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IN SELECTED ALFISOLS AND MOLLISOLS.

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Available and inorganic forms of phosphorus

in selected Alfisols and Mollisols

by

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INTRODUCTION

The soil classification scheme known as the comprehensive system of soil classification (7th Approximation, USDA, 1960; Soil Taxonomy, 1970) is a hierarchical system. It consists of six formal categories and its major emphasis is the use of defined differentiating characteristics usually referred to as diagnostic criteria. This elaborate system was drawn up for the new and natural classification of the soils of the United States, which could possibly accommodate soils of other countries also. The names given to the classes are a combination of Greek, Latin and English words and are intended to signify various properties and factors of genetic influence. The sequential nomenclature makes the characteristics of soils easier to understand and remember.

The orders are recognized by diagnostic horizons, degree of horizonation, presence or absence of certain horizons and gross composition reflecting major differences in the genesis of soils. Moisture regime, temperature, mineralogy and specific kinds of horizons are considered in differentiating suborders within the orders. Great groups are distinguished within suborders by the presence or absence of characteristic horizons or other features. The range of characteristics have been narrowed at the subgroup level. The classification at the family level is mainly based on soil temperature, texture and mineralogy, which has a direct bearing on plant growth and engineering characteristics.

Alfisols and Mollisols are among the ten soil orders. The Alfisols are those soils with a gray to brown surface horizon and a subsoil horizon of clay accumulation (argillic horizon) and moderate to high base saturation (>35 percent). The Alfisols are characteristically formed under forest or savana vegetation. The soils included in the Mollisol order are characterized by a mollic epipedon, a thick dark surface horizon with high base saturation (>50 percent) and are formed under prairie cover.

Some soil properties are distinctive features and serve as diagnostic criteria in the soil taxonomy while other properties, as some chemical and physical, also have significance in differentiating soils. Phosphorus is generally not being used as a diagnostic criterion at any level of the categories except for the identification of an anthropic epipedon. The high levels (>250 ppm) of citric acid soluble P_2O_5 differentiate the anthropic epipedon from the mollic epipedon. Phosphate is not considered a highly mobile ion and very little is likely to be leached to lower horizons. But during the long time spans involved in soil profile development, considerable redistribution of phosphorus can and does occur within the soil profile. Recently, phosphorus levels in soil profiles have been related to soil genesis and classification (Chang and Jackson, 1958; Walker, 1965; Westin and Buntley, 1966a; Smeck and Runge, 1971).

In many soils, apatite minerals are likely the parent material of nearly all soil phosphorus. Weathering and other agencies which modify the soil mass cause some of the phosphorus to be released from the apatite and then it is free to react with several soil constituents and to be utilized by plants and microbes. The effect is that phosphorus exists in many forms. Fractionation of inorganic phosphorus into discrete chemical forms has been utilized to some extent as an aid in understanding soil genesis. Phosphorus availabilty is determined by soil factors including forms and solubility of soil inorganic phosphorus.

It was postulated that the distribution of inorganic phosphorus fractions and available phosphorus in the profiles of various soils might be a sensitive indicator of different soil forming factors and processes. In addition to the soils of Iowa, some soils of moderately dry regions were studied. Thus, this investigation proposes to see if changes in a local environmental factor of parent material or regional environmental factor of climate and vegetation exert influence on the forms of phosphorus and available phosphorus contents in the profiles. It was assumed that the range and variability of phosphorus in the soils of Alfisol and Mollisol orders would provide an opportunity to characterize and differentiate the soils at various taxonomic categories with respect to phosphorus. Following are the objectives of this investigation.

1. To compare the amounts and distribution of inorganic P fraction and available phosphorus in soil profiles.

2. To find out the relationship of the distribution of phosphorus to soil forming factors and some other soil properties.
3. To characterize and differentiate various taxonomic categories with respect to the amounts and distribution of inorganic P fractions and available phosphorus.

