Inorganic phosphorus fractions and humic acid carbon to fulvic acid carbon ratios as differentiae for selected Alfisols and Mollisols

Winston Edward Hobson

Iowa State University
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INORGANIC PHOSPHORUS FRACTIONS AND HUMIC ACID CARBON TO FULVIC ACID CARBON RATIOS AS DIFFERENTIAE FOR SELECTED ALFISOLS AND MOLLISOLS

Iowa State University Ph.D. 1983

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Inorganic phosphorus fractions and humic acid carbon to fulvic acid carbon ratios as differentiae for selected Alfisols and Mollisols

by

Winston Edward Hobson

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Department: Agronomy
Major: Soil Morphology and Genesis

Approved:

Signature was redacted for privacy.

In Charge of Major Work

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For the Graduate College

Iowa State University
Ames, Iowa
1983
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INTRODUCTION

The initiation of this study was related to funding of a project by the Environmental Protection Agency (EPA). The project was titled: "Effect of agricultural land use practices on stream water quality: 1. Field-to-stream processes." The contract number of the project was CR806603-01-1.

The publication, Soil Taxonomy (Soil Survey Staff, 1975), has provided a definitive statement about the importance of separating different soils. However, ongoing work related to refinement of criteria being used to separate soils and to the development of other criteria suggests that improvements are needed in the classification of Mollisols.

In Soil Taxonomy, there are ten soil orders at the highest classification level. Each order has characteristics (central concept) related to its genetic pathway. Although attempts were made to group the soils by using differentiae which would not change readily, the major defining criterion of at least one soil order has been observed to change in a relatively short time; this is the Mollisol order. The problem with the Mollisols stems from the fact that the mollic epipedon (at the soils' surface) may be eroded under various types of management. This problem also arises with mollic intergrades of other soil orders.

Mollisols occupy a large area of the United States. Their generally fertile nature has encouraged very intensive
farming. With erosion and subsequent loss of the mollic epipedon, a decision must be made on whether or not to retain the soil in the Mollisol order. In discussions of the attributes desired in soil classification and soil taxonomy, it is stated that, if horizons important to the use or identification of a soil are lost because of truncation by erosion, then the placement of that soil in the taxonomy should be changed. However, it is also pointed out that the differentiae should be such as to keep cultivated soils and their disturbed counterparts in the same taxon, insofar as possible (Soil Survey Staff, 1975). In the case of Mollisols, these two guiding principles are at odds with each other.

T. E. Fenton (Department of Agronomy, Iowa State University, Ames, Iowa, personal communication) has indicated that, if the mollic epipedon is used too rigidly in the classification of Mollisols, the summation of all other properties that are common to soils which formed under prairie-derived vegetation is essentially negated. Guy D. Smith, who served as the chief architect of Soil Taxonomy, stated that the use of the mollic epipedon as a diagnostc horizon violated the principles of Soil Taxonomy, but its use was justified since it tied together all the dark colored soils of the great plains of the United States and Europe. He also indicated that loss of the mollic epipedon because of erosion transfers the soil to another class. The severe criticisms of the use of the mollic epipedon at the order level may thus be justified
(Smith and Leamy, 1978). Furthermore, since the mollic epipedon is only prohibited in the Entisol, Aridisol and Histosol soil orders (Smith and Leamy, 1981), there are implications for classification wherever a mollic epipedon forms and is subsequently eroded.

Once the mollic epipedon erodes, the soil may be transferred to one of at least two classes, Alfisols if there is an argillic horizon or Inceptisols if there is a cambic horizon present (Smith and Leamy, 1978). A better taxonomy may result if a way can be found to classify Alfisols and Mollicsols so that their classification will remain stable regardless of whether the mollic epipedon erodes to less than the allowable limit. Such a classification will have to be based on criteria that differ from the criteria in Soil Taxonomy.

Organic carbon and its fractions and phosphorus and phosphorus fractions seem to have more usefulness as diagnostic criteria in soils than they are given credit for in Soil Taxonomy. Much of the work on organic fractions and their relationships in soils has been done in Russia and, more recently, in Canada. Russian soil scientists have collected data on humic and fulvic carbon in Russian soils. These data indicate that the humic carbon to fulvic carbon ratio \( \frac{C_h}{C_f} \) tends to be greater in grass-derived than in forest-derived soils. Generally, \( \frac{C_h}{C_f} \) is greater than unity in grass-derived soils and less than unity in forest-derived
soils. Furthermore, while absolute amounts of carbon change with cultivation, the $C_h/C_f$ tends to show the same trends (Kononova, 1966, 1975).

Regarding phosphorus, there has been a tremendous amount of research on its distribution pattern in soils; because it is not a very mobile soil constituent, changes in its form have been thought to be related to genetic processes in soils. Some of the earlier researchers who worked with phosphorus include the following: Pearson et al. (1940) and Allaway and Rhoades (1951).

Chang and Jackson (1957) essentially formalized the fractionation procedure for soil inorganic phosphorus. Over the years, the procedure has been refined but, generally, it has stood the test of time. The relative amounts of the various fractions of soil inorganic phosphorus have proven useful in separating various soils.

Iowa is dominated by Mollisols and Alfisols. Therefore, criteria to improve the taxonomy of these soils and shed light on the problem of soil erosion and soil classification are very important. Another area that will be well served by improved criteria would be that of taxadjuncts. Taxadjuncts are:

Soils that cannot be classified in a series recognized in the classification system. Such soils are named for a series they strongly resemble and are designated as taxadjuncts to that series because they differ in ways too small to be of consequence in interpreting their use and behavior (Buckner, 1982).
It is thought that inorganic phosphorus fractions and ratios, along with humic carbon to fulvic carbon ratios are useful indicators of the status of soil development. Furthermore, the variables may prove useful in qualitatively defining the extent of erosion of selected soils. In light of the above, this study has as objectives:

1. Determination of the organic carbon content (including humic carbon and fulvic carbon) distribution, and relationships in selected profiles of Alfisols and Mollisols.

2. Determination of the amounts and distribution of the various inorganic phosphorus fractions in the soils studied. Relationships of the fractions within and between profiles will be examined.

3. Collection of benchmark data such as soil pH, total phosphorus and particle size distribution.

4. Examine selected subsurface properties that may be indicators of different genetic pathways.

5. Evaluate the potential of these properties to aid in the refinement of soil classification.
Selected definitions

In studies of the soil organic matter fraction, the terms humus and soil organic matter are, at times, used interchangeably. In addition, universal agreement has not been reached on the naming of all the fractions obtained in the soil organic matter fractionation procedure. In order that readers have a clear understanding of terms related to the soil organic fractions as used in this study, this section is included.

According to Jackson (1958):

Carbon occurs in 4 forms of mineral and organic matter:

1. Carbonate mineral forms, chiefly CaCO$_3$ and MgCO$_3$. CaCO$_3$; but highly active and important small amounts also occur as CO$_2$, and HCO$_3^-$ and CO$_3^{2-}$ ions of more soluble salts.

2. Highly condensed, nearly elemental organic carbon (charcoal, graphite, coal).

3. Altered and rather resistant organic residues of plants, animals, and microorganisms, sometimes termed "humus" or "humate," but not, as these latter terms tend to suggest, a single compound.

4. Little altered organic residues of plants and animals, and living and dead microorganisms, subject to rather rapid decomposition in soils.

The total carbon of soils obviously includes all 4 forms. Total organic carbon includes the latter 3.

Soil organic matter as defined by the Soil Science Society of America (1979) refers to the organic fraction of...
the soil; this fraction includes animal and plant residues which are at various stages of decomposition; it includes cells and tissues of soil organisms, and substances synthesized by the soil population. Soil organic matter is usually determined on soils which have been sieved through a 2.0-mm sieve.

Soil humus, which is at times used interchangeably with soil organic matter, is not defined by the Soil Science Society of America (1979) as being identical to soil organic matter. Humus is defined as "that more or less stable fraction of the soil organic matter remaining after the major portion of added plant and animal residues have decomposed. Usually it is dark colored."

Similar definitions for humus and organic matter were given by Joffe (1949) who stated that:

Actually, there is a fundamental difference between these two terms. Soil organic matter consists of any substance of organic origin, living or dead, encountered in the soil. Humus, on the other hand, is only a portion of the soil organic matter. Humus is the dark brown-black organic matter that has undergone decomposition to such an extent that one can no longer determine by inspection the nature of the material from which it was derived. The plant or animal substance of today is the humus of tomorrow.

In addition to determining the whole soil carbon or organic matter, it is possible to extract and determine the components of various fractions of the soil organic matter. If the soil is extracted with dilute alkali and subsequently acidified to about pH 1.5, the humic acid fraction precipi-
tates. The nonprecipitated fraction is called fulvic acid. The humic and fulvic acids may be further fractionated; several currently used schemes will be presented in a subsequent section.

The defining of humic acid and fulvic acid on the basis of extracting reagents is fairly well established. Examples of current literature using the above criteria for humic and fulvic acids include Lowe (1980), Boyd et al. (1980), Khan and Schnitzer (1972), Anderson et al. (1974a,b), Bettany et al. (1980), Russell (1973), and Goh and Williams (1979).

With regard to humic and fulvic acid, Russell (1973) emphasized that:

Soil chemists have been criticized for maintaining this archaic terminology, since we know that there is not a simple fulvic or humic or hymatomelanic acid; but the terms have continued to be useful and should not be misleading.

Soil organic matter and its constituents are known to be important components of soils. Some of the roles played by them in soils will be discussed subsequently.

**Importance of organic matter in soils**

The productivity of soils for plants is probably the quality that is most important for the existence of mankind (Soil Survey Staff, 1975). Furthermore, naturally productive soils in contrast to desert soils tend to contain some amount of organic matter. The current struggle by concerned individuals and organizations to reduce soil erosion (loss of
organic rich surface soil) may be taken as a measure of the premium placed on having organic matter in soils. Numerous benefits accrue from the soil organic matter. Organic matter is useful in that it is a source of several plant nutrients; it contributes cation exchange capacity; it improves the water holding capacity of the soil; it aids in the development of soil structure; it reacts with pesticides; it plays an important role in soil genesis. Some of these organic matter effects on soil will be reviewed briefly.

Nutrient source

Some of the important plant nutrients that are known constituents of organic matter include nitrogen, sulfur, and phosphorus. Stevenson (1982) reported that up to three-fourths of the total P and practically all of the sulfur, in most surface soils, occurs in organic form. The nitrogen content is usually approximately one-twentieth of the organic matter content, that is, 0.025 to 0.50%. Another important constituent of soil organic matter is carbon which is used by soil microorganisms. The microorganisms are important in that they decompose organic matter, thus freeing the nutrients in the structure of the organic matter.

Kowalenko (1978) wrote a review on organic N, P, and S in soils. He reported essentially the following: (1) N, P, and S in organic matter vary with vegetation, climate, and management; (2) organic soils contain much higher amounts of
N, P, S and C than mineral soils; (3) ratios of C:N:P:S appear remarkably similar in widely differing soils; (4) in most surface soils, the majority (95% or more) of the N is present in organic form; (5) organic S is the major form of S in most surface soils; (6) organic P may vary from as low as a few percent to as much as 75% of the total P.

The amount of a given nutrient is not an indication of availability to plants. Availability is probably more related to organic matter decomposition by microbes, and subsequent release of nutrients. Bremner (1956) reported that organic nitrogen is relatively unavailable to plants since only 1-3% is mineralized during the growing season. However, he considers this a good safeguard against N depletion. In addition, he reported that a significant proportion of the phosphorus taken up by the growing crops comes by way of the mineralization of organic phosphorus, and increasing temperature has an important effect on the rate of the mineralization of organic P. With increase in temperature, the contribution from organic P increases.

With the recent reports of sulfur deficiency in some areas, there has arisen a need to apply sulfur fertilizer. Concomitant with this has come an expansion in the long neglected area of sulfur study. Since most sulfur is in organic form, release and availability are related to mineralization. In a study which evaluated the status of S
in Iowa soils, it was reported by Tabatabai and Bremner (1972), based on sulfate S and mineralizable S analyses, that most of the agriculturally important soils have low reserves of plant-available S. Stevenson (1982) reported that, if the C/S ratio of added plant tissue is below 200, there is a net gain of $\text{SO}_4^{2-}$, whereas, for a ratio over 400, there is a net loss. There is neither gain nor loss if the ratio is between 200 and 400. $\text{SO}_4^{2-}$ is the form of S available to plants.

Cation-exchange capacity This important soil property is defined by the Soil Science Society of America (1979) as follows:

The sum total of exchangeable cations that a soil can adsorb, expressed in milliequivalents per 100 grams or per gram of soil (or of other exchangers such as clay).

Another important exchanger is organic matter. The importance of the CEC values of organic matter is brought out if one compares them to the CEC values for various types of clays. Grim (1968) reported CEC values (in meq/100 g) for various clays as follows: kaolinite, 3-15; halloysite·$2\text{H}_2\text{O}$, 5-10; halloysite·$4\text{H}_2\text{O}$, 40-50; smectite, 80-150; illite, 10-40; vermiculite, 100-150; chlorite, 10-40; sepiolite-attapulgite-palygorskite, 3-15. The reported values were determined at pH 7.0. As pH varies, the values obtained also vary. In addition, the CEC of a particular clay will also change as factors such as particle size, crystallinity, time of treatment, and replacing cation changes.
Increases in the CEC values for various soils, with increasing pH, have been reported by Davis (1945), Hanna and Reid (1948), and Pratt (1961), among others. Helling et al. (1964) studied the effect that pH of the saturating medium had on CEC values of 60 Wisconsin soils. They derived regression equations for predicting CEC based on the clay and organic matter contents of the soils. Their results showed a relatively constant increase per pH unit in CEC from pH 2.5 to 5.0, and a somewhat smaller increase from pH 5.0 to 6.0. There was a noted rise between pH 7.0 and 8.0. Furthermore, between pH 2.5 and 8.0, the CEC of organic matter increased by a factor of 6, while that of clay increased by a factor of 1.7. The findings confirm the variable charge nature of the CEC of organic matter.

Because of its variability, the CEC of soil organic matter is usually reported as a range. Furthermore, the CEC value obtained will also depend on the nature of the replacing cation. Bremner (1956), in a review of some of the problems associated with work on soil organic matter, summarized aspects of the cation exchange properties. Some of the salient points related to CEC included the following:

1. The exchange capacities of soil organic matter preparations are much higher than those of clays;
2. Methods employed to determine the CEC of organic matter are unsatisfactory, and tend to underestimate
the contribution of the organic fraction;

3. It has been found that the organic fraction was responsible for 58-83% of the exchange capacity;

4. There has been an excessive preoccupation with work on the CEC of the clay fraction and not enough attention has been given to the organic fraction;

5. Estimates of the CEC values of soil organic matter generally range from 200 to 500 meq per 100 grams of organic matter. An average value of 200 meq is generally used;

6. Groups responsible for the exchange capacity may include the carboxyl, acidic hydroxyl and phenolic or enolic hydroxyl groups.

With such a high exchange capacity, the soil organic fraction becomes all the more important to the nutrient status of the soil. Several other important functions of soil organic matter will be discussed briefly in subsequent sections.

**Water-holding capacity**

The amount of water in a given soil will have an influence on its consistency. Organic matter, which has a high absorptive capacity for water (Baver et al., 1972), tends to compound the water effect on the consistency of the soil. Because of high absorptive capacity, organic soils may have field capacities of 100 to 150% water; and some, such as sphagnum moss peat
hold as much as 500 or 600% water, by weight (Thompson and Troeh, 1978).

Baver et al. (1972) presented results to show that the plastic limits of surface horizons are higher than those of other horizons, due to high OM content. As an example: a soil with an organic matter content of 3.5% became plastic at a moisture content of 36.5%. When the organic matter was removed, the soil became plastic at a moisture content of 19.8%.

The high absorptive capacity of organic matter gives a soil the advantage of a high field capacity. This may, however, be offset by several disadvantages. At high water content, it may be difficult to operate machinery. Furthermore, if the soil has a high water content in early spring, it would take a longer time to warm up than would a soil with a lower water content.

Soil structure There are extensive data on the effects of organic matter on soil aggregation. Reviews on the topic are given in Baver et al. (1972), Russell (1973), and Allison (1973). According to the Soil Science Society of America (1979), soil structure is defined as follows:

The combination or arrangement of primary soil particles into secondary particles, units, or peds. These secondary units may be, but usually are not, arranged in the profile in such a manner as to give a distinctive characteristic pattern. The secondary units are characterized and classified on the basis of size, shape, and degree of distinctiveness into classes, types, and grades, respectively.
The tendency for land to deteriorate under intensive cultivation has sparked a renewed interest in measures to deter soil erosion. In the process of erosion, movement of smaller particles tends to occur before movement of larger particles; consequently, aggregation of a soil will improve its ability to resist erosion.

Chesters et al. (1957) summarized the evolution of thoughts on how organic matter promotes soil aggregation. Aggregate formation is a gradual process under natural conditions. Aggregation is influenced by chemical, physical, and biological processes. The earlier studies emphasized the effect of the ligno-protein complex of organic matter. Subsequent studies attributed aggregate formation to waxes, mucilages, and resins in organic matter. Following those theories was the theory that microbial polysaccharides were important in aggregate formation and stabilization.

Geoghegan and Brian (1948) studied the influence of some bacterial polysaccharides on the binding of soil particles. They reported that, for a given polymer, aggregation increased up to a point and then levelled off. Theng (1979), in explaining the nature of aggregation, pointed out that the stabilization of aggregates by polymers involves the formation of bridges between particles or groups of particles. Polysaccharides, because they have a linear, flexible chain structure, are well suited to act as agents of soil aggregation.
Soil genesis

The content and depth distribution pattern of organic matter in a soil can be correlated to the type of vegetation, if other soil-forming factors are held relatively constant. There will be a more detailed discussion in the following section.

Distribution of the organic fraction in selected soils

The purpose of this section is to review some of the available literature concerning organic carbon (or the organic fraction generally) distribution in soil profiles. Humic carbon and fulvic carbon distribution will be discussed in a later section.

In the situation where one of the soil-forming factors, vegetation, varies to a relatively greater extent than the others, climate, relief, parent material, and time, a soil will have unique characteristics associated with the particular type of vegetation. The conclusion from this is that the genetic pathway of the soil will be affected mainly by the particular type of vegetation.

As noted in an earlier section, there are several beneficial aspects of a relatively high organic matter contents in soils. The documentation on the organic matter profile is quite extensive and a partial summary was given by Broadbent (1953) in which the following points were made:

1. Environmental factors determine the nature and quantity of organic matter distribution in soil profiles.
2. Rainfall and type of vegetation are probably two of the most important factors in profile distribution of organic matter.

3. Under forested conditions, there tends to be a high accumulation of organic matter at or near the soil surface, then there is a very sharp decline with depth.

4. Under grassland conditions, most of the organic matter is formed in place in the soil, from root residues. Organic matter content in these soils is generally high in the surface horizons and decreases gradually with depth.

Furthermore, soils developed under similar type of vegetation will vary in the absolute amounts of their organic carbon contents. Nonetheless, distribution trends will tend to be similar. Two of the soils used in this study are the Tama and the Fayette soils. The Tama and Fayette soils are examples of a prairie-derived and a forest-derived soil, respectively. Smith et al. (1950), in their study of the Tama soil, which they considered the "modal" or "ideal" prairie soil, reported organic carbon with depth, under grass vegetation.

For several Tama profiles of northeastern Iowa, Fenton (1966) reported values lower than those obtained by Smith et al. (1950). However, the distribution trends were quite similar.
For the Fayette soil (modal forest-derived soil), carbon values declined sharply with depth.

Nakane and Shinozaki (1978) and Nakane (1978) used mathematical models to describe the behavior and vertical distribution of organic carbon under different forest types (different tree species). Ogawa et al., 1961, as cited in Nakane (1978), proposed the empirical formula

\[ C(z) = C_0 \exp(-\epsilon z) \]

for describing organic matter distribution near the soil surface. In the equation, C stands for concentration of carbon in the soil at depth z, C0 represents carbon concentration at the surface of a mineral soil, where z=0. The relative rate of decrease of C with depth is given by \( \epsilon \). For deeper profiles, however, more complicated mathematical models are needed. The proposed model (Nakane and Shinozaki, 1978) is \( C = C(z,t) \) where t = time. The concentration of organic carbon (C) at depth (z) at time (t) is affected to a great extent by decomposition of organic matter and its transport in the z direction. Subsequently, Nakane (1978) proposed a model which takes into account the contribution of dead roots (root litter); the model also includes the variables time, depth, and dead leaves (litter fall). Rigorous mathematical treatment of the distribution patterns of soil variables, and the pedogenic implications, is undoubtedly a positive contribution to studies about soil genesis; Jenny (1961, 1962) are examples
of early studies in this area.

**Extraction and fractionation of soil humus**

A comprehensive historical review of the work on soil humus is given in Kononova (1966). Reviews are also given in Joffe (1949), Marshall (1964), and Stevenson (1982). Currently, there is no standardized method for extraction of soil humus; however, there tends to be general acceptance of the use of caustic alkali, then of an acid (usually HCl or H$_2$SO$_4$) to separate the fulvic fraction from the humic fraction.

In the study of soil organic matter, extraction and fractionation are important first steps. Achard, 1786, as cited by Bremner (1954) was the first researcher to use caustic alkali to extract soil organic matter. Caustic alkali has been used almost exclusively since Achard first used it. Bremner (1954) in his review of research on soil organic matter cited the findings of several researchers as follows:

1. Chaminade, 1946a and b, reported three times as much humic matter extracted from soil with alkali, in the presence of oxygen, in contrast to a hydrogen atmosphere.

2. Bremner and Lees, 1949, noted that the amount of organic matter extracted by alkali, in the presence of oxygen, depended on alkali concentration and extraction time; however, Bremner, 1950, could not confirm that significantly higher amounts of humic matter were extracted in the presence of oxygen.

3. The efficiency of calcium masking agents (such as oxalate and citrate) in the extraction of humic matter indicates that calcium is one of the main interfering agents.
4. The efficiency of agents such as oxalate and citrate prompted the development of decalcification as a preliminary procedure in the extraction of soil organic matter.

5. The alkali insoluble portion of soil humus (humin) may be brought into solution by repeated alternate treatments of the soil with sulfuric acid and sodium hydroxide (0.1 N). At least 15 treatments were found to be required according to Khan, 1945.

The search for an effective extractant goes back to the late 1920s (Kononova, 1966). Bremner and Lees (1949) investigated the use of mild extractants. They were concerned that the caustic alkali would seriously affect the physico-chemical properties of the soil organic matter. Kononova (1966) did not concur with Bremner and Lees on this point. Of the neutral reagents tested by Bremner and Lees (1949), sodium pyrophosphate was found to be the most satisfactory. However, caustic alkali quantitatively extracted more organic matter. This is due to the fact that some organic constituents of soil are insoluble in neutral reagents. It was recommended that the type of extractant be related to the particular investigation.

Schnitzer et al. (1958) also investigated the use of various extractants. They reported results which concur with those of Bremner and Lees (1949). Furthermore, Schnitzer et al. (1958) found that more organic carbon is extracted from soil with sodium pyrophosphate at pH 9.8 than pH 7.0.

Kononova (1966) reported results showing that more carbon was extracted from soils with a mixture of 0.01 M sodium
pyrophosphate and 0.1 N sodium hydroxide, pH 13.0, than with either 0.1 N sodium hydroxide or 0.1 M (pH 7.0 and pH 8.3) sodium pyrophosphate.

The use of a combination of sodium pyrophosphate and sodium hydroxide for the extraction of soil organic matter has gained wide acceptance for routine work. One of its main advantages is that it provides efficient extraction for a wide range of soils without the use of acid pretreatment which is required when a sodium hydroxide extractant is used (Lowe, 1980).

Gascho and Stevenson (1958) reported an improved extraction method. The procedure involves initially treating the soil with hydrogen fluoride to destroy hydrated silica. Next organic matter is removed by treatment with 0.02 M sodium pyrophosphate, then with 0.03 N sodium hydroxide. Subsequently, inorganic contaminants are removed from the extract by dialysis using 0.3 N hydrogen fluoride.

The next step after extraction is usually fractionation. Fractionation is based upon solubility characteristics. Stevenson (1982) presents a procedure that, at present, has found wide acceptance. A single sample is extracted in sequence as follows: alkali is added to the soil, the insoluble portion of organic matter is the humin fraction. The soluble portion is acidified and the humic acid precipitates. Fulvic acid remains in solution. The humic acid may be further frac-
tionated. Hymatomelanic acid may be extracted from humic acid with alcohol; or the humic acid may be redissolved in base from which gray humic acid can be precipitated with an electrolyte. The brown humic acid remains in solution.

Anderson et al. (1974a) carried out a second extraction on the humin (clay associated humus). The resulting fractions were termed humic acid-B and fulvic acid-B. They obtained an additional 10-15% of the soil organic matter in the second extracts.

**Humic and fulvic carbon in selected soils**

Humic to fulvic carbon ratio and its distribution in selected soils will be examined. Researchers in Russia (more so than in any other country), Canada, India, parts of eastern Asia, and in Europe generally have done the most research on humic to fulvic carbon ratios in soils. Russian workers since the 1930s have been involved in humus characterization as it relates to soil types (Kononova, 1966).

Kononova (1966) summarized the Russian finding on humic carbon to fulvic carbon ratios of various soils. For strongly podzolic soils, humic/fulvic ratios of 0.56, 0.51, and 0.69 are reported for the A2 (8-12 cm), B1 (15-20 cm) and B2 (25-30 cm) horizons, respectively. For a sod-podzolic soil, values of less than unity are reported for all A horizons listed. For a gray forest soil, humic/fulvic carbon ratios of greater than unity are reported. The reason given for the
high values is that the areas were at one time colonized by meadow-steppe vegetation which still influences the humus of the soil. The lower values in the upper horizons are credited to the more recent forest influence; the higher values in the lower horizons indicate that chernozemic influences have not yet been overcome by forest influence.

For virgin and cultivated chernozems, all reported humic/fulvic carbon ratios are greater than unity (Kononova, 1966). The high values of humic acid carbon in the surface is due to stability brought about by calcium-humus complexes; the higher yield of organic substances from decalcified soils substantiates the observation.

Lowe (1969) reported data for some Canadian soils showing narrower humic/fulvic carbon ratios for forested soils than for grass-derived soils. In a more recent paper, Lowe (1980) reported a decrease of humic/fulvic carbon with depth. This conforms with the results reported by other researchers (Kononova, 1966). However, Adityachaudhury and Saha (1973) have reported increasing humic/fulvic ratio with depth for two waterlogged rice soils of alluvial origin. No explanation was given for this trend. The soils exhibit increases in pH and decreases of humic and fulvic carbon with depth.

Schnitzer et al. (1981) proposed a procedure for the characterization of humus. In a cooperative study, two samples were analyzed at four laboratories. Humic/fulvic
carbon ratios for the Ap horizon (0-10 cm) of an Orthic Dark Brown soil, as reported by the four laboratories, were 3.4, 0.7, 1.3, and 2.1; for the Bhf (25-50 cm) horizon of an Orthic Ferro-Humic Podzol, values of 0.4, 0.4, 0.3, and 0.3 were reported. The discrepancies in values for the Ap horizon are attributed to incomplete separation of humic acid from fulvic acid due to different centrifuge speeds. At low speeds, the humic acid was not completely separated from the fulvic acid.

Phosphorus in Soil Studies

In this section, an attempt will be made to document some of the salient findings that have been reported over the years on soil phosphorus. Numerous references on phosphorus were obtained through the SEARCH computer program at the Iowa State University (ISU) Library. In addition, there are many theses and dissertations with soil phosphorus data in the ISU Library.

Total phosphorus

Researchers have found that the depth distribution trends of soil phosphorus provide useful information for assessing the degree of development of soil profiles.

Pearson et al. (1940) reviewed work on the vertical distribution of phosphorus in soils. They reported wide variations in the vertical distribution. From a study of 12 soil profiles from Iowa, they reported an increase in dilute acid-
soluble phosphorus with depth. Furthermore, minimum total phosphorus values tended to occur between the lower A and upper B horizons. It was also shown that minimum total phosphorus values were higher in the profile of forest-derived soils than in grass-derived soils. In eight of the soils, phosphorus content of the C horizon was more than double that in the lower A or upper B horizons. Allaway and Rhoades (1951) conducted a study of some loess-derived soils of southern Nebraska. They found substantial similarity among the various soils. Total phosphorus content reached a maximum in or just above the top of the calcareous horizons in four profiles. In one profile, the maximum value was in the surface horizon and this was attributed to organic phosphorus. Maximum total phosphorus in the A2 horizon of one profile was attributed to phosphorus in concretions. Minimum total phosphorus values were most commonly in the upper B horizons. The authors concluded that there is some movement of phosphorus within the soil profile during development; and that the accumulation of phosphorus in the A horizon of older soils was due to redistribution by plants.

Godfrey and Riecken (1954), in a loess traverse study in Iowa, concluded that, if parent materials were all assumed to be similar, then the decrease in total phosphorus in the soils, with distance from the loess source, could be attributed to increased weathering. In addition, there tended to be a de-
crease of total phosphorus in the A horizon relative to the C horizon which could be related to the degree of profile development. There was also a decrease of total phosphorus in the B horizon as the degree of weathering increased.

Research by Fenton et al. (1967) on a wide range of soils confirmed the findings of Pearson et al. (1940). In addition, it was noted that depth to minimum total phosphorus in a prairie-forest transition soil was intermediate between that for the forest-derived and grass-derived soils.

Williams and Saunders (1956) reported highest values for total phosphorus in the topsoil of some soils from northeastern Scotland. High values of total phosphorus were related to organic phosphorus—the soils were planted to crops and subjected to manuring. It was also inferred that redistribution by roots played an important role. Larsen (1967) has indicated that the commonest way to increase the phosphorus status of a soil is by the addition of phosphorus in fertilizer or manure. Furthermore, Williams and Saunders (1956) found that most phosphorus was associated with the clay fraction. Lowest values were associated with the coarse sand fraction. Highest levels of organic phosphorus were also associated with the clay fraction. Runge and Riecken (1966), in their study of 12 loess-derived prairie soil profiles, presented data showing the relationship of minimum total phosphorus values to maximum clay.
Association of high levels of phosphorus with soil clay has been reported by Bates and Baker (1960). The high levels were for the surface horizons which also had high levels of organic phosphorus. An important but not necessarily unexpected observation made by Bates and Baker was that much phosphorus (up to 80%) may be tied up in iron concretions. Iron concretions (pipestems) are common, at depth, in many Iowa soils.

Redistribution of phosphorus by vegetation has been reported by Ghani and Aleem (1943). Runge and Riecken (1966) evaluated the pedogenetic effects of natural drainage on profile distribution of phosphorus. They gave very brief summaries of work done by Glentworth, 1947, Glentworth and Dion, 1949, and William and Saunders, 1956, in which it was shown that the poorly drained soils studied contained less total phosphorus than the better drained analogues. Runge and Riecken (1966) concluded that a similar generalization cannot be made for Iowa soils since factors other than drainage may play a role in phosphorus content of the soils. In their Iowa study, Runge and Riecken (1966) found that, for the poorly drained soils, the depth to minimum total phosphorus was closer to the surface than for the imperfectly and moderately well-drained soils.

A summary of findings on total phosphorus in soils includes the following:
1. Total phosphorus minimum corresponds to clay maximum, except where the clay maximum is close to the soil surface, in which case, phosphorus maximum corresponds to clay maximum. In this situation, maximum clay also corresponds to maximum organic phosphorus.

2. Till soils generally have lower total phosphorus values than loess-derived soils.

3. In a biosequence of soils, depth to minimum total phosphorus is closer to the surface as one goes from grass to forest-grass transition to forest.

4. Poorly drained soils have minimum total phosphorus values closer to the surface than well-drained soils.

5. For a given concentration of phosphorus, plants will take up more phosphorus from a clayey than from a sandy soil (Olsen and Watanabe, 1963).

6. Iron oxides have the capacity to adsorb phosphorus. This has been demonstrated by coating clays with iron oxide and measuring the amount of phosphate sorbed (Gunary et al., 1965). The high content of phosphorus in naturally occurring iron oxides also demonstrates this.

7. The phosphorus profile may be interpreted in terms of eluvial-illuvial processes (Runge and Riecken, 1966) and redistribution upward by vegetation (Kao and Blanchar, 1973).
8. Soil phosphorus content is lower as the degree of weathering increases.

9. Phosphorus, because of its great ecological significance, may be the key element in pedogenesis (Walker, 1965). Furthermore, since most soil phosphorus originates in parent material and is recycled over a period of time, the amount of phosphorus in the soil may be used as an index of soil development. As examples, Walker (1965) reported N/P ratios of from 3 to over 20. Low ratios were associated with productive grassland soils, while high ratios were associated with strongly weathered and leached forest soils. The role of phosphorus in pedogenesis has also been examined by Smeck (1973) and Walker and Syers (1976).

**Inorganic phosphorus: fractionation and distribution**


Currently, the procedure most widely used for fractionating soil inorganic phosphorus is that proposed by Chang and Jackson (1957). The procedure has a significant advantage
over previous methods in that it facilitates isolation of discrete fractions of soil inorganic phosphorus. Nonetheless, the procedure has been criticized and modified. The Petersen and Corey (1966) modification has been found satisfactory for routine phosphorus fractionation work. In the modified procedure, calcium phosphate is extracted last whereas in the Chang and Jackson (1957) procedure it is extracted before the occluded phosphorus fractions. Also, the procedure for reductant-soluble phosphorus is simplified, and the time-consuming use of volumetric glassware is eliminated.

In a series of papers, Fife (1959a,b, 1962, 1963) reported on the ability of ammonium fluoride to extract aluminum phosphate from soil and nonsoil systems. He found that 0.5 M NH₄F, pH 7.0, extracts contained iron (fluoferrate ion) in solution below pH 8.0 (Fife, 1959a). In addition, systems containing iron bound phosphate when extracted with 0.5 M NH₄F contained phosphorus in solution up to pH 8.0. At about pH 8.5, the iron phosphate was precipitated. The conclusion to be drawn from the work is obvious: in order to avoid extracting iron phosphate in the 0.5 M NH₄F extract, a minimum pH (8.2) should be used. Petersen and Corey (1966) recommended pH 8.2.

Fife (1963) also noted that, if a soil is extracted with ammonium chloride, a subsequent ammonium fluoride extract will yield more phosphorus than if ammonium chloride was not used.
Bromfield (1967) demonstrated that ammonium chloride dissolves calcium phosphate which is rapidly sorbed to soil sesquioxides. He suggested that dissolved calcium phosphate accounts for the "extra" phosphate that Fife (1963) observed.

The Chang and Jackson (1957) procedure (or a modification) has been employed for study of a wide variety of soils. Some of the studies in which the Chang and Jackson (1957) method or its modified version (Petersen and Corey, 1966) have been used will be discussed.

The importance of the fractionation of soil inorganic phosphorus is related to the fact that the various fractions can be related to the weathering sequence of soils. Chang and Jackson (1958) found that the distribution of soil inorganic phosphorus is a measure of the degree of chemical weathering. They proposed that the weathering sequence was, from least to most intensively weathered, calcium phosphate, aluminum phosphate, iron phosphate, and occluded phosphate. Occluded phosphate includes reductant soluble iron phosphate and aluminum-iron phosphate occluded in iron oxide. The conclusions were based on empirical research. This led to a model in which intensity of weathering in soils would increase in the order Chernozems (Mollisols), Gray-Brown Podzolic (Alfisols), Latosols (Ultisols).

Williams and Walker (1969) gave an outline of what they believed to be the stages in the transformation of phosphorus
in soils. Apatite is the predominant form initially present. In the early stages of weathering, phosphorus released in solution is incorporated into organic matter and nonoccluded fractions. Dissolution of apatite is not reversed in acid soils, unless they are limed. Concurrently, nonoccluded phosphate is steadily transformed into occluded phosphorus by incorporation into developing secondary iron and aluminum compounds, primarily concretions and coatings of hydrated oxides. Phosphorus in solution is dependent on the rate of dissolution of apatite and the ability of the organic fraction to retain it. Generally, occluded secondary inorganic phosphorus increases with soil development throughout the whole profile at the expense of other forms of phosphorus.

Myo Thant (1968) found inorganic phosphorus fractions to be useful criteria for separating three soils. Profile 1, a Compact Gray soil was alkaline, calcareous, and had a relatively large amount of calcium phosphate and much lower amounts of iron and aluminum phosphates. The Ancient Alluvial (with a laterite horizon) was dominated by occluded phosphates. The Ancient Alluvial (without laterite) had trends which were intermediate between the other two soils.

Loganathan et al. (1982) studied soils representing the order Alfisols, Ultisols, Entisols, and Oxisols. They found that, of total inorganic phosphorus, occluded phosphorus was 91, 87, 75, and 73% in Ultisols, Alfisols, Entisols, and Oxisols,
respectively. This was indicative of more intense weathering in the Ultisols and Alfisols. For Ultisols and Alfisols, the fractions decreased as follows: inactive P > Fe-P > Al-P > Ca-P, whereas for Entisols and Oxisols, the sequence was inactive P > Al-P > Fe-P > Ca-P. They concluded that the Oxisols and Entisols would be better able (than the Ultisols and Alfisols) to supply available phosphorus to plants. The soils studied had sand contents ranging from 58.3 to 98.2%.

Udo and Ogunwale (1977), in a study of highly weathered selected Nigerian soils, reported calcium phosphate values ranging from zero to 30% of the total phosphorus. Inorganic, occluded phosphate forms were relatively higher than the corresponding active forms. In five of the six profiles studied, residual (nonextractable) phosphorus contributed between 30 and 90% of the total inorganic phosphorus. The high values of nonextractable phosphorus forms are characteristic of highly weathered soils (Myo Thant, 1968; Adams and Walker, 1975; Udo, 1976).

Ahmad and Jones (1967) reported that free Fe$_2$O$_3$ rather than soil pH determines the distribution of the inorganic phosphate forms in limestone soils of Barbados.

Hawkins and Kunze (1965), in a study of Grumosols (great groups of Vertisols and vertic subgroups of Haplaquepts and Haplaquolls) from Texas, found significant correlations between aluminum phosphate and available phosphorus; they
thought that the correlations may have been "fortuitous" since, in at least 50% of the profiles, available phosphorus correlated with organic matter and organic phosphorus. They proposed that the initial aluminum phosphorus extraction (being the first in the sequence) may have included some mineralized organic phosphates. Nonetheless, they indicated that the inorganic phosphorus fractions did serve as sensitive indicators of the weathering environment.

Evaluation of inorganic phosphorus fractions as criteria for selected South Dakota soils led Westin and Buntley (1966, 1967) to conclude that the fractions were sensitive indicators of climatic effects. The authors were not able to separate the soils on the basis of parent material by using the phosphorus fractions. The findings included higher total inorganic phosphorus in Chestnut soils, due to milder weathering; increase of calcium phosphate with depth and a reverse trend for iron and aluminum phosphates in both soil groups; higher percentage of calcium phosphate and lower percentage of iron phosphate in Chestnuts, the reverse trend was observed in Chernozems.

In a study of some Iowa soils, Mausbach (1969) reported \((\text{Al-P} + \text{Fe-P})/\text{Ca-P}\) ratios of 0.82, 2.63, 3.08, and 3.29, for Tama, pal 1; Tama, WZ 1; Downs, P428; and Fayette, P32. The Tama soils are grass-derived; Fayette and Downs are forest and forest-grass transition, respectively. The ratios were cal-
culated for the 0-50 inch zone of each profile. In addition, calcium phosphate increased with depth in the four profiles. Active (iron and aluminum) phosphate and inactive (reductant soluble) phosphate were the dominant fractions in the Fayette profile. The Tama and Downs profiles had relatively lower values of iron, aluminum, and reductant-soluble phosphate. All four soils were formed in loess and subject to similar weathering regimen.

Tembhare (1973), in a study of selected Alfisols, Aridisols, and Mollisols, concluded that there were no clear-cut differences with respect to the inorganic phosphorus fractions between the soil orders. There were, however, somewhat higher values of iron phosphate and lower values of calcium phosphate in Alfisols. The reverse trend was observed in Mollisols. Furthermore, reductant-soluble phosphorus tended to be higher in Mollisols than in Alfisols. It was also concluded that inorganic phosphorus fractions tend to vary with climate, natural vegetation, pH, clay and organic carbon. Lastly, the fractions proved useful in clearly separating the soils at the suborder level.

Soil Taxonomy

As stated in the Introduction, a soil classification problem arises when the mollic epipedons of Mollisols erode. Once the epipedon erodes, the soil may be transferred to one
of at least two other classes: Alfisol or Inceptisol. Because of this problem, it is meaningful that the three soil orders be discussed at least cursorily. The discussion, unless otherwise indicated, is based on discussions in Soil Survey Staff (1975).

**Mollisols: central concept**

These are base rich soils in which it is thought there has been decomposition and accumulation of relatively large amounts of organic matter in the presence of calcium (Smith, 1965). Nearly all Mollisols have a mollic epipedon. The general definition is that of a soil with a mollic epipedon over an argillic, natric, cambic, or calcic horizon.

Although Mollisols tend to form under grasses, its formation is mostly dependent on a base-rich environment. Furthermore, the high base saturation requirement tends to restrict Mollisols to subhumid and semiarid regions where leaching of bases is slow or impossible (Smith, 1965). Generally, enough moisture to support perennial grasses seem to be essential.

There are seven suborders of Mollisols: Albolls, Aquolls, Borolls, Rendolls, Udolls, Ustolls, and Xerolls.

**Alfisols: central concept**

The central concept is that of a soil with an ochric epipedon over an argillic horizon. Base saturation is moderate to high, and water in the soil is held at <15 bar tension
for at least three months each year when the soil is warm enough to grow crops. The soil may also have a duripan, fragipan, petrocalcic horizon, natric horizon, or plinthite; these or other features are used in defining the great groups within the order. A few Alfisols have umbric epipedons.

