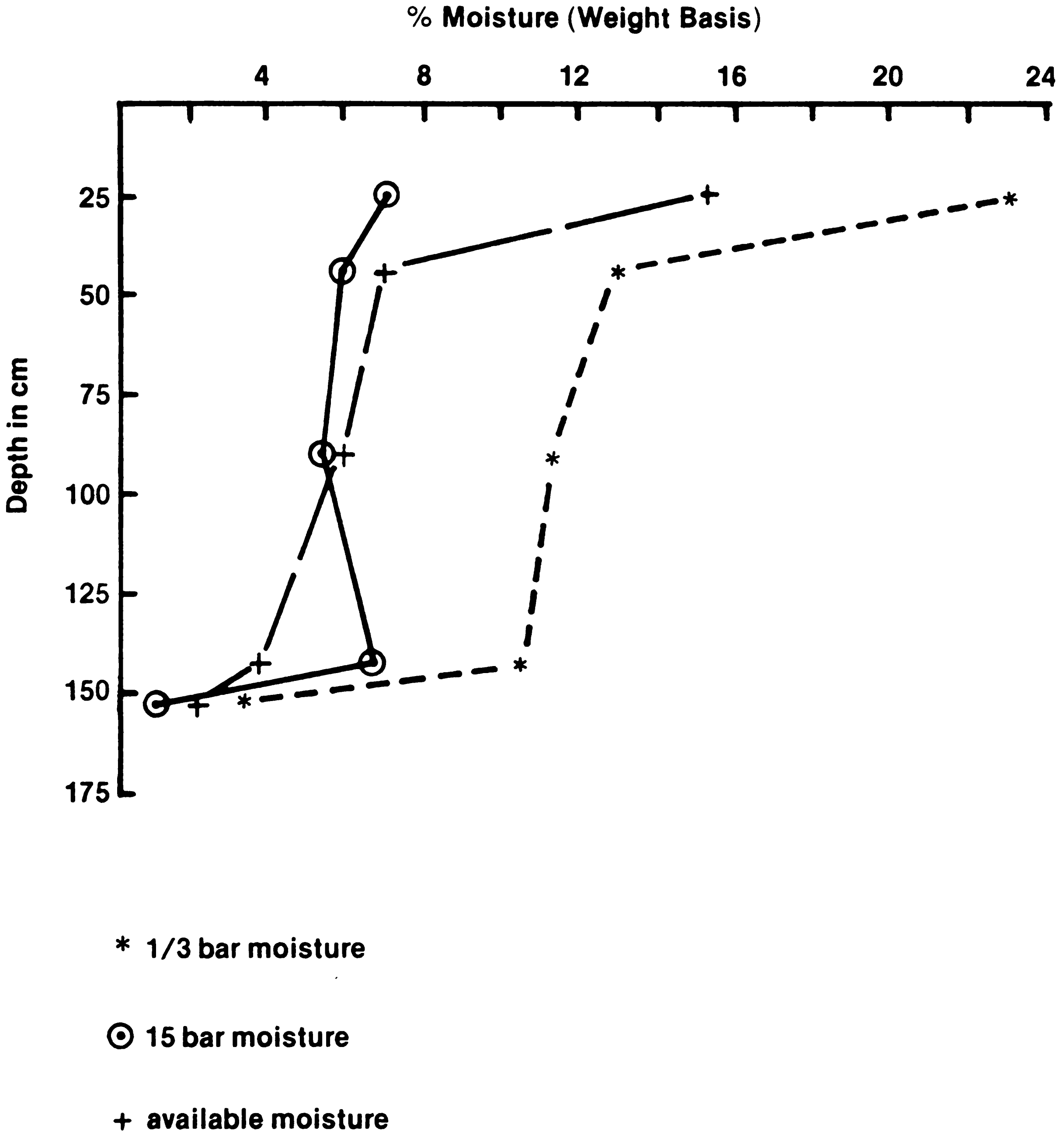
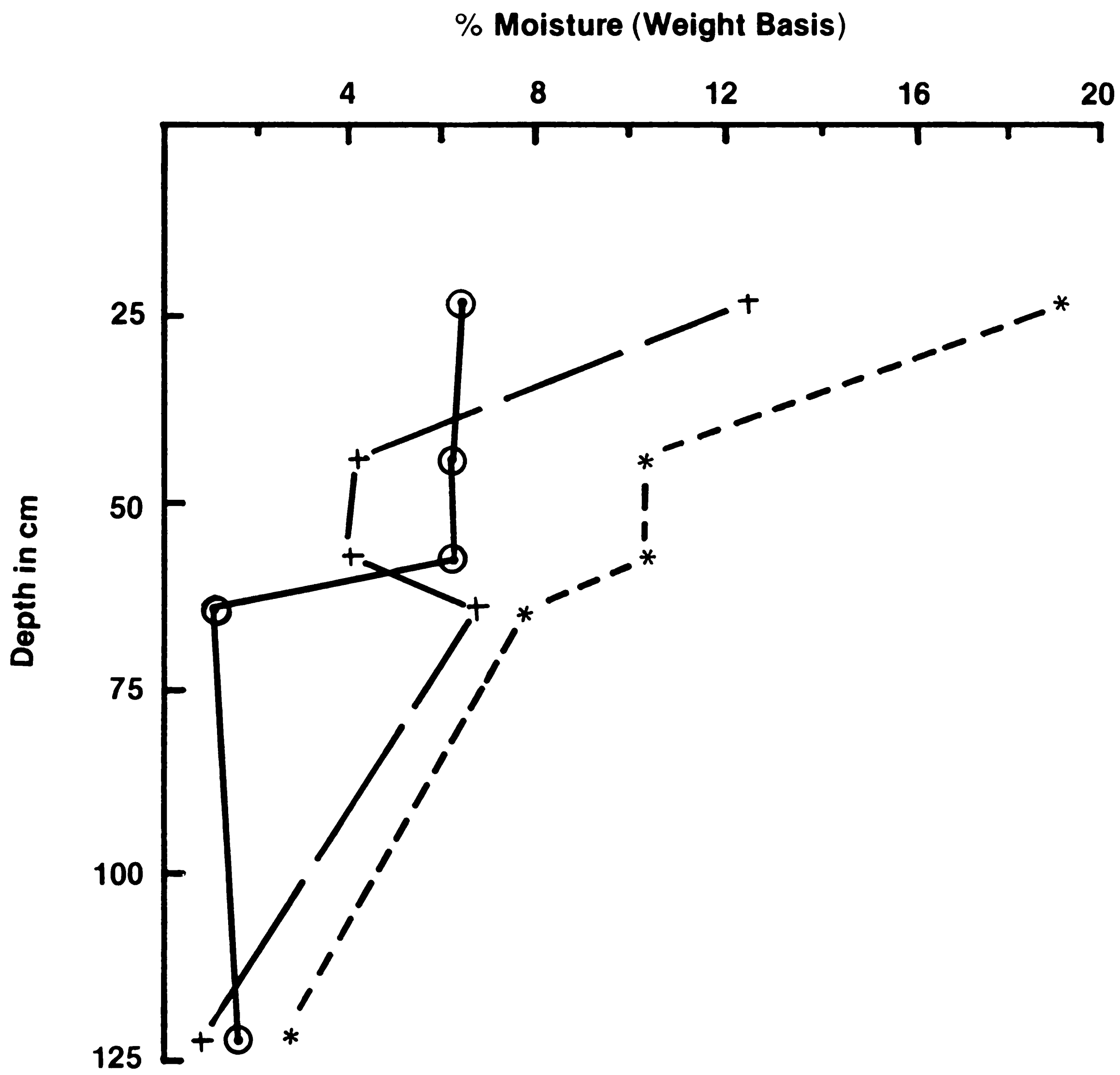


Figure 7(c). Moisture Distribution for Pedon 3 (Kalamazoo, 0-2%).



* 1/3 bar moisture

⊙ 15 bar moisture

+ available moisture

Figure 7 (d). Moisture Distribution or Pedon 4 (Bixby, 0-2%).