LITERATURE REVIEW

Inorganic Phosphorus Fractions

Phosphorus in soils occurs in inorganic and organic forms. The inorganic forms may be divided into four major fractions: aluminum phosphates (Al-P), iron phosphates (Fe-P), calcium phosphates (Ca-P) and reductant soluble phosphates (Red-P). Chang and Jackson (1957) proposed an extraction sequence for these different inorganic fractions from soil with different solutions. These investigators in 1958 reported that the distribution of inorganic phosphorus (IP) fractions in the soil reflects the degree of chemical weathering of the soil and is a sensitive indicator of the stage of soil development. The weathering sequence (towards increasing weathering condition) of phosphorus fractions is, according to Chang and Jackson (1958), Chang and Juo (1963) and other investigators (Dahnke, Malchom and Menendez, 1963; Hawkins and Kunze, 1965; Westin and Buntley, 1966a, 1967), calcium phosphate-aluminum phosphate-iron phosphate-occluded phosphate (reductant soluble iron phosphate and aluminum plus aluminum iron phosphate occluded in iron oxide).

Hsu and Jackson (1960) found that transformations of soil phosphorus are controlled mainly by soil pH, which is a result of weathering, leaching and soil development. Thus, the relative distribution of the inorganic phosphorus fractions will vary in different soils, depending on conditions and stages of weathering and therefore can be used for defining genetic relationships among soils for soil classification and fertility management purposes. These assumptions stimulated a number of investigators who determined the proportions of phosphorus fractions in different soil groups with the objectives to define genetic similarities and differences between soils and to relate phosphorus fraction to soil phosphorus availability.

Goel and Agarwal (1959) studied different forms of phosphorus in genetically related soils derived from Gangetic alluvium and reported an increasing amount of aluminum and iron phosphates with increasing stage of soil maturity. Hawkins and Kunze (1965) defined the weathering stage of four different series of Texas Grumusols, having relatively undeveloped profile morphology with no B horizon. They concluded that as weathering increases there is a shift in the abundance of inorganic phosphates from Ca-P toward Al-P and Fe-P.

Westin and Buntley (1966a, 1967) showed that the relative amounts of phosphorus fractions reflect climatic change, and that influences due to climate overcome the phosphorus fraction characteristics of the different kinds of parent material in Chernozems and Chestnut soils of South Dakota. Their studies added evidence for the separation of the Chernozem soils of South Dakota into two separate suborders; the less weathered Borolls and more intensely weathered Ustolls. The cooler and slightly drier Borolls were found to have less Fe-P and reductant P, and more Ca-P than the Ustolls. Neither parent material nor climate altered the proportional amount of Al-P present in the soil series. Among Chernozem soils the Fe-P fraction made up a proportionally larger amount, and the Ca-P fraction a proportionally smaller amount, than they each did in Chestnut soils.

Ahmed and Jones (1967) determined the inorganic phosphorus forms in limestone soils of Barbados. They found great differences in the relative amounts of different phosphorus fractions in terra rossa soils as compared to grumusols, both formed on coral limestone. Terra rossa soils had 50 to 90 percent of Fe-P of the total inorganic phosphates while the grumusols had only 10 to 20 percent Fe-P. They pointed out that a high content of Fe-P is typical of highly weathered tropical soils. Williams and Walker (1969) reported that as the degree of weathering of the profile increased acid extractable Ca-P declined to zero, NH_4F-P increased to maximum values and then declined, reductant soluble P increased and Fe-P showed no particular trend. However, there were marked irregularities in these patterns, partly reflecting differences in the Al/Fe ratio of the soil. Obeng (1970) found Fe-P as the dominant and Ca-P as the lowest IP form in profiles of highly weathered iron·pan soils. His findings reflected the fact that the deeply leached condition under which the soils have been developed has given rise to almost a complete removal of bases, hence, the low Ca-P status of the soils, and obviously accumulation of resistant sesquioxide resulted in high Fe-P values. Obeng further indicated that Fe-P dominates the A horizon of the profile in the Savanah zone, whereas Red-P is the major form in the B horizon of the profile in the forest zone.