Inceptisols: central concept

These are soils of humid regions. They have altered horizons that have lost bases or iron and aluminum but retain some weatherable minerals. The soils do not occur in arid areas, and are usually not sandy throughout, unless they have a plaggen or umbric epipedon.

The most common horizon sequences are an ochric epipedon over a cambic horizon, with or without an underlying fragipan, or an umbric epipedon overlying a cambic horizon, with or without an underlying duripan or fragipan. All soils that have a plaggen epipedon are considered Inceptisols.

Buol et al. (1973) consider Inceptisols to be immature soils whose profile features closely resemble those of the parent material. There is no unique setting for Inceptisols; however, there are at least four important features of Inceptisols. They are (1) highly resistant parent material, (2) abundance of volcanic ash, (3) extreme landscape position, that is, steep lands and depressions, or (4) geomorphic surfaces so young as to limit soil development.
Soil Erosion: Soil Loss and Some Implications for Soil Classification

According to the Soil Science Society of America (1979), erosion is defined as:

(i) The wearing away of the land surface by running water, wind, ice or other geologic agents, including such processes as gravitational creep. (ii) Detachment and movement of soil or rock by water, wind, ice or gravity.

Of the several types of erosion defined, accelerated erosion is most meaningful to this study. Accelerated erosion is "Erosion much more rapid than normal, natural, geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of animals."

Frequent tillage of land, coupled with poor land management practices are two of the major factors which encourage accelerated erosion. With the expansion of markets for agricultural products, there came a need to open up new land for agriculture and to intensify farming on land already in production. Expansion of intensive farming has been accompanied by increased soil loss; this is especially true for marginal lands.

Risser (1981) recorded a statement which outlined the gravity of the soil erosion situation:

In 1979,...Assistant Secretary of Agriculture came before the house with the message that after 40 years of conservation efforts, soil erosion now is worse than in the dust bowl days. Water erosion, in particular, is taking its toll and, few dust storms swept the plain
states, some experts (sic) see signs of their return. In 1979, 1.4 million acres of land were damaged by wind erosion in ten states that make up the Great Plains, more than double that of the previous year. Because marginal, hilly, poor-quality land has been planted, and because many farmers no longer alternate grain crops with soil-conserving grasses, rain and melting snow are able to strip millions of tons of soil from the land annually.

Hargrove (1972) reported an increase of 1 billion tons, raising to 4 billion tons, the loss of soil by water erosion, from soil in the United States, per year. Surprisingly, land being farmed has declined by 50-million acres; and while soil loss averaged 8 tons per acre nationwide in 1934, today it is 12 tons per acre.

The erosion situation confounds soil classification. This situation is of major concern in a state like Iowa where Mollisols and mollic intergrades of Alfisols are extensive. Miller et al. (1982) indicate that of a total of 26 million acres planted to row crop, small grain and forages for hay production, soil displacement averages 9.9 tons per acre per year.

In Iowa, the most severe implications of soil erosion for soil classification is in Mollisols and the mollic intergrades of Alfisols. According to Soil Survey Staff (1975), a desired attribute of the soil classification system is the ability to "keep an undisturbed soil and its cultivated or otherwise man-modified equivalents in the same taxon insofar as possible." Furthermore, "truncation by erosion should not produce changes in the placement of a soil in the taxonomy.
Smith and Leamy (1978), in an interview, stated that:

...we try throughout taxonomy to use the characteristics of the subsurface horizons rather than the surface horizons because we wanted to keep the eroded and uneroded soils in the same series as has been our practice in mapping. The use of the mollic epipedon as a diagnostic horizon violated the general principles that we started with, but we could find no escape from it. This was the only common characteristic we could find to tie together the dark-colored soils of the Great Plains in the United States and Europe. Under cultivation in Iowa and Illinois the erosion has in places been quite severe and the mollic epipedon has been largely removed by erosion. This transfers the soils, if there is only a cambic horizon, from Mollisols to Inceptisols or, if there is an argillic horizon, from Mollisols to Alfisols. This has been severely criticized and with some justification, in that the eroded soils now become different series from the uneroded soils. At present we have found no escape from this dilemma but certainly one must say that when the mollic epipedon is gone there is a marked change in the behavior of the soil.

The extent of soil erosion in Iowa may be recognized from the numerous erosion symbols on soil maps. Lewis and Witte (1980), in a study of selected pedons in Nebraska, within the central concept of the Wymore soil series, fine, montmorillonitic, mesic Aquic Argiudoll, found that large areas were severely eroded. These soils did not meet the central concept of the series and it was subsequently proposed that they should be reclassified as Aquic Dystric Eutrochrept.

It is probably undesirable to reclassify a soil after each erosion episode. However, since the soil name implies a particular meaning, proper classification is important.
Proper classification will enable users of the soil to be aware of the current status of the soil. The problem merits serious consideration. It is hoped that the variables investigated in this study will provide some additional data and ideas in understanding the classification problem.
LOCATION AND DESCRIPTION OF THE STUDY AREA

The study area is a watershed (Four Mile Creek) located in northwestern Tama County, east-central Iowa (Figure 1). The approximate latitude and longitude are $42^\circ12'$ and $92^\circ35'$, respectively. Locations from which profiles were sampled are indicated in Figure 2.

The basin drained by the Four Mile Creek (FMC) is 50.51 square kilometers (5050.57 hectares) in extent. Most of the area is intensively farmed. The principal row crops are corn and soybeans. There is rearing of some livestock in the area and, as a result, there are some areas of permanent pasture.

Kunkle (1968) described the climate of the region. Summers are hot and humid, and winters are cold and damp. Average annual temperature (1935-1964) in the study area is $8.67^\circ$C. The average length of the growing season is 154 days, from around May 15 to about October 15.

The mean annual precipitation at Traer (east end of the FMC basin) from 1947 to 1964 was 82.3 cm; however, the monthly precipitation in any given year is quite variable.

Stratigraphic and topographic descriptions of the area are given in Kunkle (1968), Ruhe et al. (1968), and Ruhe and Vreeken (1970). The area consists of a series of stepped levels which rise along interfluves from main valleys to divides. Maximum relief is 41.2 meters. Wisconsin loess covers 54% of the area; the loess ranges in thickness from
Figure 1. General location of study area in Tama County, Iowa
Figure 2. Site locations of profiles used in the study

A - FMC1WH  Grant township
B - FMC2WH  "
C - FMC3WH  "
D - FMC4WH  "
E - FMC5WH  "
F - FMC6WH  Lincoln Township
G - FMC7WH  "
H - FMC8WH  "
I - FMC9WH  "

Sections 19, 20, and 28 are in Grant Township
Section 21 is in Lincoln Township
Figure 2. (Continued)
1.2 to 10.7 meters and blankets paleosols and till. Alluvium is confined to the valleys and upland drainageways, and main valley alluvium occupies 22% of the area. The sequence of deposits in the upland area is generally Wisconsin loess, Yarmouth-Sangamon paleosol, Kansan till, Aftonian silts, Aftonian paleosol, and Nebraskan till.
MATERIALS AND METHODS

Soils: Selection and Sampling

Eleven soil profiles were used in this study. The Fayette (P32, 163B) and Tama (P27, 120B) profiles were obtained from samples at the Iowa State University Agronomy Laboratory. Professor T. E. Fenton and a fellow graduate student (Douglas Wysocki) assisted the author in locating and sampling several of the other soils. Soils were selected (based on mapping units) mainly to reflect the variation of vegetation as a soil forming factor. In addition, several eroded phases of the Downs and Tama soils were selected in order to investigate the effects of soil erosion on the variations of the selected physical and chemical properties. Three associated soils, Muscatine, Sperry, and Sawmill, were also included in the study.

An inventory of the Four Mile Creek watershed was completed in 1981 as a part of the Cooperative Soil Survey Program. A soil map of the area is included in Appendix 1. Figures 1 and 2 show the location of the study area. Tables 1 and 2 give some information about the soils. Profile descriptions are in Appendix 2.

Soil cores were extracted with a Giddings hydraulic soil coring machine, back-mounted on a truck. Cores for bulk samples were extracted with a 6.5 cm diameter tube, while
Table 1. Profile numbers and landscape positions of the soils in the study

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<th>Map unit</th>
<th>Profile number</th>
<th>Landscape position</th>
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<td>P27</td>
<td>Summit</td>
</tr>
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<td>FMC7WH</td>
<td>Sideslope</td>
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<td>120D2</td>
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</tbody>
</table>

cores for profile description were taken with a 5 cm diameter tube. All samples were brought to the laboratory and stored in a freezer until they were needed for analyses. The cores for profile description were stored in core boxes in 61 cm sections. Other samples were stored in plastic lined sample boxes.
Table 2. Taxonomic and drainage classes of the soils in the study

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Classificationa</th>
<th>Natural drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tama sicl</td>
<td>Fine-silty, mixed, mesic Typic Argiudolls</td>
<td>Well-moderately well</td>
</tr>
<tr>
<td>Sawmill sicl</td>
<td>Fine-silty, mixed, mesic Cumulic Haplaquolls</td>
<td>Poorly</td>
</tr>
<tr>
<td>Muscatine sicl</td>
<td>Fine-silty, mixed, mesic Aquic Hapludolls</td>
<td>Somewhat poorly</td>
</tr>
<tr>
<td>Sperry sicl</td>
<td>Fine, montmorillonitic, mesic Typic Argialbolls</td>
<td>Very poorly</td>
</tr>
<tr>
<td>Downs sicl</td>
<td>Fine-silty, mixed, mesic Mollic Hapludalfs</td>
<td>Well-moderately well</td>
</tr>
<tr>
<td>Fayette sicl</td>
<td>Fine-silty, mixed, mesic Typic Hapludalfs</td>
<td>Well</td>
</tr>
</tbody>
</table>

*aBased on modal profiles.*
Laboratory Analyses

Samples for physical and chemical analyses were air-dried, crushed to pass a two-millimeter sieve and stored in plastic lined bags.

Particle-size analysis

The pipette method of Kilmer and Alexander (1949), with slight modification by the ISU soil laboratory (Walter et al., 1978) was used for particle-size analysis. The procedure is as follows: exactly 10 g of oven-dried (105-110°C for several hours) soil is placed in a pyrex infant nursing bottle to which 100 ml of 1% acetic acid is added, followed by 10 ml of hydrogen peroxide. Each bottle is covered with a 5-cm watch-glass and allowed to set overnight or for at least 2 hours. Following digestion, the samples are boiled on a hot sand bath until about 50 ml of the liquid was evaporated. Digestion and boiling are repeated if one treatment is not sufficient to remove the organic matter. After the samples cool, 10 ml of sodium hexametaphosphate and sufficient distilled water to bring the total volume to approximately 150 ml are added. The bottles are next stoppered (#7 rubber stoppers) and shaken overnight. Sand is obtained by wet sieving through a 270-mesh sieve. Fine-silt and clay are obtained by pipetting, while coarse-silt is obtained by difference. Each run contains 19 samples and a standard as a check.
Soil reaction

A 1:1 soil-water mixture was stirred and allowed to stand for 30 minutes. Subsequently, an electrode was placed in the liquid and the pH reading, after 90 seconds, was recorded. A Fisher Acumet model 610 pH meter, with an Orion combination 91-05 electrode, was used. A standard with known pH was included in each set of determinations.

Total phosphorus

Total phosphorus was determined by the alkaline oxidation method of Dick and Tabatabai (1977). A minor modification of the procedure was employed. Instead of digesting the samples in 50 ml boiling flasks, pyrex centrifuge tubes were used. In addition, centrifuge conditions were 3000 rpm for 15 minutes. The molybdenum blue color was read on a Bausch and Lomb Spectronic 20 spectrophotometer set at 720 nm and using a red filter. For every set of samples run, a blank (for setting 100% transmittance) and at least one standard were included.

Inorganic phosphorus fractions

The method of Chang and Jackson (1957) as modified by Petersen and Corey (1966) was used in inorganic phosphorus fractionation. There was a further modification to the procedure. All fractions were extracted as outlined by Petersen and Corey (1966); the blue color for the reductant-soluble
fraction was determined according to the method of Peterson and Corey. Phosphorus in the other extracts was determined by the method of Dick and Tabatabai (1977). This was necessary because of problems associated with color development in the extracts when the Petersen and Corey (1966) method was used. Professor Corey (University of Wisconsin, Madison, Wisconsin) in a personal conversation concurred on the problem, especially with regard to the NaOH extracts. Modification of the pH of the NaOH extract (to near neutral) did not solve the problem. In addition, in order to eliminate fluoride interference in the NH₄F extracts, boric acid was added prior to color development (Jackson, 1958).

Extractions were made in sequence using a 50:1 extractant to soil ratio on a single sample of soil initially ground to pass a 60-mesh sieve. The extractants and the order of extractions are as follows:

1. Easily extracted P: 1 N NH₄Cl
2. Al-P: 0.5 N NH₄F, pH 8.2
3. Fe-P: 0.1 N NaOH
4. RS-P: 0.3 M Na₃C₆H₅O₇·2H₂O plus Na₂S₂O₄
5. Occl. Al-P: as in 2
7. Ca-P: 0.5 N H₂SO₄

The blue color developed was measured on a Bausch and Lomb Spectronic 20 spectrophotometer at the appropriate wavelength.
with a red filter in place.

**Organic carbon: whole soil**

Organic carbon was determined by the method of Mebius (1960) on <100-mesh soil. In this procedure, a sample containing less than 8 mg of organic carbon is digested with 10 ml of 0.5 N potassium dichromate and 15 ml of concentrated sulfuric acid. The sample is boiled in a 125 ml Erlenmayer flask, with standard-taper 84/40 ground glass joint, to which a Liebig condensor is fitted. Boiling is carried out on a digestion rack. Five samples, a boiled and unboiled blank are run in each set. A standard sample is run frequently to assess the accuracy of the procedure.

Following boiling, the samples are cooled and titrated with Mohr's salt; N-phenylanthranillic acid is used as the indicator. Percentage organic carbon is calculated as follows:

\[
\% OC = \frac{(A)(\text{normality of Mohr's salt})(0.003)(100)}{\text{g soil}}
\]

where

\[A = \left[\left(\frac{U - B}{U}\right)(B - T)\right] + (B - T)\]

and

- \(U\) = volume of Mohr's salt required to titrate the unboiled blank
- \(B\) = volume of Mohr's salt required to titrate the boiled blank
- \(T\) = volume of Mohr's salt required to titrate the sample (or standard).
Organic carbon: soil extracts

Organic carbon in each extract was determined by the method of Mebius (1960) with modifications in the normality (lowered) of the Mohr's salt and potassium dichromate. This compensates for the lower amounts of carbon in the extracts. Extraction was carried out with 0.1 M NaOH - 0.1 M Na₄P₂O₇·7H₂O, pH approximately 13 (Kononova, 1966). This extractant is advantageous in that it provides efficient extraction for a wide range of soils. The pretreatment of the soil with acid is avoided, which is not the case when NaOH is used (Lowe, 1980). The procedure (Kononova, 1966) with some modification has been recommended as a standard procedure by Schnitzer et al. (1981).

It is important for reasons of comparison to outline the steps used in the procedure for the determination of organic carbon in the soil extracts.

1. Add 250 ml extract to 10-g soil in 250-ml plastic bottle. Shake for 12 hours. Centrifuge at 2500 rpm for 20 minutes; decant and re-extract residue with additional 250 ml of extractant for 1 hour, with shaking. Centrifuge and decant into first extract.

2. Determine the organic carbon in an aliquot of the extract using the Mebius (1960) method.

3. Take a 100-200 ml aliquot of the extract and acidify to a pH of approximately 1.5. After a short time, about 30
minutes, the humic acid precipitates. Centrifuge and decant or filter off (using a glass frit) the fulvic acid. Redissolve humic acid residue in extractant and transfer it to a 50-ml volumetric; make to volume, take a 5-10 ml aliquot and determine organic carbon as in step 2.

4. Fulvic acid carbon is determined by difference. Subsequently, ratios of humic acid carbon to fulvic acid carbon are calculated.

Statistical Analysis

The Statistical Analysis System (Hewlig and Council, 1979) computer language was used in data analysis. Analysis involved the calculation of correlation coefficients. Based on values of correlation coefficients, multiple linear regression models were developed to explain depth distributions of selected variables.
RESULTS AND DISCUSSION

Introduction

The Four Mile Creek Watershed (FMC) forms a part of the Tama-Muscatine (TM) soil association area. Oschwald et al. (1965) gave descriptions of the soils in the area. They have also shown the landscape relationships of some of the important soils in the TM soil association area (Figure 3).

Smith et al. (1950) considered selected prairie soils in northeast Iowa to be medial in development. In a medial prairie soil, the B horizon is slightly higher in clay than the A horizon. The presence of light gray silt coatings on structural aggregates of prairie soils indicate that the FMC area was once forested. The prairie environment is more conducive to the accumulation of greater amounts of organic matter than the forest environment. Fayette (a forest-derived soil) was shown to contain less organic matter than a Tama (grass-derived) soil. The Fayette soil (profile P32) had less clay in the A horizon and more in the B horizon relative to the Tama profile (P27). The clay relationships indicate either more clay movement or a more rapid rate of clay formation under the forest environment.

McGee (1891) called isolated loess-capped prominences on the Iowan drift area paha. Ruhe et al. (1968) described the FMC area as a Kansan inlier with a series of paha that
Figure 3. Relationship of slope, vegetation, and parent material to soils of the Tama-Muscatine soil association area (Oschwald et al., 1965)
stand above the Iowan Erosion Surface. In addition, the FMC area has a series of six stepped levels, related to cycles of erosion. Fenton (1966) described sites in the FMC area in which the Wisconsin loess ranged in thickness from 16 to 33 feet.

The similarity of most of the parent materials in the FMC area provides a good setting for studying the effect of different types of vegetation on soil properties. Grass and forest vegetation are important in the formation of Mollisols and Alfisols, respectively. Drainage and landscape position are other important variables that may influence the chemical and physical properties of the soils. The FMC area is dominated by soils of the Mollisol and Alfisol orders. Since the study area involved neighboring townships, climate may be considered uniform. Thus, for soils on similar landscape positions, vegetation difference should be a dominant factor causing variations in soil properties.

Depth Distribution Trends of Selected Chemical and Physical Properties of the Soils

In this section, the soils will be divided into the following groups: Group 1 - Tama soils, P27 (120B), FMC7WH (120C2), FMC5WH (120D2); Group 2 - Downs soils, FMC1WH (162B), FMC2WH (162C2), FMC3WH (162D3), FMC4WH (162D2); Group 3 - Fayette profile, P32 (163B); Group 4 - selected Mollisols, FMC6WH (933B+), FMC8WH (119B), FMC9WH (122).
Group 1 - Tama soils

Particle-size distribution  Clay and sand depth distribution curves for the soils of Group 1 are plotted in Figures 4 and 5, respectively. Total silt depth distribution curves are plotted in Figure 6. There is a lithologic discontinuity at a depth of 152 cm in profile FMC7WH. At the lithologic discontinuity, sand content increases from 4.6 to 49.3% and total silt content decreases from 72.7 to 28.9%. Above 152 cm, the sand contents of the soils vary from 1.2 to 7.6%. Above a depth of 152 cm, the silt contents vary less than 10%, 63.9 to 72.7%.

Examination of the depth distribution curves in Figure 4 show that profile FMC5WH has less clay in the upper 100 cm than either of the other two profiles. Above 100 cm, the clay ranges are 25.4 to 30.6% in FMC5WH, 28.3 to 34.5% in FMC7WH, and 28.4 to 34.3% in P27. The surface horizon of FMC5WH has 25.4% clay and is a heavy silt loam in texture; that of FMC7WH contains 28.7% clay and is light silty clay loam in texture. Profile P27 has a clay content of 28.4% in the surface horizon and is a light silty clay loam in textural class.

Maximum clay contents are 30.6% at 32 cm in FMC5WH, 34.5% at 33.5 cm in FMC7WH, and 34.3% at 53.5 cm in profile P27. Thus, as slope gradient increases, depth to maximum clay content decreases. The maximum clay content is in the
Figure 4. Clay depth distributions for FMC5WH (E), FMC7WH (G), and P27 (J)
Figure 5. Sand depth distributions in FMC5WH (E), FMC7WH (G), and P27 (J)
Figure 6. Total silt depth distributions in FMC5WH (E), FMC7WH (G), and P27 (J)
Bt horizon of each profile. Table 3 summarizes weighted clay values for selected soils.

Sand and total silt contents and distributions above 152 cm indicate that the soils formed in similar parent material. The presence of a few pebbles below the lithologic discontinuity in FMC7WH indicates that the sandy material is probably not aeolian in origin. The coarse material is probably water-sorted; it has a loam texture. The overlying loess is silt loam in texture.

McKim (1972) used the B/A clay ratio as a criterion for profile development and horizon differentiation. The B/A clay ratio is based on the assumption that the more highly differentiated a soil the greater is the difference between the clay contents of the A and B horizons. Assuming uniform parent materials, the B/A clay ratios of the Group 1 Tama soils range from 1.20 to 1.21. Fenton (1966) reported B/A clay ratios of 1.14 to 1.24 for selected Tama profiles of northeastern Iowa. Collins (1977) reported a B/A ratio of 1.2 for a Tama profile from northeastern Iowa. Bicki (1981) reported B/A clay ratios which ranged from 1.20 to 1.45.

Although the soils of Group 1 have similar B/A clay ratios, the clay contents vary among profiles. Examination of Table 3 shows that clay contents in the B and Bt horizons and 25-100 cm sections are in the order P27 > FMC7WH > FMC5WH. The decrease of clay is associated with an increase in slope.
Table 3. B/A clay ratios and weighted clay contents of selected zones of Group 1 Tama soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>B horizon</th>
<th>Bt horizon</th>
<th>0-25</th>
<th>25-100</th>
<th>B/A &lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC5WH</td>
<td>28.6</td>
<td>29.7</td>
<td>27.9</td>
<td>29.6</td>
<td>1.20</td>
</tr>
<tr>
<td>FMC7WH&lt;sup&gt;b&lt;/sup&gt;</td>
<td>30.6</td>
<td>30.8</td>
<td>30.7</td>
<td>31.5</td>
<td>1.20</td>
</tr>
<tr>
<td>P27</td>
<td>31.4</td>
<td>32.9</td>
<td>29.9</td>
<td>32.2</td>
<td>1.21</td>
</tr>
</tbody>
</table>

<sup>a</sup>Maximum clay content in B horizon
<sup>b</sup>Minimum clay content in A horizon

*Excludes depth below lithologic discontinuity.*

gradient. Thus, as the stability of landscape position decreases, clay contents of the soils decrease. In addition, depth to maximum clay content decreases as slope gradient increases. Jenny (1941) proposed a model of soil development which suggests that soil (s) is a function of climate (cl), organisms (o), relief (r), parent material (pm), and time (t). The above statement may be summarized as follows:

\[ s = f(cl, o, r, pm, t, ...) \]

Based on Jenny's equation, differences in the clay contents of the soils may be related to slope gradient. Joffe (1949) suggested that geologic erosion removed some of the products of weathering from soils on slopes. As a result, soils on steep topography exhibit less development relative to soils.
on level topography. Ruhe (1969) considered sloping and eroded topography to be representative of younger geomorphic surfaces in contrast to level, stable summits.

The finding that the clay contents of the B horizons and the 25 to 100 cm zones increase as slope gradient decrease is similar to the conclusion reached by Collins (1977). She studied selected Tama soils from northeast Iowa. Collins (1977) also reported an increase of depth to maximum clay content as slope gradient decreased, which concurs with the findings for the Group 1 soils.

Based on the higher clay content of the B and Bt horizons and the 25 to 100 cm sections, a developmental sequence may be considered as P27 > FMC7WH > FMC5WH. Furthermore, the geomorphic surface on which profile FMC5WH is located may be younger than those on which P27 and FMC7WH are located. The young surface may account for the lower level of differentiation with respect to clay distribution of FMC5WH.

**Organic carbon - whole soil**

Data for organic carbon (OC) values are given in Appendix III. Figure 7 shows the depth distribution for the organic carbon values. Organic carbon values are highest in the surface horizons and decrease with depth in the three profiles. Examination of Figure 7 shows that OC content is less, and declines more rapidly with depth, as slope gradient and erosion class increase.

Table 4 lists the weighted OC values and other selected
Figure 7. Organic carbon depth distributions for FMC5WH (E), FMC7WH (G), and P27 (J)
Table 4. Weighted average organic carbon and other selected data for the profiles of Group 1

<table>
<thead>
<tr>
<th>Profile</th>
<th>Organic carbon</th>
<th></th>
<th>ST^a</th>
<th>DTC^b</th>
<th>DMC^c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-25</td>
<td>25-100</td>
<td>A hor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P27</td>
<td>1.96</td>
<td>0.79</td>
<td>1.80</td>
<td>127</td>
<td>76</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>1.90</td>
<td>0.60</td>
<td>1.85</td>
<td>122</td>
<td>61</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>0.66</td>
<td>0.24</td>
<td>1.00</td>
<td>74</td>
<td>10</td>
</tr>
</tbody>
</table>

^aSolum thickness.
^bDepth to less than 0.58% organic carbon.
^cDepth of mollic colors.
^dBased on description in Smith et al. (1950).

data for the profiles in Group 1. The values for the variables decrease as slope gradient and erosion class increase, with one exception. The weighted OC in the A horizon of profile FMC7WH is slightly higher than that of profile P27. This may be related to the amount of residue returned to the soil after cropping and the length of time the soil has been cultivated.

Based on the data presented (Table 4, Figure 7), the epipedon of profile FMC5WH (120D2) does not meet the mollic epipedon requirements in at least two instances. The solum of FMC5WH is 74 cm thick and the requirement that 0.58% OC content extend to a depth of 25 cm is not met. In addition, the dark
Munsell color does not extend deep enough into the solum. Profiles FMC7WH and P27 have epipedons which meet the organic carbon and Munsell color criteria for the mollic epipedon.

A soil classification problem arises in the case of soil profile FMC5WH. Based on Soil Survey Staff (1975), if the surface horizon is too thin to meet the requirements for a mollic epipedon then the soil should be classified as an Inceptisol if it has a cambic horizon or an Alfisol if it has an argillic horizon. Turner (1961) arrived at a similar conclusion based on his study of eroded Mollisols. A reasonable assumption is that profile FMC5WH had a mollic epipedon before postcultural time. The presumption of a mollic epipedon in a soil can be made based on characteristics of the soils in adjacent and other nearby pedons. The findings related to erosion reported above agree with those of Lewis and Witte (1980).

**Organic carbon - soil extracts** The amounts of organic carbon (OC) in the extracts of the soils (Tables 5, 6, and 7) decrease as slope gradient and erosion phase increase. Organic carbon in the humic acid fractions of P27 (120B) range from 0.52% in the surface to 0.11% at a depth of 86 cm. Humic acid carbon in FMC7WH and FMC5WH are in the ranges of 0.42% to 0.02% and 0.06% to 0.01%, respectively. Of the two extracts, humic acid (HA) and fulvic acid (FA), HA is the dominant fraction in P27. In profiles FMC5WH and FMC7WH, FA carbon exceeds HA carbon in all horizons.
Table 5. Humic acid carbon to fulvic acid carbon ratios $(H/F)$ and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100 mesh soil (Soil) for FMC5WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil %</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-10</td>
<td>1.00</td>
<td>0.06</td>
<td>0.56</td>
<td>0.11</td>
</tr>
<tr>
<td>Bwl</td>
<td>10-23</td>
<td>0.45</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>Bt1</td>
<td>23-41</td>
<td>0.32</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>Bt1</td>
<td>41-56</td>
<td>0.29</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>BC</td>
<td>56-66</td>
<td>0.23</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>BC</td>
<td>66-74</td>
<td>0.20</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>C1</td>
<td>74-89</td>
<td>0.18</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>C2</td>
<td>89-97</td>
<td>0.17</td>
<td>0.01</td>
<td>0.05</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 6. Humic acid carbon to fulvic acid carbon ratios $(H/F)$ and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100 mesh soil (Soil) for FMC7WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil %</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>2.15</td>
<td>0.42</td>
<td>0.63</td>
<td>0.67</td>
</tr>
<tr>
<td>BA</td>
<td>15-29</td>
<td>1.53</td>
<td>0.23</td>
<td>0.28</td>
<td>0.82</td>
</tr>
<tr>
<td>Bt1</td>
<td>29-38</td>
<td>0.92</td>
<td>0.06</td>
<td>0.17</td>
<td>0.35</td>
</tr>
<tr>
<td>Bt1</td>
<td>38-51</td>
<td>0.78</td>
<td>0.11</td>
<td>0.16</td>
<td>0.69</td>
</tr>
<tr>
<td>Bt2</td>
<td>51-61</td>
<td>0.68</td>
<td>0.02</td>
<td>0.04</td>
<td>0.50</td>
</tr>
<tr>
<td>Bt3</td>
<td>61-73</td>
<td>0.54</td>
<td>0.02</td>
<td>0.04</td>
<td>0.50</td>
</tr>
<tr>
<td>Bt4</td>
<td>73-90</td>
<td>0.30</td>
<td>0.02</td>
<td>0.04</td>
<td>0.50</td>
</tr>
<tr>
<td>Bt5</td>
<td>90-102</td>
<td>0.22</td>
<td>0.02</td>
<td>0.04</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Table 7. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100 mesh soil (Soil) for P27

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>2.12</td>
<td>0.52</td>
<td>0.51</td>
<td>1.02</td>
</tr>
<tr>
<td>A</td>
<td>15-25</td>
<td>1.72</td>
<td>0.43</td>
<td>0.37</td>
<td>1.16</td>
</tr>
<tr>
<td>BA</td>
<td>25-36</td>
<td>1.42</td>
<td>0.40</td>
<td>0.21</td>
<td>1.90</td>
</tr>
<tr>
<td>Bw</td>
<td>36-46</td>
<td>1.27</td>
<td>0.29</td>
<td>0.23</td>
<td>1.26</td>
</tr>
<tr>
<td>Bt1</td>
<td>46-61</td>
<td>0.86</td>
<td>0.30</td>
<td>0.13</td>
<td>2.31</td>
</tr>
<tr>
<td>Bt2</td>
<td>61-76</td>
<td>0.68</td>
<td>0.30</td>
<td>0.13</td>
<td>2.31</td>
</tr>
<tr>
<td>Bt3</td>
<td>76-86</td>
<td>0.43</td>
<td>0.18</td>
<td>0.09</td>
<td>2.00</td>
</tr>
<tr>
<td>Bt3</td>
<td>86-102</td>
<td>0.26</td>
<td>0.11</td>
<td>0.05</td>
<td>2.20</td>
</tr>
</tbody>
</table>

For profile P27, all the HA carbon to FA carbon (H/F) ratios exceed unity. In contrast, H/F ratios in FMC7WH and FMC5WH are all <1. The H/F ratios of FMC7WH are higher than those of FMC5WH for all horizons investigated. Average H/F ratios decrease as slope gradient and erosion class increase. The average H/F ratios are 0.19, 0.57, and 1.77 for FMC5WH, FMC7WH, and P27, respectively.

The data in Tables 8, 9, and 10 show carbon extracted as percentages of carbon in the soil. In profile P27, more carbon (HA+FA) was extracted in the lower part of the profile.
Table 8. Organic carbon in the humic acid (HA) and fulvic acid (FA) extracts as percentages of the carbon of the <100 mesh soil (Soil), FMC5WH

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Soil</th>
<th>HA+FA</th>
<th>HA</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Ap</td>
<td>1.00</td>
<td>62.0</td>
<td>6.0</td>
<td>56.0</td>
</tr>
<tr>
<td>10-23</td>
<td>Bwl</td>
<td>0.45</td>
<td>13.3</td>
<td>2.2</td>
<td>11.1</td>
</tr>
<tr>
<td>23-41</td>
<td>Btl</td>
<td>0.32</td>
<td>18.8</td>
<td>3.1</td>
<td>15.6</td>
</tr>
<tr>
<td>41-56</td>
<td>Btl</td>
<td>0.29</td>
<td>20.7</td>
<td>3.4</td>
<td>17.2</td>
</tr>
<tr>
<td>56-66</td>
<td>BC</td>
<td>0.23</td>
<td>26.1</td>
<td>4.3</td>
<td>21.7</td>
</tr>
<tr>
<td>66-74</td>
<td>BC</td>
<td>0.20</td>
<td>30.0</td>
<td>5.0</td>
<td>25.0</td>
</tr>
<tr>
<td>74-89</td>
<td>C1</td>
<td>0.18</td>
<td>33.3</td>
<td>.6</td>
<td>27.8</td>
</tr>
<tr>
<td>89-97</td>
<td>C2</td>
<td>0.17</td>
<td>35.3</td>
<td>5.9</td>
<td>29.4</td>
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</table>

Table 9. Organic carbon in the humic acid (HA) and fulvic acid (FA) extracts as percentages of the carbon of the <100 mesh soil (Soil), FMC7WH

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Soil</th>
<th>HA+FA</th>
<th>HA</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Ap</td>
<td>2.15</td>
<td>48.8</td>
<td>19.5</td>
<td>29.3</td>
</tr>
<tr>
<td>15-29</td>
<td>BA</td>
<td>1.53</td>
<td>33.3</td>
<td>15.0</td>
<td>18.3</td>
</tr>
<tr>
<td>29-38</td>
<td>Btl</td>
<td>0.92</td>
<td>25.0</td>
<td>6.5</td>
<td>18.5</td>
</tr>
<tr>
<td>38-51</td>
<td>Btl</td>
<td>0.78</td>
<td>34.6</td>
<td>14.1</td>
<td>20.5</td>
</tr>
<tr>
<td>51-61</td>
<td>Bt2</td>
<td>0.68</td>
<td>8.8</td>
<td>2.9</td>
<td>5.9</td>
</tr>
<tr>
<td>61-73</td>
<td>Bt3</td>
<td>0.54</td>
<td>11.1</td>
<td>3.7</td>
<td>7.4</td>
</tr>
<tr>
<td>73-90</td>
<td>Bt4</td>
<td>0.30</td>
<td>20.0</td>
<td>6.7</td>
<td>13.3</td>
</tr>
<tr>
<td>90-102</td>
<td>Bt5</td>
<td>0.22</td>
<td>27.3</td>
<td>9.1</td>
<td>18.2</td>
</tr>
</tbody>
</table>
Table 10. Organic carbon in the humic acid (HA) and fulvic acid (FA) extracts as percentages of the carbon of the <100 mesh soil (Soil), P27

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Soil</th>
<th>HA+FA</th>
<th>HA</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Ap</td>
<td>2.12</td>
<td>48.6</td>
<td>24.5</td>
<td>24.1</td>
</tr>
<tr>
<td>15-25</td>
<td>A</td>
<td>1.72</td>
<td>46.5</td>
<td>25.0</td>
<td>21.5</td>
</tr>
<tr>
<td>25-36</td>
<td>BA</td>
<td>1.42</td>
<td>43.0</td>
<td>28.2</td>
<td>14.8</td>
</tr>
<tr>
<td>36-46</td>
<td>Bw1</td>
<td>1.27</td>
<td>40.9</td>
<td>22.8</td>
<td>18.1</td>
</tr>
<tr>
<td>46-61</td>
<td>Bt1</td>
<td>0.86</td>
<td>50.0</td>
<td>34.9</td>
<td>15.1</td>
</tr>
<tr>
<td>61-76</td>
<td>Bt2</td>
<td>0.68</td>
<td>63.2</td>
<td>44.1</td>
<td>19.1</td>
</tr>
<tr>
<td>76-86</td>
<td>Bt3</td>
<td>0.43</td>
<td>62.8</td>
<td>41.9</td>
<td>20.9</td>
</tr>
<tr>
<td>86-102</td>
<td>Bt3</td>
<td>0.26</td>
<td>61.5</td>
<td>42.3</td>
<td>19.2</td>
</tr>
</tbody>
</table>

than in the upper part. The OC contents in the total extracts (HA+FA) of profiles FMC5WH and FMC7WH are lower at depths than in the surface horizons. Low values of OC in the total extracts are near the middle of the profiles. In profile FMC5WH, between 18.8% and 62.0% of the soil carbon is extracted. In profiles FMC7WH and P27, 8.8% to 48.8% and 43.0% to 63.2%, respectively, of the soil carbon was extracted.

The finding for H/F ratio, decrease with an increase in erosion class, concurs with findings by Rodionov and Vysotskaya (1967) and Openlender (1978). They also reported increase in the fulvic acid fraction relative to the humic
acid fraction with increase in soil erosion class. The high H/F ratios, all >1, in P27, are characteristic of grass-derived soils on stable landscape. The H/F ratios of P27 agree with those reported by Lowe (1980), Kononova (1966), and Bettany et al. (1980) for grass-derived soils.

The low H/F ratios obtained for profile FMC5WH (120D2) suggest that accelerated erosion has resulted in exposure of the B horizon. Low H/F ratios, <1, are characteristic of forest-derived soils and of B horizons generally (Kononova, 1966; Lowe, 1980). Kononova (1966) and Anderson et al. (1974a) have concluded that the mobility of FA in soils is responsible for its dominance over HA at depths. In addition, the presence of silt coats on peds of profiles FMC5WH and FMC7WH indicates that forest vegetation may have been present where the profiles are located. Arnold (1963) concluded that gray silt coats on peds indicate forest influence.

The significance of the findings of the H/F ratios is that, as slope gradient and erosion class increase, H/F ratios decrease. The H/F ratios for the Group 1 Tama soils are in the order 120B > 120C >> 120D2.

Total phosphorus The depth distributions of total phosphorus (TP) for Group 1 soils are given in Figure 8. A sharp decrease in TP content is at 152 cm in FMC7WH and is associated with a lithologic discontinuity. At the lithologic discontinuity (FMC7WH), sand content increases from
Figure 8. Total phosphorus depth distributions for FMC5WH (E), FMC7WH (G), and P27 (J)
4.6% to 49.3% and TP decreases from 756 ppm to 385 ppm. Unless specifically stated, data from below the lithologic discontinuity are not included in the discussions.

All the soils have TP eluvial and illuvial zones (Figure 8). However, while FMC7WH and P27 have distinct eluvial zones, profile FMC5WH has only a moderate TP decrease below the surface horizon (Figure 8). The TP eluvial zones are from 10 to 41 cm in FMC5WH, from 15 to 51 cm in FMC7WH, and 15 to 61 cm in P27. Minimum TP values and other select data are given in Table 11. Minimum TP values are in the eluvial zones of all profiles. The depth to TP minimum decreases markedly as slope gradient increases from B to C to D.

Total phosphorus values increase below the eluvial zones. The maximum TP value (809 ppm) for FMC7WH is in the Ap horizon. Below the Ap horizon, maximum TP values are in the C horizon of all profiles in Group 1. Maximum values of TP are 723, 765, and 768 ppm at depths of 186, 131, and 137 cm in FMC5WH, FMC7WH, and P27, respectively. Profile P27 was not sampled as deeply as the other two profiles.

Except for the B horizon, weighted TP values are always highest in profile FMC7WH (Table 11). Examination of the data in Table 11 show that FMC7WH has weighted TP values of up to 100 ppm greater than those of the other two profiles.

Total phosphorus eluvial zones are associated with maximum clay values. Total phosphorus and clay distribution
Table 11. Weighted average total phosphorus (TP) and depth to minimum TP (DTPM) for profiles of Group 1 Tama soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>Depth</th>
<th>DTPM</th>
<th>TPM&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Horizon</th>
<th>Ap</th>
<th>A&lt;sup&gt;b&lt;/sup&gt;</th>
<th>BC&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Solum</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC5WH</td>
<td>0-25</td>
<td>468</td>
<td>464</td>
<td>473</td>
<td>473</td>
<td>498</td>
<td>495</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25-100</td>
<td>526</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMC7WH</td>
<td>0-25</td>
<td>656</td>
<td>384</td>
<td>809</td>
<td>624</td>
<td>595</td>
<td>602</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25-100</td>
<td>550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>33.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P27</td>
<td>0-25</td>
<td>559</td>
<td>406</td>
<td>617</td>
<td>519</td>
<td>600</td>
<td>577</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25-100</td>
<td>527</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>53.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Minimum TP.

<sup>b</sup>Includes Ap, A, and BA where present.

<sup>c</sup>B and BC horizons.
trends for the profiles are plotted in Figures 9, 10, and 11. Clay maxima are at 32, 43.5, and 53.5 cm in profiles FMC5WH, FMC7WH, and P27, respectively. Thus, as slope gradient increases, depth to maximum clay decreases. Both the TP minimum and clay maximum are at a depth of 53.5 cm in profile P27.

Illuvial and eluvial zones similar to those recorded for the Group 1 soils have long been noted in soil studies (Pearson et al., 1940). Runge and Riecken (1956) described TP distribution with depth in terms of eluvial and illuvial zones. For the soils of Group 1, depth to minimum TP decreases as slope gradient increases (Table 11). Variability in depth to minimum TP has been reported by Pearson et al. (1940) and Fenton et al. (1967). However, those researchers related depth to minimum TP to soils formed under different types of vegetation, in particular, forest and grass. Fenton et al. (1967) included transition soils in their study on TP. They concluded that the more highly differentiated soils (forest-derived) had TP minima closer to the surfaces than soils which were not as well developed (grass-derived).

Relatively high TP content in the Ap horizon of FMC7WH may be due to the application of fertilizer or manure. Runge and Riecken (1966), Williams and Saunders (1956), and Pearson et al. (1940) concluded that upward translocation of phosphorus may be partly responsible for enriching the Ap horizon
Figure 9. Depth distributions of clay and TP for FMC5WH
Figure 10. Depth distributions of clay and TP for FMC7WH
Figure 11. Depth distributions of clay and TP for P27
and impoverishing the zone immediately below. However, Pearson et al. (1940) concluded that increases of phosphorus in surface horizons are not large enough to account for the phosphorus lost from the eluvial zone.