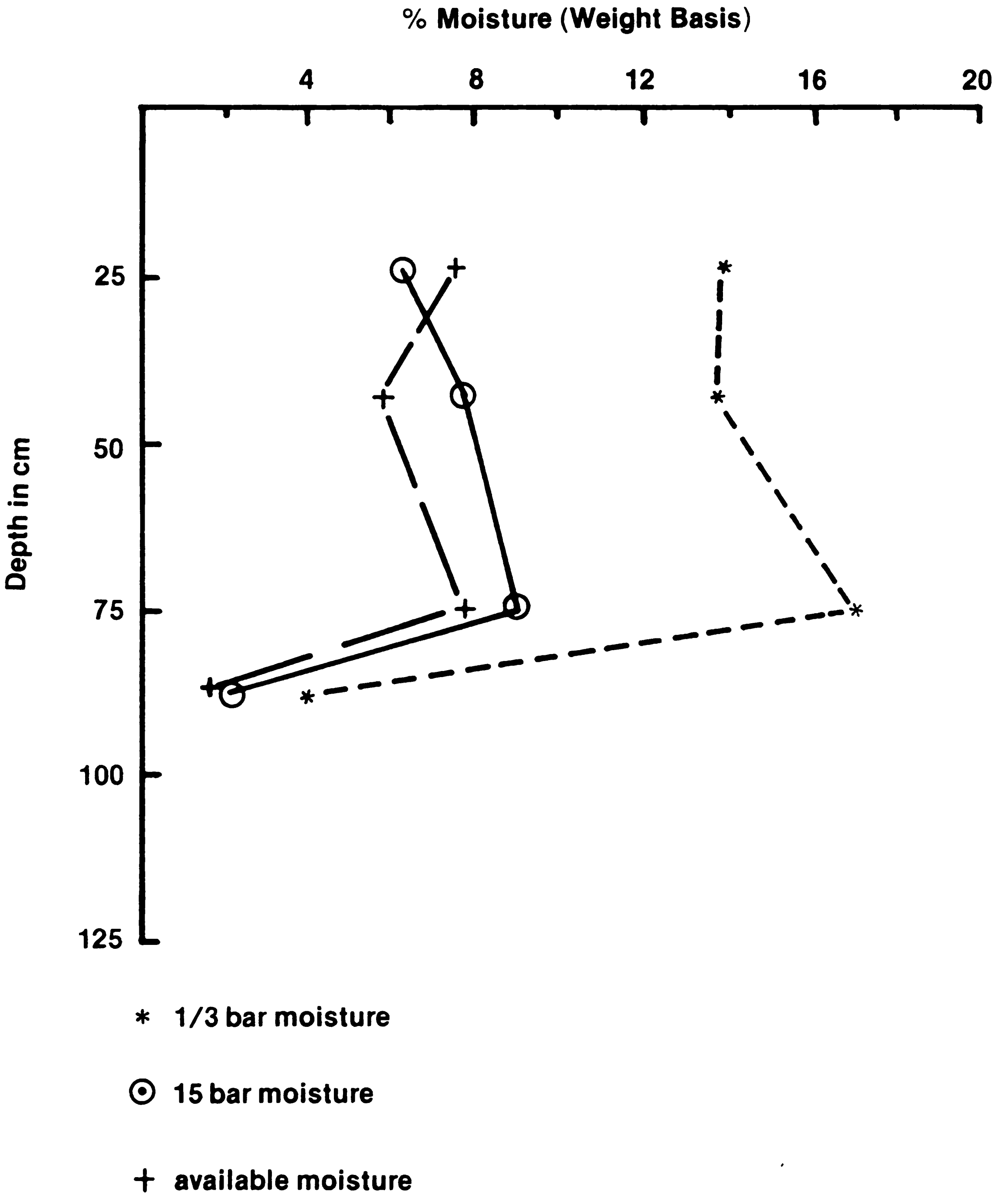
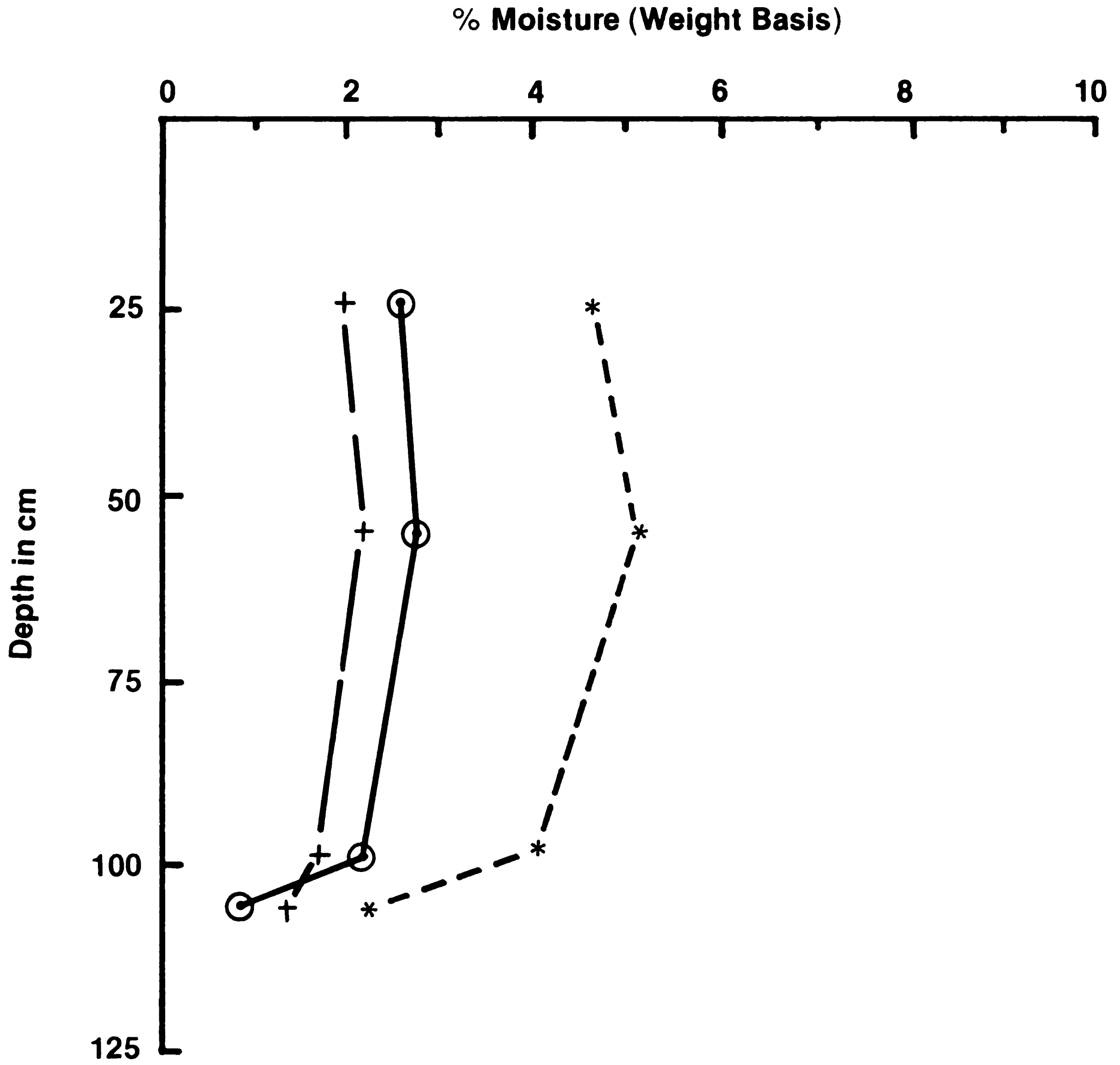


Figure 7(e). Moisture Distribution for Pedon 5 (Bixby 6-12%).



∗ 1/3 bar moisture

⊙ 15 bar moisture

+ available moisture

Figure 7(f). Moisture Distribution for Pedon 6 (Spinks, 6-12%).

with depth in Pedon 4 and in the subsoil of Pedon 1. The surface horizon of Pedon 1 had a slightly lower value than the horizon immediately below it. Fifteen bar moisture distribution in Pedons 3 and 5 followed a similar trend as clay distribution except for the surface horizon of Pedon 3 which contained higher 15 bar moisture values than the subsoil horizons. Very low amounts of both 1/3 bar and 15 bar moisture was retained in Pedon 6. Both 1/3 bar and 15 bar moisture decreased abruptly at the point of lithological discontinuity.

Percent available moisture decreased with depth except for Pedons 4 and 5 where the B3t and B2t horizons, respectively, contained higher percent available moisture than some of the overlying horizons. Surface horizons of Pedons 3 and 4 contained two times more percent available moisture than the underlying horizons.

The water holding capacity of the soil is related to both surface area and pore space volume. Therefore, water holding capacity is related to soil texture as well as structure. Soils which are high in clay content are high in both 1/3 bar and 15 bar moisture. Organic matter promotes soil aggregation and also can absorb large quantities of water at lower tensions. Research has shown that available water in many soils are correlated with silt content (Bartilli, L. J., et al., 1959; Peterson, G. W., et al., 1968). These might explain why the surface horizons which were high in both organic matter and silt content had high 1/3 bar and available moisture contents. The reason for Pedon 6 being so low in 1/3 bar, 15 bar, and available moisture was its sandy nature. It contained less than 10% silt plus clay and therefore low moisture holding capacity. A more detailed study of moisture characteristics (at lower tensions) is recommended for irrigation scheduling.

C. Chemical Properties

Distribution of mean values of selected chemical properties are shown in Table 8.

Organic Carbon

Percent organic carbon decreased with depth in all the soils. The surface horizon of Pedon 2 had the highest percent organic carbon content while Pedon 6 had the lowest (1.43% vs. 0.11%). The reason for Pedon 2 being higher in organic carbon content may have been the less than well drained condition or past management.

Nitrate Nitrogen

Nitrate nitrogen distribution did not follow any particular trend. Surface horizons of Pedons 4 and 3 had exceptionally high nitrate nitrogen (45.8 ppm vs. 36.4 ppm). All the soil horizons with high organic carbon were not high in nitrate nitrogen. Conditions for mineralization and nitrification might not be favorable even if the soil contained high organic matter. Nitrifying bacterias are aerobic and prefer more neutral to slightly acid conditions (Mengel, K. and E. A. Kirkby, 1979). Pedon 2 was moderately well drained and had strongly acid soil reactions in the upper part of the solum. These might have been the reasons for low nitrification in the surface horizon of Pedon 2. Exceptionally high nitrate nitrogen readings for the surface horizons of Pedons 3 and 4 might be the result of past management (N fertilizer application).