Recently a few studies have been reported relating P amounts and fractions with weathering intensity and classification of soils in the comprehensive system (7th Approximation) of soil classification. Westin and DeBrito (1969) pointed out a definite IP weathering trend among 23 Venezuelan soils. As weathering stage progresses in the classification systems from Entisols, Inceptisols and Mollisols through Alfisols to Ultisols and Oxisols, there is a shift from Ca-P to Fe-P. Al-P and Red-P did not change appreciably as weathering intensified, but the amounts were affected more by impeded drainage in the case of Al-P and by the degree of dryness attained in the alternately wet and dry environment in the case of Red-P. Smeck and Runge (1971) noted that fractionation of inorganic phosphorus showed increasing aluminum, iron, and reductant soluble P plus decreasing calcium phosphate along a traverse from the Haplaquoll to the Albaqualf end of the transect.

Available Phosphorus

Laboratory methods for obtaining indices of P availability of soils have involved extraction of the soil with such widely varying extractants as inorganic acids, organic acids, pure or carbonated water, dilute alkaline solutions and buffered salt solutions. Differences in procedures such as shaking time, ratio of soil to solution, etc., lead to different results. The extractants known as Bray no. 1 and Bray no. 2 solutions were developed by Bray and Kurtz (1945). These are 0.03 N NH_4F in 0.025 N HCl, and 0.03 N NH_4F in 0.1 N HCl, respectively. Generally the "adsorbed" form of P is extracted by the Bray no. 1 solution, whereas the Bray no. 2 extracts the "absorbed" as well as acid soluble forms of P. NH_4F has desirable properties for extracting P due to its ability to complex aluminum and iron in acid conditions. The phosphate which is held by these trivalent ions is released into the suspension (Turner and Rice, 1952). Addition of boric acid to the ammonium molybdate reagent eliminates the interference in reading of the intensity of the molybdate blue color caused by NH_4F (Cooke, 1951). Laverty (1963) used 1-amino-2-naphthol-4 sulfonic acid as a reducing agent to obtain a more stable color development in the extract.

Olsen, Cole, Watanabe and Dean (1954) developed a method using 0.5 M $NaHCO_3$ adjusted to pH 8.5 to extract P in soils. This was considered suitable for neutral, alkaline and calcareous soils. According to Olsen et al. (1954) there are two major mechanisms in the $NaHCO_3$ extraction process: (1) calcium phosphates increase in solubility in $NaHCO_3$ as a result of the repression of the Ca^{++} activity (common ion effect of CO_3^{--} ions in the presence of solid phase $CaCO_3$) and (2) the HCO_3^-,

CO_3^{--} and OH^- ions replace P ions on the surface of soil particles. The main effect of $NaHCO_3$ in calcareous soils is to decrease Ca^{++} activity which in turn increases the solubility of P.

A number of investigators correlate phosphorus availability as determined by chemical tests to the various phosphorus fractions. Westin and Buntley (1966b) compared the Bray 1 and Olsen availability tests with the amounts of the four inorganic P fractions. When all Chernozem samples are considered together the results of the Bray method gave higher positive correlation with P fractions than did those of the Olsen method. For Chestnut soils considered together the results of the Olsen method give higher positive correlations than did those of the Bray method. Clay content, pH and Ca-P generally were involved in more negative than positive correlations with the results of the Olsen and Bray methods for Chernozem and Chestnut soils. In an attempt to relate phosphorus extracted by Olsen's method to any of the various phosphate fractions, Hawkins and Kunze (1965) found a significant correlation between available phosphorus (AP) and aluminum phosphate for Texas grumusols.