Total phosphorus values increase below the eluvial zones of the soils in Group 1. Maximum values of TP (excluding the Ap horizon of FMC7WH) are associated with the C horizons. Maximum TP values in the C horizons of Tama profiles have been reported by Pearson et al. (1940), Smith et al. (1950), Fenton (1966), Collins (1977), and Bicki (1981). Allaway and Rhoades (1951) reported TP maxima near the top of lime zones. The lime zones coincided with the lower B or C horizon.

Weighted TP values in the soils are in the order FMC7WH, 120C > P27, 120B > FMC5WH, 120D2 (Table 11). Figure 8 shows that the TP distribution trend of FMC5WH is unlike those of P27 and FMC7WH. The TP distribution of FMC5WH may have been influenced by landscape position and soil erosion. However, while parent material of the soils is similar, initial phosphorus distribution in the loess section may have been due to sorting. The soils on C and D slopes may have formed in a different part of the loess section than the soil on B slope. Runge and Riecken (1966) reached a similar conclusion regarding sorting of phosphorus bearing minerals during loess deposition in southern Iowa and northern Missouri.
Inorganic phosphorus fractions  Data for inorganic phosphorus (IP) fractions are presented in Appendix 3. Easily extractable phosphorus (EEP) values are small and they will only be discussed briefly.

Soil pH values influence the status of the particular IP fraction in soils. Values of pH of Group 1 soils are plotted in Figure 12. Above a depth of 140 cm, pH values are in the order FMC5WH > FMC7WH > P27. The pH distributions increase with depth in each profile. The pH values in the surface horizons are 6.8 in FMC5WH, 6.5 in FMC7WH, and 6.3 in profile P27. In profile FMC7WH, highest pH values are below a depth of 152 cm. There is a lithologic discontinuity at this depth, 152 cm.

Increase of soil pH is associated with increase in slope gradient and erosion phase. Above a depth of 152 cm, the pH ranges are 6.8 to 7.2 in FMC5WH (120D2), 6.4 to 7.4 in FMC7WH (120C), and 6.3 to 6.6 in profile P27 (120B).

Selected data for IP fractions are listed in Table 12. The IP fractions are divided into active P and inactive or occluded P. Total IP fractions range from 294 to 622 ppm in FMC5WH, from 205 to 712 ppm in FMC7WH, and from 136 to 692 ppm in profile P27. Lowest total inorganic phosphorus (TIP) values are in the upper horizons, 15 to 46 cm depth range, of each profile. In the zones of low TIP contents, FeP and CaP tend to be relatively low. Highest TIP values
Figure 12. Depth distributions of soil pH for FMC5WH (E), FMC7WH (G), and P27 (J)
Table 12. Inorganic phosphorus (IP) fractions for the soils of Group 1

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>EEP</th>
<th>ALP</th>
<th>FEP</th>
<th>CAP</th>
<th>Σ1(^a)</th>
<th>RSP</th>
<th>OALP</th>
<th>OFEP</th>
<th>Σ2(^b)</th>
<th>RP(^c)</th>
<th>Σ1+Σ2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>Ap</td>
<td>0</td>
<td>5</td>
<td>113</td>
<td>9</td>
<td>127</td>
<td>151</td>
<td>17</td>
<td>17</td>
<td>185</td>
<td>161</td>
<td>312</td>
</tr>
<tr>
<td>10-23</td>
<td>Bwl</td>
<td>0</td>
<td>33</td>
<td>105</td>
<td>98</td>
<td>236</td>
<td>79</td>
<td>3</td>
<td>13</td>
<td>95</td>
<td>133</td>
<td>331</td>
</tr>
<tr>
<td>23-41</td>
<td>Btl</td>
<td>0</td>
<td>29</td>
<td>86</td>
<td>94</td>
<td>209</td>
<td>67</td>
<td>5</td>
<td>13</td>
<td>85</td>
<td>174</td>
<td>294</td>
</tr>
<tr>
<td>41-56</td>
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<td>0</td>
<td>26</td>
<td>96</td>
<td>175</td>
<td>297</td>
<td>61</td>
<td>3</td>
<td>9</td>
<td>73</td>
<td>151</td>
<td>370</td>
</tr>
<tr>
<td>56-74</td>
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<td>27</td>
<td>122</td>
<td>139</td>
<td>288</td>
<td>57</td>
<td>7</td>
<td>11</td>
<td>73</td>
<td>164</td>
<td>363</td>
</tr>
<tr>
<td>74-89</td>
<td>BC</td>
<td>0</td>
<td>33</td>
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<td>5</td>
<td>8</td>
<td>73</td>
<td>145</td>
<td>400</td>
</tr>
<tr>
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<td>C1</td>
<td>0</td>
<td>37</td>
<td>113</td>
<td>226</td>
<td>366</td>
<td>61</td>
<td>2</td>
<td>18</td>
<td>81</td>
<td>108</td>
<td>447</td>
</tr>
<tr>
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<td>C2</td>
<td>0</td>
<td>29</td>
<td>106</td>
<td>222</td>
<td>357</td>
<td>50</td>
<td>5</td>
<td>14</td>
<td>69</td>
<td>133</td>
<td>426</td>
</tr>
</tbody>
</table>

\(^a\): Σ1 = sum of active P.
\(^b\): Σ2 = sum of inactive P.
\(^c\): TP - (Σ1+Σ2) = residual phosphate (RP).

Profile FMC5WH
Table 12. (Continued)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Active P</th>
<th>Occluded P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EEP</td>
<td>ALP</td>
<td>FEP</td>
</tr>
<tr>
<td>0-15</td>
<td>Ap</td>
<td>4</td>
<td>132</td>
</tr>
<tr>
<td>15-29</td>
<td>BA</td>
<td>0</td>
<td>51</td>
</tr>
<tr>
<td>29-38</td>
<td>Bt1</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>38-51</td>
<td>Bt1</td>
<td>0</td>
<td>31</td>
</tr>
<tr>
<td>51-61</td>
<td>Bt2</td>
<td>0</td>
<td>57</td>
</tr>
<tr>
<td>61-73</td>
<td>Bt3</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>73-90</td>
<td>Bt4</td>
<td>2</td>
<td>62</td>
</tr>
<tr>
<td>90-102</td>
<td>BT5</td>
<td>3</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

Profile FMC7WH

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Active P</th>
<th>Occluded P</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td>Ap</td>
<td>2</td>
<td>27</td>
</tr>
<tr>
<td>15-25</td>
<td>A</td>
<td>2</td>
<td>31</td>
</tr>
<tr>
<td>25-36</td>
<td>BA</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>36-46</td>
<td>Bw</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>46-61</td>
<td>Bt1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>61-76</td>
<td>Bt2</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>76-86</td>
<td>Bt3</td>
<td>0</td>
<td>58</td>
</tr>
<tr>
<td>86-102</td>
<td>BC</td>
<td>0</td>
<td>61</td>
</tr>
</tbody>
</table>
are in the lower B horizons of FMC7WH and P27 and in the C horizon of FMC5WH. Maximum TIP values are 622 ppm at a depth of 185.5 cm in FMC5WH, 712 ppm at a depth of 131 cm in PMC7WH, and 692 ppm at a depth of 114.5 cm in profile P27.

Active phosphate fractions for profiles FMC5WH, FMC7WH, and P27 are plotted in Figures 13, 14, and 15, respectively. Iron phosphate is the most abundant active P form in the upper parts of FMC7WH and P27. However, CaP exceeds FeP in the upper part of FMC5WH. Table 13 lists the weighted CaP and FeP values for the 0 to 25 cm and 25 to 100 cm zones of the Group 1 soils. Calcium phosphate values are higher in the 25 to 100 cm zones than in the 0 to 25 cm zone of the profiles (Table 13). Weighted FeP values are uniform in profiles FMC5WH and FMC7WH. In profile P27, FeP is higher in the 25 to 100 cm zone.

Figures 16 and 17 show FeP and CaP depth distributions, respectively, for the soils of Group 1. Eluvial FeP zones are at a depth of 15 to 40 cm in each profile (Figure 16). Iron phosphate values increase below the eluvial zones of the profiles and decrease below 140 cm depth in profiles FMC5WH and FMC7WH. Calcium phosphate values increase with depth in each profile. However, below 150 cm in profile FMC7WH, CaP decreases. The CaP decrease at 150 cm in FMC7WH is associated with a lithologic discontinuity and a low (385 ppm) TP content.
Figure 13. Depth distribution of CaP (C), AlP (A), and FeP (I) for FMC5WH
Figure 14. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC7WH
Figure 15. Depth distributions of CaP (C), AlP (A), and FeP (I) for P27
Table 13. Weighted iron phosphate and calcium phosphate values for selected zones of the Group 1 soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>Depth (cm)</th>
<th>Calcium P (ppm)</th>
<th>Iron P (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-25</td>
<td>25-100</td>
<td>0-25</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>62</td>
<td>160</td>
<td>107</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>8</td>
<td>78</td>
<td>96</td>
</tr>
<tr>
<td>P27</td>
<td>46</td>
<td>91</td>
<td>48</td>
</tr>
</tbody>
</table>

Active, inactive (occluded), and residual P depth distributions for FMC5WH, FMC7WH, and P27 are shown in Figures 18, 19, and 20, respectively. In profile FMC5WH, the P forms are in the order active P > RSP > inactive P. In profiles P27 and FMC7WH, RSP is dominant above a depth of 50 cm and active P is dominant below this depth.

Increase of TIP with depth in the soils is associated with an increase of CaP with depth. Similar findings have been reported by Mausbach (1969) and Tembhare (1973) for selected Tama soils. Relatively low TIP values in the upper part of the profiles are most likely due to high contents of organic phosphorus (OP). Fenton (1966) reported high (>200 ppm) OP values in the upper parts of selected Tama profiles. Mausbach (1969) reported OP values that exceeded TIP values at the surfaces of two Tama profiles.
Figure 16. Depth distribution of FeP in FMC5WH (E), FMC7WH (G), and P27 (J)
Figure 17. Depth distribution of CaP in FMC5WH (E), FMC7WH (G), and P27 (J)
Figure 18. Depth distributions of active (*), occluded ($), and residual (R) P for FMC5WH
Figure 19. Depth distributions of active (*), occluded ($), and residual (R) P for FMC7WH.
Figure 20. Depth distributions of active (*), occluded ($), and residual (R) P for P27
Active P forms in FMC5WH are in the order CaP > FeP > AlP. However, FeP is the dominant active P form in the Ap horizon of FMC5WH. The presence of relatively large amounts of CaP close to the surface of FMC5WH indicates that the soil has not been extensively leached. However, the increase of CaP with depth suggests that some leaching has occurred in profile FMC5WH.

In profiles FMC5WH and P27, FeP is dominant above a depth of 80 cm and 70 cm, respectively. Calcium phosphate is the dominant active P form below 70 and 80 cm in P27 and FMC7WH, respectively. Active P distribution trends in FMC7WH and P27 indicate that the A and upper B horizons are more intensely leached and weathered than the lower B and C horizons. A similar conclusion was reached by Tembhare (1973). Chang and Jackson's (1958) weathering sequence of CaP → AlP → FeP supports the conclusion that the upper parts of FMC7WH and P27 are more intensely weathered than the lower parts.

Iron phosphate distribution trends are shown in Figure 16. Values of FeP decrease below the surfaces of the soil and increase in the B horizons. Below 130 cm (FMC7WH) and 140 cm (FMC5WH), FeP values decline markedly. Thus, iron phosphate in Group 1 soils exhibit the eluvial-illuvial trend observed in TP distribution (Pearson et al., 1940). Mausbach (1969) and Tembhare (1973) reported higher values of FeP in the Ap horizons than in the horizon below for selected Tama
profiles. Similar trends have also been reported by Hawkins and Kunze (1965), Ahmad and Jones (1967), Myo Thant (1968), and Westin and Buntley (1967). Mausbach (1969) also reported sharp declines in FeP below 200 cm in two Tama profiles.

Relatively high values of FeP in the surface horizons may be due to the inclusion of organic phosphorus since the FeP extraction reagent, NaOH, dissolves organic matter. Iron phosphate increases more than 100% from the 0 to 25 cm to the 25 to 100 cm zone of P27 (Table 13). The implication is that much OP was not extracted or that there has been significant P transformation, CaP → AlP → FeP, in the 25 to 100 cm section of profile P27. Iron phosphate contents are similar in the 0 to 25 and 25 to 100 cm sections of FMC5WH and FMC7WH (Table 13).

Calcium phosphate increases with depth in all profiles (Figure 17). This is in agreement with the findings of Westin and Buntley (1967), Mausbach (1969), and Tembhare (1973). Under the Chang and Jackson (1958) scheme, calcareous soils have mostly CaP, while FeP and AlP are dominant in acid soils. This is because P transformation is the result of solubility differences and is thus a function of soil pH (Hsu and Jackson, 1960). Figures 13, 14, and 15 show the relationships between the active P fractions. Figure 21 shows the relationships between CaP fractions and values of soil pH with depth in each profile. Profile FMC7WH has high pH values, >7.0,
Figure 21. Depth distribution of pH and CaP in the Group 1 soils
below a depth of 130 cm (Figure 21) and CaP is the dominant inactive P fraction below 70 cm (Figure 14). Examination of Figure 21 shows that FMC5WH has pH values higher than 7.0 below 170 cm, and Figure 13 shows that CaP is dominant in all horizons below the Ap. Calcium phosphate is dominant below 70 cm in P27 (Figure 15), while pH values do not exceed 6.6. Therefore, a soil does not have to be calcareous for CaP to be the dominant IP fraction. A similar conclusion was reached by Hsu and Jackson (1960). They concluded that the genetic processes that cause soil acidification proceed faster than phosphate transformation reactions.

Of the three major P forms, active P, occluded P, and residual P, active P is the most abundant. However, while active phosphate is dominant throughout profile FMC5WH, residual P exceeds other P forms in the upper parts of FMC7WH and P27. Since residual P is P that was not extracted, it includes some organic P. The significance of high values of active P is related to the fact that it is a source of IP for plants (Thomas and Peaslee, 1973; Lindsay and Moreno, 1960; Chang and Jackson, 1958; Hawkins and Kunze, 1965; Yuan et al., 1960).

Occluded phosphates RSP, and occluded iron and aluminum phosphates— are the least abundant of the three P forms (Figures 18, 19, and 20). Occluded phosphate fractions are in the order RSP > OFeP > OA1P in the Group 1 profiles.
Inclusion of RSP with occluded P in the IP weathering sequence (Chang and Jackson, 1958) may be undesirable under some situations. Tama soils are only medial in development (Smith et al., 1950). However, RSP comprise between 6% and 38% of their TP. Tembhare (1973) reported a RSP range of 40 to 56% of TIP in Tama and other moderately developed soils. Mausbach (1969) and Smeck (1970) also reported high RSP values for moderately weathered soils. For the Group 1 soils, RSP values are relatively high in the Ap horizons. Thant (1968) concluded that some OP may be included in the RSP extract.

The increase of CaP with increasing depth in the Tama soils is evidence of leaching and weathering in the upper parts of the profiles. The dominance of active P over occluded P suggests that the soils are only moderately weathered. Iron phosphate trends indicate the presence of eluvial and illuvial zones.

**Group 2 - Downs soils**

**Particle-size distribution** Clay and sand depth distributions for the soils of Group 2 are plotted in Figures 22 and 23, respectively. Total silt depth distributions are plotted in Figure 24. Profiles FMC3WH and FMC4WH have zones of high sand content (Figure 23). The sand contents in these two profiles range from 2.3 to 42.1%. In the zones of high sand contents of FMC3WH and FMC4WH, silt contents decrease (Figure 24). In profiles FMC1WH and FMC2WH, sand contents
Figure 22. Clay depth distributions in FMC1WH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
Figure 23. Sand depth distributions in FMC1WH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
Figure 24. Total silt depth distributions in FMC1WH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
range from 1.4 to 10.6%. Profiles FMC1WH and FMC2WH have silt contents that range from 61.1 to 75.2% and 60.8 to 74.6%, respectively.

The textures of the surface horizons are light silty clay loam in FMC1WH, and silty clay loam in FMC2WH, FMC3WH, and FMC4WH. The corresponding clay contents are 26.8, 33.3, 34.0, and 33.4%. Clay content generally decreases with depth and the maximum clay content is within 30 cm of the surface of each soil. Clay maxima in the soils are 33.5% at a depth of 29.5 cm in profile FMC1WH, 33.4% at a depth of 24.5 cm in profile FMC2WH, 35.0% at a depth of 21.5 cm in profile FMC3WH, and 33.4% at a depth of 7.5 cm (surface horizon) in FMC4WH. The depth to the maximum clay content decreases as slope gradient and erosion class increase. Weighted average clay contents in the 25 to 100 cm zones are 31.4, 30.4, 25.7, and 25.9% in profiles FMC1WH, FMC2WH, FMC3WH, and FMC4WH, respectively. The decrease of clay content is associated with increased slope gradient and erosion class. With the D slope soils, FMC3WH and FMC4WH, decrease in clay is associated with high sand content. Weighted average clay contents of the Bt horizons are 31.0, 30.6, and 28.6% in FMC1WH, FMC2WH, and FMC4WH, respectively. The corresponding Bt horizon thicknesses are 87, 92, and 51 cm. Profile FMC3WH was not described. Total thickness of the Bt horizons and the respective weighted average clay content decrease with increasing
slope gradient and erosion class. Weighted average sand contents of the 25 to 100 cm zone are 3.6% in FMCIWH, 1.9% in FMC2WH, 16.4% in FMC3WH, and 13.9% in FMC4WH.

The sand in the upper part of FMC3WH and FMC4WH is fine and very fine sand bordering on very coarse silt. In contrast, the sand in the lower part of the profiles is distinctly coarse and with some gravel, thus lithologic discontinuities are described.

The B/A clay ratio has been used as an index of horizon differentiation and profile development (McKim, 1972). The B/A clay ratios of profiles FMCIWH, FMC2WH, and FMC4WH are 1.25, 1.00, and 0.98, respectively. For profile FMC3WH, a B/A clay ratio of 0.99 is obtained by using the ratio of the maximum clay content of the 25 to 100 cm zone to the minimum clay content in the 0 to 25 cm zone.

Profile FMCIWH has clay films and 20% increase in clay content within 30 vertical cm. As a result, the profile meets the requirements for an argillic horizon (Soil Survey Staff, 1975). The other profiles do not meet the clay increase requirement needed for the argillic. However, they meet the argillic requirement as it applies to truncated soils (Soil Survey Staff, 1975).

The clay contents in the Bt horizons and 25 to 100 cm zones of the profiles are related to landscape position. The soils on the more strongly sloping landscape position, FMC3WH
and FMC4WH, have less clay in their 25 to 100 cm zones, and have B/A clay ratios which are <1. Because of the low B/A clay ratios, these soils are not considered highly developed; however, the presence of argillic horizons contradicts this. The low B/A clay ratios reported for the Group 2 soils are similar to those reported by Collins (1977) for moderately and severely eroded Downs soils in northeastern Iowa. The implication of the clay contents on classification of the soils will be discussed in a later section.

**Organic carbon - whole soil** The depth distributions of organic carbon (OC) for Downs soils are shown in Figure 25. All the profiles were within close proximity of each other (Figure 2). Profiles FMC1WH, FMC2WH, and FMC3WH are sampled from the same cornfield but were located on different landscape positions. The locations of the profiles are listed in Appendix II. Organic carbon contents range from a high of 2.38% in the Ap horizon of FMC2WH to 0.07 in the lower horizons of FMC3WH and FMC4WH. Organic carbon values in the surface horizons are 1.87, 2.38, 1.81, and 1.70% for profiles FMC1WH, FMC2WH, FMC3WH, and FMC4WH, respectively.

Table 14 lists selected organic carbon parameters for the soils of Group 2. A profile description of FMC3WH was not made. As a result, the value for the A horizon of FMC3WH is considered to be the same as that for the Ap horizon. Based on the data in Table 14, OC values are in the order
Figure 25. Organic carbon depth distributions for FMC1WH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
Table 14. Weighted average organic carbon values and other selected data for the profiles of Group 2

<table>
<thead>
<tr>
<th>Profile</th>
<th>0-25</th>
<th>25-100</th>
<th>Horizon</th>
<th>A&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Ap</th>
<th>ST&lt;sup&gt;b&lt;/sup&gt;</th>
<th>DTC&lt;sup&gt;c&lt;/sup&gt;</th>
<th>DMC&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>cm</td>
<td>A&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Ap</td>
<td></td>
<td>cm</td>
<td></td>
<td>cm</td>
</tr>
<tr>
<td>FMC1WH</td>
<td>1.74</td>
<td>0.66</td>
<td>1.74</td>
<td>1.87</td>
<td>170</td>
<td>66</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>FMC2WH</td>
<td>2.09</td>
<td>0.67</td>
<td>2.38</td>
<td>2.38</td>
<td>127</td>
<td>58</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>FMC3WH&lt;sup&gt;e&lt;/sup&gt;</td>
<td>1.55</td>
<td>0.42</td>
<td>1.81</td>
<td>1.81</td>
<td>-</td>
<td>41</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>FMC4WH</td>
<td>1.39</td>
<td>0.45</td>
<td>1.70</td>
<td>1.70</td>
<td>119</td>
<td>43</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes transition horizon.

<sup>b</sup>Solum thickness.

<sup>c</sup>Depth to <0.58% organic carbon.

<sup>d</sup>Depth of mollic colors.

<sup>e</sup>Profile not described, horizonation is based mainly on particle-size distribution.

FMC2WH (162C2) > FMC1WH (162B) > FMC3WH (162D3) > FMC4WH (162D2). Low values of OC below 60 cm in profile FMC3WH are associated with a sandy zone which extends from a depth of 56 cm to 91 cm. Above a depth of 60 cm, the lowest values for OC are in profile FMC4WH. This profile has a relatively high sand content, 6.3 to 26.5%, between 0 and 81 cm.

Profiles FMC1WH, FMC2WH, and FMC4WH have sola > 75 cm in thickness and the depth to >0.58% OC is > 25 cm in the three profiles. Thicknesses of mollic colors are 17, 18, and 15 cm.
in profiles FMCIWH, FMC2WH, and FMC4WH, respectively. Thus, profiles FMCIWH, FMC2WH, and FMC4WH meet the depth requirement of organic carbon for the mollic epipedon. However, they do not meet the color requirement for the mollic epipedon.

All the profiles have sharp declines in OC below the Ap horizons (Figure 25). The sharp decreases of OC are associated with erosion (Rodionov and Vysotskaya, 1967; Openlender, 1978) and the influence of forest vegetation on the soils. Downs soils are classified as Mollic Hapludalf. Profiles FMCIWH and FMC2WH have more OC in their sola than profiles FMC3WH and FMC4WH. The decrease of OC is associated with an increase in erosion class and slope gradient. The implication of the OC depth distributions is that accelerated erosion may be removing more of the humus-rich surface from the soils on D slopes than from those on B and C slopes. The D slopes may also represent younger geomorphic surfaces formed during cycles of erosion which occurred on the Iowan Erosion Surface (Ruhe, 1969). The relatively high sand contents in the upper horizons of FMC3WH and FMC4WH may also contribute to their lower organic carbon contents.

**Organic carbon - soil extracts** Organic carbon values in the extracts of the upper 100 cm of the Group 2 soils are given in Tables 15, 16, 17, and 18. Maximum percent organic carbon in the total extract (TOC) is 0.93% in the surface of profile FMC2WH. Total extract is a measure of the humic
Table 15. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil (Soil) for FMCIWH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-17</td>
<td>1.87</td>
<td>0.19</td>
<td>0.63</td>
<td>0.30</td>
</tr>
<tr>
<td>BE</td>
<td>17-25</td>
<td>1.46</td>
<td>0.08</td>
<td>0.56</td>
<td>0.14</td>
</tr>
<tr>
<td>Bt1</td>
<td>25-34</td>
<td>0.83</td>
<td>0.07</td>
<td>0.18</td>
<td>0.39</td>
</tr>
<tr>
<td>Bt2</td>
<td>34-53</td>
<td>0.78</td>
<td>0.03</td>
<td>0.21</td>
<td>0.14</td>
</tr>
<tr>
<td>Bt3</td>
<td>53-66</td>
<td>0.77</td>
<td>0.03</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>Bt4</td>
<td>66-80</td>
<td>0.57</td>
<td>0.03</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>Bt5</td>
<td>80-90</td>
<td>0.48</td>
<td>0.03</td>
<td>0.16</td>
<td>0.19</td>
</tr>
<tr>
<td>Bt6</td>
<td>90-112</td>
<td>0.44</td>
<td>0.03</td>
<td>0.16</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 16. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil (Soil) for FMC2WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-18</td>
<td>2.38</td>
<td>0.28</td>
<td>0.65</td>
<td>0.43</td>
</tr>
<tr>
<td>Bt1</td>
<td>18-31</td>
<td>1.35</td>
<td>0.15</td>
<td>0.36</td>
<td>0.42</td>
</tr>
<tr>
<td>Bt2</td>
<td>31-48</td>
<td>1.24</td>
<td>0.09</td>
<td>0.14</td>
<td>0.64</td>
</tr>
<tr>
<td>Bt3</td>
<td>48-58</td>
<td>0.62</td>
<td>0.06</td>
<td>0.13</td>
<td>0.46</td>
</tr>
<tr>
<td>Bt4</td>
<td>58-68</td>
<td>0.45</td>
<td>0.02</td>
<td>0.11</td>
<td>0.18</td>
</tr>
<tr>
<td>Bt5</td>
<td>68-85</td>
<td>0.35</td>
<td>0.02</td>
<td>0.11</td>
<td>0.18</td>
</tr>
<tr>
<td>Bt5</td>
<td>85-97</td>
<td>0.30</td>
<td>0.02</td>
<td>0.11</td>
<td>0.18</td>
</tr>
<tr>
<td>Bt5</td>
<td>97-110</td>
<td>0.29</td>
<td>0.02</td>
<td>0.11</td>
<td>0.18</td>
</tr>
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</table>
Table 17. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil (Soil) for FMC3WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-18</td>
<td>1.81</td>
<td>0.30</td>
<td>0.47</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>18-25</td>
<td>0.89</td>
<td>0.15</td>
<td>0.18</td>
<td>0.83</td>
<td></td>
</tr>
<tr>
<td>25-41</td>
<td>0.73</td>
<td>0.14</td>
<td>0.40</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>41-56</td>
<td>0.57</td>
<td>0.12</td>
<td>0.29</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td>56-64</td>
<td>0.44</td>
<td>0.11</td>
<td>0.16</td>
<td>0.69</td>
<td></td>
</tr>
<tr>
<td>64-76</td>
<td>0.28</td>
<td>0.05</td>
<td>0.09</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>76-91</td>
<td>0.18</td>
<td>0.03</td>
<td>0.06</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>91-109</td>
<td>0.17</td>
<td>0.03</td>
<td>0.06</td>
<td>0.50</td>
<td></td>
</tr>
</tbody>
</table>

*Profile not described.*

Table 18. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil (Soil) for FMC4WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>1.70</td>
<td>0.030</td>
<td>0.600</td>
<td>0.050</td>
</tr>
<tr>
<td>Bt1</td>
<td>15-25</td>
<td>0.87</td>
<td>0.004</td>
<td>0.416</td>
<td>0.010</td>
</tr>
<tr>
<td>Bt2</td>
<td>25-43</td>
<td>0.58</td>
<td>0.002</td>
<td>0.178</td>
<td>0.011</td>
</tr>
<tr>
<td>Bt3</td>
<td>43-56</td>
<td>0.55</td>
<td>0.003</td>
<td>0.127</td>
<td>0.024</td>
</tr>
<tr>
<td>Bt3</td>
<td>56-66</td>
<td>0.45</td>
<td>0.003</td>
<td>0.127</td>
<td>0.024</td>
</tr>
<tr>
<td>BC</td>
<td>66-81</td>
<td>0.35</td>
<td>0.003</td>
<td>0.127</td>
<td>0.024</td>
</tr>
<tr>
<td>BC</td>
<td>81-104</td>
<td>0.35</td>
<td>0.003</td>
<td>0.127</td>
<td>0.024</td>
</tr>
</tbody>
</table>
acid carbon (HA) and fulvic acid carbon (FA). Generally, TOC values decrease with depth in each profile. However, in profile FMC3WH, the TOC value (0.54%) at 33 cm exceeds the value (0.33%) at 20.5 cm. The ranges of TOC in the profiles are 0.19 to 0.82%, 0.13 to 0.93%, 0.09 to 0.77%, and 0.13 to 0.63% in profiles FMC1WH, FMC2WH, FMC3WH, and FMC4WH, respectively.

Fulvic acid carbon (FA) exceeds humic acid carbon (HA) throughout each profile. As a result, humic acid carbon to fulvic acid carbon (H/F) ratios are <1 in all profiles (Tables 15, 16, 17, and 18). Average H/F ratios are 0.56, 0.33, 0.22, and 0.17 for profiles FMC3WH, FMC2WH, FMC1WH, and FMC4WH. Values for organic carbon extracted as percentages of organic carbon in the <100-mesh soil fractions are given in Table 19. Highest amount of both HA and FA were extracted from profile FMC3WH (Table 19).

Currently, Downs soils are classified as Mollic Haplustolls. The surfaces of the Group 2 soils have been influenced by organic matter from several sources. The sources include grass vegetation, mixed forest-grass vegetation, and organic matter from commercial crops such as corn and soybeans.

The low, <1, H/F ratios of the Group 2 soils indicate that grass influence has been overcome by forest influence or erosion, or both. Postcultural activities have exposed the soils to accelerated erosion. Profiles FMC3WH (162D3)
Table 19. Range of organic carbon in soil extracts as percentages of organic carbon in the <100-mesh soil, Group 2 soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>HA</th>
<th>FA</th>
<th>Occurrence of high values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HA</td>
<td>FA</td>
<td>Horizon Depth (cm)</td>
</tr>
<tr>
<td>FMC1WH</td>
<td>3.9-10.2</td>
<td>20.8-38.4</td>
<td>Ap 8.5</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>4.4-11.7</td>
<td>11.3-36.7</td>
<td>Ap 9.0</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>16.6-25.0</td>
<td>20.2-54.8</td>
<td>Ap 60.0</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>0.3-1.8</td>
<td>23.1-47.8</td>
<td>Ap 7.5</td>
</tr>
</tbody>
</table>

and FMC4WH (162D2) are located on strongly sloping landscape positions and have been severely and moderately eroded, respectively. As a result, their low H/F ratios may be attributed to both forest influence and exposure of subsurface material. The low H/F ratios in FMC1WH (162B) and FMC2WH (162C2) may be due mainly to the influence of forest vegetation. These soils are located on relatively stable landscape positions.

Total phosphorus

Depth distribution curves for total phosphorus (TP) of the Group 2 soils are plotted in Figure 26. Total phosphorus values in the surface horizons are 803, 657, 610, and 533 ppm in profiles FMC3WH, FMC2WH, FMC4WH, and FMC1WH. Examination of Figure 26 shows that TP eluviation
Figure 26. Total phosphorus depth distributions for FMC1WH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
zones are below the Ap horizons. Below the eluviation zones, TP values increase to maxima in the lower B horizon (FMC1WH) and C horizons (FMC2WH and FMC3WH). A lithologic discontinuity is present at a depth of 191 cm in profile FMC3WH. At the lithologic discontinuity, TP content decreases from 658 ppm to 360 ppm and sand content increases from 6.2% to 42.1%. The ranges of TP in the profiles vary from 803 ppm in the Ap of profile FMC3WH to 284 ppm at 221 cm depth in the same profile. Selected TP values are given in Table 20. Profile FMC3WH has the highest weighted TP in the 0 to 25 cm zone, 100 to 150 cm zone, and in the Ap horizon. Depth to minimum TP content decreases as slope gradient and erosion class increase while minimum TP values in the eluviation zones decrease as slope and erosion class increase.

Figures 27, 28, 29, and 30 show the relationships between clay and TP in the soils of Group 2. Clay maxima are 35.5% at 29.5 cm depth, 33.4% at 24.5 cm depth, 35.0 at 21.5 cm depth, and 33.4% at 7.5 cm depth in profiles FMC1WH, FMC2WH, FMC3WH, and FMC4WH, respectively. In profile FMC4WH, the depth to maximum clay is in the Ap horizon. In the other three profiles, depths to maximum clay content are in the eluvial zones. Maximum clay content and minimum TP are both at a depth of 24.5 cm in profile FMC2WH. In profile FMC3WH, both minimum TP and maximum clay are at a depth of 21.5 cm. Depth to minimum TP is 49.5 cm, while depth to maximum clay
Table 20. Weighted average total phosphorus (TP) and depth to minimum TP (DTPM) for profiles of Group 2 - Downs soils

<table>
<thead>
<tr>
<th>Depth</th>
<th>0-25</th>
<th>25-100</th>
<th>100-150</th>
<th>DTPM</th>
<th>Horizon</th>
<th>Solum</th>
<th>MaxTPb</th>
<th>Horizon or depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ppm</td>
<td>ppm</td>
<td>cm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
<td></td>
</tr>
<tr>
<td>FMC1WH</td>
<td>496</td>
<td>496</td>
<td>584</td>
<td>21</td>
<td>418</td>
<td>533</td>
<td>496</td>
<td>566</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>581</td>
<td>575</td>
<td>621</td>
<td>24.5</td>
<td>449</td>
<td>657</td>
<td>657</td>
<td>574</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>677</td>
<td>413</td>
<td>701</td>
<td>21.5</td>
<td>354</td>
<td>803</td>
<td>803d</td>
<td>-</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>528</td>
<td>462</td>
<td>673</td>
<td>49.5</td>
<td>352</td>
<td>610</td>
<td>610</td>
<td>491</td>
</tr>
</tbody>
</table>

\(^a^\text{Minimum TP.}

\(^b^\text{Maximum TP.}

\(^c^\text{Profile not described; values below the lithologic discontinuity are not considered.}

\(^d^\text{Ap and Ap assumed to be the same.}

\(^e^\text{Excludes the Ap horizon.}
Figure 27. Depth distributions of clay and TP in FMCLWH
Figure 28. Depth distributions of clay and TP for FMC2WH
Figure 29. Depth distributions of clay and TP for FMC3WH
Figure 30. Depth distributions of clay and TP for FMC4WH
is at 7.5 cm (Ap horizon) of profile FMC4WH. Depth to minimum TP increases as slope increases, but depth to maximum clay content decreases as slope increases.

The decrease of TP values below the Ap horizons of the Group 2 soils are similar to trends recorded by Pearson et al. (1940), Allaway and Rhoades (1951), Godfrey and Riecken (1954), Williams and Saunders (1956), Runge and Riecken (1966), Fenton (1966), and Collins (1977). Leaching and recycling have been considered important in phosphorus distribution in soils (Pearson et al., 1940; Runge and Riecken, 1966; Smeck, 1973). High values of phosphorus at the surface of the soils are due to (1) input of inorganic (fertilizer) P, and (2) recycling by plants which absorb inorganic phosphorus and return organic phosphorus to the soil in the process of humification.

Eluviation of TP from below the Ap horizon is due to the downward movement of P in water (Runge and Riecken, 1966). Figure 26 shows zones of illuviation in the B horizons of the profiles, while TP values decrease in the C horizons. Similar results have been reported by Pearson et al. (1940), Smith et al. (1950), Godfrey and Riecken (1954), and Runge and Riecken (1966).

Weighted TP values are in the order FMC3WH > FMC4WH > FMC2WH > FMC1WH for the 100 to 150 cm zone. This zone includes the lower B and upper C horizons in profiles FMC2WH and FMC4WH, and lower B horizon in profile FMC1WH. If the soils all had
uniform parent material initially with regard to TP content and distribution, then there has been movement of phosphorus at greater depths in profiles FMC1WH and FMC2WH. Thus, lower TP content at depth indicates that due to landscape position, there has been weathering at greater depths in FMC1WH and FMC2WH. Profiles FMC1WH and FMC2WH have more TP in the 25 to 100 cm zone than the other two profiles. This may be due to the fact that profiles FMC3WH and FMC4WH have sandy zones above 100 cm. Godfrey and Riecken (1954) reported a decrease in TP with increased profile development (differentiation) along a transect which started in southwest Iowa and ended in northern Missouri. Runge and Riecken (1966) considered the mobility of phosphorus important in the differentiation of selected soils of southern Iowa. Zones of fine and very fine sand (13.6% to 31.1% total sand) are present in the upper parts of FMC3WH and FMC4WH.

Clay maxima in the Group 2 soils are associated with TP eluvial zones. Runge and Riecken (1966) considered the high clay and low TP association to be due to the ineffectiveness of clay in immobilizing phosphorus. Higher TP values in the lower B or C horizons are due to the immobilization of phosphorus by carbonates (Allaway and Rhoades, 1951).

**Inorganic phosphorus fractions** Soil pH values and inorganic phosphorus content are listed in Appendix III. Figure 31 shows the pH depth distributions for the four soils
Figure 31. Depth distributions of soil pH for FMCIWH (A), FMC2WH (B), FMC3WH (C), and FMC4WH (D)
of Group 2. The pH values in the surface horizons are 6.5 in profile FMCIWH, 6.4 in FMC2WH, 6.7 in FMC3WH, and 6.5 in FMC4WH. In profiles FMC3WH and FMC4WH, pH values increase with depth. Except for a slight increase below 140 cm in FMCIWH, the pH values of FMCIWH and FMC2WH vary only slightly with increasing depth. For profiles FMCIWH and FMC2WH, the pH ranges are 6.4 to 6.9 and 6.3 to 6.6, respectively. The pH ranges in FMC3WH and FMC4WH are 6.6 to 7.6 and 6.5 to 7.8, respectively.

Selected inorganic phosphorus (IP) fraction data for profiles FMCIWH, FMC2WH, FMC3WH, and FMC4WH are presented in Tables 21, 22, 23, and 24, respectively. Total inorganic phosphorus (TIP) values increase with depth in each soil of Group 2. The TIP values at the surfaces of the soils are 238 ppm in FMCIWH, 213 ppm in FMC2WH, 314 ppm in FMC3WH, and 328 ppm in FMC4WH. Highest TIP values are 592 ppm at 161 cm, 657 ppm at 149.5 cm, 661 ppm at 118 cm, and 644 ppm at 166 cm, in profiles FMCIWH, FMC2WH, FMC3WH, and FMC4WH, respectively. Maximum TIP values are in the BC horizon of FMCIWH, and in the C horizons of FMC2WH and FMC4WH. Increase of TIP with depth is associated with an increase of CaP and a decrease of RP in each profile.

Active P forms for profiles FMCIWH, FMC2WH, FMC3WH, and FMC4WH are plotted in Figures 32, 33, 34, and 35, respectively. Of the active P forms, A1P has the least variation with depth.
### Table 21. Inorganic phosphorus (IP) fractions and soil pH for profile FMClWH, 162B

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth</th>
<th>pH</th>
<th>Active P</th>
<th>Inactive P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td></td>
<td>A IP</td>
<td>FeP</td>
</tr>
<tr>
<td>Ap</td>
<td>0-17</td>
<td>6.5</td>
<td>44</td>
<td>87</td>
</tr>
<tr>
<td>BE</td>
<td>17-25</td>
<td>6.4</td>
<td>38</td>
<td>69</td>
</tr>
<tr>
<td>Bt1</td>
<td>25-34</td>
<td>6.4</td>
<td>51</td>
<td>102</td>
</tr>
<tr>
<td>Bt2</td>
<td>34-53</td>
<td>6.5</td>
<td>33</td>
<td>118</td>
</tr>
<tr>
<td>Bt3</td>
<td>53-66</td>
<td>6.5</td>
<td>45</td>
<td>140</td>
</tr>
<tr>
<td>Bt4</td>
<td>66-80</td>
<td>6.4</td>
<td>24</td>
<td>156</td>
</tr>
<tr>
<td>Bt5</td>
<td>80-90</td>
<td>6.5</td>
<td>17</td>
<td>88</td>
</tr>
<tr>
<td>Bt6</td>
<td>90-112</td>
<td>6.5</td>
<td>25</td>
<td>63</td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes NH₄Cl-P.

<sup>b</sup>Σ3 = Σ1 + Σ2.

<sup>c</sup>RP = residual P.
Table 22. Inorganic phosphorus (IP) fractions and soil pH for profile FMC2WH, 162C

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Active P</th>
<th>Inactive P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A1P</td>
<td>FeP</td>
</tr>
<tr>
<td>Ap</td>
<td>0-18</td>
<td>6.4</td>
<td>32</td>
<td>96</td>
</tr>
<tr>
<td>Bt1</td>
<td>18-31</td>
<td>6.5</td>
<td>9</td>
<td>90</td>
</tr>
<tr>
<td>Bt2</td>
<td>31-48</td>
<td>6.6</td>
<td>17</td>
<td>128</td>
</tr>
<tr>
<td>Bt3</td>
<td>48-58</td>
<td>6.6</td>
<td>41</td>
<td>190</td>
</tr>
<tr>
<td>Bt3</td>
<td>58-68</td>
<td>6.5</td>
<td>57</td>
<td>168</td>
</tr>
<tr>
<td>Bt4</td>
<td>68-85</td>
<td>6.5</td>
<td>59</td>
<td>183</td>
</tr>
<tr>
<td>Bt5</td>
<td>85-97</td>
<td>6.6</td>
<td>44</td>
<td>267</td>
</tr>
<tr>
<td>Bt5</td>
<td>97-110</td>
<td>6.5</td>
<td>79</td>
<td>182</td>
</tr>
<tr>
<td>BC</td>
<td>110-127</td>
<td>6.5</td>
<td>34</td>
<td>194</td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes NH<sub>4</sub>C1-P.

<sup>b</sup>Σ3 = Σ1 + Σ2.