Soil pH and Lime Requirement

Generally soil pH increased with depth in Pedons 1, 2, 5 and 6. Pedon 4 had more or less constant soil pH throughout the profile. However, in

Table 8
Mean Values of Selected Chemical Properties from Representative Pedons

Pedon	Horizon	% Organic Carbon	Nitrate N (ppm)	pH	CEC me/100 gm	% Base Saturation	Extractable Nutrients kg/ha P	K	Ca	mg	% of the Total Bases K	Ca	mg	Lime Requirement Tons/ha
1	AP	1.2	3.2	7.2	8	100	292	305	2511	442	4.6	73.8	21.6	no lime
	B_1	0.2	3.4	7.1	8	100	39	179	2631	614	2.5	70.3	27.3	--
	B21t	0.2	3.7	6.9	8	100	45	197	2631	628	2.7	69.6	27.7	--
	B22t	0.2	4.0	7.3	8	100	15	141	2511	717	1.9	66.4	31.6	--
	B3t	0.1	3.3	7.6	9	100	9	93	3109	525	1.3	77.1	21.7	--
	C_1	0.1	3.0	7.9	12	100	3	90	4612	414	0.9	86.2	12.9	--
	IIB3	0.1	2.7	8.2	2	100	10	27	677	179	1.4	68.3	30.3	--
	IIC2	0.1	1.9	8.1	3	100	1	9	1345	45	0.3	94.4	5.2	--
2	AP	1.4	2.0	5.2	12	28	152	251	1233	90	8.5	81.6	9.9	16.54
	A&B	0.3	3.0	5.3	9	51	90	144	1569	251	3.6	76.1	20.3	--
	B21t	0.2	4.9	5.4	8	72	64	153	1914	346	3.0	74.5	22.5	--
	B22t	0.1	4.7	5.5	8	65	66	135	1682	346	3.0	72.2	24.8	--
	B3t	0.1	3.5	6.2	6	100	39	135	1914	497	2.5	68.1	29.5	--
	C	0.1	2.8	7.6	12	100	8	72	4612	311	0.7	89.3	10.0	--
3	AP	1.3	36.4	6.2	7	78	58	135	1780	346	2.8	73.5	23.7	2.47
	B_1	0.3	4.8	5.9	2	100	124	98	561	168	5.7	62.9	31.4	--
	B21t	0.1	5.5	5.5	8	43	39	135	1121	215	4.5	72.4	23.2	--
	B22t	0.1	4.2	5.4	6	75	58	126	1457	299	3.2	72.1	24.7	--
	IIA&B	0.1	3.2	6.0	1	100	42	27	448	101	2.2	71.1	26.7	--
4	AP	1.2	45.8	5.9	6	83	212	386	1569	248	8.9	70.5	20.6	2.47
	B21t	0.4	4.5	6.3	3	100	105	72	1009	112	3.0	81.9	15.2	--
	B22t	0.1	4.8	6.2	4	100	51	108	1569	146	3.0	84.0	13.0	--
	B3t	0.1	3.6	6.2	1	100	63	27	336	34	3.4	82.8	13.8	--
	IIC_1	0.0	3.8	6.2	1	100	61	36	448	34	3.5	85.8	10.7	--
	IIC_2	0.0	3.5	6.1	1	100	63	27	336	11	3.7	91.2	5.1	--
5	AP	0.8	4.3	6.2	3	100	225	206	1121	135	7.3	77.3	15.5	no lime
	B_1	0.2	3.0	6.1	4	100	34	144	1457	123	4.2	83.9	11.8	--
	B2t	0.1	3.0	5.1	11	54	15	179	2032	311	3.5	76.9	19.6	--
	IIA&B	0.0	2.9	5.4	1	100	43	18	336	45	2.2	80.0	17.8	--
6	AP	0.1	4.7	6.4	3	100	128	179	897	135	2.6	73.9	18.5	no lime
	B&A	0.1	4.4	7.0	3	100	82	63	897	168	2.7	74.2	23.2	--
	A&B	0.1	5.6	7.1	2	100	73	54	897	112	2.5	80.7	16.8	--
	A&B	0.1	4.3	7.2	2	100	21	27	561	112	1.8	73.6	24.5	--

Pedon 3, pH decreased with depth up to 142 cm. from the surface (6.2 vs. 5.4) and again increased in the last horizon (6). Soil pH in Pedon 2 was in the strongly acid range up to a depth of 142 cm. and mildly alkaline in the C horizon. The increasing trend of soil pH deeper into the profile could be the result of carbonate leaching in the soil profile. Higher pH in the surface horizons of some of the soils might be the result of past lime applications. No lime was recommended for RwA, BiC and SpC mapping units (Figure 1) on the basis of pH levels of studied pedons. However, 16.54 tons/ha of lime was required for RmA and 2.47 tons/ha for KaA and BiA mapping units.

Cation Exchange Capacity

Higher Cation Exchange Capacity (CEC) values were observed in Pedons 1 and 2 than in other pedons (Table 8). Pedon 1 had constant CEC values up to a depth of 123 cm. from the surface and had the highest CEC in the calcareous C1 horizon. Pedon 2 had the highest CEC value in the surface horizon which decreased with depth in the solum. The C horizon of Pedon 2 had a CEC value equal to that of the surface soil. All other pedons showed a similar distribution pattern as that of the clay. Higher CEC values in the surface horizons were attributed to the higher percent organic matter. Variation in CEC value reflected changes in total clay content in all other horizons except the calcareous C horizons. The high CEC values in calcareous C horizons might be due to the interference of free calcium carbonate (additional Ca++ comes from the dissolution of $caCO_3$) in the cation extracting solution (1N NH4OAC) (Carpena, O., et al., 1972).

Percent Base Saturation

All pedons had relatively high percent base saturation. Pedons 1 and 6 were 100% base saturated in all horizons. The lowest base saturation value was 28.29% in the surface horizon of Pedon 2.

Extractable Nutrients

Kilogram per hectare of extractable phosphorus (available), potassium, calcium and magnesium for studied pedons are shown in Table 8. Phosphorus in general decreased with depth in all soils except for KaA where the surface horizon had a lower P value than B1 horizon. Available phosphorus level varied from 58.29 kg/ha (Pedon 3) to 292 kg/ha (Pedon 1) in the surface soil. Extractable potassium decreased with depth in Pedon 6. All other pedons had a similar distribution pattern of exchangeable potassium as total clay (Table 8). Extractable K in the surface soil varied from 134.52 (Pedon 3) to 385.62 kg/ha (Pedon 4). Fertilizer recommendations were made for selected vegetables and field crops (Table 9) on the basis of extractable phosphorus and potassium levels in the studied soils (Warncke, D. D., et al., 1976).

In general, exchangeable calcium increased with depth until the soil parent material changed from glacial till to glacial outwash (indicated by II). Surface horizons of pedons 3 and 4 were the exceptions which contained more exchangeable calcium than the horizons immediately below them. The sudden drop in exchangeable calcium in the soil horizons formed from the second parent material (glacial outwash) reflect the abrupt decrease in total clay. Higher amounts of exchangeable calcium in the surface horizons of Pedons 3 and 4 might have been the result of liming.

TABLE 9
Phosphorus and Potassium Fertilizer Recommendations for Selected Vegetables and Field Crops for the Studied Soils

Mapping Units	Available Nutrients in the Surface Soil kg/ha		Selected Crops	Fertilizer Recommendation	
	P	K		P(kg/ha)	K(kg/ha)
RwA	293	205	Field Crops		
			Corn (1,527 + kg)	none	none
			Wheat (709 + kg)	none	none
			Soybean (436 + kg)	none	none
			Vegetables		
			Cauliflower (17,936 + kg)	none	47
			Tomatoes (56,050 + kg)	none	47
RmA	152	251	Field Crops		
			Corn	none	56
			Wheat	none	28
			Soybean	none	none
			Vegetables		
			Cauliflower	25	93
			Tomatoes	49	93
KaA	58	135	Field Crops		
			Corn	37	140
			Wheat	37	93
			Soybeans	12	56
			Vegetables		
			Cauliflower	74	186
			Tomatoes	99	186
BiA	212	386	Field Crops		
			Corn	none	none
			Wheat	none	none
			Soybeans	none	none
			Vegetables		
			Cauliflower	25	47
			Tomatoes	25	47

TABLE 9 (continued)

Mapping Units	Available Nutrients in the Surface Soil kg/ha		Selected Crops	Fertilizer Recommendation	
	P	K		P(kg/ha)	K(kg/ha)
BiC	225	206	Field Crops		
			Corn	none	93
			Wheat	none	70
			Soybean	none	47
			Vegetables		
			Cauliflower	none	186
			Tomatoes	none	186
SpC	128	179	Field Crops		
			Corn	none	140
			Wheat	none	93
			Soybean	none	70
			Vegetables		
			Cauliflower	25	186
			Tomatoes	49	186

Exchangeable magnesium in Pedons 3, 4 and 5 follow a similar distribution trend as calcium. However, in Pedons 1 and 2 exchangeable magnesium increased up to 123 and 197 cm. depths from the surface and decreased deeper into the profile.