Most of the soil P tests in common use today for measuring P available to plants were developed empirically rather than from an estimation of the P fractions which are related to availability tests. These tests usually give satisfactory results within restricted soil groups, but not for combinations of soils (Soil Test Work Group, 1956). Perhaps a soil test should provide a quantitative measure of the degree to which each of the soil P fractions are related to plant availability.

Runge and Peck (1968, private communication) showed that available P soil test (Bray P1) results offer a convenient tool for rapidly assessing differences between soil profiles in a low cost manner. Smeck and Runge (1971) found progressive increase in phosphorus availability in profiles along a traverse from Haplaquoll toward the Albaqualf end of a transect. Phosphorus availability tends to increase as the degree of profile development increases. Climate was found by Koyumdjisky and Dan (1969) to be the dominant soil forming factor governing available phosphorus content in an Israel soil. Areas of higher rainfall showed higher values of available phosphorus. Parent material also had an indirect influence on available phosphorus content especially in higher rainfall areas.

Phosphorus Studies in Iowa Soils

In their study of twelve different Iowa soil profiles, Pearson, Spry and Pierre (1940) reported that total phosphorus (TP) content decreases with depth to a minimum between the lower A and upper B horizons but thereafter increases again in the C horizons. They also noted that in a Gray Brown Podzolic (Udalf) soil the minimum total phosphorus values were closer to the surface when compared to prairie (Udolls) or planosol

(Aqualfs and Albolls) soils. The magnitude of the TP value was found to be higher in loess soils than in till derived soils. According to studies by Fenton, Riecken and Seaholm (1967) on a biosequence of prairie, prairie-forest intergrade and forest soils vegetation has a marked effect on the TP content of soils. They also showed that the depth to the minimum TP values was greatest in the prairie soil, intermediate in the transitional soils and least in the forested soil. In general, total phosphorus tends to decrease with increased weathering of the soil (Godfrey and Riecken, 1954), namely a corresponding decrease in TP with increasing textural profile development.

Godfrey and Riecken (1957) also investigated P solubility in loess derived soils. They reported that Bray no. 1 extract removed small amounts of phosphorus in the lower A and the upper B horizon but much more phosphorus was extracted from the C horizon especially in the less weathered Minden and Winterset soils. Haig, Edina and Putnam gave low soil test values in C horizon. Thus, the more strongly developed profiles tended to be lowest in soluble P showing the tendency of the soil development processes to fix the phosphorus compounds into less soluble forms. Runge and Riecken (1966) recognized eluvial and illuvial horizon of total P, and evaluated the pedogenetic effects of natural drainage on the profile distribution of various forms of phosphorus. Higher amounts of available P were found in imperfectly and moderately well drained soils as compared to poorly drained soils.

Mausbach (1969) studied inorganic phosphorus fractions of some Iowa soil profiles by the Chang and Jackson method. His investigations indicated the variation in relative amounts of the fractions due to parent material, vegetation, natural drainage, textural development and landscape position of the soils. The Ca-P and Red-P were found to decrease with forest influence while the Fe-P increased. The poorly drained soils had more Ca-P but less Red-P and sesquioxide P than the well drained soils. In general, inorganic-P fractions showed promising evidence for series differentiation due to the fact that characteristic distributions were obtained for each soil included in the study.

There has long been an interest in the AP distribution in Iowa soil profiles. The studies were concerned primarily with characterizing the soils for better soil test interpretations.[1] Some AP data on Iowa soil profiles have been presented in theses, for example, Ryan (1959) and Runge (1963).

Biosequences

A sequence of soils which developed under different native vegetation is sometimes referred to as a biosequence. In a biosequence, the parent material, drainage, time and the

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[1]Professors J. J. Hanway, L. C. Dumenil and T. E. Fenton, Department of Agronomy, Iowa State University, Ames, Iowa. Personal communication.

climatic factors of soil formation are presumed constant. Vegetation thus becomes an important variable in determining the kind of soil that forms in a particular place. In the Midwest, many biosequences have been studied. These biosequences consist of native prairie soils on one extreme and native deciduous forest formed soils on the other, with transition prairie-forest or forest-prairie in between.