<sup>c</sup>RP = residual P.
Table 23. Inorganic phosphorus (IP) fractions and soil pH for profile FMC3WH, 162D3a

<table>
<thead>
<tr>
<th>Horizon Depth</th>
<th>pH</th>
<th>Active P</th>
<th>Inactive P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>cm</td>
<td>A1P</td>
<td>FeP</td>
</tr>
<tr>
<td>0-18</td>
<td>6.7</td>
<td>12</td>
<td>217</td>
</tr>
<tr>
<td>18-25</td>
<td>6.8</td>
<td>14</td>
<td>98</td>
</tr>
<tr>
<td>25-41</td>
<td>6.6</td>
<td>11</td>
<td>105</td>
</tr>
<tr>
<td>41-56</td>
<td>6.7</td>
<td>35</td>
<td>90</td>
</tr>
<tr>
<td>56-64</td>
<td>6.7</td>
<td>27</td>
<td>74</td>
</tr>
<tr>
<td>64-76</td>
<td>6.8</td>
<td>35</td>
<td>76</td>
</tr>
<tr>
<td>76-91</td>
<td>7.1</td>
<td>107</td>
<td>69</td>
</tr>
<tr>
<td>91-109</td>
<td>7.3</td>
<td>60</td>
<td>56</td>
</tr>
</tbody>
</table>

aProfile not described.
bIncludes NH₄Cl-P.
cΣ3 = Σ1 + Σ2.
dRP = residual P.
Table 24. Inorganic phosphorus (IP) fractions and soil pH for profile FMC4WH, 162D2

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth</th>
<th>pH</th>
<th>AIP</th>
<th>FeP</th>
<th>CaP</th>
<th>Σ1&lt;sup&gt;a&lt;/sup&gt;</th>
<th>RSP</th>
<th>OAIP</th>
<th>OFeP</th>
<th>Σ2</th>
<th>Σ3&lt;sup&gt;b&lt;/sup&gt;</th>
<th>RP&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>6.5</td>
<td>84</td>
<td>126</td>
<td>55</td>
<td>269</td>
<td>43</td>
<td>3</td>
<td>13</td>
<td>59</td>
<td>328</td>
<td>282</td>
</tr>
<tr>
<td>Bt1</td>
<td>15-25</td>
<td>6.5</td>
<td>14</td>
<td>67</td>
<td>67</td>
<td>148</td>
<td>38</td>
<td>1</td>
<td>9</td>
<td>48</td>
<td>196</td>
<td>209</td>
</tr>
<tr>
<td>Bt2</td>
<td>25-43</td>
<td>6.6</td>
<td>10</td>
<td>69</td>
<td>10</td>
<td>89</td>
<td>30</td>
<td>1</td>
<td>14</td>
<td>45</td>
<td>134</td>
<td>220</td>
</tr>
<tr>
<td>Bt3</td>
<td>43-56</td>
<td>6.5</td>
<td>12</td>
<td>65</td>
<td>113</td>
<td>190</td>
<td>59</td>
<td>1</td>
<td>8</td>
<td>68</td>
<td>258</td>
<td>94</td>
</tr>
<tr>
<td>Bt3</td>
<td>56-66</td>
<td>6.8</td>
<td>26</td>
<td>99</td>
<td>174</td>
<td>299</td>
<td>62</td>
<td>12</td>
<td>39</td>
<td>113</td>
<td>412</td>
<td>33</td>
</tr>
<tr>
<td>BC</td>
<td>66-81</td>
<td>6.8</td>
<td>21</td>
<td>69</td>
<td>247</td>
<td>357</td>
<td>52</td>
<td>5</td>
<td>12</td>
<td>69</td>
<td>406</td>
<td>76</td>
</tr>
<tr>
<td>BC</td>
<td>81-104</td>
<td>6.9</td>
<td>27</td>
<td>81</td>
<td>328</td>
<td>437</td>
<td>83</td>
<td>10</td>
<td>15</td>
<td>108</td>
<td>545</td>
<td>88</td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes NH<sub>4</sub>Cl-P.

<sup>b</sup>Σ3 = Σ1 + Σ2.

<sup>c</sup>RP = residual P.
Figure 32. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMClWH
Figure 33. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC2WH
Figure 34. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC3WH.
Figure 35. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC4WH
Iron phosphate is dominant in the upper horizons of each profile and CaP is the dominant active P form in the deeper horizons. Iron phosphate contributes from 1.1 to 39.0% of TP. High FeP values are in the upper horizons of the profiles. Calcium phosphate is between 0.2 and 88.6% of TP. High CaP values are in the lower parts of the profiles. Highest values of CaP as percentages of TP are 82.2% in FMC3WH and 88.6% in FMC4WH. Aluminum phosphate is between 0.3 and 24.5% of TP in the Group 2 profiles. Aluminum phosphate is less than 10% of the TP in more than 90% of the Group 2 samples.

Weighted active P values for the 0 to 25 cm and 25 to 100 cm depths are listed in Table 25. In each profile, the CaP value in the 25 to 100 cm zone is higher than in the 0 to 25 cm zone. In profiles FMC1WH and FMC2WH, FeP trends indicate accumulation in the 25 to 100 cm zones (Table 25). Iron phosphate values are lower in the 25 to 100 cm zones than in the 0 to 25 cm zones of profiles FMC3WH and FMC4WH. Profiles FMC3WH and FMC4WH have sandy subsoils which may influence the FeP content. Decrease of CaP and increase of FeP in the 25 to 100 cm zones of the profiles are associated with increased slope gradient and erosion class.

Depth distributions of active, inactive, and residual phosphate for FMC1WH, FMC2WH, FMC3WH, and FMC4WH are plotted in Figures 36, 37, 38, and 39, respectively. In the upper horizons of the profiles, RP is the dominant P form; active P
Table 25. Weighted values of active phosphates for the Group 2 - Downs soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>AlP 0-25</th>
<th>AlP 25-100</th>
<th>FeP 0-25</th>
<th>FeP 25-100</th>
<th>CaP 0-25</th>
<th>CaP 25-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC1WH (162C)</td>
<td>42</td>
<td>32</td>
<td>81</td>
<td>116</td>
<td>7</td>
<td>90</td>
</tr>
<tr>
<td>FMC2WH (162C2)</td>
<td>26</td>
<td>41</td>
<td>94</td>
<td>175</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>FMC3WH (162D3)</td>
<td>13</td>
<td>46</td>
<td>184</td>
<td>81</td>
<td>9</td>
<td>131</td>
</tr>
<tr>
<td>FMC4WH (162D2)</td>
<td>56</td>
<td>19</td>
<td>102</td>
<td>75</td>
<td>60</td>
<td>178</td>
</tr>
</tbody>
</table>

is dominant in the lower horizons. Inactive P is the second most abundant P form in profiles FMC1WH and FMC2WH (Figures 36 and 37). In profiles FMC1WH and FMC2WH, inactive P is highest in the B horizons. In profiles FMC3WH and FMC4WH, RP is the second most abundant P form in the lower horizons.

Increase of TIP with depth in the Group 2 soils is associated with an increase of CaP with depth in each profile. The relatively low TIP contents in the upper parts of the profiles are due to high contents of organic phosphorus (Mausbach, 1969). Relatively high values of FeP and lower CaP in the 25 to 100 cm zones and B horizons of FMC1WH and FMC2WH (Table 25) indicate that more transformation of phosphorus has occurred in these soils than in FMC3WH and FMC4WH. Apatite is the primary source of CaP. Calcium phosphate is
Figure 36. Depth distributions of active (*), occluded ($), and residual (R) P in FMClWH
Figure 37. Depth distributions of active (*), occluded ($), and residual (R) P in FMC2WH
Figure 38. Depth distributions of active (*), occluded ($), and residual (R) P in FMC3WH.
Figure 39. Depth distributions of active (*), occluded ($), and residual (R) P in FMC4WH
the initial form of P in the P transformation cycle (Syers et al., 1967).

In the Group 2 soils, RP values are highest in the upper horizons. Residual phosphate includes organic P and "lattice P" (Kurtz, 1953). Moderately weathered soils have been found to have high values of RP. The RP in these soils is dispersed in the matrices of concretions and iron oxide coatings. Syers et al. (1967) attributed RP to apatite inclusions in minerals such as hypersthene, augite, and plagioclase.

The relatively low content of inactive (occluded P) in the Group 2 soils indicates that there has not been substantial transformation of phosphorus. The dominance of active P is important in that this form of P is related to plant available P (Chang and Jackson, 1957; Hawkins and Kunze, 1965). The inclusion of RSP with occluded P may be misleading since high RSP contents have been found in soils which are not considered severely weathered (Smeck and Runge, 1971; Hawkins and Kunze, 1965; Westin and Buntley, 1967; Mausbach, 1969; Tembhare, 1973). Reductant-soluble phosphate makes up more than 50% of the occluded P in each profile.

**Group 3 - Fayette profile**

**Particle-size analysis** The clay, sand, and silt depth distribution curves for profile P32 are plotted in Figures 40, 41, and 42, respectively. The surface horizon is silt loam in texture and has a clay content of 19.3%. Clay content
Figure 40. Clay depth distribution for profile P32
Figure 41. Sand depth distribution for profile P32
Figure 42. Total silt depth distribution for profile P32
ranges from 18.9 to 21.1% above a depth of 33 cm. This depth, 33 cm, is the lower limit of the E2 horizon. Below 33 cm, the clay content increases abruptly from 21.1 to 26.2%, from the E2 horizon to the horizon. Below the BE transition horizon, clay content increases to a maximum value of 35.9% at a depth of 75.0 cm. The maximum clay content is in the Bt2 horizon. Clay content decreases to 28.5% in the BC horizon.

Total silt content is uniform to a depth of 18 cm. Below this depth, total silt decreases to a minimum, 62.1%, at a depth of 75 cm. The zone of low silt content is associated with the zone of maximum clay content. Below 75 cm, total silt increases with depth to a value of 69.1% in the BC horizon.

Sand content is highest, 2.8%, at a depth of 98 cm. Sand contents in the BC horizons are higher than those in the horizons above. The range of sand content is 1.6 to 2.8%. Thus, the range of sand content is only 1.2%.

The B/A clay ratio of the Fayette profile is 1.90. The weighted average clay content in the Bt and 25 to 100 cm zone are 33.9% and 31.4%, respectively. Based on the ratio, greater than 1.2, of clay in the illuvial to eluvial horizon, and the presence of clay coats, profile P32 meets the requirements for an argillic horizon.

Based on a high B/A clay ratio (McKim, 1972; Collins, 1977) and the presence of an argillic horizon (Soil Survey
Staff, 1975), the Fayette profile may be considered more differentiated, with respect to particle-size distribution, relative to the Tama and Downs soils (discussed previously). Collins (1977) reported a B/A clay ratio of 1.7 for a Fayette profile (B slope) from northeastern Iowa.

**Organic carbon - whole soil**  The depth distribution of organic carbon for the Fayette profile is shown in Figure 43. The maximum content of organic carbon, 3.56%, is in the surface horizon. Below the surface horizon, organic carbon content decreases sharply. It is a minimum of 0.22% at a depth of 121 cm. The soil solum is >75 cm thick and depth to >0.58% organic carbon extends to 28 cm. Weighted average percent organic carbon for the A horizon, soil solum, 0-25 cm zone, and 25 to 100 cm zone are 3.56, 0.58, 2.22, and 0.41%, respectively.

The organic carbon depth distribution trend for the Fayette profile is characteristic of a forest-derived soil (Broadbent, 1953). Under forest vegetation, the organic fraction is mainly leaf litter which accumulates at or near the soil surface. This leads to a very sharp decrease of organic matter below the soil surface. Smith et al. (1950) and Mausbach (1969) also studied Fayette (P32) profiles. They reported depth distribution trends similar to that reported in this study.
Figure 43. Organic carbon depth distribution for profile P32
Organic carbon - soil extracts

Selected organic carbon (OC) contents of the soil extracts are given in Table 26. Humic acid carbon contents range from 0.42% in the A horizon to 0.05% in the BE and lower horizons. Fulvic acid carbon exceeds HA carbon in all horizons and is in the range 1.07 to 0.11%. Consequently, H/F ratios are all <1. The average H/F ratio is 0.39. The H/F ratios below the BE horizon are slightly higher than those in the upper horizons.

Organic carbon contents in the extracts as percentages of organic carbon in the <100-mesh soil are given in Table 27. Between 33.3 and 63.2% of the carbon was extracted (HA+FA). Of the carbon extracted, FA comprises the dominant fraction. Fulvic acid carbon is between 22.9 and 51.7% of the extracted carbon. Humic carbon is between 10.4 and 19.3% of the extracted carbon (Table 27 and Appendix III).

Fayette soils developed under forest vegetation and are classified as Typic Hapludalfs. Because the profile (P32) is from a stable landscape position, the low H/F ratios are associated with forest influence on the soil. The H/F ratios for the Fayette profile agree with those reported by Kononova (1966) for other forest-derived soils.

Total phosphorus

The total phosphorus (TP) depth distribution for profile P32 is plotted in Figure 44. The TP content of the surface horizon (A) is 639 ppm. Below the surface, TP values decrease to a minimum of 414 ppm at a depth
Table 26. Selected humic acid carbon to fulvic acid carbon (H/F) ratios and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil, profile P32

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-5</td>
<td>3.56</td>
<td>0.42</td>
<td>1.07</td>
<td>0.39</td>
</tr>
<tr>
<td>E1</td>
<td>5-10</td>
<td>1.74</td>
<td>0.19</td>
<td>0.90</td>
<td>0.21</td>
</tr>
<tr>
<td>E2</td>
<td>10-18</td>
<td>1.27</td>
<td>0.17</td>
<td>0.45</td>
<td>0.38</td>
</tr>
<tr>
<td>E2</td>
<td>18-28</td>
<td>0.89</td>
<td>0.10</td>
<td>0.33</td>
<td>0.30</td>
</tr>
<tr>
<td>E2</td>
<td>28-33</td>
<td>0.49</td>
<td>0.07</td>
<td>0.24</td>
<td>0.29</td>
</tr>
<tr>
<td>BE</td>
<td>33-41</td>
<td>0.48</td>
<td>0.05</td>
<td>0.19</td>
<td>0.26</td>
</tr>
<tr>
<td>Bt1</td>
<td>41-48</td>
<td>0.48</td>
<td>0.05</td>
<td>0.11</td>
<td>0.45</td>
</tr>
<tr>
<td>Bt1</td>
<td>48-56</td>
<td>0.42</td>
<td>0.05</td>
<td>0.11</td>
<td>0.45</td>
</tr>
<tr>
<td>Bt2</td>
<td>56-64</td>
<td>0.36</td>
<td>0.05</td>
<td>0.11</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Table 27. Organic carbon in the humic acid (HA) and fulvic acid (FA) as percentages of carbon in the <100-mesh soil, profile P32

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>HA+FA</th>
<th>HA</th>
<th>FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0-5</td>
<td>41.9</td>
<td>11.8</td>
<td>30.1</td>
</tr>
<tr>
<td>E1</td>
<td>5-10</td>
<td>62.6</td>
<td>10.9</td>
<td>51.7</td>
</tr>
<tr>
<td>E2</td>
<td>10-18</td>
<td>48.8</td>
<td>13.4</td>
<td>35.4</td>
</tr>
<tr>
<td>E2</td>
<td>18-28</td>
<td>48.3</td>
<td>11.2</td>
<td>37.1</td>
</tr>
<tr>
<td>E2</td>
<td>28-33</td>
<td>63.2</td>
<td>14.3</td>
<td>49.0</td>
</tr>
<tr>
<td>BE</td>
<td>33-41</td>
<td>50.0</td>
<td>10.4</td>
<td>39.6</td>
</tr>
<tr>
<td>Bt1</td>
<td>41-48</td>
<td>33.3</td>
<td>10.4</td>
<td>22.9</td>
</tr>
<tr>
<td>Bt1</td>
<td>48-56</td>
<td>38.1</td>
<td>11.9</td>
<td>26.2</td>
</tr>
<tr>
<td>Bt2</td>
<td>56-64</td>
<td>44.4</td>
<td>13.9</td>
<td>30.6</td>
</tr>
</tbody>
</table>
Figure 44. Total phosphorus depth distribution for profile P32
of 30.5 cm. The TP minimum is in the TP eluviation zone. Below this zone, TP increases to a maximum of 741 ppm in the BC horizon at a depth of 131 cm. Total phosphorus contents of the B horizons range from 484 ppm to 741 ppm. Weighted TP values in selected zones are given in Table 28. The lowest TP content, 414 ppm, is associated with the E horizons. The highest TP value, 741 ppm, is in the BC horizon.

Table 28. Weighted total phosphorus (TP) values for selected zones of profile P32

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>I/E ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>E</td>
<td>B</td>
</tr>
<tr>
<td>ppm</td>
<td>ppm</td>
<td>ppm</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
<td>-----------</td>
</tr>
<tr>
<td>630</td>
<td>456</td>
<td>599</td>
</tr>
</tbody>
</table>

Clay and TP depth distributions are shown in Figure 45. Maximum clay content is at a depth of 67.5 cm and the minimum TP content is at a depth of 30.5 cm.

Total phosphorus eluvial and illuvial zones similar to those reported here have been recorded by Pearson et al. (1940) and Runge and Riecken (1966). They considered vertical mobility of P important in the TP profile. Pearson et al. (1940) considered redistribution of TP by native vegetation over a long period of time to be important in enriching the Ap horizon and depleting subjacent horizons of soils.
Figure 45. Depth distributions of clay and TP for profile P32
The lack of correspondence between TP maximum and clay maximum has been alluded to by Runge and Riecken (1966). They attributed the association between minimum TP and maximum clay to be due to the inability of clay to immobilize phosphorus.

Inorganic phosphorus fractions    Soil pH has an important effect on the relative abundance of the various forms of soil inorganic phosphorus. As a result, it will be discussed in this section along with the inorganic phosphorus content of the soil, Fayette (P32). The depth distribution for soil pH is plotted in Figure 46. The Fayette profile has pH values that range from 4.8 to 6.1. The lowest pH value is in the E2 horizon while the highest value is in the BC horizon at a depth of 131 cm. The pH value in the surface horizon is 5.2. Below the surface horizon, values decrease in the eluviation zone (E horizon). Below the eluviation zone to a depth of 94 cm, the values vary between a pH of 5.2 and a pH of 5.4. Below 94 cm, pH values increase gradually to a maximum of 6.1 in the BC horizon.

The higher pH values in the lower horizons of the profile indicate that leaching is less intense at greater depths. Leaching is most intense in the E horizons where the pH values are lowest.

Selected data for the inorganic phosphorus (IP) fractions are given in Table 29. The total inorganic phosphorus (TIP)
Figure 46. Depth distribution of soil pH in profile P32
Table 29. Inorganic phosphorus (IP) fractions and soil pH for profile P32, Fayette

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Active P</th>
<th>Inactive P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>A1P</td>
<td>FeP</td>
</tr>
<tr>
<td>A</td>
<td>0-5</td>
<td>5.2</td>
<td>97</td>
<td>125</td>
</tr>
<tr>
<td>E1</td>
<td>5-10</td>
<td>5.1</td>
<td>68</td>
<td>100</td>
</tr>
<tr>
<td>E2</td>
<td>10-18</td>
<td>4.8</td>
<td>65</td>
<td>74</td>
</tr>
<tr>
<td>E2</td>
<td>18-28</td>
<td>4.9</td>
<td>86</td>
<td>88</td>
</tr>
<tr>
<td>E2</td>
<td>28-33</td>
<td>5.1</td>
<td>58</td>
<td>120</td>
</tr>
<tr>
<td>BE</td>
<td>33-41</td>
<td>5.3</td>
<td>93</td>
<td>149</td>
</tr>
<tr>
<td>Bt1</td>
<td>41-48</td>
<td>5.3</td>
<td>135</td>
<td>170</td>
</tr>
<tr>
<td>Bt1</td>
<td>48-56</td>
<td>5.2</td>
<td>135</td>
<td>170</td>
</tr>
<tr>
<td>Bt2</td>
<td>56-64</td>
<td>5.4</td>
<td>66</td>
<td>164</td>
</tr>
<tr>
<td>BC</td>
<td>117-125</td>
<td>5.9</td>
<td>72</td>
<td>164</td>
</tr>
</tbody>
</table>

<sup>a</sup>Includes NH<sub>4</sub>Cl-P.

<sup>b</sup>Σ3 = Σ1 + Σ2.

<sup>c</sup>Rp = residual P.
fraction in the A horizon is 347 ppm. The TIP values decrease below the A horizon, from 5 to 28 cm, then increase with increasing depth. Maximum TIP is 689 ppm at a depth of 113 cm. The minimum TIP content is 224 ppm at a depth of 14 cm. Inorganic phosphorus fractions are divided into active P and inactive P. Figure 47 shows depth distributions of the active P forms. Aluminum phosphate values range from 58 to 168 ppm. The highest value, 168 ppm, is in the Bt horizon and the lowest value, 58 ppm, is in the E2 horizon. Aluminum phosphate values make up between 8.9 and 26.4% of the total phosphorus (TP). Iron phosphate content varies from 74 ppm in the E2 horizon to 256 ppm in the BC horizon, at a depth of 98 cm. Iron phosphate makes up from 15.4 to 37.9% of the TP. Iron phosphate values in the B horizons range from 20.4 to 37.9%. Iron phosphate content decreases below the A horizon. Values then increase with depth in the B horizons and decrease in the BC horizons (Figure 47).

Calcium phosphate values in profile P32 are between 9 and 40 ppm from the surface horizon to a depth of 109 cm. In the zone above 109 cm, CaP comprises between 1.4 and 8.9% of the TP. Below 109 cm, CaP values increase sharply and the contribution to TP is between 24.5 and 36.6%. Figure 47 shows CaP depth distribution relative to those of AlP and FeP.

Depth distributions for active P, inactive (occluded) P,
Figure 47. Depth distributions of CaP (C), AlP (A), and FeP (I) in P32
and residual P for profile P32 are plotted in Figure 48. Above 20 cm, the P forms are in the order residual P > active P > occluded P. Below 20 cm, the relative abundance of the P forms is in the order active P > occluded P > residual P. The dominance of active P is associated with high levels of FeP above a depth of 110 cm and a high content of CaP in the soil below a depth of 110 cm.

The dominance of CaP in the BC horizons of profile P32 indicates that the leaching intensity decreases with depth. Mausbach (1969) and Tembhare (1973) reported dominance of CaP in the C horizons of the soils they studied. Hawkins and Kunze (1965) and Westin and Buntley (1967) have also reported the dominance of CaP in the C horizons of the soils they studied.

Iron phosphate, RSP, and AIP are the dominant IP fractions in the B horizons of the Fayette soil. Calcium phosphate values in the Bt horizons range from 21 to 38 ppm. Smeck and Runge (1971) considered horizons with low CaP contents to be more weathered than horizons with higher CaP contents.

**Group 4 - selected Mollisols**

Three soil profiles representing three different series comprise the Group 4 soils. The represented series are Sawmill (933B), Sperry (122), and Muscatine (933B+). Landscape positions and morphological descriptions of the soils
Figure 48. Depth distributions of active (*), occluded ($), and residual (R) P in P32.
are given in Appendix II. The Group 4 soils all have restricted drainage.

**Particle-size distribution**  Clay and sand depth distributions for the Group 4 soils are plotted in Figures 49 and 50, respectively. Total silt depth distributions for the same soils are shown in Figure 51. In profile FMC6WH, the sand content increases with depth to a maximum of 35.7% at a depth of 208 cm (Figure 50). In the upper 224 cm of FMC8WH, the sand content is less than 4%. Below a depth of 224 cm, the sand content increases and reaches a maximum of 48.1 cm at a depth of 240 cm. Above a depth of 231 cm in profile FMC9WH, the sand content is less than 3%. Below 231 cm, the sand content reaches a maximum of 18.9% at a depth of 226 cm. Increases in sand content at 236 cm in FMC8WH and 221 cm in FMC9WH reflect changes in parent material. These depths, 236 and 221 cm, mark the base of the loess and the top of the till.

The Group 4 soils have surface horizons which are light silty clay loam in texture. The clay contents in the surface horizons of FMC6WH, FMC8WH, and FMC9WH are 28.7, 30.7, and 31.7%, respectively. The maximum clay content is 35.4% at a depth of 61 cm in FMC6WH (Sawmill), 35.5% at a depth of 43.5 cm in FMC8WH (Muscatine); and 41.7% at a depth of 44.5 cm in FMC9WH (Sperry). Maximum clay content is in the Alb horizon of FMC6WH, the BA horizon of FMC8WH, and the Bt2 horizon of
Figure 49. Clay depth distributions for FMC6WH (F), FMC8WH (H), and FMC9WH (I)
Figure 50. Sand depth distributions for FMC6WH (F), FMC8WH (H), and FMC9WH (I)
Figure 51. Total silt depth distributions for FMC6WH (F), FMC8WH (H), and FMC9WH (I)
FMC9WH. The B/A clay ratio is 1.16 for FMC8WH, and 1.70 for FMC9WH. In FMC6WH, B horizons were not described in the post-cultural sediments. The B/A clay ratio of the buried solum is 0.97.

The weighted average clay content of the 25 to 100 cm zone is 32.7% in FMC6WH, 32.6% in FMC8WH, and 36.5% in FMC9WH. Clay skins were described in the Sperry profile (FMC9WH) and there is a 20% increase of clay within 30 vertical cm. As a result, the Sperry profile meets the requirements for a soil with an argillic horizon. The weighted average clay contents of the argillic horizon and the control section are 35.4 and 39.5%, respectively. Profiles FMC6WH and FMC8WH do not have argillic horizons. In the Sperry soil (FMC9WH), the argillic horizon extends from a depth of 28 cm to a depth of 117 cm.

The similar and relatively uniform sand depth distributions of FMC8WH and FMC9WH suggest a similar parent material. The sand content, 2.2 to 3.8%, in the loess of FMC8WH compares well to the range, 2.6 to 3.4%, reported by Collins (1977). Collins' Muscatine profile, Col-86-7, was also from Tama County, Iowa. Bicki (1981) studied a Sperry soil (52B209) from a high terrace in southeastern Iowa. He reported a higher sand content than is recorded for profile FMC9WH. There was also a shallower depth, 137 cm, to the lithologic discontinuity. In profile FMC6WH, the sand content increases with depth. The maximum sand content in this profile, FMC6WH,
is 35.7% at a depth of 208 cm.

The clay depth distribution trends (Figure 49) indicate that profile FMC9WH is highly differentiated. This is supported by the high B/A clay ratio, 1.70. Bicki (1981) reported a B/A clay ratio of 1.62 for a Sperry profile from southeastern Iowa. The B/A clay ratio has been used as an index of horizon differentiation and profile development (McKim, 1972). The low B/A clay ratios of FMC6WH and FMC8WH indicate a lesser degree of horizon differentiation than exists in FMC9WH. The B/A clay ratio of FMC8WH agrees with values reported by Collins (1977) and Bicki (1981).

**Organic carbon - whole soil** The depth distributions of organic carbon for the Group 4 soils are shown in Figure 52. Organic carbon contents in the surface horizons are 3.48, 2.68, and 2.67%, for FMC6WH (933B+), FMC9WH (122), and FMC8WH (119B), respectively. Of the three profiles, FMC6WH has the highest organic carbon content. In FMC6WH, the organic carbon content decreases below the surface horizon, then increases to 3.31% at the buried surface, at a depth of 61 cm. Below 61 cm, the organic carbon content decreases to a minimum of 0.33% at a depth of 208 cm. Organic carbon values decrease with depth in profiles FMC8WH and FMC9WH. However, there is a sharper decline closer to the surface in FMC9WH than in FMC8WH. The depth to <0.58% organic carbon is 46 cm in the Muscatine soil, 51 cm in the Sperry soils, and
Figure 52. Organic carbon depth distributions for FMC6WH (F), FMC8WH (H), and FMC9WH (I)
168 cm in the Sawmill soil. The thickness of overlying postcultural sediment is 53 cm in FMC6WH. One of the requirements for the mollic epipedon is >0.58% OC (Soil Survey Staff, 1975). The Group 4 soils meet the OC criterion required for the mollic epipedon. However, the postcultural sediment of FMC6WH is not the result of pedogenesis. The depth of mollic colors is 66 cm in profile FMC6WH, 57 cm in profile FMC8WH, and 38 cm in profile FMC9WH. Based on color and organic carbon content, the mollic epipedon is 46 cm in profile FMC8WH, 38 cm in profile FMC9WH, and 66 cm in the buried soil of FMC6WH. The postcultural sediments do not qualify for a mollic epipedon.

The organic carbon distribution trend of profile FMC6WH is due to the effect of postcultural sediment (Collins and Fenton, 1982). The surface horizons of the buried soils studied by Collins and Fenton (1982) had total carbon contents ranging from 2.5 to 4.0%. The depth to less than 0.58% organic carbon is 51 cm for profile FMC9WH (Sperry). Bicki (1981) reported depth to less than 0.58% total carbon of 55.6 cm in a Sperry soil from southeastern Iowa. Fenton (1966) reported greater depth, 81.3 cm, for a Muscatine soil than that obtained for the Muscatine profile (FMC8WH) in this study. Fenton's profile was also from northeastern Iowa.
Organic carbon - soil extracts

Organic carbon (OC) in the soils and extracts of selected horizons of profiles FMC5WH, FMC8WH, and FMC9WH are given in Tables 30, 31, and 32, respectively. Generally, carbon in the extracts, HA and FA, decreases with depth. Organic carbon in the HA fractions of the Sawmill profile (FMC6WH) ranges from 0.98% at a depth of 61 cm to 0.23% at a depth of 148.5 cm. In profile FMC8WH, the HA carbon range is 0.60% at a depth of 11.5 cm to 0.06% at all depths below 46 cm. Humic acid carbon contents range from 0.85% in the surface horizon to 0.08% below a depth of 38 cm. Humic acid carbon exceeds FA carbon in the Sawmill profile (FMC6WH). As a result, the H/F ratios exceed unity. In the Muscatine profile, FMC8WH, H/F is low, <1, because of relatively high FA carbon content. The H/F ratios above 41 cm are between 0.54 and 0.79. Below 41 cm, H/F ratios are similar, 0.26. In profile FMC9WH (Sperry), H/F ratios range from 0.80 to 1.31. The average H/F ratios are 1.89, 0.42, and 0.86 for the Sawmill (FMC6WH), Muscatine (FMC8WH), and Sperry (FMC9WH) profiles, respectively.

Carbon extracted (HA+FA) as percent of carbon in the soil ranges from 38.5 to 76.3% in FMC6WH, 42.6 to 82.1% in FMC8WH, and 25.3 to 85.7% in FMC9WH.

The high H/F ratios in FMC6WH and FMC9WH are related to the influence of grass vegetation on the soils (Kononova, 1966; Lowe, 1980; Bettany et al., 1980). High H/F ratios
### Table 30. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil for FMC6WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-13</td>
<td>3.48</td>
<td>0.80</td>
<td>0.71</td>
<td>1.13</td>
</tr>
<tr>
<td>C</td>
<td>25-43</td>
<td>2.76</td>
<td>0.85</td>
<td>0.48</td>
<td>1.77</td>
</tr>
<tr>
<td>Alb</td>
<td>53-69</td>
<td>3.31</td>
<td>0.98</td>
<td>0.48</td>
<td>2.04</td>
</tr>
<tr>
<td>A2b</td>
<td>84-94</td>
<td>2.18</td>
<td>0.56</td>
<td>0.28</td>
<td>2.00</td>
</tr>
<tr>
<td>A3b</td>
<td>94-106</td>
<td>1.97</td>
<td>0.65</td>
<td>0.47</td>
<td>2.04</td>
</tr>
<tr>
<td>BAb</td>
<td>106-119</td>
<td>1.54</td>
<td>0.82</td>
<td>0.16</td>
<td>5.13</td>
</tr>
<tr>
<td>Bw1b</td>
<td>119-129</td>
<td>1.18</td>
<td>0.54</td>
<td>0.36</td>
<td>1.50</td>
</tr>
<tr>
<td>Bw1b</td>
<td>129-138</td>
<td>1.00</td>
<td>0.24</td>
<td>0.33</td>
<td>0.73</td>
</tr>
<tr>
<td>Bw2b</td>
<td>138-159</td>
<td>0.89</td>
<td>0.23</td>
<td>0.23</td>
<td>1.00</td>
</tr>
</tbody>
</table>

### Table 31. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil in FMC8WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-8</td>
<td>2.67</td>
<td>0.40</td>
<td>0.74</td>
<td>0.54</td>
</tr>
<tr>
<td>Ap</td>
<td>8-15</td>
<td>2.19</td>
<td>0.60</td>
<td>0.89</td>
<td>0.67</td>
</tr>
<tr>
<td>A</td>
<td>15-28</td>
<td>1.69</td>
<td>0.46</td>
<td>0.58</td>
<td>0.79</td>
</tr>
<tr>
<td>BA</td>
<td>28-41</td>
<td>1.62</td>
<td>0.57</td>
<td>0.72</td>
<td>0.79</td>
</tr>
<tr>
<td>BA</td>
<td>41-46</td>
<td>1.33</td>
<td>0.15</td>
<td>0.63</td>
<td>0.24</td>
</tr>
<tr>
<td>Bwl</td>
<td>46-57</td>
<td>0.54</td>
<td>0.06</td>
<td>0.26</td>
<td>0.23</td>
</tr>
</tbody>
</table>
Table 32. Humic acid carbon to fulvic acid carbon ratios (H/F) and percent organic carbon in the humic acid (HA) and fulvic acid (FA) extracts and <100-mesh soil in FMC9WH

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Soil</th>
<th>HA</th>
<th>FA</th>
<th>H/F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-8</td>
<td>2.68</td>
<td>0.85</td>
<td>0.65</td>
<td>1.31</td>
</tr>
<tr>
<td>Ap</td>
<td>8-15</td>
<td>2.64</td>
<td>0.69</td>
<td>0.81</td>
<td>0.85</td>
</tr>
<tr>
<td>E</td>
<td>15-28</td>
<td>1.12</td>
<td>0.47</td>
<td>0.49</td>
<td>0.96</td>
</tr>
<tr>
<td>Bt1</td>
<td>28-38</td>
<td>0.92</td>
<td>0.11</td>
<td>0.16</td>
<td>0.69</td>
</tr>
<tr>
<td>Bt2</td>
<td>38-51</td>
<td>0.71</td>
<td>0.08</td>
<td>0.10</td>
<td>0.80</td>
</tr>
<tr>
<td>Bt2</td>
<td>51-64</td>
<td>0.56</td>
<td>0.08</td>
<td>0.10</td>
<td>0.80</td>
</tr>
</tbody>
</table>

(up to 5.13) were obtained for buried horizons of the Sawmill profile. Lowe (1980) has reported high H/F ratios (average 4.32) for buried Ah horizon from Turbic Cryosols. Turbic Cryosols in the Canadian Taxonomy are equivalent to Pergelic Cryochrepts in Soil Taxonomy (Bentley, 1979).

The H/F ratios of the Muscatine profile (FMC8WH) were high enough in the A horizon to be considered characteristic of grass-derived soils. The H/F ratios to a depth of 41 cm range from 0.54 to 0.79 (Table 31). Below 41 cm, the H/F ratios in FMC8WH are lower than are characteristic of H/F ratios of subsoils (Kononova, 1966; Lowe, 1980).

**Total phosphorus** The total phosphorus (TP) depth distributions for the Group 4 soils are plotted in Figure 53. The Group 4 soils are three Mollisols with restricted drainage.
Figure 53. Total phosphorus depth distribution for FMC6WH (F), FMC8WH (H), and FMC9WH (I)
Total phosphorus contents in the surface horizons of the soils are 829 ppm in the Sawmill profile (FMC6WH), 514 ppm in the Muscatine soil (FMC8WH), and 973 ppm in the Sperry soil (FMC9WH). All three profiles in Group 4 have TP eluviation zones. In profiles FMC8WH and FMC9WH, the eluviation zones are distinct and are at depths of 28 to 57 cm and 15 to 51 cm, respectively. In the Sawmill soil, TP decreases with depth to a minimum of 364 ppm in the A2b horizon. Below the A2b horizon, TP content varies only slightly to a depth of 138 cm. Total phosphorus content then increases to a maximum of 2102 ppm at a depth of 195.5 cm in the Cglb horizon. In the Sawmill profile, TP content is >1000 ppm between 168 and 200 cm. Profile FMC8WH has a lithologic discontinuity at a depth of 236 cm. At the lithologic discontinuity, TP content decreases from 571 to 278 ppm. Sand content increases from 14.4 to 48.1% at the lithologic discontinuity. Above the lithologic discontinuity in FMC8WH, a low TP value, 326 ppm, is in the TP eluviation zone. Below the TP eluviation zone, TP increases to a maximum value of 789 ppm at a depth of 163.5 cm in the C1 horizon. Total phosphorus then decreases with depth. In the Sperry soil (FMC9WH), the minimum TP value is at a depth of 33 cm. The TP eluviation zone is associated with the E, Bt1, and Bt2 horizons. Below the eluviation zone, TP content increases to 1208 ppm at a depth of 124.5 cm. Total phosphorus contents of >1000 ppm are between depths of 94 and
132 cm. Between 170 and 213 cm, TP content is >900 ppm.

Weighted average TP for selected zones are given in Table 33. Profile FMC6WH has postcultural sediment above a depth of 53 cm. Each soil has minimum TP in the 25 to 100 cm zone. There is an accumulation of TP in the 100 to 200 cm zone of each profile. Highest TP, below the surface horizons is in profile FMC9WH (Sperry). The Sperry profile is from an upland depression.

Figures 54, 55, and 56 show TP and associated clay depth distributions for profiles FMC6WH, FMC8WH, and FMC9WH, respectively. Clay illuviation zones are associated with TP eluviation zones. In the Sawmill profile, minimum TP is at a depth of 76.5 cm and maximum clay is at a depth of 61 cm. Clay maximum is at a depth of 43.5 cm in FMC8WH. Minimum TP of 326 ppm in the soil solum is at a depth of 51.5 cm. The lowest TP value in FMC8WH is below the lithologic discontinuity. In the Sperry soil, the clay maximum is at a depth of 44.5 cm and the TP minimum is at a depth of 33 cm.

The presence of TP eluviation and illuviation zones similar to those reported for the Group 4 profiles have been reported by Pearson et al. (1940) and Runge and Riecken (1966). In the Sawmill profile, TP generally decreases to a depth of 138 cm then increases (Figure 53).

Total phosphorus decreases below the surface horizon, increases in the B or C horizon then decreases with greater
Table 33. Weighted average total phosphorus (TP) values for selected zones of the soils with restricted drainage - Group 4

<table>
<thead>
<tr>
<th>Profile</th>
<th>Depth (cm)</th>
<th>B horizon</th>
<th>B horizon</th>
<th>B horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-25</td>
<td>25-100</td>
<td>0-130</td>
<td>100-200</td>
</tr>
<tr>
<td>FMC6WH</td>
<td>798&lt;sup&gt;a&lt;/sup&gt;</td>
<td>460&lt;sup&gt;b&lt;/sup&gt;</td>
<td>520</td>
<td>859&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>FMC8WH</td>
<td>481</td>
<td>446</td>
<td>762</td>
<td>503</td>
</tr>
<tr>
<td>FMC9WH</td>
<td>776</td>
<td>600</td>
<td>992</td>
<td>778</td>
</tr>
</tbody>
</table>

<sup>a</sup>Overwash.

<sup>b</sup>Buried soil below 53 cm depth.

depth in the Group 4 soils; these zones are not very distinct in FMC8WH (Figure 53). Similar TP decreases and increases have been reported by Pearson et al. (1940), Allaway and Rhoades (1951), Godfrey and Riecken (1954), and Runge and Riecken (1966). Runge and Riecken (1966) considered the zones of TP minimum and maximum to be eluviation and illuviations zones, respectively. Vertical redistribution of phosphorus has been proposed as being responsible for the TP profile (Pearson et al., 1940; Ghani and Aleem, 1943). The most strongly expressed TP eluviation zone is in the Sperry soil (Figure 53). This finding is similar to that reported by Bicki (1981) for a Sperry soil from southeast Iowa. In the Sperry profile studied by Bicki (1981), TP minimum in the eluviation zone was associated with the albic horizon. In FMC9WH, the TP minimum is
Figure 54. Clay and TP depth distributions for FMC6WH
Figure 55. Depth distributions of clay and TP for FMC8WH
Figure 56. Depth distributions of clay and TP for FMC9WH
subjacent to the E horizon.

In the Sperry and Sawmill profiles, there are zones of high TP content (>900 ppm). The Sperry soil (FMC9WH) has two distinct zones of high TP content below a depth of 90 cm. Runge and Riecken (1966) related TP variability in deoxidized and unleached loess to segregation of phosphorus in pipestems (iron segregation). The high phosphorus contents in the Sawmill and Sperry soils may be related to their positions on the landscape (Appendix II). Both soils are in positions that collect runoff from surrounding soils. This conclusion is supported by the high TP contents in the surface horizons of the soils relative to the Muscatine soil (Table 33). Smeck and Runge (1971) reported high TP content in soils located in water collecting landscape positions. They considered the transport of phosphorus as surface water flow to be important. In FMC6WH and FMC9WH, phosphorus in water may be mobilized downward and precipitated in mottles or iron segregations or both. Other agents may also be involved in phosphorus precipitation.

The low TP, 278 ppm, at 236 cm depth in profile FMC8WH (Muscatine) is associated with a high sand content, 48.1%. Bicki (1981) also related decreases in TP content to increasing sand content. Bicki's relationship was for a Muscatine soil from southeast Iowa.

In the Sperry (FMC9WH) and Muscatine (FMC8WH) soils, TP eluviation zones are associated with the zones of maximum
clay. Similar results have been obtained by Godfrey and Riecken (1954) for poorly drained soils. Runge and Riecken (1966) concluded that the association between TP minimum and clay maximum is related to the inability of clay to immobilize phosphorus. High TP content in the lower B or C horizons is related to the ability of calcium to immobilize phosphorus.