Extractable calcium values were higher than that of the extractable magnesium and potassium in all soil horizons. Calcium is the dominant cation in all the soils which accounts for greater than 60% of the total bases. Magnesium and potassium percentages varied from 5.1 to 29 and 0.3 to 8.9, respectively.

D. Classification of Representative Pedons

Surface horizons of all studied pedons did not meet the criteria for a mollic epipedon on moist and dry color basis (Appendix A, Soil Survey Staff, 1975). Therefore, all the pedons had ochric epipedons. Clay films were observed in B horizons of all pedons studied (Appendix A). Elluvial horizons of all pedons had less than 15% total clay and B horizons of all except Pedon 6 had greater than 3% total clay increase (Table 4). B horizon of Pedon 6 on the other hand consisted of lamellae greater than or equal to 1 cm. thick which had a combined thickness of greater than 15 cm. Therefore, B horizons of all pedons met the qualifications of an argillic horizon. All the representative pedons had greater than 35% base saturation at 1.25 m. depth below the upper boundary of the argillic horizon (Table 8). Hence, all pedons fell into the soil order Alfisols. The study area had a mesic temperature regime (Table 3) and all studied pedons had an udic moisture regime (Appendix A). This put all six pedons into the suborder Udalfs.

There is no agric, natric, or fragipan horizon in any of these pedons and no tongues of albic materials (Appendix A). All of the pedons also met the requirement of clay distribution, color of the argillic horizon, and difference of mean summer and mean winter temperature for the great group Hapludalfs (Soil Survey Staff, 1975). Pedons 1 through 5 met all the criteria of mottles, bulk density, interfingering of albic material, color of the surface horizon, soil temperature, texture of the surface, and argillic horizon for the subgroup Typic Hapludalfs. Pedon 6 did not have a continuous argillic horizon greater than or equal to 20 cm. thick with a soil texture finer than loamy fine sand. Therefore, Pedon 6 was classified at the subgroup level as Psammentic Hapludalfs.

Pedon 1 had 19.18% clay in the upper 50 cm. of the argillic horizon and fell into the fine-loamy family textural class. Pedon 2 on the other hand had only 16.91% clay and fell into the coarse-loamy category. Pedons 3 and 5 had strongly contrasting particle sizes (abrupt textural change) within 1 meter from the top of the argillic horizon. The upper parts of the control sections had 14.79% and 18% clay, respectively, while a lower part of the control sections had only 1.38% and 0.98% clay with greater than 96% total sand. Therefore, Pedon 3 was within the coarse-loamy over sandy family textural class. Pedon 5 on the other hand fell in the fine-loamy over sandy textural class. Pedon 4 had 10.4% total clay in the argillic horizon and was placed in the coarse-loamy family. Pedon 6 had less than 3% clay in the control section and belongs to the sandy textural family. Pedon 2 was close to the fine-loamy family. No minerological study of these soils were performed as a part of this research. It was assumed that all of these pedons had mixed minerology (Soil Conservation Service, 1980).

The mean annual soil temperature of the area was 9.92°C (Table 3) which was estimated by adding 1°C to the mean annual air temperature (Soil Survey Staff, 1975). The difference between mean summer and mean winter temperature was more than 5°C. Therefore, all the pedons had a mesic soil temperature class. All the representative pedons were classified as follows at the family level.

Pedon No.	Soil Mapping Unit	Family Classification
1	RwA	Typic Hapludalfs, fine-loamy, mixed, mesic
2	RmA	Typic Hapludalfs, coarse-loamy, mixed, mesic
3	KaA	Typic Hapludalfs, coarse-loamy over sandy, mixed, mesic
4	BiA	Typic Hapludalfs, coarse-loamy, mixed, mesic
5	BiC	Typic Hapludalfs, fine-loamy over sandy, mixed, mesic
6	SpC	Psammentic Hapludalfs, sandy, mixed, mesic

Pedons 1, 5, and 6, respectively, fell in the range of characteristics of Riddles (Dryden), Bixby, and Spinks soil series. All other remaining pedons differ from their official series classification (Michigan Cooperative Soil Survey, 1981). Pedon 2 better fits the Lapeer series than Riddles. RwA and RmA mapping units were respectively mapped as Dryden and Lapeer soil series in the Soil Survey of Ionia County (Threlkeld, G. and S. Alfred, 1967). It agreed well with the result of my study because Pedon 1 is also very close to the coarse-loamy family. Pedon 3 did not fit the Kalamazoo series because it is coarse-loamy over sandy instead of fine-loamy over sandy. Pedon 4 also did not meet the requirement of the Bixby soil series because it is coarse-loamy instead of fine-loamy over sandy.

E. Limitations of Studied Soils for the Production of Selected Fruits, Vegetables and Field Crops

Table 10 shows the degree of limitations of studied soils for the production of different crops. The criteria used in preparing this table is shown in Tables 13, 14, and 15. Mapping units, RwA, RmA, KaA, BiA, BiC all had slight limitations for the production of selected fruits and vegetables. However, mapping units BiA and BiC had moderate limitations for selected field crop production. The SpC mapping unit on the other hand had moderate to severe limitations for the production of selected fruits, vegetables and field crops. Pedon 6 had the lowest organic carbon content (.114%) among all pedons and also had lower CEC values (Table 8). Sandier soils such as the Spinks are also commonly low in fertility in addition to being droughty. Pedons 1 through 5 representing mapping units RwA, RmA, KaA, BiA, and BiC had moderate limitations for crop production on the basis of total available water holding capacity (Table 10). Pedon 6 had very low available water holding capacity and therefore SpC mapping unit had severe limitation for crop production. All the mapping units studied except RmA were well drained and had slight limitation on the basis of drainage. RmA was moderately well drained and had moderate limitation for selected fruit production.

Soil mapping units with nearly level slopes (0-2%) had slight limitations for selected vegetable and field crops. If there is no frost problem, these soils also had slight limitation for fruit production. Therefore, a detailed study on frost problems (air drainage pattern) is recommended before establishing a fruit orchard (apple, pear or peach) on these flat

TABLE 10
Degree of Limitation of Studied Soils for the Production of Selected Fruit, Vegetable and Field Crops

Pedon No.	Soil Mapping Units	Soil Properties	Degree of Limitation for Management			
			Fruits		Vegetables	Field Crops
			Apple & Pear	Peach		
1	RwA	Soil Texture-Loam	slight	slight	slight	slight
		T.A.W.C.--Low (7.12 cm.)	moderate	moderate	moderate	moderate
		Natural Drainage--Well Drained	slight	slight	slight	slight
		Soil Slope--Nearly level (0-2%)	*slight	*slight	slight	slight
2	RmA	Soil Texture-Loam	slight	slight	slight	slight
		T.A.W.C.--Low (9.56 cm.)	moderate	moderate	moderate	moderate
		Natural Drainage--Moderately Well Drained	moderate	moderate	slight	slight
		Soil Slope--Nearly level (0-2%)	*slight	*slight	slight	slight
3	KaA	Soil Texture-Sandy Loam	slight	slight	slight	moderate
		T.A.W.C.--Medium 11.5 cm.	slight	slight	slight	slight
		Natural Drainage--Well Drained	slight	slight	slight	slight
		Soil Slope--Nearly level (0-2%)	*slight	*slight	slight	slight

TABLE 10 (continued)

Pedon No.	Soil Mapping Units	Soil Properties	Degree of Limitation for Management			
			Fruits		Vegetables	Field Crops
			Apple & Pear	Peach		
4	BiA	Soil Texture-Sandy Loam	slight	slight	slight	moderate
		T.A.W.C.--Low (7.33 cm.)	moderate	moderate	moderate	moderate
		Natural Drainage--Well Drained				
		Soil Slope--Nearly level (0-2%)	*slight	*slight	slight	slight
5	BiC	Soil Texture-Sandy Loam	slight	slight	slight	moderate
		T.A.W.C.--Low (9.04 cm.)	moderate	moderate	moderate	moderate
		Natural Drainage--Well Drained	slight	slight	slight	slight
		Soil Slope--Moderately Sloping (6-12%)	slight moderate	slight moderate	moderate	moderate moderate
6	SpC	Soil Texture-Fine Sand	severe	moderate	severe	severe
		T.A.W.C.--Very Low (3.06 cm)	severe	severe	severe	severe
		Natural Drainage--Well Drained	slight	slight	slight	slight
		Soil Slope--Moderately Sloping (6-12%)	moderate	moderate	moderate	moderate

Note: 1. T.A.W.C. = Total available water holding capacity in upper 90 cm. of soil.
2. *Assuming no frost or freezing problems.
3. For liming and fertilizer requirements, see Ext. Bull. E. 550 (Coop. Ext. Serv. M.S.U.). Soil reaction and low fertility problems can be easily overcome by lime and fertilizer application and such limitations are not included.

soils. Mapping units, BiC and SpC had moderate slopes (6-12%) and moderate limitation for crop production. Soil erosion was the major problem in such slopes. Conservation practices must be followed for using these soils in crop production.

All the studied soils had very low to medium available water holding capacity (Table 9) and therefore, they might need supplemental irrigation for good crop production. Irrigation is more critical on the Spinks soil because of its sandy nature. It had very low available water holding capacity and rapid percolation rate. Therefore, frequent and light irrigation would be more efficient in such a soil. Wind erosion problems are serious in sandy soils such as the Spinks. Wind erosion can also be minimized by keeping the soil moist with frequent irrigation or by the use of cover crops and mulches. RmA mapping unit is not well suited for apple, pear and peach production unless there is provision for drainage. Moderately sloping soils (BiC, SpC) should not be used for clear tilled crops such as corn unless a no till system is employed. If these soils are used for orchards, ground cover should be maintained.