Gray-Brown-Podzolic soils were first named by Baldwin (1928). Marbut (1936) designated Gray-Brown-Podzolic as a Great Soil Group and this classification was retained by Thorp and Smith (1949). These soils developed under deciduous hardwood forest. The term Brunizem was proposed by Simonson, Riecken and Smith (1952) as the name for those soils previously called Prairie by Thorp and Smith (1949). These soils developed under prairie vegetation. The terms Brunizem, transition and Gray-Brown-Podzolic are of long standing interest in the relationship of Prairie and forest on soil formation. The 7th Approximation terminology is listed also where desirable in this thesis.

Simonson et al. (1952) described the characteristics and formation of Brunizems as follows: The A1 horizon of Brunizems is generally very dark grayish brown, thick and slightly acid and is underlain by a dark yellowish brown to dark grayish brown B horizon. The underlying C horizon is often leached and yellowish brown in color. The A, B and C horizons have gradual boundaries. The content of organic matter in the plow layer is normally about 5 percent and decreases gradually from the surface downward. Typically, the pH is lowest in the surface, then increases gradually with depth into the B horizon and may increase abruptly in the parent material layer to pH 7 or 8. The chief soil forming processes leading to the development of Brunizems have been the addition of organic matter in the surface layer, the leaching of bases and development of acidity in the A and B horizons, and the formation of high cation exchange capacity clay with its accumulation in the B horizon.

Changes in profile characteristics from Brunizem to Gray-Brown-Podzolic soils occur gradually. Shrader (1950) reported marked differences in the surface clay content of Prairie and forest soils with the transition soil occupying an intermediate position. According to Smith, Allaway and Riecken (1950) and White and Riecken (1955), the first perceptible change is an increase in the degree of development of structural aggregates in the B horizon or the appearance of gray coatings in the lower part of the A1 horizon. Cardoso (1957) noted a continuous gradual variation going from the soils developed under prairie to the soils developed under deciduous forest. In this progression, according to his findings, the most important biosequence relationships are: (1) a decrease in percentage clay and the thickness of the A1 horizon, consequently an increase in ratio of clay maximum in B/clay minimum in A; (2) an increase in depth to carbonates;

(3) a decrease in the value of organic carbon and total nitrogen, a decrease in percent base saturation of subsurface soil and of the B2 horizon as a result of an increase in exchangeable hydrogen of the B horizon; (4) a decrease in pH of the subsurface soil and of the B2 horizon, exchangeable bases, and the ratio of exchangeable Ca/Mg.

Transitional soils have properties that are intermediate between Brunizems and Gray-Brown-Podzolic soils. They may occur on lightly forested areas and/or areas of recent forest invasion. Bailey, Odell and Boggess (1964) reviewed the genetic relationships of transitional soils. In general, the transitional soils have a thicker and darker A1 horizon with higher organic carbon and higher base status, less A2 development, and less structural development in the B horizon than comparable Gray-Brown-Podzolic soils. White and Riecken (1955) concluded that transitional soils are closely related to Gray-Brown-Podzolic soils but with some distinct Brunizem characteristics. This realization is reflected in the 7th Approximation, where transitional soils generally are included in different subgroups of Hapludalf, Ochraqualfs and Albaqualfs Great Groups rather than with the Argiudolls.

The Gray-Brown-Podzolic soils are more weathered and show more forest influence than the transitional soils. This is indicated by higher clay maxima, lower Ca/Mg ratios and lower base status in the B2 horizons and less organic matter in the lower horizons of the Gray-Brown-Podzolic soils than in the transition soils (Bailey et al., 1964). The major soil forming processes have been described by Ulrich (1950) which are: (1) accumulation of organic materials in the A0 and A1 horizons, (2) removal of soluble materials such as carbonates and exchangeable bases from the solum, (3) formation of silicate clays accompanied with the movement of silicate clays and associated sesquioxides from the A horizon with their accumulation in the B horizons, and (4) development of platy structure in A2 and angular and subangular blocky structure in the B horizons.