Inorganic phosphorus fractions The soil pH data will be discussed along with the data for the inorganic phosphorus (IP) fractions. The pH depth distributions for the Group 4 soils are plotted in Figure 57. In the upper 20 cm of the sola, the pH values range from 6.3 to 6.8 and are in the order FMC9WH (Sperry) < FMC8WH (Muscatine) < FMC6WH (Sawmill). Between depths of 20 and 80 cm, the Sawmill profile is the most acid of the three profiles. Low pH values in the Sawmill profile are associated with the C horizons of the postcultural sediments and the Alb horizon. Between 80 and 190 cm, FMC8WH has the highest pH; values range from 6.7 to 7.7. The pH distributions of FMC6WH and FMC9WH are similar between depths of 80 and 190 cm. The pH values between these depths, 80 and 190 cm, for FMC6WH and FMC9WH range from 6.6 to 7.2 with values increasing with depth.

Selected data for IP fractions are given in Table 34. Total inorganic phosphorus (TIP) fractions range from 252 to 2045 ppm in FMC6WH, from 61 to 736 ppm in FMC8WH, and from 241 to 1143 ppm in FMC9WH. The TIP contents generally increase
Figure 57. Depth distribution of soil pH for FMC6WH (F), FMC8WH (H), and FMC9WH (I).
Table 34. Selected inorganic phosphorus (IP) fractions for the Group 4 soils

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Active P</th>
<th>Occluded P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AIP</td>
<td>FeP</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-13</td>
<td>Ap</td>
<td>102</td>
<td>188</td>
</tr>
<tr>
<td>13-25</td>
<td>Ap</td>
<td>115</td>
<td>156</td>
</tr>
<tr>
<td>25-43</td>
<td>C</td>
<td>51</td>
<td>103</td>
</tr>
<tr>
<td>43-53</td>
<td>C</td>
<td>39</td>
<td>90</td>
</tr>
<tr>
<td>53-69</td>
<td>A1b</td>
<td>41</td>
<td>107</td>
</tr>
<tr>
<td>69-84</td>
<td>A2b</td>
<td>38</td>
<td>87</td>
</tr>
<tr>
<td>84-94</td>
<td>A2b</td>
<td>37</td>
<td>79</td>
</tr>
<tr>
<td>94-106</td>
<td>A3b</td>
<td>42</td>
<td>85</td>
</tr>
</tbody>
</table>

FMC6WH

| 0-8       | Ap      | 16       | 49        | 26         | 92  | 19   | 1    | 3  | 23 | 399    | 115  |
| 15-28     | A       | 4        | 25        | 10         | 39  | 15   | 0    | 7  | 22 | 399    | 61   |
| 28-41     | BA      | 0        | 30        | 5          | 35  | 23   | 3    | 14 | 40 | 306    | 75   |
| 46-57     | Bw1     | 12       | 75        | 20         | 107 | 11   | 5    | 31 | 47 | 172    | 154  |
| 57-73     | Bw2     | 25       | 81        | 37         | 143 | 37   | 0    | 25 | 62 | 235    | 205  |
| 73-89     | Bw3     | 12       | 78        | 271        | 361 | 52   | 0    | 12 | 64 | 57     | 425  |
| 89-96     | Bw4     | 11       | 80        | 390        | 481 | 48   | 4    | 4  | 56 | 67     | 537  |
| 96-112    | Bw5     | 6        | 68        | 446        | 520 | 56   | 3    | 3  | 62 | 78     | 582  |

\*\(\Sigma_1 = \text{sum of active P.}\)

\(\Sigma_2 = \text{sum of inactive (occluded) P.}\)

\(\Sigma_1 + \Sigma_2 = \text{residual phosphate (RP).}\)
Table 34. (Continued)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Horizon</th>
<th>Active P</th>
<th>Occluded P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AlP</td>
<td>FeP</td>
</tr>
<tr>
<td>0-8</td>
<td>Ap</td>
<td>108</td>
<td>165</td>
</tr>
<tr>
<td>15-28</td>
<td>E</td>
<td>34</td>
<td>53</td>
</tr>
<tr>
<td>28-38</td>
<td>Bt1</td>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>38-51</td>
<td>Bt2</td>
<td>31</td>
<td>65</td>
</tr>
<tr>
<td>64-74</td>
<td>Bt3</td>
<td>21</td>
<td>48</td>
</tr>
<tr>
<td>74-79</td>
<td>Bt4</td>
<td>29</td>
<td>71</td>
</tr>
<tr>
<td>94-102</td>
<td>Bt5</td>
<td>41</td>
<td>182</td>
</tr>
<tr>
<td>117-132</td>
<td>BC</td>
<td>78</td>
<td>206</td>
</tr>
</tbody>
</table>

FMC9WH
with depth in the profiles. The lowest values are in the 15 to 53 cm depth range of each profile. In the upper horizons where TIP content is low, CaP values are also low. Highest TIP values are at a depth of 195.5 cm in FMC6WH, 163.5 cm in FMC8WH, and 124.5 cm in FMC9WH. In FMC6WH and FMC8WH, maximum TIP contents are in the C horizon. In profile FMC9WH, the maximum TIP content is in the BC horizon. Increase of TIP with depth is associated with an increase of CaP with depth in each profile.

Active P forms increase with depth in each profile. The increase in each instance is associated with an increase in CaP content. However, in FMC6WH, FeP is the dominant active P form below a depth of 180 cm. Active P content ranges from 181 to 1790 ppm in FMC6WH, from 35 to 709 ppm in FMC8WH, and from 113 to 839 ppm in FMC9WH. Figures 58, 59, and 60 show the depth distributions of the active P forms for profiles FMC6WH, FMC8WH, and FMC9WH, respectively. In FMC6WH, FeP is the dominant active P form in the upper 90 cm and below a depth of 180 cm. Between 90 and 180 cm, CaP is the dominant active P form. Aluminum P is the least abundant P form in FMC6WH. Calcium phosphate is the dominant active P form below a depth of 70 cm in FMC8WH (Figure 59). Iron phosphate is the second most abundant active P form and A1P is the least abundant in FMC8WH. Calcium phosphate is dominant below a depth of 30 cm in FMC9WH (Figure 60). Above a depth of 30 cm,
Figure 58. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC6WH.
Figure 59. Depth distribution of CaP (C), AlP (A), and FeP (I) for FMC8WH
Figure 60. Depth distributions of CaP (C), AlP (A), and FeP (I) for FMC9WH
active inorganic phosphorus fractions are in the order FeP > AIP > CaP in profile FMC9WH.

Active, inactive (occluded), and residual P for FMC6WH, FMC8WH, and FMC9WH are plotted in Figures 61, 62, and 63, respectively. Residual phosphate is dominant in the upper parts of FMC6WH and FMC8WH. In the lower horizons of the three soils, active P is the most abundant P form. In the lower horizons of FMC6WH and FMC9WH, the P forms are in the order active P > occluded P > residual P.

The increasing TIP content with depth in the Group 4 soils is similar to that reported by Mausbach (1969) and Tembhare (1973). Increasing TIP with depth is mainly associated with high CaP content in the lower horizons of the Group 4 soils. Of the active P forms, AlP is least abundant in the Group 4 soils. Mausbach (1969) considered the competition between clay and P for Al ions to be important in determining the content of AlP in poorly drained soils. Of the three active P fractions discussed, AlP varies least in the soils. Hawkins and Kunze (1965), Juo and Ellis (1968), and Tembhare (1973) also reported relatively uniform AlP content with depth in selected soils. Tembhare (1973) concluded that AlP may serve mainly as a transition phase for decreasing CaP and increasing FeP. Leaching and transformation may be responsible for relatively low CaP contents in the Upper horizons of the Group 4 sola. The upper horizons of the Group 4 sola have lower pH
Figure 61. Depth distributions of active (*), occluded ($), and residual (R) P in FMC6WH
Figure 62. Depth distributions of active (*), occluded ($), and residual (R) P in FMC8WH
Figure 63. Depth distributions of active (*), occluded (§), and residual (R) P in FMC9WH
than the lower horizons. In calcareous soils, inorganic phosphates are mainly associated with calcium and, in acid soils, inorganic phosphates are mainly associated with iron and aluminum (Chang and Jackson, 1957; Stelly and Pierre, 1942). Based on the preceding conclusion, P transformation in the upper horizons of the Group 4 soils has occurred as follows: CaP → AlP → FeP. This scheme is in agreement with that proposed by Chang and Jackson (1958). The dominance of CaP with increasing depth in the Group 4 soils is in agreement with the findings of Hawkins and Kunze (1965), Westin and Buntley (1967), Mausbach (1969), Smeck and Runge (1971), and Tembhare (1973).

Residual phosphate (RP) and active phosphate are the dominant P forms in the three Group 4 profiles (Figures 61, 62, and 63). Relatively high RP values in the upper horizons indicate high contents of organic phosphorus. Based on the Chang and Jackson (1958) scheme, profiles FMC6WH and FMC8WH would be considered highly developed since they have high contents of RSP. Particle-size distribution, discussed earlier, does not support this conclusion. Westin and Debrito (1969), Mausbach (1969), Smeck and Runge (1971), and Tembhare (1973) also found high percentages of RSP in soils. Some of the soils studied by the above authors are only medial in development (Smith et al., 1950).
Comparison of Selected Properties in the Tama, Downs, and Fayette Profiles

Morphological properties

The Tama, Downs, and Fayette series represent a biosequence. The Tama soils (Group 1) and Downs soils (Group 2) represent a range of slope and erosion classes. Profiles P27 (Tama 120B) and P32 (Fayette 163B) are considered modal profiles. Also, they are end members of the biosequence. The Fayette soil developed under forest vegetation while the Tama soil developed under grass vegetation. Tables 35, 36, and 37 list selected properties in the "Range in Characteristics" for the Tama, Downs, and Fayette series, respectively (Soil Survey Staff, 1979, 1982, 1981, respectively). Selected morphological data for the soils are summarized in Table 38. Samples to a depth of 137 cm were available for the Fayette profile (P32). The solum may extend below this depth. The Downs soils on 5 to 9% slopes have an average solum thickness of 149 cm. This compares to a solum thickness of 122 cm in the Tama profile on 5 to 9% slopes, FMC7WH. The relatively thick (170 cm) solum of FMC1WH is probably related to its location at a summit position on the landscape. The soils which developed on sideslopes, FMC2WH and FMC7WH, have solum thicknesses of 127 and 122 cm, respectively.

Profiles FMC5WH (120D2) and FMC4WH (162D2) have solum thickness of 74 cm and 119 cm, respectively. Both soils are
Table 35. Selected properties in the range of characteristics for the Tama series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range of characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solum thickness</td>
<td>91 to 152+ cm</td>
</tr>
<tr>
<td>pH</td>
<td>Medium to strongly acid in most acid part of solum</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Usually lacking above 122 cm</td>
</tr>
<tr>
<td>Sand content</td>
<td>Typically &lt;10%, can include more</td>
</tr>
<tr>
<td>Color: A1 or Ap horizon</td>
<td>10YR2/1 or 10YR2/2 or 10YR3/2</td>
</tr>
<tr>
<td>Texture: A horizon</td>
<td>Sic1 or sil</td>
</tr>
<tr>
<td>Color: B1 horizon</td>
<td>10YR3/3 or 10YR4/3 or 10YR3/2</td>
</tr>
<tr>
<td>Color: B2 and B3 horizons</td>
<td>10YR4/3 or 10YR4/4 or 10YR5/4</td>
</tr>
<tr>
<td>Chroma and value</td>
<td>Commonly increase with depth</td>
</tr>
<tr>
<td>Clay content: B horizon</td>
<td>27 to 35%</td>
</tr>
<tr>
<td>Mottles</td>
<td>Lower B horizon</td>
</tr>
<tr>
<td>Silt coats</td>
<td>B horizon</td>
</tr>
<tr>
<td>Clay coats</td>
<td>B horizon</td>
</tr>
<tr>
<td>Color: C horizon</td>
<td>10YR hue; value 4 or 5; chroma 3-6</td>
</tr>
</tbody>
</table>

*Thickens of the A horizon, depth to carbonates, depth to mottling, depth to subhorizon highest in clay, maximum percent clay, and solum thickness usually decrease as gradient increases on convex slopes; sandy substratum phases are within the range of the series (Soil Survey Staff, 1979).*
Table 35. Selected properties in the range of characteristics for the Downs series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range of characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solum thickness</td>
<td>107 to 152+ cm</td>
</tr>
<tr>
<td>pH</td>
<td>Medium to very strongly acid in most acid part</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Lacking above 152 cm</td>
</tr>
<tr>
<td>Sand content</td>
<td>Typically &lt;10%</td>
</tr>
<tr>
<td>Color: A1 or Ap horizon</td>
<td>10YR2/2 to 10YR3/1</td>
</tr>
<tr>
<td>Thickness: A1 or Ap horizon</td>
<td>15 to 23 cm</td>
</tr>
<tr>
<td>E horizon</td>
<td>Ranges from distinct to incipient; mixed in with Ap in many pedons</td>
</tr>
<tr>
<td>Color: E horizon</td>
<td>10YR3/2 or 10YR4/2 or 10YR5/3</td>
</tr>
<tr>
<td>Silt coats</td>
<td>E and B horizons</td>
</tr>
<tr>
<td>Color: upper B horizon</td>
<td>10YR4/3; grades to values of 4 or 5 and chromas of 4 to 6 with increasing depth</td>
</tr>
<tr>
<td>Clay content: B horizon</td>
<td>27 to 35%</td>
</tr>
<tr>
<td>Texture: B horizon</td>
<td>Sicl</td>
</tr>
<tr>
<td>Mottles&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Below a depth of 76 cm</td>
</tr>
<tr>
<td>Texture: C horizon</td>
<td>Typically SIC</td>
</tr>
</tbody>
</table>

<sup>a</sup>Mottles below a depth of 76 cm are related to relict weathering (Soil Survey Staff, 1982).
Table 37. Selected properties in the range of characteristics for the Fayette series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range of characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solum thickness</td>
<td>91 to 152 cm</td>
</tr>
<tr>
<td>pH</td>
<td>Very strongly or strongly acid in most acid part of solum</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Present below 102 cm in some profiles</td>
</tr>
<tr>
<td>Color; A horizon</td>
<td>10YR3/1 or 10YR3/2 or 10YR2/2; Ap is 10YR4/2 or 10YR4/3 where cultivated or eroded</td>
</tr>
<tr>
<td>Color; E horizon</td>
<td>Value of 4 or 5 and chroma of 1 to 4; upper part has a value of 3 in some pedons</td>
</tr>
<tr>
<td>Structure; E horizon</td>
<td>Platy, weak or moderate and thin or medium</td>
</tr>
<tr>
<td>Color; Bt horizon</td>
<td>10YR hue, value of 4 or 5 and chroma of 3 or 4</td>
</tr>
<tr>
<td>Texture; Bt horizon</td>
<td>Sicl</td>
</tr>
<tr>
<td>Clay content; B horizon</td>
<td>28 to 35%</td>
</tr>
<tr>
<td>Mottles</td>
<td>Below 76 cm in some profiles; 10YR or 2,5Y hue, value of 5 and chroma of 2</td>
</tr>
<tr>
<td>BC and C horizons</td>
<td>Sicl or sicl; 10YR4/4 or 10YR5/4</td>
</tr>
</tbody>
</table>

The depth to subhorizon highest in clay, thickness of the A, E and Bt horizons, maximum percent clay, depth to mottles and carbonates, and solum thickness usually decrease as slope gradient increases on convex slopes (Soil Survey Staff, 1981).
Table 38. Selected characteristics of the Tama (Group 1), Downs (Group 2), and Fayette (Group 3) soils

<table>
<thead>
<tr>
<th>Map unit</th>
<th>Profile number</th>
<th>Soil type</th>
<th>Solum cm</th>
<th>Ap</th>
<th>A cm</th>
<th>Color (moist)</th>
<th>Cons (moist)</th>
<th>Str</th>
<th>pH</th>
<th>Mollic pedon</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Tama</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>120B</td>
<td>P27</td>
<td>hsi</td>
<td>122 15 46</td>
<td>10YR3/2</td>
<td>fr</td>
<td>1fmgr</td>
<td>6.3</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120C</td>
<td>FMC7WH</td>
<td>lsic1</td>
<td>122 15 46</td>
<td>10YR2/2</td>
<td>fr</td>
<td>1mgr</td>
<td>6.5</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120D2</td>
<td>FMC5WH</td>
<td>hsi1</td>
<td>74 10 10</td>
<td>10YR3/2</td>
<td>fr</td>
<td>1fgr</td>
<td>6.8</td>
<td>-</td>
<td></td>
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<td>Group 2</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>162B</td>
<td>FMC1WH</td>
<td>lsic1</td>
<td>170 17 25</td>
<td>10YR3/2</td>
<td>fr</td>
<td>2fmgr</td>
<td>6.5</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162C</td>
<td>FMC2WH</td>
<td>sicl</td>
<td>127 18 18</td>
<td>10YR3/2</td>
<td>fr</td>
<td>2fmgr</td>
<td>6.4</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162D3</td>
<td>FMC3WH</td>
<td>sicl</td>
<td>118 18</td>
<td>10YR3/3</td>
<td>fr</td>
<td>2fsbk</td>
<td>6.7</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162D2</td>
<td>FMC4WH</td>
<td>sicl</td>
<td>119 15 15</td>
<td>10YR3/3</td>
<td>fr</td>
<td>2fsbk</td>
<td>6.5</td>
<td>-</td>
<td></td>
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<tr>
<td>Group 3</td>
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<td></td>
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<td>Fayette</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>163B</td>
<td>P32</td>
<td>sil</td>
<td>137 41</td>
<td>10YR3/2</td>
<td>fr</td>
<td>1fgr</td>
<td>5.2</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Coded according to Soil Survey Staff (1951).
* Morphological data based on Smith et al. (1950).
* Includes E and/or BE.
* Profile not described.
* Soil sampled to this depth.
* A horizon.
located at noseslope positions on the landscape. The thickness of the solum of FMC4WH is related to the fact that a relatively thick BC horizon, 53 cm, was described. Leaching to a relatively great depth in FMC4WH is no doubt facilitated by the high sand content in the upper 81 cm of the solum.

The matrix color of the Ap horizon of FMC5WH (Tama D2) is very dark grayish brown (moist) and yellowish brown (dry). The moist and dry matrix colors of the Ap horizon of FMC7WH are very dark brown and dark brown, respectively. The Downs soils, FMC1WH and FMC2WH, have a moist matrix color in the Ap that is very dark grayish brown. The dry colors in the Ap of the two Downs profiles, FMC1WH and FMC2WH, are dark brown and brown, respectively. Thus, within the Tama group, the dry matrix colors of the Ap horizons increase in value and chroma as slope phase and erosion class increase. The Downs profiles, FMC1WH and FMC2WH, have dry matrix colors that are higher in value than that in the C slope Tama profile (FMC7WH). Profile FMC4WH (162D2) has a moist color of 10YR3/3 in the Ap horizon. The other Downs profiles and the Tama profiles have matrix colors with lower value and/or chroma than FMC4WH.

Within the Tama group of soils, as erosion class increases, structure grade increases close to the surfaces of the soils. A similar situation exists in the Downs profiles.

The Ap and A horizons decreased in thickness as the slope gradient and erosion phase increased in the Group 1 and Group 2 soils. The A horizon in FMC5WH (120D2) is only 10 cm thick;
this soil does not have a mollic epipedon. Based on the criteria listed previously, FMC5WH does not qualify for a Typic Argiudoll. Based on Soil Survey Staff (1975), profile FMC5WH meets the criteria for a Typic Hapludalf. The Tama soils (as a group) have thicker A horizons than the Downs soils. The combined thickness of the A, E, and BE horizons in the Fayette profile is 41 cm. In FMC1WH (162B) and P32 (163B), the E or BE horizons or both are included with the Ap in making up the A horizons. Neither E nor BE horizons were identified in other members of the Group 2 soils.

In the Group 1 and Group 2 soils, pH values in the Ap generally increase with increasing erosion class and slope gradient. The pH values in the Ap horizons are influenced by management and exposure of subsoil. Addition of dust from limestone roads may also affect pH values in these soils. The surface horizon of the Fayette soil is more acid (pH 5.2) than those of the other soils.

Chemical properties such as clay, organic carbon, and phosphorus contents will be discussed in subsequent sections.

**Particle-size distribution**

**Tama and Downs**

Total sand, silt, and clay depth distributions are plotted in Figures 64, 65, and 66, respectively, for the soils on B and C slopes from Groups 1 (Tama) and 2 (Downs). Profiles FMC1WH, FMC2WH, FMC7WH, and P27 have less than 5% sand to a depth of 90 cm (Figure 65). Profiles FMC1WH and FMC2WH have loess parent material to depths of 224 and
Figure 64. Sand depth distributions for FMC1WH (A), FMC2WH (B), FMC7WH (G), and P27 (J)
Figure 65. Total silt depth distributions for FMC1WH (A), FMC2WH (B), FMC7WH (G), and P27 (J)
Figure 66. Clay depth distributions for FMC1WH (A), FMC2WH (B), FMC7WH (G), and P27 (J)
240 cm, respectively. Profile P27 has loess to the depth of sampling, 147 cm, and FMC7WH has a loess thickness of 152 cm. Silt contents range from 60.8 to 75.2% in the Tama and Downs soils located on B and C slopes. The narrow range of silt and sand contents above a depth of 152 cm suggests a similar (loess) parent material for the Tama and Downs soils on B and C slopes. Profile FMC7WH (120C) has a change of material at a depth of 152 cm (Figures 64 and 65). The loess thicknesses reflect the landscape positions of the soils. Profile FMC1WH is on a summit landscape position and FMC2WH is on a sideslope, close to the summit. Profile FMC7WH is on a sideslope landscape position. Thicker loess is associated with the summit position.

The clay depth distributions for the B slope and C slope Tama and Downs profiles are shown in Figure 66. Table 39 lists some selected characteristics of the Group 1 and Group 2 soils. Profile P27 is considered to be a modal "prairie soil" (Smith et al., 1950).

Sand, silt, and clay depth distributions for the D slope Downs and Tama soils are plotted in Figures 67, 68, and 69, respectively.

The maximum clay content, 35%, of the Group 1 and Group 2 soils are within the limits for the Tama and Downs soils (Soil Survey Staff, 1979, 1982, respectively). However, profiles FMC3WH (162D3) and FMC4WH (162D2) contain more than 10%
Table 39. Selected particle-size data for the Group 1 (Tama), Group 2 (Downs), and Group 3 (Fayette) soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>Map unit</th>
<th>Clay max (%)</th>
<th>Depth clay max (cm)</th>
<th>B/A clay ratio^</th>
<th>0-25</th>
<th>25-100</th>
<th>△clay</th>
<th>Bt clay</th>
<th>Bt (cm)</th>
<th>Ar-gillic</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC1WH</td>
<td>162B</td>
<td>33.5</td>
<td>29.5</td>
<td>1.25</td>
<td>27.2</td>
<td>31.4</td>
<td>+4.2</td>
<td>31.0</td>
<td>87</td>
<td>+</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>162C</td>
<td>33.4</td>
<td>24.5</td>
<td>1.00</td>
<td>33.3</td>
<td>30.4</td>
<td>-2.9</td>
<td>30.6</td>
<td>92</td>
<td>+</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>120C</td>
<td>34.5</td>
<td>33.5</td>
<td>1.20</td>
<td>30.7</td>
<td>31.5</td>
<td>+0.8</td>
<td>30.8</td>
<td>73</td>
<td>+</td>
</tr>
<tr>
<td>P27</td>
<td>120B</td>
<td>34.3</td>
<td>53.5</td>
<td>1.21</td>
<td>29.9</td>
<td>32.2</td>
<td>+2.3</td>
<td>32.9</td>
<td>40</td>
<td>+</td>
</tr>
<tr>
<td>P32</td>
<td>163B</td>
<td>35.9</td>
<td>75.0</td>
<td>1.90</td>
<td>19.6</td>
<td>31.4</td>
<td>+11.8</td>
<td>33.9</td>
<td>45</td>
<td>+</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>162D3</td>
<td>35.0</td>
<td>21.5</td>
<td>0.99^</td>
<td>34.3</td>
<td>25.7</td>
<td>-8.6</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>162D2</td>
<td>33.4</td>
<td>7.5</td>
<td>0.98</td>
<td>33.1</td>
<td>24.7</td>
<td>-7.4</td>
<td>28.6</td>
<td>51</td>
<td>+</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>120D2</td>
<td>30.6</td>
<td>32.0</td>
<td>1.20</td>
<td>27.9</td>
<td>29.6</td>
<td>+1.7</td>
<td>29.7</td>
<td>23</td>
<td>+</td>
</tr>
</tbody>
</table>

^Maximum clay content in B horizon/minimum clay content in A horizon.

Maximum clay content in 25-100 cm/minimum clay content in 0-25 cm.
Figure 67. Sand depth distributions for FMC3WH (C), FMC4WH (D), and FMC5WH (E)
Figure 68. Total silt depth distributions for FMC3WH (C), FMC4WH (D), and FMC5WH (E)
Figure 69. Clay depth distributions for FMC3WH (C), FMC4WH (D), and FMC5WH (E)
sand in their sola. The high sand contents (greater than 10%) are outside the range specified for the typical pedon in the Downs series. The greater clay content of the Bt and the greater depth to maximum clay in profile P27 relative to profile FMC7WH are a function of the respective landscape positions. Profile FMC7WH is located on a sideslope position and P27 is located on a stable summit. The greater $\Delta$ clay (weighted clay content in the 25 to 100 cm section - weighted clay content in the 0 to 25 cm section) in the B slope Tama (P27) may also be related to landscape positions of the soils. Both soils, P27 and FMC7WH, are within the allowable range of the Tama series.

Profile FMC2WH (Downs, 162C) has greater depths to maximum clay content than does FMC7WH (Tama, 120C). The difference in depth to maximum clay may be related to the landscape positions at which the soils formed. Also, profile FMCWH formed under prairie-forest vegetation and FMC7WH formed under grass vegetation. The two soils are in the fine-silty particle-size class which is specified in the "Range in Characteristics" for the Downs and Tama series. Also, the Downs soil, FMC2WH, on 5 to 9% slopes has a lower average B/A clay ratio, 1.00, than the Tama soil, FMC7WH, on 5 to 9% slopes. The B/A clay ratio of FMC7WH is 1.20. The low B/A clay ratio, clay maximum, and shallow depth to clay maximum suggest that accelerated erosion has removed more of the soil surface
from the Downs profile (FMC2WH) relative to the Tama profile (FMC7WH).

The Downs soils which are located on D slopes, FMC3WH and FMC4WH, have higher maximum clay contents but shallower depths to maximum clay content than does the Tama profile on D slope, FMC5WH (Table 39). Also, while FMC3WH and FMC4WH are generally similar to each other, they are distinctly different from FMC5WH (Table 39). The shallow depths to maximum clay content in FMC3WH and FMC4WH imply removal of part of the surface of each soil by erosion.

Profile FMC5WH has a maximum sand content of 7.6%. Profiles FMC3WH and FMC4WH have high sand contents above a depth of 100 cm and below a depth of 190 cm. Erosion class and slope gradient are two factors which may influence the particle-size distribution in the Group 1 and Group 2 soils. When the C slope soils, FMC2WH and FMC7WH, are compared, the Downs profile has a shallower depth to maximum clay content than the Tama soil. Similar results have been reported by Collins (1977).

Some of the soils in this study, especially those on D slopes, fall outside the "Range in Characteristics" for the respective series. The classification problem is not new, but it is still unresolved. Collins (1977) studied eroded Tama, Downs, and Fayette soils. She proposed creating a new
subgroup of soils. This situation implies at least one eroded subgroup within each soil order. The eroded subgroups proposed by Collins are soils which would be genetically similar to their stable counterparts. However, soils which are continuously eroding may eventually become dissimilar to their stable counterparts. It may be worthwhile to examine (1) the creation of a soil order for soil located on unstable landscape position or (2) the use of geomorphic surfaces in the classification of soils.

Tama, Downs, and Fayette In this section, the particle-size distribution of the Fayette (P32), Downs (FMC1WH and FMC2WH) and Tama (P27) soils will be examined. All three soils are in the fine-silty particle-size class (Soil Survey Staff, 1981, 1982, 1979, respectively). The Tama (prairie-derived) and Fayette (forest-derived) are considered to be the end members of the biosequence. The Tama and Downs profiles were discussed in some detail previously. Sand depth distributions for the four soils are plotted in Figure 70. The sand contents in the soils range from 1.6% in P27 and P32 to 10.6% in FMC1WH and FMC2WH. The high sand content, 10.6%, occurs at a depth of 101 cm in FMC1WH and at a depth of 118.5 cm in FMC2WH. These Downs profiles, FMC1WH and FMC2WH, are located close to each other. Profiles FMC3WH and FMC4WH, the D slope Downs soils, have high sand contents (>13%) close to their surfaces (Figure 67).
Figure 70. Sand depth distributions for FMC1WH (A), FMC2WH (B), P27 (J), and P32 (K)
Total silt and clay depth distributions for profiles P27, FMC1WH, FMC2WH, and P32 are plotted in Figures 71 and 72, respectively. Total silt content ranges from 60.8% in FMC2WH to 79.3% in P32. The highest silt content, 79.3%, is in the upper part of profile P32 (Figure 71) and is associated with a low clay content, 18.9% (Figures 71 and 72). The low clay content in the upper part of P32 has been used to distinguish it from the less differentiated Tama soils (Smith et al., 1950). Table 39 lists selected particle-size data for P32, P27, FMC1WH, and FMC2WH. Profile P32 has a higher B/A clay ratio, greater maximum clay content (35.9%), and greater depth to maximum clay content (75 cm) than the Tama and Downs profiles (Table 39). Collins (1977) also reported a high B/A clay ratio (1.7) for a Fayette profile from northeast Tama County.

**Organic carbon**

*Tama and Downs* The organic carbon (OC) depth distribution of the Group 1 (Tama) and Group 2 (Downs) soils are plotted in Figures 73 and 74. The OC depth distributions for the soils on relatively stable landscape, 2 to 9% slopes, are plotted in Figure 73. The OC depth distributions for the soils on D slopes, 9 to 14%, are plotted in Figure 74. The OC trends are shown for the 0 to 25 cm and 25 to 100 cm zones in the Group 1, Group 2, and Group 3 soils (Table 40). The OC content in P27 is higher than that in the C slope Tama
Figure 71. Total silt depth distributions for FMClWH (A), FMC2WH (B), P27 (J), and P32 (K)
Figure 72. Clay depth distributions for FMClWH (A), FMC2WH (B), P27 (J), and P32 (K)
Figure 73. Depth distributions of OC in FMC1WH (A), FMC2WH (B), FMC7WH (G), P27 (J), and P32 (K)
Figure 74. Depth distributions of OC in FMC3WH (C), FMC4WH (D), and FMC5WH (E)
Table 40. Organic carbon (OC) content in the 0 to 25 cm and 25 to 100 cm zones of the Group 2 and Group 3 soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>Map unit</th>
<th>Depth (cm)</th>
<th>ΔOC</th>
<th>DOC&lt;sub&gt;a&lt;/sub&gt; (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0-25</td>
<td>25-100</td>
<td></td>
</tr>
<tr>
<td>FMC1WH</td>
<td>162B</td>
<td>1.74</td>
<td>0.66</td>
<td>1.08</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>162C</td>
<td>2.09</td>
<td>0.66</td>
<td>1.43</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>120C</td>
<td>1.90</td>
<td>0.60</td>
<td>1.30</td>
</tr>
<tr>
<td>P27</td>
<td>120B</td>
<td>1.96</td>
<td>0.79</td>
<td>1.17</td>
</tr>
<tr>
<td>P32</td>
<td>163B</td>
<td>2.22</td>
<td>0.41</td>
<td>1.81</td>
</tr>
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<td>FMC3WH</td>
<td>162D3</td>
<td>1.55</td>
<td>0.42</td>
<td>1.13</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>162D2</td>
<td>1.39</td>
<td>0.45</td>
<td>0.94</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>120D2</td>
<td>0.66</td>
<td>0.24</td>
<td>0.42</td>
</tr>
</tbody>
</table>

<sup>a</sup>Depth to <0.58% organic carbon.

(FMC7WH). In addition, the change in OC (ΔOC) from the upper (0 to 25 cm) to lower (25 to 100 cm) zone is less in P27 than in FMC7WH (Table 40). Profile FMC2WH has the highest OC content, 2.09%, in the 0 to 25 cm zone. Profile FMC2WH has a higher OC content in the 0 to 25 cm zone than does FMC7WH, 2.09% and 1.90%, respectively. Both profiles are located on C slopes, sideslope landscape positions. The OC content in the 25 to 100 cm section of P27 is 0.79%. This value is the high value and may serve as a criterion for distinguishing the
stable P27 from the other soils in Groups 1 and 2.

The D slope soils of Group 1 and Group 2 separate easily from the B and C slope soils of the groups. Profile FMC5WH has the lowest OC content of all the soils in Group 1, Group 2, and Group 3. The D slope Downs has a weighted average OC content of 1.47% in the 0 to 25 cm zone and 0.44% in the 25 to 100 cm zone. The B and C slope Downs average 1.92 and 0.67% OC in the 0 to 25 cm and 25 to 100 cm zone, respectively. In both the Down soils (Group 1) and the Tama soils (Group 2), the depth to less than 0.58% organic carbon decreases as slope gradient and erosion class increase. If the high OC content in the 0 to 25 cm zone is excluded then the OC content in this zone may be used to distinguish the Tama soils from the Downs soils.

In order to further test the ability of OC as a criterion for distinguishing the Group 1 soils from the Group 2 soils, the OC in various extracts was examined. Table 41 lists the OC contents in selected extracts of the Group 1, Group 2, and soils. In particular, the OC contents of extracts from the surface horizons are examined. Contrasts of OC contents within series were examined in previous sections. When the soils with C slopes (Downs and Tama) are compared, H/F ratio decreases from Tama to Downs soils (Table 41). The lower H/F ratios in the Downs soils may be due to the influence of forest in the mixed vegetation under which the soils formed.
Table 41. Characteristics of organic carbon (OC) in selected extracts of the Group 1, Group 2, and Group 3 soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>EXTROCl</th>
<th>HC %</th>
<th>FC</th>
<th>H/F ratio</th>
<th>H/F RANGE</th>
<th>Ap a</th>
<th>EXTROCl range</th>
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</thead>
<tbody>
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<td>FMC1WH</td>
<td>0.82</td>
<td>0.19</td>
<td>0.63</td>
<td>0.30</td>
<td>0.14-0.39</td>
<td>43.8</td>
<td>24.7-43.9</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>0.93</td>
<td>0.28</td>
<td>0.65</td>
<td>0.43</td>
<td>0.18-0.64</td>
<td>39.1</td>
<td>18.5-48.1</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>1.05</td>
<td>0.42</td>
<td>0.63</td>
<td>0.67</td>
<td>0.35-0.67</td>
<td>48.8</td>
<td>8.8-48.8</td>
</tr>
<tr>
<td>P27</td>
<td>1.03</td>
<td>0.58</td>
<td>0.51</td>
<td>1.02</td>
<td>1.01-2.31</td>
<td>48.6</td>
<td>40.9-62.7</td>
</tr>
<tr>
<td>P32</td>
<td>1.49</td>
<td>0.42</td>
<td>1.07</td>
<td>0.39</td>
<td>0.21-0.45</td>
<td>41.6</td>
<td>33.3-63.3</td>
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<tr>
<td>FMC3WH</td>
<td>0.77</td>
<td>0.30</td>
<td>0.47</td>
<td>0.64</td>
<td>0.35-0.83</td>
<td>42.5</td>
<td>37.1-74.0</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>0.63</td>
<td>0.03</td>
<td>0.60</td>
<td>0.05</td>
<td>0.01-0.05</td>
<td>37.1</td>
<td>23.6-48.3</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>0.62</td>
<td>0.06</td>
<td>0.56</td>
<td>0.11</td>
<td>0.11-0.20</td>
<td>62.0</td>
<td>13.3-62.0</td>
</tr>
</tbody>
</table>

a A horizon in P32. EXTROCl, HC+FC; HC, OC in precipitate of EXTROCl; FC, OC in acidified portion of EXTROCl; H/F, HC/FC; Ap EXTROCl, OC in extract as a percentage of OC in the soil; EXTROCl, range throughout profile.
Also, the humic acid carbon in the Ap horizon is lower in the Downs soils relative to the Tama soil.

In the profiles on 9 to 14% slopes, FMC3WH, FMC4WH, and FMC5WH, the H/F ratios, in the Ap horizons, are all less than unity. Profile FMC3WH has a relatively high H/F ratio, 0.64. Profiles FMC4WH and FMC5WH have very low H/F ratios, 0.05 and 0.11, respectively. The very low H/F ratios reflect forest influence or exposure of subsoil or both. Profile FMC5WH (120D2) may be distinguished from FMC4WH (162D2) on the basis of (1) higher H/F ratio and (2) a larger amount of organic carbon in the extract of the Ap horizon (Table 41).

**Tama, Downs, and Fayette** Organic carbon (OC) depth distributions for P32, P27, FMC1WH, and FMC2WH are plotted in Figure 75. Profile P32 has the highest OC content (2.22%) in the 0 to 25 cm zone (Table 40). However, it has a low OC content (0.41%) in the 25 to 100 cm zone. The low OC content in the 25 to 100 cm zone of P32 is generally similar to values for the same zone in the D slope Downs soil (Table 40). The ΔOC value is 1.81% for P32. This value is higher than those reported for either the Tama or Downs profiles (Table 40).

Table 41 summarizes data for OC in selected extracts of profile P32. Profile P32 is located on a stable landscape position. As a result, the low H/F ratio in the surface horizon of the soil is not related to exposure of the subsoil.
Figure 75. Depth distributions of organic carbon for P27 (J), FMCIWH (A), FMC2WH (B), and P32 (K)
Rather, it is interpreted to be related to the influence of forest vegetation. Kononova (1966) also reported low H/F ratios in selected soils which formed under forest vegetation.

Soil pH

Tama and Downs  The Downs soils on B and C slopes, FMC1WH and FMC2WH, respectively, have lower pH values than the Tama profile (FMC7WH) on C slope (Figure 76). In profile FMC7WH, pH values tend to increase with depth and highest values (greater than pH 7.0) are associated with material below a depth of 152 cm (Figure 64). A lithologic discontinuity is at 152 cm in profile FMC7WH. The three soils on C slopes are slightly acid in their upper horizons. Profile FMC2WH is slightly acid throughout and in profile FMC1WH, the pH values are below neutral to a depth of 183 cm. The pH values in FMC1WH, FMC2WH, and FMC7WH are higher than specified in the "Range of Characteristics" for Downs and Tama series (Soil Survey Staff, 1979, 1982). Profile P27 is also very slightly acid throughout. Figure 77 shows the pH depth distributions for the soils located on D slopes, FMC3WH, FMC4WH, and FMC5WH.

Within the Tama and Downs group of soils, pH values generally increase with an increase in slope gradient and erosion class. Above a depth of 140 cm, P27, FMC1WH, and FMC2WH generally have similar pH values, with a range 6.3 to 6.6. An F test, critical region $F_{\text{cal}} > F_{0.005}(2)(27) = 6.49$, revealed
Figure 76. Depth distributions of soil pH for FMC1WH (A), FMC2WH (B), FMC7WH (G), and P27 (J)
Figure 77. Depth distribution of soil pH for FMC3WH (C), FMC4WH (D), and FMC5WH (E)
no significant difference between the pH values of the three soils above a depth of 140 cm. When profile FMC7WH is included in the analysis of soil pH, it is found to be significantly different from P27, FMC1WH, and FMC2WH. The critical region for comparing the pH values of FMC7WH with P27, FMC1WH, and FMC2WH is $F_{\text{cal}} > F_{0.05}(3)(36) = 2.86$. In the soils on D slopes, FMC3WH, FMC4WH, and FMC5WH, the pH values increase with depth. The Downs soils, FMC3WH and FMC4WH, are slightly more acid in the upper parts and less acid in the lower parts than FMC5WH. However, an F test revealed no significant difference in pH values of the three profiles. The critical region for the F test is $F_{\text{cal}} > F_{0.01}(2)(40) = 5.18$.

The general trend of pH distribution in the Tama and Downs soils is for pH values to increase as the stability of the locations on the landscape decrease. Collins (1977) reported relatively high pH for selected Downs soils in Tama County.

**Tama, Downs, and Fayette** The pH depth distribution for the Tama, Downs, Fayette biosequence are plotted in Figure 78. Of the four profiles, P27, FMC1WH, FMC2WH, and P32, profile P32 is the most acid. The pH profile of P32 is significantly different from those of P27, FMC1WH, and FMC2WH. The critical region for the F test is $F_{\text{cal}} > F_{0.05}(3)(36) = 2.86$. The pH trends for the Tama, Downs, and Fayette soils are similar to trends reported by Collins (1977) for a Tama,
Figure 78. Depth distributions of soil pH for P27 (J), FMClWH (A), FMC2WH (B), and P32 (K).
Downs, Fayette biosequence, also from northeastern Iowa.

**Total phosphorus**

The TP depth distribution curves for FMC1WH, FMC2WH, FMC7WH, and P27 are plotted in Figure 79. Figure 80 shows the TP curves for the Group 1 and Group 2 soils on 9 to 14% slopes. Table 42 lists some characteristics of the Group 1 and Group 2 soils. For the soils located on relatively stable landscape, TP contents in the Ap horizons are in the order FMC7WH > FMC2WH > P27 > FMC1WH. In the 0 to 25 cm zone, the Downs soils on B and C slopes have lower weighted average TP than FMC7WH (120C). The high TP content in the Ap horizon of profiles FMC3WH and FMC7WH causes the soils to have high TP contents in the 0 to 25 cm zones (Table 42). Several characteristics of the TP distribution are useful for distinguishing the Downs soil on C slope (FMC2WH) from Tama profile FMC7WH. The characteristics include lower I/E ratios in the Downs profile, lower TP minimum and greater depth to TP minimum in FMC7WH, and higher maximum TP content in FMC7WH (Table 42).