SUMMARY AND CONCLUSION

Characteristics of some Hapludalfs were studied at the Clarksville Horticultural Experiment Station in Ionia County, Southern Michigan. Six pedons representing six soil mapping units were described in the field. Representative samples from the studied pedons were analyzed for particle size; 15 bar moisture; organic carbon; nitrate nitrogen; extractable phosphorus, potassium, calcium, magnesium; and soil pH. Saturated hydraulic conductivity, bulk density and 1/3 bar moisture were determined on core samples.

All the pedons were classified as Hapludalfs at the great group level. Pedon 6 (Spinks loamy sand, 6-12%) was classified as Psammentic Hapludalfs while all other pedons fell into the Typic Hapludalfs subgroup. Pedons 2 and 4 (Riddles moderately well drained 0-2% and Bixby 0-2%, taxadjuncts) were classified at the family level as Typic Hapludalfs, coarse-loamy, mixed, mesic. Pedon 1 (Riddles well drained, 0-2%), Pedon 3 (Kalamazoo, 0-2% taxadjunct) and Pedon 5 (Bixby, 6-12%) all had the same classification at the family level except the textural class. They respectively had fine-loamy, coarse-loamy over sandy, and fine-loamy over sandy textural classes instead of coarse-loamy. Pedon 6 (Spinks, 6-12%) is classified as Psammentic Hapludalfs, sandy, mixed, mesic at the family level.

Limitations of studied soils for the production of selected fruits (apple, pear, and peach), vegetables (cauliflower and tomatoes) and field crops (corn, wheat, and soybean) were estimated on the basis of soil-site properties (Table 10). Spinks loamy sand (6-12%) soil had severe limitations for both horticultural and agronomic crop production on the basis of soil texture and total available water holding capacity. All other studied soils

had slight or moderate limitations for the above-mentioned crops. A moderately well drained Riddles (Pedon 2) because of its seasonal wetness problem had moderate limitations for the selected fruits while all other soils had slight limitations. Studied soils on C slopes (BiC and SpC) had moderate limitations because of erosion hazards.

All the studied soils might need supplemental irrigation for good crop production. Irrigation is more critical on sandy soils such as Spinks. Wind erosion problems are also serious in sandy soils which can be minimized with conservation practices. Moderately well drained soils are not well suitable for decidious fruit production unless there is provision for artificial drainage.

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APPENDIX A

APPENDIX A

Pedon Descriptions

Pedon 1

Map Unit:	RwA
Pedon Classification:	Typic Hapludalfs, fine-loamy, mixed, mesic
Soil:	Riddles (Dryden)
Location:	Ionia County, Michigan; NW 1/4, SE 1/4, SW 1/4, Sec. 28; T6N, R8W
Vegetation and Land Use:	Cropland--Rye
Parent Material:	Glacial Till
Physiography:	Till Plain
Topography:	Nearly Level
Drainage:	Well Drained
Ground Water:	Below 230 cm.
Erosion:	Slight
Permeability:	Slow
Described by:	B. R. Khakural, G. D. Lemme and D. L. Mokma
Date:	June 9, 1980

(Colors are for moist soil unless otherwise stated)

Ap-0-31 cm; dark brown (10YR3/3) moist and pale brown (10YR6/3) dry silt loam; moderate fine granular structure; friable; many fine roots; abrupt smooth boundary. Ap fillings to a depth of 60 cm.

B1-31-59 cm; dark yellowish brown (10YR4/4) loam; moderate medium subangular blocky structure; firm; clear wavy boundary.

B21t-59-95 cm; dark yellowish brown (10YR4/4) clay loam; moderate medium angular blocky structure; firm; common fine distince dark brown (7.5YR4/4) mottles; common thin discontinuous dark brown (7.5YR4/4) clay films; clear wavy boundary. Also have pale brown (10YR6/3) fine sandy loam pockets with weak fine subangular blocky structure and friable consistency.

B22t-95-123 cm; dark yellowish brown 910YR4/4) fine sandy loam; moderate medium angular blocky structure; firm; few fine distinct dark brown (7.5YR4/4) mottles; common medium continuous dark brown (7.5YR4/4) clay films, abrupt wavy boundary.

B3t-123-186 cm; yellowish brown 910YR5/4) fine sandy loam; weak moderate platy parting to weak fine subangular blocky structure; firm; common discontinuous thin dark yellowish brown (10YR4/4) clay films; moderately effervescent; clear wavy boundary.

C1-186-203 cm; yellowish brown (10YR5/4) fine sandy loam; weak very coarse platy structure; friable; moderately effervescent; clear wavy boundary.

IIB3-203-230 cm; yellowish brown (10YR5/4) sand; weak medium platy structure; very friable; common discontinuous medium dark yellowish brown (10YR4/4) clay films; abrupt wavy boundary.

IIC2-Over 230 cm; very pale brown (10YR7/3) sand; structureless single grained; loose; mildly effervescent.

Pedon 2

Map Unit:	RmA
Pedon Classification:	Typic Hapludalfs, coarse-loamy, mixed, mesic
Soil:	Lapeer
Location:	Ionia County Michigan; NE 1/4, SW 1/4, SW 1/4, Sec. 28; T6N, R8W
Vegetation and Land Use:	Cropland--Rye
Parent Material:	Glacial Till
Physiography:	Till Plain
Topography:	Nearly Level
Drainage:	Moderately Well Drained
Ground Water:	Below 197 cm.
Permeability:	Slow
Described by:	B. R. Khakural, G. D. Lemme and D. L. Mokma
Date:	June 9, 1980

(Colors are for moist soil unless otherwise stated.)

Ap-0-21 cm; dark brown (10YR4/3) moist and pale brown (10YR6/3) dry silt loam; moderate fine granular structure; friable; many fine roots; abrupt smooth boundary; 3% pebbles in each horizon.

A&B-21-33 cm; pale brown (10YR6/3) tongues of A2 in yellowish brown (10YR5/4) B2 loam; moderate fine angular blocky structure; friable; common fine distinct yellowish brown (10YR4/4) mottles along the tongue walls; clear irregular boundary.

B21t-33-86 cm; dark yellowish brown (10YR4/4) loam; moderate medium angular blocky structure; firm; common large distinct yellowish brown (10YR4/4) mottles along walls of tongues; common thin dark brown (7.5YR4/4) clay films; clear wavy boundary.

B22t-86-142 cm; dark yellowish brown (10YR4/4) fine sandy loam; moderate fine angular blocky structure; firm; thin continuous dark brown (7.5YR4/4) clay films; clear wavy boundary.

B3t-142-197 cm; yellowish brown (10YR5/6) fine sandy loam; moderate fine subangular blocky structure; firm; thin discontinuous dark brown (7.5YR4/4) clay films; abrupt wavy boundary.

C-Over 197 cm; yellowish brown (10YR5/4) fine sandy loam; weak coarse platy structure; friable; slightly effervescent.

Pedon 3

Map Unit:	KaA
Pedon Classification:	Typic Hapludalfs, coarse-loamy over sandy, mixed, mesic
Soil:	Kalamazoo, taxadjunct
Location:	Ionia County, Michigan; NW 1/4, SW 1/4, SE 1/4, Sec. 28; T6N, R8W
Vegetation and Land Use:	Peach Orchard
Parent Material:	Glacial Till
Physiography:	Till Plain
Topography:	Nearly Level
Drainage:	Well Drained
Groundwater:	Below 153 cm.
Permeability:	Moderately Slow
Described by:	B. R. Khakural, G. D. Lemme and D. L. Mokma
Date:	June 9, 1980

(Colors are for moist soil unless otherwise stated.)

Ap-0-23 cm; dark brown (10YR3/3) moist and pale brown (10YR6/3) dry loam; moderate fine granular structure; friable; many fine roots; abrupt smooth boundary.

B1-23-43 cm; dark yellowish brown (10YR4/4) fine sandy loam; moderate fine subangular blocky structure; friable; clear wavy boundary.

B21t-43-89 cm; dark yellowish brown (10YR4/4) sandy loam; moderate medium angular blocky structure; friable; many medium continuous dark brown (7.5YR4/4) sandy clay loam clay films; clear wavy boundary.

B22t-89-142 cm; yellowish brown (10YR5/4) sandy clay loam with pale brown (10YR6/3) sandy loam pockets; moderate medium angular blocky structure; firm; abrupt wavy boundary.

IIA&B-Over 142 cm; pale brown (10YR6/3) sand (A2); structureless single grained; loose; bands of dark yellowish brown (10YR4/4) sandy loam (Bt); weak fine subangular blocky structure; friable; B bands are 1-10 cm thick and 3-12 cm apart.