In order to characterize and differentiate the biosequence soils with respect to phosphorus availability and contents, several biosequences were included in this investigation.

Diagnostic Criteria in Soil Classification

The soil classification systems change as the knowledge about soils expands. In the 7th Approximation (USDA, 1960), classification has been defined as a mirror in which the present condition of science is reflected, thus a series of classification schemes reflect the phases of the development of science. Many systems are possible and, in fact, many are being used in different countries.

From the foregoing it is clear that conflicting ideas exist as to how soils should be classified. To illustrate different approaches and concepts in soil classification systems being used, the more common systems are briefly reviewed.

In the modern USSR soil classification system, three components are used (Buol, Hole and McCracken, 1973). These are: the soil properties, the pedogenic processes, and the factors of soil formation. In Europe, Kubiena placed emphasis on the chemical and mineralogical properties as differentiating criterion. In Australia, Stephens (1962) defined qualitatively 47 great soil groups, primarily on the basis of morphology of central concept profiles. Northcote (1960) proposed a bifurcating scheme, with two classes per category with specific values and limits for the properties of soils in each. Based upon recent information from various states and the work of the All India Soil Survey, Govinda Rajan and Rao (1971) indicated the distribution of 23 major soil units in India. These soils are defined on the basis of texture, color and depth of solum. The FAO/UNESCO system utilizes a set of diagnostic horizons used in the United States comprehensive soil classification system, and in part from other classification systems (Buol et al., 1973). The highest or upper classes are approximately equivalent to the "great group" level of the United States and to the "soil type" of the USSR system. The lower category is composed of soil intergrades with special horizons or features of note.

In recent years there has been a tendency to produce a definitive system of soil classification based upon the intrinsic characteristics of the soil, but also using genesis where appropriate. Leeper (1956) suggested that soil properties should be used for classifying soils. He stated that the properties should be used for each horizon and ordered according to their importance. But a given property always has a certain level of importance. The 7th Approximation (USDA, 1960) developed by a series of stages during the 1950's relies on recognizing and defining a number of horizons. It emphasizes the need for greater precision and more criteria for soil characterization. The most striking feature of Soil Taxonomy (USDA, 1970) is the overall appearance of orderliness. The subdivisions appear to follow logically one from the other and the names seem to be comprehensive and informative.

In the context of searching for more and better criteria for soil characterization and its possible use in soil classification the phosphorus status of soils is the concern of this study.

SOILS AND METHODS OF ANALYSIS

Soils from Outside Iowa

The majority of the soil samples, except the two profiles from Texas, were collected by others (Table 1). The author collected samples of the Amarillo and Arvana soil profiles with the help of Dr. B. L. Allen, Professor of Agronomy at Texas Technological University, Lubbock. All samples were collected by soil horizons and subhorizons. The morphological descriptions of the series studied are given in Appendix I. The information about soils with respect to general location, parent material, native vegetation and climate is given in Table 1. The criteria for soil profile selection were that:

(a) the soils were classified as Alfisols or Mollisols

(b) the soils occurred on a stable or a near stable upland landscape position.

Soils from Iowa

The soil samples analyzed in the laboratory consist of:

(a) profiles from Boone County; this is also referred to as "traverse study".

(b) profiles representing different biosequences; this is referred to as "biosequence study".

(c) profiles from Adair County; this is referred to as "study of soil mapping units".