In comparing the three moderately and severely eroded soils, profiles FMC3WH and FMC4WH have the lowest TP values, 354 and 352 ppm, respectively. The low TP contents may be related to the relatively high sand content in the upper part of each profile. The TP minimum in FMC5WH is 464 ppm. The Downs soils on D slopes have more sharply defined eluvial and
Figure 79. Total phosphorus depth distributions for FMC1WH (A), FMC2WH (B), P27 (J), and FMC7WH (G)
Figure 80. Total phosphorus depth distributions for FMC3WH (C), FMC4WH (D), and FMC5WH (E)
<table>
<thead>
<tr>
<th>Profile</th>
<th>Map unit</th>
<th>Ap</th>
<th>0-25</th>
<th>25-100</th>
<th>Solum</th>
<th>TP max</th>
<th>DTPmax (cm)</th>
<th>TPmin (ppm)</th>
<th>DTPmin (cm)</th>
<th>I/E* ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC1WH</td>
<td>162B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>533</td>
<td>496</td>
<td>496</td>
<td>555</td>
<td>618</td>
<td>131(BC)</td>
<td>418</td>
<td>21</td>
<td>1.48</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>162C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>657</td>
<td>581</td>
<td>575</td>
<td>586</td>
<td>693</td>
<td>168(C2)</td>
<td>449</td>
<td>25</td>
<td>1.54</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>120C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>809</td>
<td>656</td>
<td>550</td>
<td>602</td>
<td>765</td>
<td>131(C1)</td>
<td>384</td>
<td>34</td>
<td>1.99</td>
</tr>
<tr>
<td>P27</td>
<td>120B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>617</td>
<td>559</td>
<td>527</td>
<td>577</td>
<td>768</td>
<td>137(C)</td>
<td>406</td>
<td>54</td>
<td>1.89</td>
</tr>
<tr>
<td>P32</td>
<td>163B</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>639</td>
<td>511</td>
<td>536</td>
<td>580</td>
<td>741</td>
<td>131(BC)</td>
<td>414</td>
<td>31</td>
<td>1.79</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>162D3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>803</td>
<td>677</td>
<td>413</td>
<td></td>
<td>779</td>
<td>118</td>
<td>354</td>
<td>22</td>
<td>2.20</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>162D2</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>610</td>
<td>528</td>
<td>462</td>
<td>506</td>
<td>692</td>
<td>125(C1)</td>
<td>352</td>
<td>50</td>
<td>1.97</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>120D2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>473</td>
<td>468</td>
<td>526</td>
<td>495</td>
<td>723</td>
<td>186(C6)</td>
<td>464</td>
<td>17</td>
<td>1.56</td>
</tr>
</tbody>
</table>

\(^\text{a}\)TP values below depths of lithologic discontinuity are not included.

\(^\text{b}\)Maximum TP below Ap/minimum TP below Ap.

\(^\text{c}\)A horizon.
illuvial TP zones than does the Tama profile (FMC7WH). As a result, FMC5WH has a lower I/E ratio than FMC3WH and FMC4WH (Table 42).

The I/E ratio has been used as a criterion in assessing the relative degree of development of Tama, Downs, and Fayette profiles (Collins, 1977). She reported I/E ratios of 1.6, 1.5, and 2.0 for a Tama, Downs, and Fayette profile, respectively. Based on I/E ratios and other data, she concluded that the Downs and Tama profiles are closely related to each other in stage of development.

The Downs soils, FMC1WH and FMC2WH, have lower I/E ratios than the Tama profile, FMC7WH. Thus, while I/E ratios differ between Downs and Tama profiles, they are probably not a useful index of soil development in this study. The high I/E ratios in FMC3WH and FMC4WH are a function of low TP minima which in turn are probably related to the high sand content in the upper part of each profile. The relatively shallow depths to TP minima in FMC1WH and FMC2WH provide good evidence of their transition nature (Pearson et al., 1940; Fenton et al., 1967).

**Tama, Downs, and Fayette** The TP depth distributions for profiles FMC1WH, FMC2WH, P27, and P32 are shown in Figure 81. Total phosphorus eluviation and illuviation zones are present in the soils (Figure 81). Characteristics of TP distribution for the Tama, Downs, and Fayette profiles are
Figure 81. Total phosphorus depth distributions for FMC1WH (A), FMC2WH (B), P27 (J), and P32 (K)
listed in Table 42. Profile P32 has 639 ppm TP in the surface horizon. This value is lower than the value for FMC2WH, but higher than those for FMC1WH and P27. Total phosphorus contents are in the order FMC7WH > FMC2WH > P32 > P27 > FMC1WH. The total phosphorus minimum in P32 is 414 ppm at a depth of 30.5 cm. The shallower depth to minimum TP in P32 as compared to P27 is similar to the trend reported by Pearson et al. (1940). The Downs profiles FMC1WH and FMC2WH have the shallowest depths to minimum TP, 21 and 24.5 cm, respectively. Fenton et al. (1967) reported trend in depth to minimum TP as being grass-derived soils > transition soils > forest-derived soils. The shallow depth to the TP minimum for the Downs soils may be related to the landscape positions of the soils. Accelerated erosion may have removed a part of the surface horizon of each soil. Maximum TP content is in the BC horizon of P32 and FMC1WH, and in the C horizon of P27 and FMC2WH.

**Inorganic phosphorus fractions**

**Tama and Downs**

Chang and Jackson (1958) proposed a scheme of P transformation in soils, CaP → AlP → FeP → RSP. Calcium phosphate tends to dominate in basic soils. As soils develop and acidity increases, CaP is transformed into AlP, FeP, and RSP. The Group 1 and Group 2 soils are divided into relatively stable (B and C slopes) and less stable (D slopes and moderately or severely eroded) for comparison.
Table 43 lists selected weighted average percentage IP for the 0 to 25 cm and 25 to 100 cm zones of the Group 1 and Group 2 soils. Examination of Tables 43 and 44 show that active P exceeds occluded P in all the soils with the exception of the 0 to 25 cm zone of P27. The data for the 25 to 100 cm zones of the Downs and Tama soils on B and C slopes are plotted in Figure 82. Figure 83 shows the IP fraction of the 25 to 100 cm zone of the soils on D slopes. Profile FMC2WH has a higher FeP content and a lower CaP content than the other profiles (Figure 82). Occluded phosphate (Occ1P) includes RSP, occluded FeP (OFeP) and occluded AlP (OA1P). As a result, Occ1P is equal to or greater than RSP. The Downs profiles (FMC1WH and FMC2WH) have more FeP, RSP, and occluded P than the Tama profiles (FMC7WH and P27). Profile P27 has higher AlP, FeP, RSP, and occluded P than FMC7WH.

The severely (FMC3WH) and moderately eroded soils (FMC4WH and FMC5WH) are dominated by CaP and active P in the 25 to 100 cm zone (Figure 82). These soils have slight accumulations of FeP. Figure 83 shows the trends of the IP. Active P and CaP are the dominant P forms. Table 44 lists data for active P and occluded P as percent of TP.

Active P exceeds occluded P in all the profiles of Group 1 and Group 2. Active P includes NH₄Cl-P, AlP, FeP, and CaP. The importance of active P relates to the fact that it is a source of available P for plants (Thomas and Peaslee, 1973).
Table 43. Weighted average percent of the inorganic phosphorus fractions in the 0-25 and 25-100 cm zones of the Group 1 (Tama), Group 2 (Downs, and Group 3 (Fayette) soils

<table>
<thead>
<tr>
<th>Profile</th>
<th>CaP</th>
<th>AlP</th>
<th>FeP</th>
<th>RSP</th>
<th>OCCLP</th>
<th>ACTIVEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMC1WH</td>
<td>7</td>
<td>42</td>
<td>81</td>
<td>72</td>
<td>105</td>
<td>132</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>1</td>
<td>25</td>
<td>94</td>
<td>45</td>
<td>77</td>
<td>126</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>8</td>
<td>100</td>
<td>96</td>
<td>60</td>
<td>111</td>
<td>235</td>
</tr>
<tr>
<td>P27</td>
<td>46</td>
<td>89</td>
<td>48</td>
<td>184</td>
<td>200</td>
<td>125</td>
</tr>
<tr>
<td>P32</td>
<td>20</td>
<td>78</td>
<td>93</td>
<td>67</td>
<td>78</td>
<td>192</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>9</td>
<td>13</td>
<td>184</td>
<td>41</td>
<td>78</td>
<td>205</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>60</td>
<td>56</td>
<td>102</td>
<td>41</td>
<td>55</td>
<td>221</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>62</td>
<td>22</td>
<td>107</td>
<td>108</td>
<td>130</td>
<td>190</td>
</tr>
</tbody>
</table>

| 25-100 cm |     |     |     |     |       |         |
| FMC1WH   | 90  | 32  | 116 | 146 | 176   | 239     |
| FMC2WH   | 25  | 41  | 175 | 141 | 173   | 243     |
| FMC7WH   | 78  | 51  | 94  | 94  | 133   | 222     |
| P27      | 91  | 34  | 103 | 121 | 138   | 248     |
| P32      | 49  | 111 | 172 | 169 | 187   | 310     |
| FMC3WH   | 131 | 46  | 81  | 50  | 63    | 260     |
| FMC4WH   | 178 | 19  | 75  | 57  | 79    | 276     |
| FMC5WH   | 160 | 29  | 104 | 62  | 79    | 297     |

^OCCLP = OAIP + OFeP + RSP; ACTIVEP = NH4ClP + AlP + FeP + CaP.
Table 44. Active P and occluded P as percentages of TP and pH ranges in the Group 1, Group 2, and Group 3 soils, 25 to 100 cm zone

<table>
<thead>
<tr>
<th>Profile</th>
<th>Active P % of TP</th>
<th>Occluded P</th>
<th>pH range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC1WH</td>
<td>37-60</td>
<td>26-45</td>
<td>6.4-6.5</td>
</tr>
<tr>
<td>FMC2WH</td>
<td>22-54</td>
<td>14-38</td>
<td>6.5-6.6</td>
</tr>
<tr>
<td>FMC7WH</td>
<td>28-54</td>
<td>18-30</td>
<td>6.4-7.0</td>
</tr>
<tr>
<td>P27</td>
<td>18-65</td>
<td>14-36</td>
<td>6.3-6.5</td>
</tr>
<tr>
<td>P32</td>
<td>47-65</td>
<td>15-45</td>
<td>4.8-6.1</td>
</tr>
<tr>
<td>FMC3WH</td>
<td>31-91</td>
<td>5-25</td>
<td>6.6-7.3</td>
</tr>
<tr>
<td>FMC4WH</td>
<td>25-70</td>
<td>13-25</td>
<td>6.5-6.9</td>
</tr>
<tr>
<td>FMC5WH</td>
<td>45-66</td>
<td>12-21</td>
<td>7.0-7.2</td>
</tr>
</tbody>
</table>

Hawkins and Kunze (1965) reported good correlations between available P and AlP and between available P and CaP in select Grumosols (Vertisols) from Texas. Mausbach (1969) found a negative correlation between available P and CaP. However, he found highly significant (> .50) positive correlations between available P and NH₄ClP, AlP, FeP, and RSP. Tembhare (1973) studied a wide range of Alfisols and Mollisols. He reported that, in general, the trend of available P distribution was similar to those of AlP, FeP, and, in some cases, RSP. However, the available P trend did not follow the CaP trend. This is mainly because CaP tended to increase with depth and
Figure 82. Inorganic P content in the 25 to 100 cm zone of FMC1WH, FMC2WH, P27, and FMC7WH
Figure 83. Inorganic P content in the 25 to 100 cm zone of FMC5WH, FMC4WH, and FMC3WH
available P decreased with depth. An increase of CaP with depth was found in all the Group 1 and Group 2 soils of this study. Correlation between available P and active P may be related to the use of NH₄F (Bray reagent) to extract available P and AlP (Hawkins and Kunze, 1965) and the ability of the Bray reagent to extract some FeP and CaP (Fife, 1959a).

The relatively low values of occluded P in the Group 1 and Group 2 soils imply that they are not highly developed soils. However, the tendency for CaP to increase with depth and for FeP and RSP to decrease with depth, relative to CaP, implies more development in the A and B horizons relative to the C horizons.

Based on higher amounts of FeP, RSP, and occluded P in the 25 to 100 cm zones (Table 43 and Figure 82), profiles FMC1WH and FMC2WH may be considered more developed than either FMC7WH or P27. Based on the same criteria, profile P27 is more developed than FMC7WH. Profile FMC2WH has the lowest CaP and highest FeP.

Profiles FMC3WH, FMC4WH, and FMC5WH have low contents of AlP, FeP, and RSP. The very high contents (>250 ppm) of active P implies little development of these soils. Lack of development of the eroded soils may be related to either (1) removal of previously weathered soil horizons by erosion or (2) these soils may be located on younger geomorphic surfaces. The slight accumulation of FeP in the eroded soils indicates that
some transformation of P has occurred.

All the soils have low contents (<51 ppm) of A1P in the 25 to 100 cm zone. This implies that below a depth of 25 cm, A1P does not make a large contribution to available P. Also, low A1P may be due to its transformation into FeP. Low and relatively constant amount of A1P with depth have also been reported by Hawkins and Kunze (1965), Mausbach (1969), and Tembhare (1973). Tembhare considered low A1P contents to be due to transformation into FeP and competition between clay and P for Al ions.

Within the 25 to 100 cm zone, the three soils, FMClWH, FMC2WH, and P27, with the lowest pH also have the highest contents of FeP, RSP, and occluded P. The relationship indicates greater transformation of CaP → A1P → FeP → RSP in the more acid soils. Hsu and Jackson (1960) reviewed literature which showed that the various IP fractions are related to soil pH. In the same paper, the authors found relationships which led them to conclude that the genetic processes which cause soil acidity proceed faster than the completion of the P transformation reactions.

Based on the relative amounts of IP in the soils, FMClWH and FMC2WH may be distinguished from FMC7WH and P27. It is difficult to distinguish the eroded soils from each other using the IP data in the 25 to 100 cm zone (Figure 83). The distribution of the IP fractions allows relatively easy
distinction of the D slope soils from the soils on B and C slopes.

**Tama, Downs, and Fayette** Table 43 lists weighted percent of the various inorganic phosphorus (IP) fractions in the Tama, Downs, and Fayette soils. A plot of IP fractions in the 25 to 100 cm zone is shown in Figure 84. Excluding CaP, which is 49 ppm, P32 has more FeP, RSP, OcclP and active P in the 25 to 100 cm zone than the Downs and Tama soils. The Downs is intermediate in FeP, RSP, and OcclP contents. Based on the scheme of Chang and Jackson (1958), the trend in IP distribution suggests a development sequence in the order Fayette > Downs > Tama.

The high content of active P in profile P32 is associated with relatively high values of FeP and AlP. Occluded P is a larger portion of the TP in the more developed Fayette profile.

**Comparison of Selected Properties in the Sperry, Tama, and Muscatine Series**

**Morphological properties**

Along with the Garwin series, the Muscatine and Tama series comprise a topo-hydrosequence. The Garwin series is located on slightly concave heads of drainageways on uplands and is poorly drained. The Garwin series is classified as Typic Haplaquoll. Comparisons in this section will deal mainly with the Sperry (FMC9WH), Muscatine (FMC8WH), and Tama
Figure 84. Selected inorganic P fractions in the 25 to 100 cm zone of P32, FMC1WH, FMC2WH, FMC7WH, and P27
(P27) profiles. Tables 45 and 46 list selected properties in the range of characteristics for the Muscatine and Sperry series, respectively (Soil Survey Staff, 1979, 1980, respectively). Selected morphological data for the profiles P27, FMC8WH and FMC9WH are summarized in Table 47. The Sperry (FMC9WH) and Muscatine (FMC8WH) both have thicker sola than the Tama (P27) profile (Table 47). In each case, the solum thickness is within the "Range of Characteristics" for the particular soil.

The Ap horizons of FMC8WH and FMC9WH have a darker moist color (10YR2/1) than P27 (10YR3/2). Profile FMC9WH has a dry color of 10YR5/1 at a depth of 15 cm. Darker dry colors extend deeper in FMC8WH. The gray color (10YR5/1) in FMC9WH is associated with the eluvial (E) horizon.

All three soils have granular structure in the Ap horizon. The soils also have mollic epipedons. Profile FMC9WH is leached throughout. There was strong effervescence between a depth of 152 cm and 236 cm in FMC8WH. Silt coats were not identified in either FMC8WH or FMC9WH. Organic coats (N2/0) and mottles at a depth of 94 cm were described in FMC9WH. In profile FMC8WH, mottles are at a depth of 54 cm. Loess thickness is 221 cm in FMC9WH and 236 cm in FMC8WH.

In the B horizons of FMC9WH, the structural units are mostly moderate and medium. The B horizon structure units in
Table 45. Selected properties within the range of characteristics for the Muscatine series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range of characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solum thickness</td>
<td>102 to 152 cm</td>
</tr>
<tr>
<td>pH</td>
<td>Typically medium or strongly acid in A and upper B but the range is neutral; medium acid to neutral in lower part of solum</td>
</tr>
<tr>
<td>Carbonates</td>
<td>As shallow as 122 cm in some pedons</td>
</tr>
<tr>
<td>Color: A1 horizon</td>
<td>10YR2/1 or 10YR2/2, value of 3 in lower A or upper B of most pedons</td>
</tr>
<tr>
<td>Texture: A1 horizon</td>
<td>Sicl or sil</td>
</tr>
<tr>
<td>Color: B horizon</td>
<td>10YR4/2 or 2.5Y4/2 in the upper part; lower B has value of 5 or 6 and chroma of 2 to 4</td>
</tr>
<tr>
<td>Clay content: B2t horizon</td>
<td>27 to 35%</td>
</tr>
<tr>
<td>Mottles</td>
<td>Lower BC and C horizon</td>
</tr>
<tr>
<td>Color: mottles</td>
<td>Hue 10YR, 7.5YR, and 5YR, high value and chroma</td>
</tr>
<tr>
<td>Texture: C horizon</td>
<td>Sil or sicl</td>
</tr>
</tbody>
</table>

aSandy substratum phases are within the range of the series; borderline with respect to the 20% increase in clay within 31 vertical cm; organic carbon content is greater than 0.5% to depths between 76 and 91 cm; high croma colors are generally expressed as mottles rather than matrix colors (Soil Survey Staff, 1979).
Table 46. Selected properties in the range of characteristics for the Sperry series

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Range of characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solum thickness</td>
<td>102 to 173 cm</td>
</tr>
<tr>
<td>pH</td>
<td>Most acid part of the solum is medium or strongly acid</td>
</tr>
<tr>
<td>Carbonates</td>
<td>Absent above a depth of 152 cm</td>
</tr>
<tr>
<td>Color: Al or Ap horizon</td>
<td>10YR3/1 or 10YR2/1</td>
</tr>
<tr>
<td>Texture: Al or Ap horizon</td>
<td>Typically silt loam</td>
</tr>
<tr>
<td>Structure: Al horizon</td>
<td>Weak or moderate fine granular</td>
</tr>
<tr>
<td>Structure: E horizon</td>
<td>Weak subangular blocky or weak or moderate platy structure</td>
</tr>
<tr>
<td>Thickness: A and E horizons</td>
<td>41 to 51 cm</td>
</tr>
<tr>
<td>Color: B2t horizon</td>
<td>Hue of 10YR to 5Y; value of 3 to 5; chroma of 1</td>
</tr>
<tr>
<td>Clay contents: B2t horizon</td>
<td>36 to 45%</td>
</tr>
<tr>
<td>Silt coats</td>
<td>Upper part of B2 horizon</td>
</tr>
<tr>
<td>Mottles</td>
<td>Few to many and increase in number as depth increases</td>
</tr>
<tr>
<td>Color: mottles</td>
<td>Hue of 10YR or 7.5YR; value of 4 or 5; chroma of 3 through 8</td>
</tr>
<tr>
<td>Color: BC and upper C horizon</td>
<td>Hue 2.5Y or 5Y; value of 5 or 6; chroma of 1 or 2</td>
</tr>
<tr>
<td>Texture: C horizon</td>
<td>Sicl grading to sil at depths between 152 and 183 cm</td>
</tr>
</tbody>
</table>

\(^{a}\)Nonmollic E horizon may interrupt mollic epipedon; mollic epipedon is 25 to 41 cm thick; secondary carbonates may be present below the solum; silty clay loam texture is within the range for the Al or Ap horizon (Soil Survey Staff, 1980).
<table>
<thead>
<tr>
<th>Profile number</th>
<th>Map unit</th>
<th>Soil type</th>
<th>Solum thickness</th>
<th>Ap</th>
<th>A</th>
<th>Color (moist)</th>
<th>Cons (moist)</th>
<th>Str</th>
<th>l:1</th>
<th>pH</th>
<th>Mollic l:1</th>
<th>epi-H₂O</th>
<th>pedon</th>
</tr>
</thead>
<tbody>
<tr>
<td>FMC9WH</td>
<td>119B</td>
<td>Sperry</td>
<td>Isicl</td>
<td>147</td>
<td>15</td>
<td>28</td>
<td>10YR2/1</td>
<td>fr</td>
<td>2fgr</td>
<td>5.5</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FMC8WH</td>
<td>122</td>
<td>Muscatine</td>
<td>Isicl</td>
<td>152</td>
<td>15</td>
<td>46</td>
<td>10YR2/1</td>
<td>fr</td>
<td>1fgr</td>
<td>6.7</td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P27</td>
<td>120B</td>
<td>Tama</td>
<td>hsicl</td>
<td>122</td>
<td>15</td>
<td>46</td>
<td>10YR3/2</td>
<td>fr</td>
<td>1fmgr</td>
<td>6.3</td>
<td>+</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FMC8WH range from moderate fine subangular blocky in the upper part to weak medium prismatic and massive in the lower part.

The Sperry (FMC9WH) and Muscatine (FMC8WH) profiles have darker Ap colors and thicker sola than the Tama profile. All three profiles have mollic epipedon. An E horizon is present in FMC9WH. The combined thickness, A and E horizons, in FMC9WH is 28 cm.

Particle-size distributions

Above a depth of 221 cm, the sand content in P27, FMC8WH, and FMC9WH is less than 4% (Figure 85). Profile P27 was analyzed to a depth of 147 cm. The low sand content and its narrow range imply a similar, relatively sand-free loess parent material for profiles FMC8WH, FMC9WH, and P27.

The total silt depth distributions for P27, FMC8WH, and FMC9WH are plotted in Figure 86. Above a depth of 221 cm in FMC9WH and 224 cm in FMC8WH, the total silt contents range from a low of 56.6% in FMC9WH to 75.7% in FMC8WH. Below the lithologic discontinuities, total silt content decreases to 35.1% in FMC8WH and 48.8% in FMC9WH. The total silt depth distributions are generally similar. However, FMC9WH has a more pronounced total silt eluviation zone between a depth of 30 and 80 cm.

The clay depth distributions for P27, FMC8WH, and FMC9WH are plotted in Figure 87. Lowest clay contents, 16.8 and
Figure 85. Sand depth distributions for FMC8WH (H), FMC9WH (I), and P27 (J)
Figure 86. Total silt depth distributions for FMC8WH (H), FMC9WH (I), and P27 (J)
Figure 87. Clay depth distributions for FMC8WH (H), FMC9WH (I), and P27 (J)
19.6%, are below the lithologic discontinuity in FMC8WH. In FMC9WH, the clay content of 32.3%, below the lithologic discontinuity, exceeds that in most horizons above. Above a depth of 221 cm, the clay contents range from 21.1% in FMC8WH (Muscatine) to 41.7% in FMC9WH (Sperry). All the soils meet the respective particle-size criterion. Table 48 lists some selected particle-size characteristics of FMC9WH, FMC8WH, and P27. The maximum clay contents in the soils are in the order FMC9WH, Sperry > FMC8WH, Muscatine > P27, Tama (Table 48). The depth (53.5 cm) to maximum clay content is greatest in P27. Since the three profiles formed under grass vegetation, the high clay contents may be related to landscape positions and associated soil moisture regimes (Appendix II).

The B/A clay ratios are in the order FMC9WH >> P27 > FMC8WH. The Δ clay contents follows the same trend as the B/A clay ratios. The B/A clay ratios and the Δ clay contents both support the conclusion that differentiation of the profiles is in the order FMC9WH >> P27 > FMC8WH. Also, the low Δ clay content and the absence of an argillic horizon are indicative of a low degree of differentiation in the Muscatine profile (FMC8WH).

The implications of the clay distribution trends (Table 48) in FMC8WH, FMC9WH, and P27 are that landscape position and drainage regime influence the extent of clay formation and its distribution throughout the profiles. Collins (1977)
Table 48. Selected particle-size data for FMC9WH, FMC8WH, and P27

<table>
<thead>
<tr>
<th>Profile</th>
<th>Map unit</th>
<th>Clay max (%)</th>
<th>Depth clay max (cm)</th>
<th>B/A clay ratio</th>
<th>Weighted clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0-25</td>
</tr>
<tr>
<td>FMC9WH</td>
<td>122</td>
<td>41.7</td>
<td>44.5</td>
<td>1.70</td>
<td>28.6</td>
</tr>
<tr>
<td>FMC8WH</td>
<td>119B</td>
<td>35.5</td>
<td>43.5</td>
<td>1.16</td>
<td>32.5</td>
</tr>
<tr>
<td>P27</td>
<td>120B</td>
<td>34.3</td>
<td>53.5</td>
<td>1.21</td>
<td>29.9</td>
</tr>
</tbody>
</table>
reported B/A clay ratios of 1.23 and 1.19 for a Tama and a Muscatine profile, respectively. Both soils were located on stable landscape positions. She also reported a lack of clay coats in the Muscatine soil. The results obtained for FMC8WH and P27 concur with Collins' findings. Fenton (1966) also reported low B/A clay ratios for a Tama soil (1.15) and a Muscatine soil (1.09). Both Collins and Fenton reached a conclusion similar to that found for this study: based on clay distribution and B/A clay ratio the Muscatine soil is not highly differentiated. The presence of mottles at a depth of 57 cm and a zone of strong effervescence (152 to 236 cm) imply restriction of the downward movement of water in the Muscatine soil, FMC8WH. Profiles FMC9WH (Sperry) and P27 (Tama) are leached throughout. The greater accumulation of clay in FMC9WH, relative to P27 and FMC8WH, is probably related to landscape position.

Organic carbon

The organic carbon (OC) depth distributions for FMC9WH, FMC8WH, and P27 are plotted in Figure 88. Weighted OC contents in the 0 to 25 cm zones are 2.04% in FMC9WH, 2.14% in FMC8WH, and 1.96% in P27. In the 25 to 100 cm zones, weighted OC contents decline to 0.79% in P27, 0.78% in FMC8WH, and 0.60% in FMC9WH. The depths to less than 0.58% OC are 76 cm in P27, 51 cm in FMC9WH, and 46 cm in FMC8WH. In the well-drained Tama profile (P27), the difference in OC between the
Figure 88. Depth distributions of OC in FMC8WH (H), FMC9WH (I), and P27 (J)
0 to 25 cm zone and the 25 to 100 cm zone (ΔOC) is less than in FMC8WH and FMC9WH. The ΔOC values are 1.44, 1.36, and 1.17% in FMC9WH, FMC8WH, and P27, respectively. The ΔOC values imply greater accumulation of OC in the 0 to 25 cm zone relative to the 25 to 100 cm zone in FMC9WH and FMC8WH. In the well-drained P27, OC content decreases gradually with depth.

The implications from the OC comparisons is that impeded drainage causes greater production and accumulation of organic matter in the soils with impeded drainage relative to the well-drained soil.

Profiles FMC9WH and P27 have humic acid carbon to fulvic acid carbon (H/F) ratios which are greater than unity (Appendix III). High H/F ratios (>1) are characteristic of soils which formed under prairie vegetation. The H/F ratios in FMC8WH vary between 0.23 and 0.79. The relatively low H/F ratios in FMC8WH may be due to one of the following: (1) forest vegetation may have been present when the soil was forming or (2) if fulvic acid is considered a precursor of humic acid, then OC decomposition is not very advanced. Generally, H/F ratios are less than unity in soils formed under forest vegetation and in subsurface horizons (Kononova, 1966). Nissenbaum and Schallinger (1974) consider fulvic acid to be an intermediate product in the formation of humic substances. Thus, in environment where organic matter is not completely
humified, fulvic acid exceeds humic acid.

**Total phosphorus**

The total phosphorus (TP) depth distributions for P27, FMC8WH, and FMC9WH are plotted in Figure 89. The TP depth distribution trends are generally similar in the three soils. In each profile, TP content decreases below the A horizon then increases in the B horizons (Figure 89). Below a depth of 191 cm in FMC8WH, TP content declines. Profile FMC9WH has three zones of high TP (>1000 ppm) accumulation. The three zones are the Ap horizon, 94 to 132 cm, and 170 to 213 cm. Table 49 lists selected characteristics of P27, FMC8WH, and FMC9WH. Examination of Table 49 shows that profile P27 has a greater amount of phosphorus than profile FMC8WH. Profile FMC8WH has a higher maximum TP content, 789 ppm at a depth of 163 cm, than P27 which has a maximum TP content of 768 ppm at a depth of 137 cm. The I/E ratios are 1.89 in P27 and 2.42 in FMC8WH. Profile FMC9WH has the highest TP content of the three profiles. However, within the eluviation zones, FMC9WH has the lowest TP content, 284 ppm.

The high TP content and its depth distribution show how distinctly different profile FMC9WH (Sperry) is from the other two profiles, P27 (Tama), and FMC8WH (Muscatine). The Sperry profile (FMC9WH) has two distinct TP maxima below the Ap horizon. Smeck and Runge (1971) found similar TP profiles in Aqualfs and Aquolls in Illinois. They also reported high
Figure 89. Total phosphorus depth distributions for FMC8WH (H), FMC9WH (I), and P27 (J)
Table 49. Selected TP characteristics of profiles P27, FMC8WH, and FMC9WH

<table>
<thead>
<tr>
<th>Profile</th>
<th>Map unit</th>
<th>Ap</th>
<th>0-25 cm</th>
<th>25-100 cm</th>
<th>Solum</th>
<th>TPmax (cm)</th>
<th>DTPmax (cm)</th>
<th>TPmin&lt;sup&gt;a&lt;/sup&gt; (ppm)</th>
<th>DTP min (cm)</th>
<th>I/E ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>P27</td>
<td>120B</td>
<td>617</td>
<td>559</td>
<td>527</td>
<td>577</td>
<td>768</td>
<td>137(C)</td>
<td>406</td>
<td>54</td>
<td>1.89</td>
</tr>
<tr>
<td>FMC8WH</td>
<td>119B</td>
<td>493</td>
<td>481</td>
<td>446</td>
<td>554</td>
<td>789</td>
<td>164(C)</td>
<td>326</td>
<td>52</td>
<td>2.42</td>
</tr>
<tr>
<td>FMC9WH</td>
<td>122</td>
<td>991</td>
<td>776</td>
<td>600</td>
<td>775</td>
<td>1208</td>
<td>125(BC)</td>
<td>284</td>
<td>33</td>
<td>4.25</td>
</tr>
</tbody>
</table>

<sup>a</sup>Above lithologic discontinuity.
 (>900 ppm) TP content in a Mollic Albaqualf.

The TP contents of the Ap horizons, 0 to 25 cm zone, 25 to 100 cm zone, and soil solum are in the order FMC9WH > P27 > FMC8WH. Thus, TP content increases with increase in profile differentiation which in turn is related to landscape position. Smeck and Runge (1971) reached a similar conclusion. The conclusion from the TP profile of FMC9WH is that there has been a substantial accumulation of phosphorus by runon, and subsequent redistribution. The TP content at a depth of 137 cm in P27 is 768 ppm. In FMC8WH, the TP content at a depth of 145 cm is 769 ppm. This may be a useful index of parent material similarity in the two soils.

Based on particle-size distribution, discussed previously, profiles FMC8WH, FMC9WH, and P27 have a similar loess parent material. Sand contents in the soils are similar and relatively uniform with depth above the lithologic discontinuities (Figure 85). The original phosphorus content of the loess parent material may be considered to be approximately 770 ppm. The TP content (770 ppm) is based on the TP contents at relatively similar depths in FMC8WH and P27. The implication of the parent material phosphorus is that profile FMC9WH has gained substantial amounts of phosphorus (Figure 89). Thus, in profile FMC9WH, TP gains are more than 400 ppm.
**Soil pH**

The pH depth distributions for these soils are plotted in Figure 90. The highest pH value, 7.8, and lowest pH value, 6.2, are in profile FMC8WH. Profile P27 is generally more acid than FMC8WH. The pH values in P27 do not exceed 6.6, and the values generally increase with depth. The generally low pH values in P27 imply a greater degree of leaching relative to FMC8WH and FMC9WH. However, an F test revealed no significant differences among pH means, above a depth of 140 cm. The critical region for the F test is $F_{0.05}(2)(27) = 4.21$.

**Inorganic phosphorus fractions**

Table 50 lists selected weighted inorganic phosphorus (IP) fractions for P27, FMC8WH, and FMC9WH. A model showing weighted IP form in the 25 to 100 cm zone is presented in Figure 91. Based on higher amounts of AlP, FeP, RSP, and occluded P, profile P27 is more developed than profile FMC8WH. Profile FMC9WH has less FeP than P27, but more occluded P and RSP. Profile FMC9WH also has relatively large amounts of occluded FeP and occluded AlP than does P27. As a result, FMC9WH may be considered more developed than P27.

Iron phosphate and CaP depth distributions for P27, FMC8WH, and FMC9WH are plotted in Figures 92 and 93, respectively. The three soils have FeP eluviation zones below the A horizons. This concurs with the finding of Mausbach (1969).
Figure 90. Depth distributions of soil pH for FMC8WH (H), FMC9WH (K), and P27 (J)
Table 50. Weighted average percent inorganic phosphorus fractions in the 0-25 and 25-100 cm zones of P27, FMC8WH, and FMC9WH

<table>
<thead>
<tr>
<th>Profile</th>
<th>CaP</th>
<th>AlP</th>
<th>FeP</th>
<th>RSP</th>
<th>OCCLP</th>
<th>ACTIVE?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0-25 cm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P27</td>
<td>46</td>
<td>29</td>
<td>48</td>
<td>184</td>
<td>200</td>
<td>125</td>
</tr>
<tr>
<td>FMC8WH</td>
<td>17</td>
<td>8</td>
<td>39</td>
<td>15</td>
<td>20</td>
<td>64</td>
</tr>
<tr>
<td>FMC9WH</td>
<td>64</td>
<td>80</td>
<td>122</td>
<td>172</td>
<td>218</td>
<td>267</td>
</tr>
<tr>
<td><strong>25-100 cm</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P27</td>
<td>91</td>
<td>34</td>
<td>116</td>
<td>146</td>
<td>176</td>
<td>239</td>
</tr>
<tr>
<td>FMC8WH</td>
<td>131</td>
<td>11</td>
<td>64</td>
<td>34</td>
<td>52</td>
<td>206</td>
</tr>
<tr>
<td>FMC9WH</td>
<td>156</td>
<td>33</td>
<td>71</td>
<td>176</td>
<td>260</td>
<td>261</td>
</tr>
</tbody>
</table>

In profile FMC9WH, relatively high values of FeP are associated with high values of TP. The CaP values increase with depth in the three profiles. High values of FeP and CaP in FMC9WH support the conclusion of Smeck and Runge (1971) that calcium and iron are agents of phosphorus immobilization in soils with impeded drainage.

Profile P27 has more FeP and less CaP than FMC8WH. Higher CaP and lower sesquioxide P in the Muscatine soil (FMC8WH) as compared to the Tama soil (P27) support the conclusion of Mausbach (1969). Mausbach considered this condition to be related to high pH and reducing conditions in the
Figure 91. Inorganic P content in the 25 to 100 cm section of FMC9WH, P27, and FMC8WH.
Figure 92. Depth distributions of FeP in FMC8WH (H), FMC9WH (I), and P27 (J)
Figure 93. Depth distributions of CaP in FMC8WH (H), FMC9WH (I), and P27 (J)
poorly drained soils. The Muscatine soil (FMC8WH) has higher pH than the Tama soil (P27). Mausbach also reported lower RSP in the poorly drained soils.

Statistical Analysis

Correlation study

The first step in the statistical analysis was the determination of simple correlation coefficients (r). The coefficients were used to determine independent variables which would go into multiple regression models. Analyses were restricted to the upper 100 cm of each profile as this is the depth to which organic carbon data are available. The soils were divided into six groups for correlation analysis. Groups 1, 2, and 3 were retained as used previously; Group 5 (Group 1 and FMC8WH); Group 6 (all profiles except FMC6WH); Group 7 (Group 5 and FMC9WH).

Within each soil group the organic carbon fractions were highly intercorrelated (0.70 to 1.00). The organic fractions include total organic carbon, extractable organic carbon, humic acid carbon, and fulvic acid carbon. All the correlation coefficients were significant at the 1% level.

Several variables were coded (Table 51) to facilitate statistical analysis. Within the Downs and Tama groups, there are several slope and erosion classes. Drainage becomes a variable when the Muscatine or Sperry or both soils are
Table 51. Codes for selected variables used in statistical analysis

<table>
<thead>
<tr>
<th>Variable</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biosequence</strong></td>
<td></td>
</tr>
<tr>
<td>Prairie</td>
<td>1</td>
</tr>
<tr>
<td>Prairie-forest</td>
<td>2</td>
</tr>
<tr>
<td>Forest</td>
<td>3</td>
</tr>
<tr>
<td><strong>Drainage</strong></td>
<td></td>
</tr>
<tr>
<td>Well and moderately well</td>
<td>10</td>
</tr>
<tr>
<td>Somewhat poorly</td>
<td>20</td>
</tr>
<tr>
<td>Very poorly</td>
<td>30</td>
</tr>
<tr>
<td><strong>Slope class (%)</strong></td>
<td></td>
</tr>
<tr>
<td>0-2</td>
<td>00</td>
</tr>
<tr>
<td>2-5</td>
<td>02</td>
</tr>
<tr>
<td>5-9</td>
<td>05</td>
</tr>
<tr>
<td>9-14</td>
<td>09</td>
</tr>
<tr>
<td><strong>Erosion class</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
included in a group. Only one profile (P32) makes up Group 3. As a result, almost all variables are highly correlated (negatively or positively) with one another.

Correlations between P forms (including total phosphorus (TP)) varied from very low to high correlation. Tables 52 through 57 list select P correlation coefficients, greater than ± 0.30, for the soil groups. Aluminum P and FeP have high correlations in the Tama soils and Fayette soil (Tables 52 and 54, respectively). When Muscatine and Sperry soils are included with the Tama soils (Group 7), the correlation between AlP and FeP increases to 0.67 and 0.70, respectively. Mausbach (1969) suggested that a positive correlation between AlP and FeP is indicative of soil development. This means that as soils develop, AlP and FeP both increase. Furthermore, he concluded that FeP and AlP form under similar pH conditions.

Reductant-soluble P and FeP are related to the iron status of the soil (Mausbach, 1969). In this study, correlation between RSP and FeP was 0.30 in Group 1 - Tama soils, 0.52 in Group 5 - Tama and Muscatine soils, and 0.84 in the Tama, Muscatine, and Sperry combination - Group 7. The relative amounts of FeP and RSP in P27, FMC8WH, and FMC9WH are shown in Figure 91. The well-drained profile, P27, has more FeP than the profiles with impeded drainage.

When all profiles, except FMC6WH, are examined (Group 6), the correlation for RSP and FeP is 0.49. This relatively
Table 52. Simple correlation coefficients ($r > \pm 0.30$) of the P forms for the Group 1 soils, FMC5WH, FMC7WH, and P27*.

<table>
<thead>
<tr>
<th></th>
<th>NH$_4$ClP</th>
<th>AlP</th>
<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
</tr>
</thead>
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<td>NH$_4$ClP</td>
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<tr>
<td>AlP</td>
<td>.65**</td>
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<td></td>
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</tr>
<tr>
<td>FeP</td>
<td>-</td>
<td>.54**</td>
<td>1.00</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSP</td>
<td>-</td>
<td>-</td>
<td>.30+</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ResidP</td>
<td>.64**</td>
<td>.43*</td>
<td></td>
<td></td>
<td>-</td>
<td>- .59**</td>
<td>1.00</td>
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<td></td>
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<tr>
<td>ActiveP</td>
<td>-</td>
<td>.44*</td>
<td>.72**</td>
<td>-</td>
<td>.90**</td>
<td>-</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SesqoxP</td>
<td>.35+</td>
<td>.60**</td>
<td>.67**</td>
<td>.64**</td>
<td>-</td>
<td>.64**</td>
<td>.43*</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OcclP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.93**</td>
<td>-</td>
<td>.93**</td>
<td>-</td>
<td>-</td>
<td>.77**</td>
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<tr>
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<td>.64**</td>
<td>-</td>
<td>.49**</td>
<td>-</td>
<td>.75**</td>
<td>.71**</td>
<td>.32+</td>
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</tbody>
</table>

*Number of samples (horizons) = 25.