Pedon 4

Map Unit:	BiA
Pedon Classification:	Typic Hapludalfs, coarse-loamy, mixed, mesic
Soil:	Bixby, taxadjunct
Location:	Ionia County, Michigan; NW 1/4, NE 1/4, SE 1/4, Sec. 28; T6N, R8W
Vegetation and Land Use:	Cropland
Parent Material:	Glacial Till
Physiography:	Till Plain
Topography:	Nearly Level
Natural Drainage:	Well Drained
Ground Water:	Below 153 cm.
Permeability:	Moderately Slow
Described by:	B. R. Khakural, G. D. Lemme and D. L. Modma
Date:	June 5, 1980

(Colors are for moist soil unless otherwise specified.)

Ap-0-24 cm; dark brown (10YR3/3) moist and pale brown (10YR6/3) dry sandy loam; moderate fine granular structure; friable; common fine roots; abrupt smooth boundary.

B21t-25-45 cm; dark yellowish brown (10YR4/4) sandy loam; moderate fine subangular blocky structure; friable; common earthworm channels; thin continuous dark brown (7.5YR4/4) clay films; clear discontinuous boundary.

B22t-45-58 cm; dark yellowish brown (10YR4/4) sandy loam; moderate fine angular blocky structure; friable; thin continuous dark brown (7.5YR4/4) clay films; clear wavy boundary.

B3t-58-65 cm; brown (10YR5/3) sandy loam; moderate medium subangular blocky structure; friable; thin discontinuous dark brown (7.5YR4/4) clay films; clear wavy boundary.

IIC1-65-112 cm; yellowish brown (10YR5/4) sand with thin 1 mm. bands of dark yellowish brown (10YR4/4) loamy sand 4-6 cm. apart; structureless single grained; loose; gradual wavy boundary.

IIC2-Over 122 cm; yellowish brown (10YR5/4) sand; structureless single grained; loose.

Pedon 5

Map Unit	BiC
Pedon Classification:	Typic Hapludalfs, fine-loamy over sandy, mixed, mesic
Soil:	Bixby
Location:	Ionia County, Michigan; NE 1/4, NE 1/4, NW 1/4, SW 1/4, Sec. 27; T6N, R8W
Vegetation and Land Use:	Cropland, Alfalfa
Parent Material:	Glacial Till
Physiography:	Moraine
Topography:	Moderately Slopping (6-12% slope)
Drainage:	Well Drained
Groundwater:	Below 153 cm.
Permeability:	Moderately Slow
Described by:	B. R. Khakural, G. D. Lemme and D. L. Mokma
Date:	June 9, 1980

(Colors are for moist soil unless otherwise specified.)

Ap-0-23 cm; dark brown (10YR3/3) moist pale brown (10YR6/3) dry fine sandy loam; weak very fine granular structure; friable; common fine roots; abrupt smooth boundary.

B1-23-43 cm; yellowish brown (10YR5/4) fine sandy loam; moderate fine subangular blocky structure; friable; crack fillings of Ap material; clear wavy boundary.

B2t-43-75 cm; dark yellowish brown (10YR4/4) heavy fine sandy loam; moderate medium angular blocky structure; friable; common continuous thin dark brown (7.5YR4/4) sandy clay loam to clay loam clay films; wavy boundary.

IIA&B-Over 75 cm; very pale brown (10YR7/4) sand (A2); structureless single grained; loose; .5-30 mm. bands of dark brown (10YR4/4) loamy sand (Bt); weak very fine subangular blocky structure; very friable. Top 3 cm. of the horizon has common continuous medium dark brown (10YR4/4) clay films. The B bands are 5-10 cm. apart.

Pedon 6

Map Unit:	SpC
Pedon Classification:	Psammentic Hapludalfs, sandy, mixed, mesic
Soil:	Spinks
Location:	Ionia County, Michigan; NW 1/4, NE 1/4, NW 1/4, SW 1/4, Sec. 27; T6N, R8W
Vegetation and Land Use:	Cropland, Alfalfa
Parent Material:	Glacial Outwash
Physioraphy:	Moraine
Topography:	Moderately Sloping (6-12% slope)
Drainage:	Well Drained
Ground Water:	Below 153 cm.
Permeability:	Rapid
Described by:	B. R. Khakural, G. D. Lemme and D. L. Mokma
Date:	June 10, 1980

(Colors for moist soil unless otherwise stated.)

Ap-0-24 cm; dark yellowish brown (10YR4/4) moist light yellowish brown (10YR6/4) dry loamy sand; weak very fine granular structure; very friable; common fine roots; abrupt smooth boundary.

B&A-25-54 cm; bands of yellowish brown (10YR5/6) loamy fine sand (Bt); weak fine subangular blocky structure; very friable; and pale brown (10YR6/3) fine sand (A2); structureless single grained; loose. B bands are 1-4 cm. thick and 1-2 cm. apart; common thin discontinuous dark brown (10YR4/3) clay films.

A&B-54-97; pale brown (10YR6/3) fine sand (A2); structureless single grained; loose; bands of yellowish brown (10YR5/6) loamy fine sand; weak fine subangular blocky structure; vary friable; common patchy thin dark yellowish brown (10YR4/4) clay films. B bands are 5-30 mm. thick and 2-15 cm. apart.

APPENDIX B

TABLE 11

Distribution of > 2 mm. Size Fraction

Pedon No.	Horizon	% > 2 mm. Fraction
1	Ap	3.77
	B1	4.09
	B21t	4.27
	B22t	5.91
	B3t	8.67
	C1	10.43
	IIB3	3.82
	IIC2	1.11
2	Ap	3.52
	A&B	4.27
	B21t	6.24
	B22t	4.38
	B3t	3.50
	C	5.79
3	Ap	3.70
	B1	2.56
	B21t	1.73
	B22t	3.60
	IIA&B	0.16
4	Ap	2.38
	B21t	3.35
	B22t	1.47
	IIC1	0.01
	IIC2	0.00
5	Ap	0.58
	B1	0.41
	B2t	0.21
	IIA&B	0.00
6	Ap	6.75
	B&A	7.13
	A&B	4.08
	A&B	0.15

TABLE 12

Selected Physical Properties from Representative Pedons

Horizon Pedon 1	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	Bulk Density (gm/cm^3) oven dry	% Moisture 1/3 bar	% Moisture 15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
AP	1	1.04	1.50	1.27	17.87	7.76	10.11	12.84	
	2	0.99	1.48	1.24	19.06	7.83	11.23	13.93	
	3	--	1.53	1.29	18.83	10.37	8.46	10.91	
	4	1.01	1.70	1.45	17.53	10.70	6.83	9.90	
	5	--	1.74	1.49	17.26	11.04	6.22	9.27	
	Y	1.02	1.59	1.35	18.11	9.54	8.57	11.57	Total =
	S	0.02	1.08	1.10	0.71	1.44	7.90	1.76	3.59 cm
B_1	1	--	1.80	1.56	14.93	9.57	5.36	8.36	
	2	0.55	1.86	1.63	14.41	9.30	5.11	8.33	
	3	0.74	1.79	1.56	14.95	11.54	3.41	5.31	
	4	0.94	--	--	--	10.70	--	--	
	5	--	1.90	1.65	15.06	11.04	4.02	6.63	
	Y	0.74	1.84	1.60	14.84	10.43	4.41	7.06	Total =
	S	0.16	0.0	0.04	0.25	0.8	0.80	1.28	1.98 cm
B21t	1	--	--	--	--	9.37	--	--	
	2	1.90	1.73	1.39	13.34	9.57	--	--	
	3	0.72	--	--	--	9.40	--	--	
	4	1.97	--	--	--	11.28	--	--	
	5	2.36	--	--	--	11.22	--	--	
	Y	1.74	1.73	1.39	13.34	10.17	3.37	4.68	Total =
	S	0.61	--	--	--	0.8	--		1.68 cm
B22t	1	0.87	1.70	1.52	11.94	8.07	3.87	5.88	
	2	--	1.81	1.61	13.84	8.05	5.79	9.32	
	3	0.65	1.79	1.58	13.22	8.07	5.15	8.14	
	4	0.55	1.76	1.57	12.63	9.48	3.15	4.95	
	5	0.79	1.72	1.51	14.19	9.59	4.60	6.95	
	Y	0.71	1.76	1.56	13.16	8.65	4.51	7.04	Total =
	S	0.12	0.04	0.04	0.81	0.72	0.93	1.56	1.97 cm
B3t	1	0.93	1.75	1.57	11.35	6.55	4.80	7.54	
	2	0.77	1.91	1.72	11.04	6.82	4.22	7.26	
	3	0.51	1.87	1.69	10.52	6.79	3.73	6.30	
	4	--	1.97	1.77	11.32	8.35	2.97	5.26	
	5	--	2.02	1.86	10.61	8.56	2.05	3.81	
	Y	0.74	1.90	1.72	10.97	7.41	3.56	6.12	Total =
	S	0.17	0.09	0.10	0.348	0.85	0.96	0.41	3.86 cm

TABLE 12 (continued)