Table 1. General information about soils from outside of Iowa

Series name[a]	Location	Parent material
Grantsburg (Typic Fragiudalfs)	Illinois, Saline Co.	Loess, over sandstone
Cisne (Mollic Albaqualfs)	Illinois, Jasper Co.	Loess over Illinoian till
Amarillo (Aridic Paleustalfs)	Texas, Andrews Co.	Old eolian deposit
Arvana (Petrocalcic Paleustalfs)	Texas, Hockley Co.	Old eolian deposit
Pullman (Torrertic Paleustolls)	New Mexico, Curry Co.	Strongly calcareous sea land deposits
Forrest (Ustollic Haplargids)	Arizona Cochise Co.	Mixed alluvium from granite quartzite, rholite, limestone, etc.
Tubac (Typic Paleargids)	Arizona Cochise Co.	Mixed alluvium
Gwalior (Typic Haplustalfs)	India (M.P.) Dist. Gwalior	Alluvium
Podua (Aquic Nastrustalfs)	India (M.P.)	Alluvium

[a]Subgroup classification is given in parentheses below series name.

Native vegetation	Climate	Natural drainage	Source
Hardwood forest	Subhumid, temperate, mean annual precip. 40-45 inches	Moderately well	Fehrenbacher
Prairie grass with widely spaced trees		Poor	Fehrenbacher
Short grasses with woody plants like mesquite and cat claw	Semiarid, mean annual precip. 18-20 inches	Well	Allen
Short grasses (buffalograss and gramma grass	Semiarid, mean annual precip. 17-22 inches	Well	Buchanan and Harper
Scattered mesquite	Arid climate, mean annual precip. 12-13 inches	Well	Richmond and Havens
Semi xerophytic mainly thorny and bushy types	Semiarid, dry & hot for long periods, mean annual precip. 25-30 inches	Well Somewhat poor	Khanna and Fehrenbacher

Traverse study

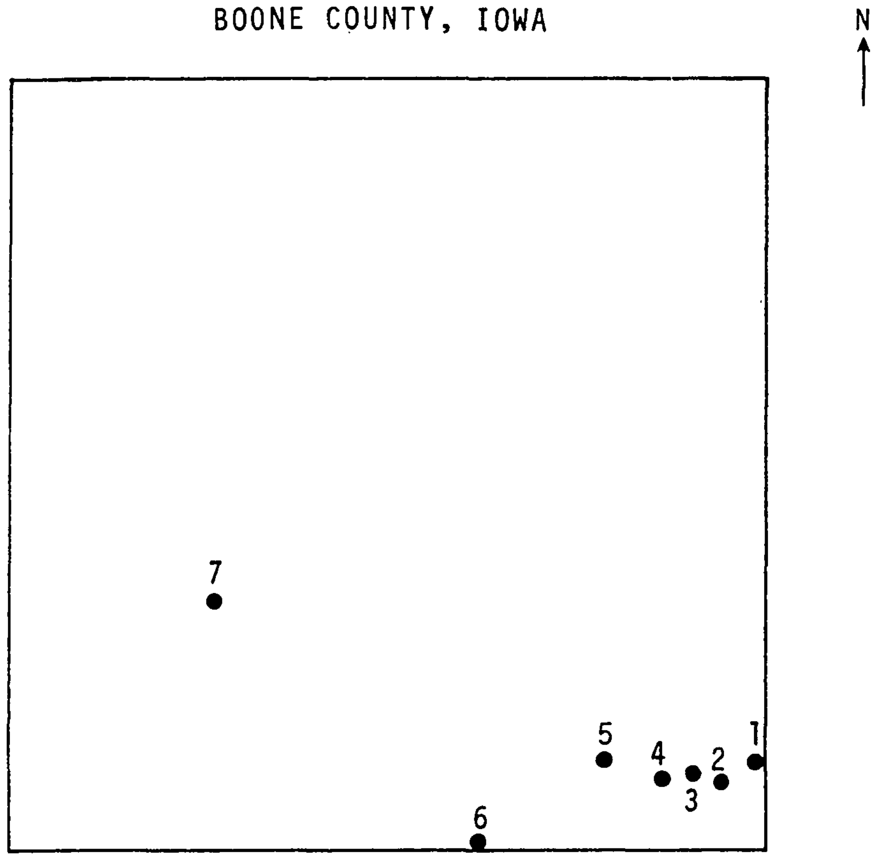
A transect composed of sites 1 through 7 is shown in Figure 1. These profiles from Boone County were sampled in August 1972, with the help of G. A. Miller and J. L. Richardson. Each profile was sampled to 4 feet, and the samples were collected at 6 inch increments. The soil horizon depth was noted. The soils are of the Clarion, Lester and Hayden series, formed on Cary till. Clarion is prairie derived, Lester is transition and Hayden is forest derived. According to the 7th Approximation, the subgroup classification for each series is Clarion, Typic Hapludolls; Lester, Mollic Hapludalfs; and Hayden, Typic Hapludalfs (Soil Survey Staff, 1972). The objective for selecting these profiles was to evaluate the influence of vegetation on inorganic and available P.