**, *, +Significant at the 1%, 5%, and 20% levels, respectively.
Table 53. Simple correlation coefficients (r > ±0.30) of P forms for the Group 2 soils, FMC1WH, FMC2WH, FMC3WH, and FMC4WH\(^a\)

<table>
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<tr>
<th></th>
<th>NH(_4)ClP</th>
<th>Al(_3)P</th>
<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
</tr>
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<td>Al(_3)P</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FeP</td>
<td>-</td>
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<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>RSP</td>
<td>-</td>
<td></td>
<td></td>
<td>0.52**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaP</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>-0.32+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ResidP</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.32+</td>
<td>-0.88**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ActiveP</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.42**</td>
<td>-0.82**</td>
<td>-0.54**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>SesqoxP</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.41**</td>
<td>0.84**</td>
<td>0.85**</td>
<td>1.00</td>
</tr>
<tr>
<td>OcclP</td>
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<td></td>
<td></td>
<td></td>
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<td>-0.56**</td>
<td>0.99**</td>
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<td>TotP</td>
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<td></td>
<td></td>
<td>-0.36*</td>
<td>0.44**</td>
</tr>
</tbody>
</table>

\(^a\)Number of samples (horizons) = 32.

**,*,+Signficant at the 1%, 5%, and 20% levels, respectively.
Table 54. Simple correlation coefficients \((r > \pm 0.30)\) of P forms for the Group 3 soil, P32a

<table>
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<tr>
<th></th>
<th>NH(_4)ClP</th>
<th>A1P</th>
<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
</tr>
</thead>
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<td>NH(_4)ClP</td>
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<td>A1P</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>FeP</td>
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<td>1.00</td>
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</tr>
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<td>RSP</td>
<td>-</td>
<td>.42+</td>
<td>.84**</td>
<td>1.00</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaP</td>
<td>-.47+</td>
<td></td>
<td>.41+</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ResidP</td>
<td>.53*</td>
<td>-.45+</td>
<td>-.70**</td>
<td>-.79**</td>
<td>-.64**</td>
<td>1.00</td>
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</tr>
<tr>
<td>ActiveP</td>
<td>-</td>
<td>.86**</td>
<td>.94**</td>
<td>.73**</td>
<td>.48+</td>
<td>-.69**</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SesqoxP</td>
<td>-</td>
<td>.73**</td>
<td>.97**</td>
<td>.91**</td>
<td>.36+</td>
<td>-.76**</td>
<td>.94**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OcclP</td>
<td>-</td>
<td>.44+</td>
<td>.87**</td>
<td>.99**</td>
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<td>-.78**</td>
<td>.75**</td>
<td>.92**</td>
<td>1.00</td>
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</tr>
<tr>
<td>TotP</td>
<td>.39+</td>
<td>.56*</td>
<td>.64**</td>
<td>.40+</td>
<td></td>
<td></td>
<td>.62**</td>
<td>.59*</td>
<td>.45+</td>
<td>1.00</td>
</tr>
</tbody>
</table>

\(^a\)Number of samples (horizons) = 14.

**, *, +Significant at the 1%, 5%, and 20% levels, respectively.
Table 55. Simple correlation coefficients (r > +0.30) of P forms for the Group 5 soils, FMC5WH, FMC7WH, FMC8WH, and P27.

<table>
<thead>
<tr>
<th></th>
<th>NH₄ClP</th>
<th>AlP</th>
<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
</tr>
</thead>
<tbody>
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<td>NH₄ClP</td>
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<td>AlP</td>
<td>0.64**</td>
<td>1.00</td>
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<tr>
<td>FeP</td>
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<td>0.67**</td>
<td>1.00</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSP</td>
<td></td>
<td></td>
<td>0.38*</td>
<td>1.00</td>
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<td></td>
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</tr>
<tr>
<td>CaP</td>
<td></td>
<td></td>
<td></td>
<td>0.30+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>ResidP</td>
<td>0.34*</td>
<td></td>
<td></td>
<td></td>
<td>0.50**</td>
<td>0.42**</td>
<td>-0.67**</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ActiveP</td>
<td>0.36*</td>
<td></td>
<td>0.63**</td>
<td></td>
<td>0.92**</td>
<td>0.69**</td>
<td>1.00</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SesqoxP</td>
<td>0.35*</td>
<td></td>
<td>0.73**</td>
<td>0.81**</td>
<td>0.80**</td>
<td>-0.43**</td>
<td>0.45**</td>
<td>1.00</td>
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</tr>
<tr>
<td>OcclP</td>
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<td></td>
<td>0.51**</td>
<td>0.96**</td>
<td></td>
<td>-0.36*</td>
<td></td>
<td>0.88**</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>TotP</td>
<td>0.56**</td>
<td>0.69**</td>
<td>0.61**</td>
<td>0.32*</td>
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<td>0.75**</td>
<td>0.63**</td>
<td>0.40**</td>
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</tbody>
</table>

*Number of samples (horizons) = 35.

**,*,+Significant at the 1%, 5%, and 20% levels, respectively.
Table 56. Simple correlation coefficients ($r > 0.30$) of P forms for the Group 7 soils, FMC5WH, FMC7WH, FMC8WH, FMC9WH, and P27^a

<table>
<thead>
<tr>
<th></th>
<th>NH₄ClP</th>
<th>AlP</th>
<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₄ClP</td>
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<tr>
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<td>-</td>
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<td>.40**</td>
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</tr>
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<td>CaP</td>
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<td>.35**</td>
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<td>ResidP</td>
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<td>-.30*</td>
<td>-.61**</td>
<td>1.00</td>
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<td></td>
</tr>
<tr>
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<td>-</td>
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<td>.69**</td>
<td>.36**</td>
<td>.91**</td>
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<td>.36**</td>
<td>.96**</td>
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<td>.35*</td>
<td>.36**</td>
<td>.83**</td>
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<td>.72**</td>
<td>.64**</td>
<td>.54**</td>
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<td>.76**</td>
<td>.83**</td>
<td>.63**</td>
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</table>

^aNumber of samples (horizons) = 45.

**,** Significant at the 1% and 5% levels, respectively.
Table 57. Simple correlation coefficients ($r > +0.30$) of P forms of the Group 6 soils, all profiles except FMC6WH$^a$

<table>
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<th>FeP</th>
<th>RSP</th>
<th>CaP</th>
<th>ResidP</th>
<th>ActiveP</th>
<th>SesqoxP</th>
<th>OcclP</th>
<th>TotP</th>
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<td>0.41**</td>
<td>0.49**</td>
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<tr>
<td>CaP</td>
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<td>0.43**</td>
<td>1.00</td>
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<td>0.33**</td>
<td>0.78**</td>
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<td>0.84**</td>
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<td>0.34**</td>
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<td>0.35**</td>
<td>0.44**</td>
<td>0.96**</td>
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<td>0.35**</td>
</tr>
<tr>
<td>TotP</td>
<td>0.33**</td>
<td>0.41**</td>
<td>0.52**</td>
<td>0.53**</td>
<td>0.38**</td>
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<td>0.68**</td>
<td>0.61**</td>
<td>0.56**</td>
<td>1.00</td>
</tr>
</tbody>
</table>

$^a$Number of profiles = 10. Number of samples (horizons) = 91.

**Significant at the 1% level.
high correlation is associated with high correlation between RSP and FeP in the Downs and Fayette groups.

The active P form includes NH₄ClP, AlP, FeP, and CaP. Correlation between active P and CaP yielded a value of 0.90 in the Tama soils, 0.82 in the Downs soils, and 0.48 in the Fayette profile. The implication of the correlation values for the CaP and active P comparison is that CaP decreases in importance as a component of active P as soils grade from prairie-derived to transition to forest-derived. Including the Muscatine or Sperry soil with the Tama soils inflates the correlation between CaP and active P slightly (Tables 52, 55, and 56). The correlation value for CaP and active P in the Group 6 soils is 0.78. This high correlation reflects the low correlation between CaP and active P in the Downs and Fayette soils.

In Group 3 (Fayette soil), there are high correlations between AlP and active P (0.86), and FeP and active P (0.94). These high correlations reflect the importance of AlP and FeP as components of the active P form in the Fayette soil.

Table 58 lists select simple correlation coefficients for the soils of this study. In all but Group 3, Fayette, the correlations for clay and CaP are negative. Mausbach (1969) interpreted this trend to be indicative of profile development; as soils develop, clay increases and pH decreases. The positive correlation coefficient, 0.48, for the Fayette soil may
Table 58. Selected simple correlation coefficients (r > ±0.30) for the soil groups, except Group 4

<table>
<thead>
<tr>
<th>Soil group</th>
<th>No.</th>
<th>Clay v CaP</th>
<th>Clay v FeP</th>
<th>Clay v AlP</th>
<th>pH v CaP</th>
<th>pH v FeP</th>
<th>pH v AlP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>-.52**</td>
<td>-.42*</td>
<td>-</td>
<td>.61**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>-.71**</td>
<td>.37*</td>
<td>-</td>
<td>.58**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>14</td>
<td>.48++</td>
<td>.82**</td>
<td>.59*</td>
<td>.31++</td>
<td>.95*</td>
<td>.50++</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>-.57**</td>
<td>-.54**</td>
<td>-</td>
<td>.66**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>91</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.46**</td>
<td>-.31**</td>
<td>-.57**</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>-.34*</td>
<td>-.43**</td>
<td>-</td>
<td>.54**</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**,*,++,**Significant at the 1%, 5%, 10%, and 30% levels, respectively.
be related to the trend of the variables with which they were analyzed statistically. Soil pH and clay content generally increase with depth. However, pH values are low, 5.4 or less. The Fayette soil, Group 3, has higher correlation coefficients than the other soils groups for clay and FeP, clay and AlP, FeP and pH, and AlP and pH. The correlation between CaP and pH is lowest for the Group 3 soil (Table 58).

Within the Group 1 soils, slope and H/F ratio had a highly significant negative correlation (-0.85). The correlation coefficient indicates that, as slope increases, H/F ratio decreases. Also, slope and clay had a highly significant negative correlation (-0.65). There was also a high correlation (0.86) between pH and slope. A correlation of -0.49 between slope and occluded P may be interpreted as a decrease in soil development with increasing slope gradient. Slope and erosion were highly correlated (0.91). As a result, they had similar effects on the parameters they were correlated with.

In the Group 2 soils, slope was highly correlated with erosion (0.91), RSP (-0.63), sesqoxP - AlP, FeP, RSP (-0.60), occluded P (-0.65), fine silt (-0.63), total silt (-0.51), and pH (0.64). The implication of the correlation coefficients is similar to that in the Tama soils: as slope increases, soil development decreases.

Based on simple correlation coefficients (r values),
Independent variables were selected for multiple regression models. These will be discussed in the next section.

**Multiple regression model**

Based on correlation analysis, variables were selected for multiple linear regression models. The models provide estimates of the effects of selected independent variables on selected dependent variables. The multiple regression model has the form:

\[ Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + e_i \]

\(\beta_0, \beta_1, \beta_2, \ldots, \beta_k\) are partial regression coefficients, sometimes called partial slopes or simple regression coefficients. When all the X's are equal to zero, Y is equal to the intercept, \(\beta_0 + e_i\). The term \(e_i\) represents error residual since the independent variables, X's, do not completely explain \(Y_i\). The error term is a random quantity which is normally independently distributed with zero means and constant variance, \(e_i, \text{NID}(0, \sigma)\). Each \(\beta\) is an increment in Y corresponding to a unit increase in \(X_i\) when the other variables are held constant. The method of least squares, minimization of the sum of squared residuals, is used to estimate \(\beta\)'s. For a sample of \(n\) values the prediction equation is

\[ \hat{Y}_i = \hat{b}_0 + \hat{b}_1 X_{1i} + \hat{b}_2 X_{2i} + \ldots + \hat{b}_p X_{pi} \]

The square of the multiple correlation coefficient, \(R^2\), is used to assess the adequacy of fit of the model, \(1 \geq R^2 \geq 0\).
Generally, the better the model, the closer $R^2$ is to 1 because the observed and predicted values are close to each other.

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}$$

In model building, it is desirable to minimize the sum of the difference between the observed and predicted values, $\sum(y_i - \hat{y}_i)$.

In developing the linear multiple regression models, variables with correlations $> \pm 0.50$ were excluded. Subsequently, the t-test of significance was applied to each of the partial regression coefficients. If $\alpha$ was greater than 0.05, the partial regression coefficients were deleted one at a time starting with the coefficients that had the highest $t$ values. The intercept, $\beta_0$, was retained in all equations regardless of the associated $\alpha$. In the final model, $\alpha$ was less than 0.05 for all the retained regression coefficients.

The models were fitted using the "PROC SYSREG" procedure (Hewlig and Council, 1979). Models were developed for the following sets of soils: (1) Tama soils, FMC5WH, FMC7WH, and P27; (2) Downs soils, FMC1WH, FMC2WH, FMC3WH, and FMC4WH; (3) Tama and Muscatine soils, 1 and FMC8WH; (4) Tama, Muscatine, and Sperry soils, 3 and FMC9WH. Models were not developed for the Fayette soil since most variables were too highly correlated.
Tables 59, 60, 61, and 62 list the multiple regression models and corresponding $R^2$ statistic. The percentage of total error accounted for by the regression is measured by $R^2$. In Table 59, $R^2$ is 83.6% for the TOTP model. The variations in $\text{NH}_4\text{ClP}$, IRONP (FeP), and CAP explain 83.6% of the variation in TOTP (total phosphorus) in the Tama soils. Within the Downs group of soils, four of seven models have $R^2 < 0.5$. The lowest $R^2$, 0.173, is for the ALUMP (aluminum phosphate) model for the Downs soils (Table 62). The highest $R^2$ value, 0.958, is for the CAP model in the Tama and Muscatine soils (Table 60).
Table 59. Multiple linear regression model and $R^2$ for the Tama profiles, FMC5WH, FMC7WH, and P27

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTP</td>
<td>307.941+57.983NH$_4$CLP**+1.562IRONP**+0.454CAP</td>
<td>.836**</td>
</tr>
<tr>
<td>CAP</td>
<td>-137.810-.692RESIDP**+10.049CSILT**</td>
<td>.627**</td>
</tr>
<tr>
<td>ALUMP</td>
<td>-10.055+0.425IRONP**+14.091NH$_4$CLP**</td>
<td>.656**</td>
</tr>
<tr>
<td>IRONP</td>
<td>-19.940+0.384SESQ0XP**+5.136SLOPE**</td>
<td>.684**</td>
</tr>
<tr>
<td>RSOLP</td>
<td>-112.787+0.400SESQ0XP+3.724FSILT</td>
<td>.555**</td>
</tr>
<tr>
<td>TOTOC</td>
<td>3.195+0.299NH$_4$CLP**-0.002ACTIVEP**-0.062CSILT**+0.107P15*</td>
<td>.865**</td>
</tr>
<tr>
<td>HFRATIO</td>
<td>-2.586+2.205HUMICCC**+0.102CLAY*</td>
<td>.491**</td>
</tr>
</tbody>
</table>

**, *Significant at the 1% and 5% levels, respectively.
Table 60. Multiple linear regression models for profiles FMC5WH, FMC7WH, P27, and FMC8WH

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTP</td>
<td>719.194-10.423CLAY**+2.633ALUMP**+0.372CAP**</td>
<td>0.823**</td>
</tr>
<tr>
<td>CAP</td>
<td>45.619+51.723TOTOC**+1.156ACTIVEP**-0.432TOTP**-4.111P15**</td>
<td>0.958**</td>
</tr>
<tr>
<td>ALUMP</td>
<td>167.558+0.186TOTP**+1.213P15**-28.131pH**-0.1440CCLP**-2.832DRAIN**</td>
<td>0.825**</td>
</tr>
<tr>
<td>IRONP</td>
<td>59.825-2.542DRAIN**-16.478TOTOC**+0.141TOTP**</td>
<td>0.652**</td>
</tr>
<tr>
<td>RSOLP</td>
<td>-288.408-4.436DRAIN**+30.142HFRATIO**+6.040TSILT*</td>
<td>0.567**</td>
</tr>
<tr>
<td>TOTOC</td>
<td>-3.843-0.161SLOPE**-0.019DEPTH**+0.018P15**+0.950pH**</td>
<td>0.860**</td>
</tr>
<tr>
<td>HFRATIO</td>
<td>6.194-0.011DEPTH**+1.933HUMICC**+0.005RSOLP**-1.017pH**</td>
<td>0.676**</td>
</tr>
</tbody>
</table>

**,** Significant at the 1% and 5% levels, respectively.
Table 61. Multiple linear regression models for profiles FMC5WH, FMC7WH, P27, FMC8WH, and FMC9WH

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTP</td>
<td>$300.590 + 40.389NH_4CLP** + 2.308ALUMP** + 0.797RSOLP** + 0.664CALP**$</td>
<td>.864**</td>
</tr>
<tr>
<td>CAP</td>
<td>$-29.277 - 110.332TOTOC*** + 0.613TOTP** - 1.074IRONP**$</td>
<td>.701**</td>
</tr>
<tr>
<td>ALUMP</td>
<td>$-24.130 + 8.958NH_4CLP** - 0.305IRONP** + 0.066TOTP** - 0.077CAP**$</td>
<td>.775**</td>
</tr>
<tr>
<td>IRONP</td>
<td>$123.794 + 0.899ALUMP** + 0.084CAP** - 2.436CLAY**$</td>
<td>.655**</td>
</tr>
<tr>
<td>RSOLP</td>
<td>$-81.440 + 1.942DRAIN** + 36.263HFRATIO** + 0.223TOTP**$</td>
<td>.537**</td>
</tr>
<tr>
<td>TOTOC</td>
<td>$-1.189 - 0.043SLOPE** + 0.319NH_4CLP** - 0.002CAP** + 0.074FSILT**$</td>
<td>.732**</td>
</tr>
<tr>
<td>HFRATIO</td>
<td>$8.194 + 0.002RSOLP** - 1.154pH**$</td>
<td>.388**</td>
</tr>
</tbody>
</table>

**, *Significant at the 1% and 5% levels, respectively.
Table 62. Multiple linear regression models for profiles FMC1WH, FMC2WH, FMC3WH, and FMC4WH

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Model</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTP</td>
<td>$39.158 + 0.678 \text{ACTIVEP}^{<strong>} + 1.880 \text{SILT}^{</strong>}$</td>
<td>.451**</td>
</tr>
<tr>
<td>CAP</td>
<td>$21.138 - 0.228 \text{RESIDP}^{*} + 9.639 \text{SILT}^{**}$</td>
<td>.715**</td>
</tr>
<tr>
<td></td>
<td>$-10.195 \text{SILT}^{**}$</td>
<td></td>
</tr>
<tr>
<td>ALUMP</td>
<td>$13.378 + 0.092 \text{ACTIVEP}^{*}$</td>
<td>.173*</td>
</tr>
<tr>
<td>IRONP</td>
<td>$71.870 + 0.490 \text{RSOLP}^{**}$</td>
<td>.265**</td>
</tr>
<tr>
<td>RSOLP</td>
<td>$636.534 + 1.159 \text{DEPTH}^{*<strong>} + 4.717 \text{SILT}^{</strong>} - 110.546 \text{pH}^{**}$</td>
<td>.610**</td>
</tr>
<tr>
<td>TOTOC</td>
<td>$0.442 - 0.002 \text{ACTIVEP}^{**<em>} + 0.036 \text{SILT}^{</em>}$</td>
<td>.429**</td>
</tr>
<tr>
<td>HFRATIO</td>
<td>$-2.751 + 1.951 \text{HUMICC}^{*<strong>} + 0.440 \text{pH}^{</strong>}$</td>
<td>.547**</td>
</tr>
</tbody>
</table>

**,*Significant at the 1% and 5% levels, respectively.
SUMMARY

Eleven profiles were investigated for selected morphological and chemical characteristics. A major objective of this research was to examine the use of inorganic phosphorus (IP) fractions and humic carbon to fulvic carbon (H/F) ratios as differentiae in a biosequence of selected soils, Alfisols and Mollisols. In addition, eroded analogues of a relatively stable Mollisol, Tama 120B, and an Alfisol, Downs 162B, were investigated. The utility of the IP fractions and H/F ratios as differentiating characteristics among soils at the management level (slope gradient and erosion phase) was also investigated.

Profile FMC6WH formed in alluvium. All other profiles in this study have loess parent material. Within the Downs group of soils, loess thickness was related to landscape position. The profiles on the more stable landscape positions had thicker loess than those on less stable landscape positions. Within the Tama soil group, loess was thicker under the soil with D slope, located on a paha, than under the soil on C slope. The Tama 120B profile had a loess thickness >147 cm. The presence of lithologic discontinuities confirm a loess mantle over coarser textured material. Within the Tama and Downs series, as erosion class and slope phase increased, depth to maximum clay content decreased. Within the Tama-
Downs-Fayette biosequence, the B/A clay ratio supported the conclusion that the Fayette profile is more highly differentiated than the Downs or Tama profiles. A high B/A clay ratio was also associated with the highly differentiated Sperry profile. The Sperry profile, FMC9WH, is located in an upland depression. High positive Δ clay (weighted clay content in the 25 to 100 cm zone - weighted clay content in the 0 to 25 cm zone) were associated with the highly differentiated soils.

Depth distribution trends of OC were examined in all the profiles. Within a series (Tama or Downs), OC content decreased with increase in slope gradient and erosion phase. The forest-derived soil and the soils with impeded drainage had the highest accumulation of OC in the upper horizons. The depth to >0.58% OC varied among the soils. This depth decreased as the stability of the landscape position decreased. When the well-drained soils are examined, depth to >0.58% OC is in the order prairie-derived > transition > forest derived. Depth to >0.58% OC is less in soils with impeded drainage (Muscatine and Sperry) than in the well-drained analogue (Tama). Organic carbon in selected soil extracts and H/F ratios have been used in separating taxonomic units in Russian (Kononova, 1966; Volobuyev, 1968) and Canadian (Lowe, 1980) soil classification systems. Within the Tama series, H/F ratios decreased as slope gradient and erosion class increased. In the Tama soil on a relatively stable
landscape position, B slope, H/F ratios were >1. In the Tama soils on less stable landscape positions, H/F ratios were <1. In the Downs profiles, lowest H/F ratios were associated with the profile on D slope. The H/F ratios were <1 in all the Downs profiles. In the Fayette profile, all H/F ratios were <1. Of the soils with impeded drainage, H/F ratios were highest in the profile located on a toeslope landscape position. This profile (Sawmill) has a buried solum. The H/F ratios may be considered most useful for separating the soils of this study at the order level.

Soil pH values generally increased as stability of the landscape position decreased in the Group 1 (Tama) and Group 2 (Downs) soils. Within a given group of soils, lowest pH values were generally associated with the most highly differentiated profile. Based on soil pH values, the Downs soils are more closely related to the Tama soils than to the Fayette profile.

All profiles except FMC5WH and FMC6WH had distinct total phosphorus (TP) eluviation and illuviation zones. The TP maxima occurred in the C or BC horizon of the Group 1, Group 2, and Group 3 soils. Lowest TP values, above the lithologic discontinuities, were associated with the Group 2 soils located on unstable landscape positions. The TP minima are associated with sandy subsoil. The I/E ratios (maximum TP below the Ap horizon/minimum TP values below the
Ap horizon) could not consistently separate the Group 1 and Group 2 soils. In the Group 1, Group 2, and Group 3 soils on stable landscape, depth to minimum TP values were in the order prairie-derived > forest-derived > transition. Profile FMC9WH (Sperry) from an upland depression had a highly differentiated TP profile, and a high I/E ratio. This profile, FMC9WH, is highly enriched in TP relative to the initial TP content of the loess parent material. The TP profile of FMC9WH supports a conclusion of phosphorus run-on and lateral subsurface movement from surrounding soils and a high degree of phosphorus translocation. The TP content in FMC9WH is highly correlated with the FeP content. Thus, there seems to be a dynamic relationship between landscape position, water movement, and Fe and P precipitation in the soil located in an upland depression.

Inorganic phosphorus was fractionated (NH₄ClP, AlP, FeP, RSP, OA1P, OFeP, and CaP). The importance of the individual fractions and selected combinations were assessed for each of the 11 profiles investigated. Calcium phosphate generally increased with depth in all profiles. Decreasing CaP values in the lower C horizons of some profiles were associated with lithologic discontinuities, indicated by high sand contents or high FeP contents. The CaP fraction was generally low in the upper parts of the sola. However, the soils on D slopes and those with restricted drainage had relatively high values close to the surface. Since soil pH gen-
erally increased with depth, highest CaP values were associated with high pH values. However, CaP was not always dominant at pH values >7. Soils with impeded drainage had higher values of CaP than their well-drained analogues. Also, within the biosequence, the forest-derived soils had lower pH and lower CaP than the prairie-derived and transition profiles.

Residual P represents phosphorus that was not extracted in the IP procedure. In the upper sola, it is mostly organic P. Residual P generally declined with depth. The soils with impeded drainage generally had more residual P close to the surface than did the other soils. This implies that the soils with impeded drainage have a higher organic P content than did the well-drained analogues.

The NH₄ClP values were very low. The AlP values were generally low and did not vary much with depth. The profiles which were considered more highly differentiated had higher values of FeP, RSP, and Oocl P. Weighted IP fractions in the 0 to 25 cm and 25 to 100 cm zones were evaluated. The transition soils (Downs) on relatively stable landscape had more FeP, RSP, and Oocl P than their prairie-derived counterparts (Tama soils). The forest-derived Fayette profile had more AlP, FeP, RSP, and Oocl P than the Tama and Downs profiles. A development sequence based on IP fractions of the soils in the biosequence is Fayette > Downs > Tama. The soils
on less stable landscape positions, D slopes, are dominated by active P (NH$_4$ClP, AlP, FeP, and CaP). Of the active P fractions, CaP is most abundant. The IP contents were useful for separating the soils at the series level. The more highly differentiated soils, Alfisols, generally had higher levels of AlP, FeP, RSP, and Ooccl P than did the Mollisols. However, the highly differentiated Group 4 soil, FMC9WH, had a relatively low level of FeP in the 25 to 100 cm zone.

In this study, it has been demonstrated that IP fractions are generally useful for separation of the soils investigated into a biosequence. The eroded soils had characteristic IP distributions. Consequently, the eroded soils could be distinguished from stable analogues on the basis of the relative amounts of IP in the 25 to 100 cm section.

The H/F ratios were generally useful for separating the soils studied at the order level. Mollisols had higher H/F ratios than Alfisols. Within the Mollisols investigated, H/F ratios declined with increasing slope gradient and erosion class. Within the Downs series, one profile, located on a D slope, had a relatively high H/F ratio. When the soil (FMC3WH) is excluded, H/F ratios generally decline as slope gradient and erosion phase increase.
CONCLUSIONS

(1) Profile FMC6WH (Sawmill) developed in alluvium, the other profiles formed in loess parent material.
(2) The presence of coarse material (high sand content) at depth in the profiles confirms a blanket of loess over loam till.
(3) The presence of lithologic discontinuities is marked by abrupt increase in sand content and abrupt decrease in total phosphorus content.
(4) Uniformity of loess above the till contact is confirmed by generally low (<5%) sand content.
(5) Profile FMC9WH (Sperry) is in the fine (35-59% clay) particle-size class. The other profiles are in the fine-silty (18-35% clay) particle-size class.
(6) Within the biosequence, T-D-F, the Fayette profile has the highest B/A clay ratio, highest ∆ clay, greatest depth to maximum clay content, and lowest amount of clay in the upper horizons.
(7) The relatively high clay content in FMC9WH implies an effect due to the depression landscape position.
(8) The ∆ clay content was at times more useful than the B/A clay ratio as an index of profile development.
(9) Profile FMC5WH (120D2) and FMC6WH (933B+) do not have distinct TP eluviation and illuviation zones in the sola.
Where material is uniform, a distinct TP eluvial/illuvial zone is a good index of profile development.

(10) Accumulation of phosphorus in FMC6WH and FMC9WH implies much lateral and vertical movement of P. These soils are enriched with TP relative to the more freely drained soils.

(11) The upper zone of high TP in FMC9WH may correspond to the zone of most frequent wetting and drying (and P precipitation), whereas the lower zone corresponds to zone of relatively high pH and unweathered loess. TP is highly correlated with Fe-P in profile FMC9WH.

(12) Total phosphorus maximum generally corresponds to clay minimum in prairie-derived soils. High TP contents are in the lower horizons (BC or C). Implication: Inability of clay to immobilize P, P immobilized by CaCO$_3$ and Fe.

(13) The I/E ratio was not consistently useful as an index of soil development.

(14) Ca-P increases with depth, this corresponds to an increase in soil pH. Ca-P is dominant at depth even when soil pH is <7. As a proportion of active-P, Ca-P is greater in prairie soils and transition soils. Fe-P, Al-P, and occluded-P make up a larger proportion of active P in the forest-derived soil. Reductant soluble-P values are highest in the upper sola. RS-P values are lower in the eroded soils and in the soils considered
less developed relative to the soils on more stable landscape positions. Al-P content implies that this fraction is transient.

(15) The IN-P fractions in the 25-100 cm sections are useful as accessory properties for separating the soils on the basis of series, erosion, drainage, and stage of development.

(16) OC decrease is sharper in the forest-derived soil, Fayette, soils with impeded drainage, Muscatine and Sperry, and in the eroded soils relative to the other soils.

(17) OC contents were lower in the eroded analogues of relatively stable soils. In the "uneroded" prairie-derived soils, H/F ratio > 1 generally. H/F ratios decrease as erosion phase and slope gradient increase. In the transition soils (Downs), H/F ratios <1 and generally decrease as slope phase and erosion class increase (trend not as obvious as in Tama group). Generally, H/F ratio is a good erosion index. The H/F ratio of the buried soil (Sawmill) is very high and may be useful as an index to define buried soils with relatively fresh overwash.

(18) The H/F ratios are useful for separating prairie-derived soils (>1) from forest-derived and transition soils (<1), i.e., Mollisols vs Alfisols.
(19) Generally, loess thickness ranges from 5 to 9 ft. Erosion of the soils exposes clayey subsoil which is low in OM content. Management practices should emphasize improvement of OM status of the eroded soils.
LITERATURE CITED


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Acknowledgment is also made to Dr. L. C. Dumenil and Mr. M. Kazemi who provided valuable counsel.

My wife Doreen and my daughter Tashia Ayana were constant sources of inspiration.

Finally, a few words for my parents Mr. and Mrs. E. A. Hobson and sister Winsome:

One bright morning when
man work is over man
will fly away home

Quote from the Hon. R. H. Marley
APPENDIX I: SOIL MAP AND LEGEND FOR THE FOUR MILE CREEK WATERSHED
### Soils Legend

**Four Mile Creek Watershed**

**Tama County, Iowa**

<table>
<thead>
<tr>
<th>Field sheet symbol</th>
<th>Mapping unit</th>
<th>CSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>8B</td>
<td>Judson silty clay loam, 2 to 5% slopes</td>
<td>95</td>
</tr>
<tr>
<td>11B</td>
<td>Colo-Ely complex, 2 to 6% slopes</td>
<td>68</td>
</tr>
<tr>
<td>11B+</td>
<td>Colo overwash-Ely complex, 2 to 6% slopes</td>
<td>68</td>
</tr>
<tr>
<td>118</td>
<td>Garwin silty clay loam, 0 to 2% slopes</td>
<td>95</td>
</tr>
<tr>
<td>119</td>
<td>Muscatine silty clay loam, 0 to 2% slopes</td>
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<tr>
<td>119B</td>
<td>Muscatine silty clay loam, 2 to 5% slopes</td>
<td>95</td>
</tr>
<tr>
<td>120B</td>
<td>Tama silty clay loam, 2 to 5% slopes</td>
<td>95</td>
</tr>
<tr>
<td>120C</td>
<td>Tama silty clay loam, 5 to 9% slopes</td>
<td>80</td>
</tr>
<tr>
<td>120C2</td>
<td>Tama silty clay loam, 5 to 9% slopes, moderately eroded</td>
<td>78</td>
</tr>
<tr>
<td>120C3</td>
<td>Tama silty clay loam, 5 to 9% slopes, severely eroded</td>
<td>73</td>
</tr>
<tr>
<td>120D2</td>
<td>Tama silty clay loam, 9 to 14% slopes, moderately eroded</td>
<td>68</td>
</tr>
<tr>
<td>120D3</td>
<td>Tama silty clay loam, 9 to 14% slopes, severely eroded</td>
<td>63</td>
</tr>
<tr>
<td>120E2</td>
<td>Tama silty clay loam, 14 to 18% slopes, moderately eroded</td>
<td>58</td>
</tr>
<tr>
<td>122</td>
<td>Sperry silt loam, 0 to 1% slopes</td>
<td>63</td>
</tr>
<tr>
<td>133</td>
<td>Colo silty clay loam, 0 to 2% slopes</td>
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<tr>
<td>133+</td>
<td>Colo silt loam, overwash, 0 to 2% slopes</td>
<td>80</td>
</tr>
<tr>
<td>162B</td>
<td>Downs silt loam, 2 to 5% slopes</td>
<td>90</td>
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*aThe soil maps and soils legend are preliminary and subject to change.*
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<td>Downs silt loam, 5 to 9% slopes</td>
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<tr>
<td>162C2</td>
<td>Downs silt loam, 5 to 9% slopes, moderately eroded</td>
<td>73</td>
</tr>
<tr>
<td>162D2</td>
<td>Downs silt loam, 9 to 14% slopes, moderately eroded</td>
<td>63</td>
</tr>
<tr>
<td>162D3</td>
<td>Downs silt loam, 9 to 14% slopes, severely eroded</td>
<td>60</td>
</tr>
<tr>
<td>162E2</td>
<td>Downs silt loam, 14 to 18% slopes, moderately eroded</td>
<td>53</td>
</tr>
<tr>
<td>162E3</td>
<td>Downs silt loam, 14 to 18% slopes, severely eroded</td>
<td>48</td>
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<td>162F2</td>
<td>Downs silt loam, 18 to 24% slopes, moderately eroded</td>
<td>30</td>
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<tr>
<td>162F3</td>
<td>Downs silt loam, 18 to 24% slopes, severely eroded</td>
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<tr>
<td>175D2</td>
<td>Dickinson fine sandy loam, 9 to 14% slopes, moderately eroded</td>
<td>28</td>
</tr>
<tr>
<td>179C2</td>
<td>Gara soils, 5 to 9% slopes, moderately eroded</td>
<td>53</td>
</tr>
<tr>
<td>179C3</td>
<td>Gara soils, 5 to 9% slopes, severely eroded</td>
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</tr>
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<td>179D2</td>
<td>Gara soils, 9 to 14% slopes, moderately eroded</td>
<td>43</td>
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<td>Gara soils, 9 to 14% slopes, severely eroded</td>
<td>38</td>
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<td>Adari soils, 9 to 14% slopes, severely eroded</td>
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<tr>
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<td>Adair soils, 14 to 18% slopes, severely eroded</td>
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<tr>
<td>377C</td>
<td>Dinsdale silty clay loam, 5 to 9% slopes</td>
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<td>377C2</td>
<td>Dinsdale silty clay loam, 5 to 9% slopes, moderately eroded</td>
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<td>377D2</td>
<td>Dinsdale silty clay loam, 9 to 14% slopes, moderately eroded</td>
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<td>377D3</td>
<td>Dinsdale silty clay loam, 9 to 14% slopes, severely eroded</td>
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<td>428B</td>
<td>Ely silty clay loam, 1 to 4% slopes</td>
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<td>430B</td>
<td>Ackmore silt loam, 2 to 5% slopes</td>
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<tr>
<td>683C2</td>
<td>Liscomb loam (firm subsoil variant), 5 to 9% slopes, severely eroded</td>
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<tr>
<td>683D2</td>
<td>Liscomb loam (firm subsoil variant), 9 to 14% slopes, severely eroded</td>
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<tr>
<td>763C2</td>
<td>Exette silt loam, 5 to 9% slopes, moderately eroded</td>
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<td>Exette silt loam, 9 to 14% slopes, moderately eroded</td>
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<td>Exette silt loam, 9 to 14% slopes, severely eroded</td>
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<td>Exette silt loam, 14 to 18% slopes, moderately eroded</td>
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<td>Exette silt loam, 14 to 18% slopes, severely eroded</td>
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<td>763F3</td>
<td>Exette silt loam, 18 to 24% slopes, severely eroded</td>
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<td>933</td>
<td>Sawmill silty clay loam, 0 to 2% slopes</td>
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<tr>
<td>933B</td>
<td>Sawmill-Muscatine complex, 2 to 5% slopes</td>
<td>68</td>
</tr>
</tbody>
</table>
Symbol Legend

Four Mile Creek Watershed
Tama County, Iowa

•••••• Sand spot
× × × × × × Gray paleosol
× × × × × × Adair spot
# # # # # # Glacial outcrop
¥ ¥ ¥ ¥ ¥ ¥ Wet spot
♀ ♂ ♂ ♂ ♂ Calcareous spot
♂ ♂ ♂ ♂ ♂ Gravel spot
•••••• Short steeper slope

← → ← → ← → ← → ← → Drainage ditch, perennial
← → ← → ← → ← → ← → Intermittent, crossable waterway
← → ← → ← → ← → ← → Intermittent, noncrossable waterway
← → ← → ← → ← → ← → Perennial stream

WATER ¥ ¥ ¥ ¥ ¥ ¥ Ponds
← → ← → ← → ← → ← → Drainage end
← → ← → ← → ← → ← → Muck spot
← → ← → ← → ← → ← → Severely eroded spot

Soil survey conducted by SCS personnel.
Kermit Voy, leader, SCS, Des Moines, Iowa.
APPENDIX II: DESCRIPTIONS OF SOIL PROFILES
Terms used in the descriptions of soil profiles are based on standard horizon nomenclature (Soil Survey Staff, 1951), except horizon designations are based on the Revised Soil Survey Manual (Soil Survey Staff, 1978). Munsell colors are for moist soil unless specified otherwise. Definitions of erosion classes are also included in this section.

**Soil Erosion Classes**

In soil mapping, the effect of erosion on the epipedon is described in terms of erosion classes. In the Iowa Cooperative Soil Survey program, erosion classes are defined in quantitative terms. These are listed below:

**Erosion Class 1:** None or slight erosion. Little or no mixing of the subsoil with the plow layer. The plow layer consists mainly of the A horizon or A + E horizons. Dark colored material is greater than 180 mm thick.

**Erosion Class 2:** Moderate erosion. Only 76 to 180 mm of A or (A + E) horizon remaining. Some of the B or AB are mixed with the plow layer.

**Erosion Class 3:** Severe erosion. Less than 76 mm of A or (A + E) horizon remaining. Most of the plow layer is B (or AB) horizon.