Horizon Pedon 1	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	oven dry	% Moisture 1/3 bar	15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
C_1	1	0.14	1.87	1.69	10.61	6.80	3.81	6.44	
	2	0.29	1.87	1.69	10.36	7.88	2.48	4.19	
	3	1.22	1.92	1.73	10.61	7.13	3.48	6.02	
	4	0.41	1.90	1.71	10.89	7.47	3.42	5.85	
	5	0.14	1.99	1.81	10.34	7.39	2.95	5.34	
	$\bar{Y}$	0.44	1.91	1.73	10.56	7.33	3.23	5.59	Total =
	S	0.40	0.04	0.05	0.20	0.36	0.46	0.77	0.95 cm
Pedon 2 AP	1	2.33	1.62	1.25	16.63	8.52	8.31	10.39	
	2	4.52	1.61	1.38	16.33	8.46	7.87	10.86	
	3	4.21	1.63	1.38	18.14	8.54	9.60	13.25	
	4	3.34	1.70	1.43	18.58	9.42	9.16	13.10	
	5	--	1.63	1.39	17.43	9.69	7.74	10.76	
	$\bar{Y}$	3.60	1.64	1.37	17.42	8.93	8.54	11.70	Total =
	S	0.85	0.03	0.06	0.86	0.53	0.73	1.24	2.46 cm
A&B	1	3.76	1.69	1.43	17.97	8.50	9.47	13.54	
	2	4.65	1.54	1.31	17.14	8.58	8.56	11.21	
	3	2.19	1.80	1.57	14.31	8.73	5.58	8.76	
	4	5.12	1.71	1.51	13.52	9.18	4.34	6.55	
	5	2.08	1.70	1.44	18.41	9.56	8.85	12.74	
	$\bar{Y}$	3.56	1.69	1.45	16.27	8.91	7.36	10.67	Total =
	S	1.26	0.84	0.09	1.98	0.40	2.02	2.58	1.28 cm
B21t	1	0.30	1.81	1.60	13.41	8.72	4.69	7.50	
	2	0.25	1.95	1.68	15.92	8.69	7.23	12.15	
	3	0.32	1.88	1.62	15.90	9.08	6.82	11.05	
	4	--	1.96	1.71	15.01	8.93	6.08	10.40	
	5	--	1.87	1.61	15.23	8.65	6.58	10.59	
	$\bar{Y}$	0.29	1.89	1.64	15.09	8.81	6.28	10.30	Total =
	S	0.03	0.06	0.04	0.92	0.17	0.88	1.54	5.46 cm
B22t	1	0.18	1.89	1.69	11.70	8.49	3.21	5.42	
	2	0.31	1.83	1.63	11.95	8.57	3.38	5.51	
	3	0.34	1.81	1.60	13.09	9.59	3.50	5.60	
	4	0.36	1.81	1.61	12.63	8.71	3.92	6.31	
	5	0.48	1.80	1.59	13.31	9.01	4.3	6.84	
	$\bar{Y}$	0.33	1.83	1.62	12.54	8.87	3.67	5.95	Total =
	S	0.10	0.03	0.04	0.63	0.40	0.40	0.55	3.33 cm

TABLE 12 (continued)

Horizon Pedon 2	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	Bulk Density (gm/cm^3) oven dry	% Moisture 1/3 bar	% Moisture 15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
B3t	1	0.14	1.80	1.59	12.96	8.37	4.59	7.30	
	2	0.10	1.76	1.60	10.09	8.33	1.76	2.82	
	3	0.19	1.73	1.56	11.45	8.29	3.16	4.92	
	4	0.36	1.84	1.68	9.43	8.30	1.13	1.90	
	5	0.29	1.73	1.52	13.53	8.37	5.16	7.84	
	$\bar{Y}$	0.22	1.77	1.59	11.49	8.33	3.16	5.02	Total =
	S	0.10	0.04	0.05	1.58	0.03	1.56	2.35	2.76 cm
C	1	0.14	1.99	1.81	10.31	5.74	4.57	8.27	
	2	0.29	1.97	1.80	9.60	5.72	3.88	6.96	
	3	1.22	--	--	--	5.69	--	--	
	4	0.41	2.01	1.85	9.20	5.93	3.27	6.05	
	5	0.14	2.09	1.91	9.62	6.16	3.46	6.61	
	$\bar{Y}$	0.44	2.02	1.84	9.68	5.85	3.83	7.05	
	S	0.40	0.05	0.04	0.40	0.18	0.59	0.82	
Pedon 3 AP	1	12.64	1.44	1.19	20.89	6.88	14.01	16.67	
	2	3.65	1.52	1.25	21.92	6.95	14.97	18.71	
	3	5.24	1.49	1.20	23.89	7.03	16.86	20.23	
	4	9.71	1.55	1.24	24.66	7.40	17.26	21.40	
	5	0.83	1.69	1.41	20.15	7.04	13.11	18.49	
	$\bar{Y}$	6.42	1.54	1.26	22.30	7.06	15.24	19.20	Total =
	S	4.24	0.08	0.08	1.73	0.18	1.60	1.65	4.42 cm
B_1	1	4.79	1.66	1.45	14.20	5.14	9.06	13.14	
	2	2.16	1.75	1.54	13.79	4.94	8.85	13.63	
	3	2.23	1.70	1.50	9.60	6.40	3.20	4.80	
	4	2.14	1.67	1.47	14.07	6.33	7.74	11.38	
	5	0.70	1.85	1.64	12.78	6.64	6.14	10.07	
	$\bar{Y}$	2.83	1.73	1.52	12.89	5.89	7.00	10.64	Total =
	S	1.13	0.07	0.07	1.72	0.70	2.16	3.17	2.13 cm
B21t	1	0.62	1.91	1.71	11.54	5.04	6.50	11.12	
	2	1.01	1.95	1.77	9.91	4.84	5.07	8.97	
	3	0.66	1.80	1.63	10.46	5.76	4.70	7.66	
	4	0.58	2.03	1.79	12.46	5.68	6.60	11.81	
	5	0.43	1.95	1.74	12.52	5.61	6.91	12.02	
	$\bar{Y}$	0.66	1.93	1.73	11.38	5.39	5.99	10.36	Total =
	S	0.19	0.08	0.06	1.05	0.37	0.89	1.71	4.77 cm

TABLE 12 (continued)

Horizon Pedon 3	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	oven dry	% Moisture 1/3 bar	15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
B22t	1	1.34	1.84	1.70	8.21	6.41	1.80	3.06	
	2	0.53	1.90	1.75	9.11	6.58	2.53	4.43	
	3	0.48	1.91	1.73	10.65	6.43	4.22	7.30	
	4	0.46	1.82	1.63	11.43	7.12	4.31	7.03	
	5	0.57	1.91	1.66	14.00	7.45	6.55	10.87	
	$\bar{Y}$	0.68	1.88	1.69	10.68	6.80	3.88	6.56	Total =
	S	0.33	0.04	0.04	2.01	6.42	1.65	6.29	3.48 cm
IIA&B	1	16.19	1.57	1.54	1.99	1.19	0.80	1.23	
	2	4.47	1.61	1.56	3.40	1.21	2.19	3.42	
	3	45.70	1.59	1.55	2.34	1.10	1.24	1.92	
	4	4.26	1.61	1.56	3.76	1.28	2.48	3.87	
	5	5.43	1.61	1.53	5.47	1.24	4.23	6.47	
	$\bar{Y}$	17.65	1.60	1.55	3.39	1.20	2.19	3.39	
	S	16.89	0.02	0.01	1.23	0.06	1.19	1.82	
Pedon 4 AP	1	4.33	1.64	1.37	20.31	6.25	14.06	19.26	
	2	--	1.69	1.43	18.95	6.54	12.41	17.75	
	3	6.25	1.58	1.30	18.62	6.36	12.26	15.94	
	4	4.54	1.63	1.36	18.98	6.98	12.00	16.32	
	5	--	1.37	1.15	19.37	7.14	12.23	14.06	
	$\bar{Y}$	5.03	1.58	1.32	19.25	6.65	12.60	16.63	Total =
	S	0.85	0.11	0.10	0.58	0.35	0.75	1.75	3.99 cm
B21t	1	4.57	1.76	1.63	11.62	5.35	6.27	10.22	
	2	9.91	1.64	1.47	11.57	5.24	6.33	9.31	
	3	7.31	1.71	1.55	10.45	6.55	3.90	6.05	
	4	--	1.66	1.54	7.44	6.82	0.62	0.95	
	5	--	--	--	--	6.87	--	--	
	$\bar{Y}$	7.26	1.69	1.55	10.27	6.17	4.10	6.36	Total =
	S	2.18	0.05	0.06	1.70	0.72	2.33	3.63	1.27 cm
B22t	1	2.41	1.81	1.76	8.5	5.83	2.67	4.70	
	2	0.74	1.95	1.76	10.78	5.96	4.82	8.48	
	3	1.71	1.90	1.70	11.46	6.11	5.35	9.10	
	4	2.70	1.83	1.64	11.19	6.61	4.58	7.51	
	5	--	1.79	1.64	9.20	6.32	2.88	4.72	
	$\bar{Y}$	1.89	1.86	1.70	10.23	6.17	4.06	6.90	Total =
	S	0.76	0.06	0.05	1.17	0.28	1.08	1.86	0.90 cm

TABLE 12 (continued)

Horizon Pedon 4	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	oven dry	% Moisture 1/3 bar	15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
B3t	1	21.24	1.44	1.38	4.44	1.45	2.99	4.13	
	2	19.51	1.70	1.55	9.53	0.89	8.64	13.39	
	3	19.40	2.06	1.88	9.46	0.81	8.65	16.26	
	4	13.98	--	--	--	1.03	--	--	
	5	--	--	--	--	1.05	--	--	
	$\bar{Y}$	18.53	1.73	1.60	7.81	1.05	6.76	10.82	Total =
	S	2.28	0.25	0.21	2.38	0.22	2.67	5.18	0.76 cm
IIC_1	1	54.56	1.50	1.45	2.87	1.73	1.14	1.65	
	2	52.41	1.40	1.38	2.22	1.60	0.62	0.86	
	3	57.39	--	--	--	1.54	--	--	
	4	--	--	--	--	1.70	--	--	
	5	--	--	--	--	1.96	--	--	
	$\bar{Y}$	54.79	1.45	1.42	2.55	1.71	0.84	1.19	Total =
	S	2.04	0.05	0.04	0.33	0.15	0.26	0.52	0.68 cm
Pedon 5 AP	1	11.64	1.65	1.44	15.03	5.22	9.81	14.12	
	2	16.51	1.64	1.45	13.56	5.21	8.35	12.11	
	3	10.84	1.74	1.52	14.35	5.56	8.79	13.36	
	4	--	1.76	1.54	13.77	6.12	7.65	11.78	
	5	--	1.69	1.50	12.64	8.62	4.02	6.03	
	$\bar{Y}$	13.00	1.70	1.49	13.87	6.15	7.72	11.50	Total =
	S	2.50	0.05	0.04	0.80	1.28	1.98	2.85	2.65 cm
B_1	1	0.26	1.88	1.65	13.65	7.06	6.59	10.87	
	2	0.84	1.90	1.66	14.26	7.13	7.13	11.84	
	3	0.87	1.85	1.64	13.29	8.61	4.68	7.67	
	4	1.32	1.85	1.62	13.92	8.61	5.31	8.60	
	5	--	--	--	--	7.85	--	--	
	$\bar{Y}$	0.82	1.87	1.64	13.78	7.85	5.93	9.73	Total =
	S	0.38	0.02	0.02	0.36	0.68	0.88	1.68	1.95 cm
B2t	1	0.87	1.92	1.66	15.24	8.93	6.31	10.74	
	2	0.60	1.91	1.65	16.61	8.78	7.83	12.92	
	3	0.62	1.92	1.63	17.44	8.66	8.78	14.31	
	4	1.51	1.64	1.37	18.97	9.41	9.56	13.10	
	5	--	1.88	1.61	17.16	10.21	6.95	11.19	
	$\bar{Y}$	0.90	1.85	1.58	17.08	9.20	7.88	12.45	Total =
	S	0.37	0.12	0.11	1.21	0.57	1.18	1.31	3.98 cm

TABLE 12 (continued)

Horizon Pedon 5	Sample	Saturated Hydraulic Conductivity cm/hr	Bulk Density (gm/cm^3) 1/3 bar	Bulk Density (gm/cm^3) oven dry	Moisture 1/3 bar	Moisture 15 bar	% Available Moisture by Weight	% Available Moisture by Volume	
IIA&B	1	64.17	1.54	1.49	3.75	0.91	2.84	4.23	
	2	60.37	1.56	1.53	2.20	0.97	1.23	1.88	
	3	48.15	1.55	1.52	1.83	0.69	1.14	1.73	
	4	40.46	1.60	1.57	2.13	1.08	1.05	1.65	
	5	69.06	1.53	1.51	1.29	1.28	0.01	0.02	
	$\bar{Y}$	56.42	1.56	1.52	2.24	0.99	1.25	1.90	
	S	10.36	0.02	0.03	0.82	0.56	0.74	1.35	
Pedon 6 AP	1	20.85	1.58	1.51	2.70	2.65	0.05	0.08	
	2	16.34	1.70	1.61	5.72	2.60	3.12	5.02	
	3	18.67	1.63	1.56	4.46	2.45	2.01	3.14	
	4	23.95	1.60	1.52	5.15	2.61	2.54	3.86	
	5	13.12	1.66	1.58	5.00	2.59	2.41	3.81	
	$\bar{Y}$	19.95	1.63	1.56	4.61	2.58	2.03	3.17	Total =
	S	2.80	0.04	0.04	1.03	0.07	1.05	1.66	0.76 cm
B&A	1	15.09	1.63	1.57	4.10	2.49	1.61	2.53	
	2	12.08	1.69	1.62	4.13	2.54	1.59	2.58	
	3	14.29	--	--	--	3.11	--	--	
	4	13.04	1.71	1.61	6.07	2.85	3.22	5.18	
	5	10.18	1.70	1.61	5.78	2.70	3.08	4.96	
	$\bar{Y}$	12.93	1.68	1.60	5.02	2.74	2.38	3.80	Total =
	S	1.72	0.03	0.02	0.91	0.23	0.78	1.26	1.14 cm
A&B	1	21.12	1.60	1.54	2.25	2.18	0.07	0.11	
	2	21.60	1.63	1.56	4.65	2.17	2.48	3.87	
	3	23.89	1.63	1.52	4.25	2.36	1.89	2.87	
	4	17.03	1.66	1.56	4.03	2.25	1.78	2.78	
	5	15.30	1.59	1.51	4.89	2.31	2.58	3.90	
	$\bar{Y}$	19.79	1.62	1.54	4.01	2.25	1.76	2.71	Total =
	S	3.15	0.03	0.02	0.93	0.07	0.90	1.38	3.05 cm
A&B	1	46.49	1.59	1.56	1.60	0.78	0.82	1.28	
	2	47.81	1.57	1.54	1.44	0.84	0.60	0.92	
	3	39.84	1.63	1.60	1.91	1.03	0.88	1.41	
	4	34.62	1.62	1.68	2.46	0.93	1.53	2.57	
	5	--	1.64	1.58	4.06	0.85	3.21	5.07	
	$\bar{Y}$	37.00	1.61	1.59	2.29	0.89	1.40	2.23	
	S	11.42	0.03	0.05	0.9	0.05	0.95	1.51	

TABLE 13
Criteria for Determining the Degree of Limitations for Selected Vegetable Production (Cauliflower and Tomatoes) On Southern Michigan Soils

Soil Properties	Degree of Limitations for Management: Slight	Moderate	Severe
1. Profile Soil Texture (weighted average of upper 1 m.)	Clay Loam, Sandy Clay Loam, Silt Loam, Loam Sandy Loam, Silt Loamy Sand	Silty Clay Loam Sandy Clay	Clay, Silty Clay Sand
2. Total Available Water Holding Capacity in Upper 90 cm. of Soil	Medium or High (>10 cm.)	Low (5-10 cm.)	Very Low (< 5 cm.)
3. Natural Drainage (Artificial Drainage will correct the problem.)	Well Drained	Moderately Well Drained	Somewhat Poorly and Very Poorly Drained
4. Soil Slope	Nearly Level to Gently Sloping 0-6%	Sloping (6-12%)	Steep and Very Steep >12%

Note: For liming and fertilizer requirements, see Ext. Bull. E550 (Coop. Ext. Serv., M.S.U.).

Slight = denotes those situations where no special management is required to overcome limitations.

Moderate = denotes those situations where some special management is required to overcome limitations.

Severe = denotes those situations where extensive management is required to overcome limitations.

TABLE 14.
Criteria for Determining the Degree of Limitations for Selected Fruit Production (Apple, Pear, Peach) On Southern Michigan Soils

Soil Properties	Degree of Limitations for Management		
	Slight	Moderate	Severe
1. Profile Soil Texture # (weighted average of upper 1 m.)	Loam, Silt Loam Sandy Loam	Clay Loam, Silty Clay Loam, Sandy Clay Loam	Clay, Silty Clay Sandy Clay Silt, Loamy Sand, Sand
2. Total Available Water Holding Capacity in Upper 90 cm. of Soil	Medium or High (>10 cm.)	Low (5-10 cm.)	Very Low (<5 cm.)
3. Natural Drainage (Artificial drainage will correct the problem)	Well Drained	Moderately Well Drained	Somewhat Poorly, Poorly, Very Poorly
4. Soil Slope	Nearly Level (0-2%), Gently	Moderately Sloping (6-12%)	Strongly Sloping Steep, Very Steep (>12%)

Note: #In the case of peaches: Loamy sand and sand textures have moderate limitations; clay loam, clay loam, sandy clay loam and silty clay loam have severe limitations.

*Assuming no frost problems.

Soil reaction and fertility problems can be overcome with lime and fertilizer use and therefore are not included in this table.

TABLE 15

Criteria for Determining the Degree of Limitations for Selected Field Crop Production (corn, wheat, soybeans) On Southern Michigan Soils

Soil Properties	Degree of Limitations for Management		
	Slight	Moderate	Severe
1. Profile Soil Texture (weighted average of upper 1 m.)	Sandy Loam Loam, Silt Loam Clay Loam, Silty Clay Loam, Sandy Clay Loam	Sandy Loam Clays, Silty Clay Sandy Clay	Loamy Sand Sand
2. Total Available Water Holding Capacity in Upper 90 cm. of Soil	Medium or High (>10 cm.)	Low (5-10 cm.)	Very Low <5 cm.
3. Natural Drainage (Artificial drainage will correct the problem.)	Well and Moderately Well Drained	Somewhat Poorly Drained	Poorly and Very Poorly Drained
4. Soil Slope	Nearly Level (0-2%)	Gently to Moderately Sloping	Strongly Sloping Steep and Very Steep

Note: For liming and fertilizer requirements, see Ext. Bull. E550 (Coop. Ext. Serv., M.S.U.).