In this system, soil properties may be used to estimate the degree of accelerated erosion and the amount of A horizon that has been removed.
Profile: FMCIWH

Mapping unit: 162C2 - Downs silt loam, 5 to 9% slopes, moderately eroded
Taxonomic class: Fine-silty, mixed, mesic Mollic Hapludalfs
Drainage: Well
Parent material: Wisconsin loess
Physiographic position: Slightly convex summit
Location: 77 ft N of EW fenceline marking the southern boundary and 404 ft E of NS fenceline marking the western boundary of S\text{\textsubscript{2}}, NW\text{\textsubscript{4}}, NW\text{\textsubscript{3}}, S28, T86\text{\textsuperscript{N}}, R15\text{\textsuperscript{W}}, Grant Township, Tama County
(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Horizon</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap 0-17</td>
<td>Very dark grayish brown (10YR3/2) light silty clay loam, dark brown (10YR4/3) dry; moderate fine and medium granular structure; friable, many fine roots; pH 6.5; clear smooth boundary</td>
<td></td>
</tr>
<tr>
<td>BE 17-25</td>
<td>Very dark grayish brown (10YR3/2) ped coats, dark brown (10YR4/3) in interior of peds; light silty clay loam; yellowish brown (10YR5/4) dry; moderate fine and medium subangular blocky structure; friable; very few fine roots; pH 6.4; gradual smooth boundary</td>
<td></td>
</tr>
<tr>
<td>Bt1 25-34</td>
<td>Dark yellowish brown (10YR4/4) silty clay loam, yellowish brown (10YR5/4) dry; moderate medium subangular blocky structure; firm; thin discontinuous dark brown (10YR4/3) clay films; pH 6.4; gradual smooth boundary</td>
<td></td>
</tr>
<tr>
<td>Bt2 34-53</td>
<td>Same as above (Bt1) except weak medium angular blocky structure parting to moderate fine subangular blocky; friable; pH 6.5; gradual smooth boundary</td>
<td></td>
</tr>
<tr>
<td>Bt3 53-66</td>
<td>Same as above (Bt2) except for the presence of a few thin, patchy light brownish gray (10YR 6/2) silt coats; pH 6.5</td>
<td></td>
</tr>
<tr>
<td>Bt4 66-80</td>
<td>Yellowish brown (10YR5/4) matrix, silty clay loam; weak medium prismatic structure parting to moderate medium subangular blocky; friable; few fine faint grayish brown (10YR5/2) and dark yellowish brown</td>
<td></td>
</tr>
</tbody>
</table>
(10YR4/6) mottles; few thin discontinuous dark brown (10YR4/3) clay films; pH 6.4; gradual smooth boundary

Bt5  80-90  Yellowish brown (10YR5/4) matrix, silty clay loam; moderate medium prismatic structure parting to moderate medium angular blocky; friable; common medium distinct gray (10YR6/1) and dark yellowish brown (10YR4/6) mottles; few thin discontinuous dark brown (10YR4/3) clay films; few sand inclusions; pH 6.5; gradual smooth boundary

Bt6  90-112  Yellowish brown (10YR5/4) matrix, silty clay loam; weak medium prismatic structure parting to weak medium subangular blocky; friable; common medium distinct gray (10YR6/1) and few dark yellowish brown (10YR4/6) mottles; thin discontinuous dark brown (10YR4/3) clay films; few dark brown (7.5YR3/2) manganese concretions; pH 6.5; gradual smooth boundary

BC  112-170  Sand as above (Bt6) except heavy silt loam; weak medium prismatic structure; pH 6.6

C  170-224  Yellowish brown (10YR5/4) matrix, heavy silt loam; massive; friable; few medium distinct gray (10YR6/1) mottles; few dark brown (7.5YR3/2) manganese oxides; common yellowish brown (10YR5/8) iron oxides around root channels; pH 6.9; clear smooth boundary

2C1  224-247  Mixed yellowish brown (10YR5/4) sand and grayish brown (10YR5/2) loess; sandy loam; single grained; friable; abrupt smooth boundary

2C2  247-290  Yellowish brown (10YR5/4) silt loam; single grained; friable

Remarks: Soil is erosion class 1; profile located on B slope; Profile leached throughout; corn field
**Profile:** FMC2WH

**Mapping unit:** 162C2-Downs silt loam, 5 to 9% slopes, moderately eroded

**Taxonomic class:** Fine-silty, mixed mesic Mollic Hapludalfs

**Drainage:** Well

**Parent material:** Wisconsin loess

**Physiographic position:** Gentle sideslope

**Location:** 102 ft N of EW fenceline marking the southern boundary and 583 ft E of NS fenceline marking the western boundary of S^1_; NW^1/4, NW^2/4, S28, T85N,R15W, Grant Township, Tama County

(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Ap 0-18</td>
<td>Very dark grayish brown (10YR3/2) silty clay loam, brown (10YR5/3) dry; moderate fine and medium granular structure; friable; many roots; few dark brown (10YR 3/3) mixings; pH 6.4; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bt1 18-31</td>
<td>Dark brown (10YR3/3) ped coats, brown to dark brown (10YR4/3) ped interiors; silty clay loam; yellowish brown (10YR5/4) dry; weak subangular blocky structure; friable; few fine and very fine root channels; pH 6.5; gradual smooth boundary</td>
</tr>
<tr>
<td>Bt2 31-48</td>
<td>Dark brown (10YR4/3) silty clay loam, yellowish brown (10YR5/4) dry; moderate fine and medium subangular blocky structure; friable; thin discontinuous dark brown (10YR3/3) clay films; few fine and very fine root channels; pH 6.6, gradual smooth boundary</td>
</tr>
<tr>
<td>Bt3 48-68</td>
<td>Yellowish brown (10YR5/4) matrix, silty clay loam, light olive brown (2.5Y5/4) dry; moderate medium subangular blocky structure; friable; thin discontinuous clay films over matrix; few fine faint yellowish brown (10YR5/6) mottles; very thin patchy light grayish brown (10YR 6/2) silt coats; few dark brown (7.5YR 3/2) manganese oxides; few fine roots; pH 6.6; gradual smooth boundary</td>
</tr>
<tr>
<td>Bt4 68-85</td>
<td>Yellowish brown (10YR5/4) matrix, silty clay loam; moderate medium subangular</td>
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blocky structure; friable; common fine faint dark yellowish brown (10YR4/6) and grayish brown (10YR5/2) mottles; thin discontinuous dark yellowish brown (10YR 4/4) clay films; thin discontinuous light brownish gray (10YR6/2) silt coats; few fine roots; pH 6.5; gradual smooth boundary

Bt5  85-110  Same as above (Bt4) except thin continuous light grayish brown 10YR6/2 silt coats; few fine roots to 95 cm; pH 6.6

BC  110-127  Yellowish brown (10YR5/4) matrix, silty clay loam; moderate medium prismatic structure parting to weak medium subangular blocky; friable; common medium distinct gray (10YR6/1) and yellowish brown (10YR5/6) mottles; common dark brown (7.5YR3/2) manganese concretions; pH 6.8; gradual smooth boundary

C1  127-139  Same as above (BC) except massive; pH 6.4; gradual smooth boundary

C2  139-176  Yellowish brown (10YR5/4), silt loam; massive; friable; many medium distinct gray (10YR6/1) and yellowish brown (10YR 5/6) mottles; common very dark grayish brown (10YR3/2) manganese concretions; pH 6.4; gradual smooth boundary

C3  176-215  Same as above (C2) except few strong brown (7.5YR4/6) iron segregations (pipe-stems); many coarse dark brown (7.5YR 3/2) manganese concretions

C4  215-240  Gray (10YR6/1) and yellowish brown (10YR 5/4) matrix, silt loam; massive; friable; common yellowish brown (10YR5/6) mottles; few dark brown (7.5YR3/2) manganese concretions; abrupt smooth boundary

2C1  240-287  Yellowish brown (10YR5/4) matrix, sandy loam; massive; friable

Remarks: Corn field; profile leached throughout.
Profile: FMC3WH
Mapping unit: 162D3-Downs silt loam, 9 to 14% slopes, severely eroded
Taxonomic class: Fine-silty, mixed, mesic Mollic Hapludalfs
Drainage: Well
Parent material: Wisconsin loess
Physiographic position: Noseslope
Location: 435 ft N of EW fenceline marking the southern boundary and 144 ft E of NS fenceline marking the western boundary of S\textsubscript{1/2}, NW\textsubscript{1/4}, NW\textsubscript{1/4}, S28, T86N, R15W, Grant Township, Tama County

Remarks: Field description not made; corn field.
Profile: FMC4WH
Mapping unit: 162D3-Downs silt loam, 9 to 14% slopes, severely eroded
Taxonomic class: Fine-silty, mixed, mesic Mollic Hapludalfs
Drainage: Well
Parent material: Wisconsin loess
Physiographic position: Noseslope
Location: S\textsuperscript{1/2}, SE\textsuperscript{1/4}, SE\textsuperscript{1/4}, S20, T86N, R15W (721 ft W of NS fenceline and 174 ft N of EW fenceline), Grant Township, Tama County
(colors are for moist soil unless indicated otherwise)

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<td>0-15</td>
<td>Dark brown (10YR3/3) silty clay loam, brown (10YR5/3) dry; moderate fine subangular blocky structure; very friable and friable; few mixings of dark yellowish brown (10YR4/4); few fine roots; pH 6.5; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bt1</td>
<td>15-25</td>
<td>Dark yellowish brown (10YR3/4) ped coats, dark yellowish brown (10YR4/4) ped interiors; silty clay loam; yellowish brown (10YR5/4) dry; moderate fine subangular blocky structure; friable; some peds with dark brown (10YR3/3) and very dark brown (10YR2/2) coats; very few fine and clear sand grains; pH 6.5; clear smooth boundary</td>
</tr>
<tr>
<td>Bt2</td>
<td>25-43</td>
<td>Dark yellowish brown (10YR4/4) light clay loam; light olive brown (2.5Y5/4) dry; moderate medium subangular blocky structure; friable; some peds with very dark brown (10YR2/2) discontinuous coats; few black (10YR2/1) inclusions; pH 6.2; gradual smooth boundary</td>
</tr>
<tr>
<td>Bt3</td>
<td>43-66</td>
<td>Dark brown (10YR4/3) and dark yellowish brown (10YR4/4) matrix, heavy silt loam, light yellowish brown (2.5Y6/4) dry; weak coarse prismatic and weak medium subangular blocky structure; friable; some peds with very dark brown (10YR2/2) coats; Very few fine roots; few fine and medium very dark brown (10YR2/2) inclusions; pH 6.5; clear smooth boundary</td>
</tr>
<tr>
<td>BC</td>
<td>66-81</td>
<td>Dark brown (10YR4/3) heavy silt loam; weak coarse prismatic structure parting to weak fine subangular blocky; friable; few fine distinct yellowish brown (10YR5/8) mottles; very few fine roots; band of yellowish brown (10YR5/6) material at 66 cm; few fine very dark brown (10YR2/2) rotted roots; pH 6.8; gradual smooth boundary.</td>
</tr>
<tr>
<td>BC</td>
<td>81-104</td>
<td>Dark yellowish brown (10YR4/6) heavy silt loam; weak coarse prismatic and weak medium subangular blocky structure; friable; few warm coats; very few fine roots; few fine faint yellowish brown (10YR5/8) and gray (10YR6/1) mottles; pH 6.6; gradual smooth boundary.</td>
</tr>
<tr>
<td>BC</td>
<td>104-117</td>
<td>Dark brown (10YR4/3) heavy silt loam; weak medium prismatic structure; friable; common medium distinct strong brown (7.5YR5/8) and gray (10YR6/1) mottles; few fine faint olive yellow (2.5Y6/6) mottles; few fine roots; very few yellowish brown (10YR5/8) coated root channels surrounded by very dark brown (10YR2/2) coats; pH 7.0; gradual smooth boundary.</td>
</tr>
<tr>
<td>C1</td>
<td>119-150</td>
<td>Dark yellowish brown (10YR4/4) heavy silt loam; massive; friable; very few very fine roots; few very dark brown (10YR2/2) inclusions; common medium distinct gray (10YR6/1) and strong brown (7.5YR5/8) mottles; pH 7.3; gradual smooth boundary.</td>
</tr>
<tr>
<td>C2</td>
<td>150-175</td>
<td>Olive brown (2.5Y4/4) silt loam; massive; friable; vertical partings throughout; mixings of sand at 165-175 cm; few very dark brown (10YR2/2) inclusions; common medium distinct gray (2.5Y6/0) and few fine faint yellowish brown (10YR5/8) mottles; pH 7.5; clear smooth boundary.</td>
</tr>
<tr>
<td>C3</td>
<td>175-193</td>
<td>Light olive brown (2.5Y5/4) silt loam; massive; friable; mixings of coarse material throughout; accumulation of very dark brown (10YR2/2) material at 185-188 cm; common medium distinct yellowish brown (10YR5/8) and gray (10YR6/1) mottles; pH 7.8; clear smooth boundary.</td>
</tr>
</tbody>
</table>
C4  193-208 Light olive brown (2.5Y5/4) silt loam; massive; friable; common medium distinct gray (10YR6/1) and few fine faint yellowish brown (10YR5/8) mottles; some mixings of loamy material; vertical partings; horizontal band of brownish yellow (10YR6/8) material at 194 cm; pH 7.7; clear smooth boundary

C5  208-218 Yellowish brown (10YR5/4) silt loam; massive; friable; few channels with very dark brown (10YR2/2) coatings; clear smooth boundary

2C1  218-331 Light olive brown (10YR5/4) silt loam; massive; friable; brownish yellow (10YR6/8) sand lens surrounded by yellowish brown (10YR5/8) material at 229 cm; few very dark brown (10YR2/2) accumulations; channels with gray (10YR6/1) coats; clear smooth boundary

2C2  231-252 Light olive brown (2.5Y5/4) loam; massive; friable; free carbonates; common coarse prominent gray (10YR1/1) and common medium prominent yellowish brown (10YR5/8) mottles; approximately 1% (4 cm x 1 cm) sharp edged pebbles; clear smooth boundary

2C3  252-272 Mixed brownish yellow (10YR6/8) and yellowish brown (10YR5/8) matrix, loam; massive; firm; free carbonates; approximately 1% pebbles, rounded and subrounded; abrupt smooth boundary

2C4  272-305 Mixed yellowish brown (10YR6/6) and gray (10YR6/1) matrix, loam; massive; firm; few black (10YR2/1) accumulations; approximately 1% pebbles, subrounded; vertical partings; free carbonates; abrupt smooth boundary

Remarks: Mixing of till and loess at 218 to 231 cm; calcareous till 231-305 cm; cornfield; erosion class 2 by morphological description
Profile: FMC5WH
Mapping unit: 120D2-Tama silt loam, 9 to 14% slopes, moderately eroded
Taxonomic class: Fine-silty, mixed, mesic Typic Argiudolls
Drainage: Well and moderately well
Parent material: Wisconsin loess
Physiographic position: Noseslope
Location: 584 ft W of road T55 and 196 ft N of fenceline marking southern boundary of SE1/4, NE1/4, S19, T86N, R15W, Grant Township, Tama County
(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
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<td>Ap</td>
<td>0-10</td>
<td>Mixed very dark grayish brown (10YR3/2) and dark brown (10YR3/3) heavy silt loam, yellowish brown (10YR5/4) dry; weak fine granular structure parting to moderate fine subangular blocky; friable; few fine roots; pH 6.8; clear smooth boundary</td>
</tr>
<tr>
<td>BW1</td>
<td>10-23</td>
<td>Dark brown (10YR4/3) heavy silt loam, light olive brown (2.5Y5/4) dry; moderate fine subangular blocky structure; friable; some ped faces with dark brown (10YR3/3) faces; few fine roots; very few black (10YR2/1) accumulations; pH 6.8; gradual smooth boundary</td>
</tr>
<tr>
<td>Btl</td>
<td>23-56</td>
<td>Dark yellowish brown (10YR4/4) light silty clay loam, light olive brown (2.5Y5/4) dry; moderate fine and medium subangular blocky structure; friable; few fine roots; continuous dark yellowish brown (10YR3/6) clay coats on peds; few continuous light gray (10YR7/1) silt coats on peds; few root channels with very dark gray (10YR3/1) coatings; few black (10YR2/1) accumulations; pH 7.0; gradual smooth boundary</td>
</tr>
<tr>
<td>BC</td>
<td>56-74</td>
<td>Dark yellowish brown (10YR4/4) light silty clay loam; weak medium subangular blocky; friable; few fine faint gray (10YR6/1) and yellowish brown (10YR5/8) mottles; few dark reddish brown (5YR2/2) manganese stains; pH 7.0; gradual smooth boundary</td>
</tr>
</tbody>
</table>
C1 74-89 Dark brown (10YR4/3) and dark yellowish brown (10YR4/4) matrix, heavy silt loam; massive; friable; common vertical channels with black (10YR2/1) coatings; few black (10YR2/1) accumulations; common medium distinct gray (10YR6/1) and few fine faint yellowish red (5YR5/6) mottles; pH 7.2; gradual smooth boundary

C2 89-117 Dark yellowish brown (10YR4/4) light silty clay loam; massive; friable; few fresh roots; some root channels with dark yellowish brown (10YR4/6) coatings; few black (10YR2/1) accumulations; continuous gray (10YR6/1) silt coats on some peds; pH 7.2; gradual smooth boundary

C3 117-135 Dark yellowish brown (10YR4/4) light silty clay loam; massive; friable; common medium distinct light gray (10YR7/1) and few fine faint strong brown (7.5YR5/8) mottles; few fresh roots; few root channels with light gray (10YR7/1) coatings; pH 7.2; gradual smooth boundary

C4 135-152 Dark grayish brown (10YR4/2) and dark brown (10YR4/3) matrix, heavy silt loam; massive; friable; few fine roots; few yellowish red (5YR5/8) coats along some root channels; few continuous light gray (10YR7/1) coatings; pH 7.2; gradual smooth boundary

C5 152-175 Grayish brown (2.5Y5/2) heavy silt loam; massive; friable; few root channels with very dark grayish brown (10YR3/2) coatings; few black (10YR2/1) accumulations; common medium distinct yellowish brown (10YR5/6) surrounded by yellowish brown (10YR5/8) coats; pH 7.3; gradual smooth boundary

C6 176-196 Gray (5&5/1) heavy silt loam; massive; friable; calcareous; large strong brown (7.5YR5/8) pipestem with some very dark brown (10YR2/2) inclusions; pH 7.5; gradual smooth boundary

C7 196-234 Light gray (10YR7/1) heavy silt loam; massive; friable; very few root channels
with dark brown (10YR3/3) coats; few fine faint yellowish brown (10YR5/8) mottles at upper and lower ends of horizon; calcareous; pH 7.6; gradual smooth boundary

C8  234-259  Light gray (10YR7/1) heavy silt loam; massive; friable; few medium prominent soft concretions, very dark brown (10YR 2/2) surrounded by dark yellowish brown (10YR4/6) surrounded by yellowish brown (10YR5/8); few medium distinct light gray (10YR7/1) and common medium distinct yellowish brown (10YR5/8) mottles; few loamy yellowish brown (10YR5/8) accumulations; calcareous; pH 7.9; gradual smooth boundary

C9  259-274  Light gray (10YR7/1) heavy silt loam; common medium distinct yellowish brown (10YR5/8) mottles; loamy yellowish brown (10YR5/8) accumulations; calcareous; gradual smooth boundary

2C1  274-279  Yellowish brown (10YR5/8) loam; massive; loose; noncalcareous

Remarks: Pedisediment at 274+ cm, calcareous 175-274 cm.
Profile: FMC6WH
Mapping unit: 933B-Sawmill silty clay loam, 2 to 5% slopes
Taxonomic class: Fine-silty, mixed, mesic Cumulic Haplaquolls
Drainage: Poorly
Parent material: Alluvial sediments
Physiographic position: Toeslope
Location: 900 ft W of NS fence next to T47 and 360 ft N of EW fence (¼ mile S of D65) which marks the southern boundary of NE¼, NE¼, S21, R16W, T86N, Lincoln Township, Tama County
(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-25</td>
<td>Very dark gray (10YR3/1) light silty clay loam, very dark grayish brown (10YR3/2) dry; fine moderate granular structure; friable; pH 6.7; gradual smooth boundary</td>
</tr>
<tr>
<td>C</td>
<td>25-53</td>
<td>Same as above except with dark grayish brown (10YR4/2) stratifications; pH 6.0; gradual smooth boundary</td>
</tr>
<tr>
<td>Alb</td>
<td>53-69</td>
<td>Black (10YR2/1) silty clay loam, very dark brown (10YR2/2) rubbed, very dark gray (10YR3/1) dry; moderate fine granular and weak fine subangular blocky structure; friable; few fine roots; pH 6.0; clear smooth boundary</td>
</tr>
<tr>
<td>A2b</td>
<td>69-94</td>
<td>Same as above (Abl) except moderate fine granular structure; pH 6.7; clear smooth boundary</td>
</tr>
<tr>
<td>A3b</td>
<td>94-106</td>
<td>Black (10YR2/1) silty clay loam, very dark gray (10YR3/1) dry; moderate fine and medium subangular blocky structure; friable; few fine roots; few fine clear sand grains; few fine faint yellowish brown (10YR5/4) mottles; pH 6.6; clear smooth boundary</td>
</tr>
<tr>
<td>BAb</td>
<td>106-119</td>
<td>Very dark gray (10YR3/1) silty clay loam, very dark grayish brown (10YR3/2) dry; weak medium prismatic structure parting to moderate fine subangular blocky; friable; few fine roots; common fine distinct dark yellowish brown (10YR4/6) mottles; pH 6.8; clear smooth boundary</td>
</tr>
</tbody>
</table>
Bw1b 119-129 Very dark gray (10YR3/1) silty clay loam; weak medium prismatic structure parting to moderate medium angular blocky; friable; few fine roots; many medium prominent yellowish brown (10YR5/6) mottles; pH 6.8; clear smooth boundary

Bw1b 129-138 Same as above (Bwbl) except with moderate medium prismatic structure; few fine faint yellowish brown (10YR5/6) mottles; root channels with very dark grayish brown (10YR3/2) coatings; few rotted roots; pH 6.9

Bw2b 138-159 Dark gray (10YR4/1) silty clay loam; moderate medium prismatic; friable; few roots rotted in channels with very dark grayish brown (10YR3/2) coats; few fine distinct yellowish brown (10YR5/6) mottles; soft (incipient) olive brown (2.5Y4/6) pipistem; few subrounded gravel; pH 7.0; clear smooth boundary

BCgb 159-180 Grayish brown (2.5Y5/2) silty clay loam; weak medium prismatic structure; friable; few medium roots rotted in channels with strong brown (7.5YR5/6) coatings; many fine prominent strong brown (7.5YR5/6) mottles; pH 7.2; clear smooth boundary

Cglb 180-200 Mixed dark greenish gray (5BG4/1) and dark yellowish brown (10YR3/6) matrix; clay loam; massive; friable; few root channels with dark gray (10YR4/1) coatings; some sand inclusions; few subrounded gravel; pH 7.0; clear smooth boundary

Cg2b 200-216 Dark greenish gray (5BG4/1) loam; massive; friable; few fine rotted roots in channels with very dark grayish brown (10YR3/2) coatings; few subrounded gravel; increased number of sand inclusions; large crotovina filled with black (10YR2/1) silty clay loam material; pH 7.2; abrupt smooth boundary

2C1 216-254 Gray (5Y5/1) sand; single grained; loose; greenish gray (5G5/1) sandy loam inclusion at 241 cm; gradual smooth boundary
<table>
<thead>
<tr>
<th>Layer</th>
<th>Depth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2C2</td>
<td>254-297</td>
<td>Same as above (2C1) except few root channels with rotted roots; silty clay loam inclusion at 280 cm; much of the sand in this horizon is washed clean; abrupt smooth boundary</td>
</tr>
<tr>
<td>3C1</td>
<td>297-305</td>
<td>Mixed dark gray (5Y4/1) and dark greenish gray (5GY4/1) matrix, silt loam; massive; friable; unleached</td>
</tr>
</tbody>
</table>

Remarks: Soil fits description of overwash phase of Sawmill.
Profile: FMC7WH
Mapping unit: 120C2-Tama silty clay loam, 5 to 9% slopes, moderately eroded
Taxonomic class: Fine-silty, mixed, mesic Typic Argiudoll
Drainage: Well
Parent material: Wisconsin loess
Physiographic position: Gentle sideslope
Location: 1250 ft W of fence next to T47 and 30 ft N of fence which marks the southern border of NE\(^4\), NE\(^3\), S21, R16W, T86N, Lincoln Township, Tama County
(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Depth (cm)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>Very dark brown (10YR2/2) light silty clay loam, dark brown (10YR3/3) dry; weak medium granular structure parting to moderate fine subangular blocky; friable; few fine roots; pH 6.5; abrupt smooth boundary</td>
</tr>
<tr>
<td>BA</td>
<td>15-29</td>
<td>Very dark grayish brown (10YR3/2) silty clay loam, dark grayish brown (10YR4/2) dry; weak fine granular structure parting to moderate fine subangular blocky; friable; few fine roots; some mixings of dark brown (10YR3/3) and dark yellowish brown (10YR3/4) material; few channels filled with black (10YR2/1) material; pH 6.4; clear smooth boundary</td>
</tr>
<tr>
<td>Bt1</td>
<td>29-51</td>
<td>Dark brown (10YR4/3) with mixings of very dark grayish brown (10YR3/2) silty clay loam, brown (10YR5/3) dry; weak fine granular structure parting to weak fine subangular blocky; friable; few fine roots; some root channels with black (10YR2/1) and very dark brown (10YR2/2) coatings; some ped faces with very dark brown (10YR 2/2) coats; pH 6.6; gradual smooth boundary</td>
</tr>
<tr>
<td>Bt2</td>
<td>51-61</td>
<td>Dark yellowish brown (10YR4/4) silty clay loam, light yellowish brown (10YR6/4) dry; few fine distinct yellowish brown (10YR 5/8) and gray (10YR6/1) mottles; few black (10YR2/1) inclusions; pH 6.6; gradual smooth boundary</td>
</tr>
</tbody>
</table>
Bt3 61-73 Dark yellowish brown (10YR4/4) silty clay loam; moderate fine and medium subangular blocky structure; friable; few fine roots; thin discontinuous clay coats on some ped faces; few very dark brown (10YR2/2) inclusions; few fine faint gray (10YR6/1) and yellowish red (5YR5/8) mottles; pH 6.8; gradual smooth boundary

Bt4 73-90 Dark brown (10YR4/3) silty clay loam; moderate fine and medium subangular blocky structure parting to fine weak prismatic; few root channels; discontinuous light gray (10YR7/1) silt coats on faces of some peds; few fine faint gray (10YR6/1) and yellowish brown (10YR5/8) mottles; thin continuous clay coats on ped faces; pH 6.9; gradual smooth boundary

Bt5 90-102 Dark brown (10YR4/3) silty clay loam; weak coarse prismatic; continuous clay coats on ped faces; discontinuous light gray (10YR7/1) silt coats on faces of some peds; common root channels; few very dark grayish brown (10YR3/2) inclusions; pH 6.9; gradual smooth boundary

BC 102-122 Dark brown (10YR4/3) silty clay loam; massive and very weak coarse prismatic structure; friable; few fine faint yellowish brown (10YR5/8) and common fine and medium prominent gray (10YR6/1) mottles; pH 7.0; gradual smooth boundary

C1 122-140 Dark yellowish brown (10YR4/4) silt loam; massive; friable; few fine faint yellowish brown (10YR5/6) and (10YR5/8) and common fine and medium prominent gray (10YR6/1) mottles; pH 7.0; gradual smooth boundary

C2 140-152 Same as above (C1) except with very few sandy inclusions; pH 7.4; abrupt smooth boundary

2C1 152-158 Dark yellowish brown (10YR4/4) loam; massive; friable; calcareous few fine faint gray (10YR6/1) mottles; few very dark brown (10YR2/2) inclusions and coats; pH 7.7; clear smooth boundary
2C2 158-180  Yellowish brown (10YR5/8) loam; massive; friable; calcareous; large CaCO₃ nodule; few gravel and pebbles; sand lens at 159 cm; few fine faint yellowish red (5YR5/8) mottles; pH 7.7; clear smooth boundary

2C3 180-195  Dark yellowish brown (10YR4/6) sandy loam; massive; friable; sand lens at 188 cm; few gravel; many medium coarse gray (10YR 6/1) and yellowish red (5YR5/8) mottles; calcareous; pH 7.7; gradual smooth boundary

2C4 195-216  Dark yellowish brown (10YR4/4) sandy loam; massive; friable; few pebbles and gravel approximately 2½ cm diameter; common fine prominent yellowish red (5YR5/8) and many medium prominent gray (10YR6/1) mottles; calcareous; pH 7.9; gradual smooth boundary

2C5 216-246  Yellowish brown (10YR5/6) sandy loam; massive; friable; calcareous; vertical partings; approximately 1% gravel; sand lens at 244 cm; few fine and medium faint gray (10YR6/1) and yellowish red (5YR5/8) mottles; clear smooth boundary

2C6 246-254  Yellowish brown (10YR5/8) heavy sandy clay loam; massive; friable; few pebbles and gravel; few fine prominent gray (10YR6/1) and few fine faint strong brown (7.5YR5/8) mottles; calcareous; clear smooth boundary

2C7 254-269  Dark yellowish brown (10YR4/6) heavy sandy clay loam; massive; friable; calcareous; less than 1% gravel and pebbles—approximately 1½ cm in diameter; vertical partings; common medium prominent strong brown (7.5YR5/6) and common medium distinct gray (5Y6/1) mottles; gradual smooth boundary

2C8 269-290  Brownish yellow (10YR6/6) heavy sandy clay loam; massive; friable; calcareous; sand inclusion at 287 cm; many pebbles and 1-2% gravel with brownish yellow (10YR6/6) coatings; common medium distinct yellowish red (5YR5/8) and dark reddish brown (2.5 YR3/4) mottles; gradual smooth boundary
Mixed brownish yellow (10YR6/8) and yellowish brown (10YR5/8) matrix, heavy sandy loam; massive; friable; calcareous; vertical partings; common rounded and sub-rounded gravel and few pebbles (approximately 1%, 1 1/2 cm diameter; few olive yellow (2.5Y6/6) loamy inclusions; few fine distinct very dark brown (10YR2/2) mottles

Remarks: Area is a long gentle slope; calcareous 152-305 cm.
Profile: FMC8W
Mapping unit: 119B-Muscatine silty clay loam, 1 to 2% slope
Taxonomic class: Fine-silty, mixed, mesic Aquic Hapludolls
Drainage: Somewhat poorly
Parent material: Wisconsin loess
Physiographic position: Broad level summit
Location: 97 ft S of EW fenceline marking the northern boundary of the SW1/4 and 111 ft W of the NS fence-line marking the eastern boundary of the SW1/4; NE1/4, SW1/4, S21, T86N, R16W, Lincoln Township, Tama County
(colors are for moist soil unless indicated otherwise)

<table>
<thead>
<tr>
<th>Horizon</th>
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<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>Black (10YR2/1) light silty clay loam, dark grayish brown (10YR4/2) dry; weak fine granular structure; friable; pH 6.7; abrupt smooth boundary</td>
</tr>
<tr>
<td>A</td>
<td>15-28</td>
<td>Black (10YR2/1) silty clay loam, dark grayish brown (10YR4/2) dry; weak fine granular structure; friable; pH 6.5; clear smooth boundary</td>
</tr>
<tr>
<td>BA</td>
<td>28-46</td>
<td>Very dark brown (10YR2/2) silty clay loam, dark brown (10YR3/3) dry; weak fine subangular blocky structure; friable; pH 6.5; clear smooth boundary</td>
</tr>
<tr>
<td>Bw1</td>
<td>46-57</td>
<td>Very dark grayish brown (10YR3/2) silty clay loam, with mixings of dark grayish brown (10YR4/2), dark brown (10YR4/3) dry; moderate fine subangular blocky structure; pH 6.2; clear smooth boundary</td>
</tr>
<tr>
<td>Bw2</td>
<td>57-73</td>
<td>Dark yellowish brown (10YR4/4) silty clay loam, with mixings of black (5YR2/1) and strong brown (7.5YR5/6), light olive brown (2.5Y5/4) dry; moderate fine subangular blocky structure; friable; few fine faint grayish brown (10YR5/2) mot­tles; pH 6.5; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bw3</td>
<td>73-89</td>
<td>Grayish brown (10YR5/2) silty clay loam, with mixings of black (5YR2/1) and strong brown (7.5YR5/6); weak fine subangular blocky structure; friable; pH 6.7; clear smooth boundary</td>
</tr>
</tbody>
</table>
Bw4  89-112  Grayish brown (10YR5/2) light silty clay loam; weak medium and coarse subangular blocky structure parting to prismatic friable; common black (5YR2/1) oxides; common medium prominent strong brown (7.5 YR5/6) mottles; pH 7.1; gradual smooth boundary

Bw5  112-137  Grayish brown (10YR5/2) heavy silt loam; moderate medium subangular blocky structure parting to prismatic; friable; common medium distinct strong brown (7.5YR 5/6) mottles; pH 7.3; clear smooth boundary

BC   137-152  Gray (10YR5/1) heavy silt loam; weak medium prismatic structure parting to massive; pH 7.5; clear smooth boundary

C1   152-175  Grayish brown (10YR5/2) heavy silt loam, with increasing sand content; massive; friable; few strong brown (7.5YR5/6) and yellowish brown (10YR5/6) accumulations; common medium distinct yellowish brown (10YR5/6) mottles; few broken snail shells; pH 7.7; gradual smooth boundary

C2   175-191  Grayish brown (10YR5/2) heavy silt loam; massive; friable; calcareous; many medium distinct yellowish brown (10YR5/6) mottles; few black (5YR2/1) oxides; pH 7.5; gradual smooth boundary

C3   191-224  Gray (10YR5/1) heavy silt loam; massive; friable; calcareous; some mixing of till; few black (5YR2/1) oxides; common fine prominent dark yellowish brown (10YR4/4) mottles; pH 7.7; gradual smooth boundary

C4   224-236  Same as above (C3) with higher sand content; pH 7.6; abrupt smooth boundary

2C1  236-302  Mixed strong brown (7.5YR5/6) and light gray (10YR7/1) loam; massive; firm; leached; few subrounded pebbles approximately 1 cm diameter; few large black (10 YR2/1) stains; pH 7.8

Remarks: Strong effervescence 152-236 cm; basal loess with little till mixing 191-236; till at 236+ cm; profile moist throughout.
Profile: FMC9WH
Mapping unit: 122-Sperry silt loam, 0 to 2% slopes
Taxonomic class: Fine-montmorillonitic, mesic Typic Argialboll
Drainage: Very poorly
Parent material: Local alluvium over Wisconsin loess
Physiographic position: Upland depression
Location: 48 ft S of EW fenceline which marks the northern border of SW^4 and 414 ft W of the NS fenceline which marks the eastern border of the SW^4; NE^4, SW^4, S21, T86N, R15W, Lincoln Township, Tama County
(colors are for moist soil unless indicated otherwise)

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<tbody>
<tr>
<td>Ap</td>
<td>0-15</td>
<td>Black (10YR2/1) light silty clay loam, dark grayish brown (10YR4/2) dry; moderate fine granular structure; friable; pH 6.5; abrupt smooth boundary</td>
</tr>
<tr>
<td>E</td>
<td>15-28</td>
<td>Black (10YR2/1) heavy silt loam, dark gray (10YR5/1) dry; moderate medium angular blocky structure parting to moderate medium platy; friable; pH 6.3; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bt1</td>
<td>28-38</td>
<td>Very dark gray (10YR3/1) light silty clay loam, gray (10YR5/1) dry; moderate medium subangular blocky and moderate medium platy structure; firm; continuous dark gray (10YR4/1) coatings of ped faces; pH 6.5; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bt2</td>
<td>38-64</td>
<td>Dark gray (10YR4/1) light silty clay, gray (10YR5/1) dry; moderate medium granular and moderate medium subangular blocky structure; firm; continuous black (N2/0) coatings on ped faces; pH 6.8; abrupt smooth boundary</td>
</tr>
<tr>
<td>Bt3</td>
<td>64-74</td>
<td>Gray (10YR5/1) heavy silty clay loam; moderate medium granular and moderate medium subangular blocky structure; firm; common black (10YR2/1) channel fills; continuous black (10YR2/1) coatings on ped faces; pH 6.7; clear smooth boundary</td>
</tr>
<tr>
<td>Layer</td>
<td>Range</td>
<td>Description</td>
</tr>
<tr>
<td>-------</td>
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</tr>
<tr>
<td>Bt4</td>
<td>74-94</td>
<td>Dark gray (10YR4/1) light silty clay loam; moderate medium subangular blocky structure; friable; common yellowish red (10YR4/6) accumulations; continuous very dark gray (10YR3/1) clay films on ped faces; pH 6.6; clear smooth boundary</td>
</tr>
<tr>
<td>Bt5</td>
<td>94-117</td>
<td>Gray (10YR6/1) light silty clay loam; moderate medium subangular blocky structure parting to massive; friable; common medium distinct yellowish red (5YR5/8) mottles; few very dark gray (10YR3/1) clay films on peds; pH 6.7; clear smooth boundary</td>
</tr>
<tr>
<td>BC</td>
<td>117-147</td>
<td>Gray (5Y5/1) light silty clay loam; massive; friable; few fine faint strong brown (7.5YR5/6) mottles; pH 6.9; clear smooth boundary</td>
</tr>
<tr>
<td>C1</td>
<td>147-178</td>
<td>Gray (5Y5/1) light silty clay loam; massive; friable; common medium distinct strong brown (7.5YR5/6) mottles; pH 7.1; clear smooth boundary</td>
</tr>
<tr>
<td>C2</td>
<td>178-213</td>
<td>Gray (5Y5/1) light silty clay loam; massive; friable; few black (5YR2/1) accumulations; many medium prominent yellowish brown (10YR5/6) and strong brown (7.5YR 5/8) mottles; root channels with very dark gray (10YR3/1) fillings; pH 7.0; gradual smooth boundary</td>
</tr>
<tr>
<td>C3</td>
<td>213-221</td>
<td>Dark gray (5Y4/1) heavy silt loam; massive; friable; common medium faint olive brown (2.5Y4/4) mottles; pH 6.5; clear smooth boundary</td>
</tr>
<tr>
<td>2C1</td>
<td>221-254</td>
<td>Mixed light olive brown (2.5Y5/4) and brownish yellow (10YR6/8) light silty clay loam; gradual smooth boundary</td>
</tr>
<tr>
<td>2C2</td>
<td>254-279</td>
<td>Grayish brown (10YR5/2) light clay loam; massive; friable; clear smooth boundary</td>
</tr>
<tr>
<td>2C3</td>
<td>279-305</td>
<td>Mixed yellowish brown (10YR5/8) and (10YR5/6) light clay loam; massive; friable; common medium distinct (10YR6/1) mottles; till.</td>
</tr>
</tbody>
</table>

Remarks: Profile leached throughout; 221-279 is reworked till; profile very moist throughout.
Profile: P27B
Remarks: For description of modal Tama soil see Smith et al. (1950)
Profile P32

Tama County, Iowa
Slope 3% SE
Five hundred-fifty feet west and 100 feet south of NE corner of NE 40 of SW¼, Sec. 2, T83N, R16W. A gently rolling to rolling dissected loess plain with good drainage. Open stand of oak-hickory, many elms and herbaceous plants in the open spaces. Sampled by R. W. Simonson, August 24, 1938.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Ap</td>
<td>0-5</td>
<td>Weak brown silt loam, browner when crushed. Fine crumb structure; aggregates soft, with numerous plant roots. About 1 inch of leaf litter on the surface.</td>
</tr>
<tr>
<td>E1</td>
<td>5-10</td>
<td>Light brownish-gray silt loam. Fine platy structure; aggregates small, vesicular, lightly coated with light gray, crushing with slight resistance. A few filled worm burrows; plant roots less abundant than in 0-2 inch layer.</td>
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<td>Light brownish-gray and pale brown silt loam, friable, floury when dry. Fine platy structure; aggregates vesicular, coarser in lower part, coated with light gray. Tree roots and worm burrows numerous</td>
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<td>E2/BE</td>
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<td>Light to moderate yellowish-brown light silty clay loam, lighter when crushed. Irregular medium blocky structure; aggregates larger in lower part, vesicular, with some light gray coating</td>
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<td>Moderate yellowish-brown silty clay loam, lighter when crushed. Medium blocky structure; aggregates vesicular, sprinkled with gray. A few worm burrows.</td>
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<td>Bt2</td>
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<td>Moderate brown silty clay loam, lighter when crushed. Mixed medium and fine sub-angular blocky structure; aggregates moderately vesicular. Firm when moist, plastic when wet.</td>
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BC  84-114  Moderate to light yellowish-brown silty clay loam. Coarse blocky structure; aggregates vesicular, firm when moist, plastic when wet, coated with dark yellowish-brown. Small dark brown concretions and weak orange mottles.

C  114-152  Light yellowish-brown silt loam. Weakly developed coarse blocky structure; aggregates vesicular, firm to friable when moist, with some dark yellowish-brown coating, and with small weak orange mottles. Worm burrows abundant.

APPENDIX III: DATA FROM LABORATORY ANALYSES
Glossary of Terms

Abbreviations used in description of data from laboratory analyses are as follows:

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<p>|   | 88  | AP  | 0   | 13  | 6.5 | 7   | 102 | 188 | 56  | 353 | 38  | 0   | 8   | 46  | 399 | 328 | 430 | 102 | 196 | 829 | 6.8 |
|   | 89  | AP  | 13  | 25  | 19.0| 11  | 115 | 156 | 41  | 323 | 47  | 0   | 9   | 56  | 379 | 318 | 386 | 115 | 165 | 765 | 6.6 |
|   | 90  | C   | 25  | 43  | 34.0| 0   | 51  | 103 | 43  | 197 | 54  | 0   | 3   | 57  | 254 | 208 | 352 | 51  | 106 | 606 | 6.1 |
|   | 91  | C   | 43  | 53  | 48.0| 0   | 39  | 90  | 52  | 181 | 68  | 0   | 3   | 71  | 252 | 197 | 279 | 39  | 93  | 531 | 5.8 |
|   | 92  | A1B | 53  | 69  | 61.0| 0   | 41  | 107 | 57  | 205 | 72  | 25  | 9   | 106 | 311 | 220 | 173 | 66  | 116 | 484 | 6.0 |
|   | 93  | A2B | 69  | 84  | 76.5| 0   | 38  | 87  | 65  | 190 | 63  | 26  | 13  | 102 | 292 | 188 | 72  | 64  | 100 | 364 | 6.6 |
|   | 94  | A2B | 84  | 94  | 89.0| 0   | 37  | 79  | 124 | 240 | 49  | 29  | 12  | 90  | 330 | 165 | 57  | 66  | 91  | 387 | 6.7 |
|   | 95  | A3B | 94  | 106 | 100.0| 0  | 42  | 85  | 131 | 260 | 63  | 15  | 20  | 98  | 358 | 190 | 80  | 57  | 105 | 438 | 6.6 |
|   | 96  | BAB | 106 | 119 | 112.5| 0 | 59  | 76  | 140 | 275 | 60  | 28  | 35  | 123 | 398 | 195 | 45  | 87  | 111 | 443 | 6.8 |
|   | 97  | BW1B| 119 | 129 | 124.0| 0 | 47  | 64  | 162 | 273 | 77  | 21  | 11  | 109 | 382 | 188 | 55  | 68  | 75  | 437 | 6.8 |
|   | 98  | BW1B| 129 | 138 | 133.5| 0 | 32  | 69  | 187 | 288 | 108 | 1   | 1   | 110 | 398 | 209 | 34  | 33  | 70  | 432 | 6.9 |
|   | 99  | BW2B| 138 | 159 | 148.5| 0 | 41  | 106 | 296 | 483 | 126 | 8   | 14  | 148 | 591 | 273 | 83  | 49  | 120 | 674 | 7.0 |
|   | 100 | BCGB| 159 | 168 | 163.5| 0 | 34  | 109 | 319 | 462 | 110 | 11  | 47  | 168 | 630 | 253 | 58  | 45  | 156 | 688 | 7.2 |
|   | 101 | BCGB| 168 | 180 | 174.0| 5 | 42  | 267 | 331 | 645 | 221 | 6   | 81  | 308 | 953 | 530 | 80  | 48  | 348 | 1033 | 7.2 |
|   | 102 | CG1B| 180 | 191 | 185.5| 1 | 94  | 1123| 219 | 1437| 264 | 7   | 169 | 436 | 1873| 1481| 84  | 101 | 1288 | 1957 | 7.0 |
|   | 103 | CG1B| 191 | 200 | 195.5| 1 | 89  | 1509| 191 | 1790| 126 | 1   | 128 | 255 | 2045| 1724| 57  | 90  | 1637 | 2102 | 6.9 |
|   | 104 | CG2B| 200 | 216 | 208.0| 1 | 62  | 292 | 184 | 539 | 147 | 4   | 65  | 216 | 755 | 501 | 50  | 66  | 357 | 805 | 7.2 |
|   | 105 | 2C1 | 216 | 254 | 235.0| . | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |
|   | 106 | 2C2 | 254 | 297 | 275.5| . | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |
|   | 107 | 3C1 | 297 | 305 | 301.0| . | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   | .   |</p>
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