Biosequence study

The profiles selected are shown in Table 2 along with the series name, location and their source where profile description and other data are given. The set of profiles listed in the table were selected to investigate differences in Bray 1 P content due to vegetation. The profiles were selected to give a wide range in textural profile development, a range of drainage class and parent material differences in contrast to the traverse set of samples. The soils have been arranged according to biosequences, degree of profile development and natural drainage in Table 3. The biosequences were established by

Figure 1. Site locations of biosequence traverse in Boone County, Iowa

SEC. 34, T84N R27W
BOONE COUNTY, IOWA



SCALE 4"=1 MILE

SITE 1 - HAYDEN-1
SITE 2 - HAYDEN - 2
SITE 3 - LESTER-2
SITE 5 - LESTER-2
SITE 6 - CLARION-1
SITE 7 - CLARION-2

Table 2. Series name, identification number, county location, and source for soils of biosequences

Series name	Identification no.	County location	Source
Ames	P568	Boone	Cardoso (1957)
Appanoose	P908	Appanoose	Fenton (1969)
Beckwith	P421	Jefferson	Cain (1956)
Belinda	P614	Van Buren	Corliss (1956)
Clarion	P97	Dickinson	Cardoso (1957)
Clinton	P126	Washington	Corliss (1956)
Dundas	P567	Story	Cardoso (1957)
Edina	P223	Davis	Ulrich (1949)
Givin	54-75	Keokuk	Protz (1965)
Grundy	P3	Lucas	White (1953)
Haig	P220	Decatur	Ulrich (1949)
Hayden	P401	Webster	Cardoso (1957)
Kaomah	P613	Washington	Corliss (1956)
Kniffin	P903	Wayne	Fenton (1969)
Ladoga	P612	Washington	Corliss (1956)
Lester	P561	Story	Cardoso (1957)
LeSueur	P489	Polk	Cardoso (1957)
Luther	P565	Story	Cardoso (1957)
Mahaska	P715	Washington	Runge (1963)
Marion	P424	Adair, Missouri	Cain (1956)
Nicollet	P563	Boone	Cardoso (1957)
Otley	P712	Keokuk	Runge (1963)
Pershing	P911	Monroe	Fenton (1969)
Putnam	P186	Knox, Missouri	Godfrey (1951)
Rathbun	P906	Wayne	Fenton (1969)
Rubio	P610	Washington	Corliss (1956)
Rushville	P423	Washington	Cain (1956)
Seymour	P780	Wayne	Protz (1965)
Taintor	P714	Keokuk	Runge (1963)
Webster	P137	Humboldt	Cardoso (1957)
Weller	P910	Lucas	Fenton (1969)

Table 3. Array of 31 soils by biosequence, parent material, stage of profile development and natural drainage

Prairie soils	Transition	Forest soils	Stage of profile development	Natural drainage
Till biosequences				
Clarion[a] P94[b] Typic Hapludolls[c]	Lester P561 Mollic Hapludalfs	Hayden P401 Typic Hapludalfs	Minimal	Well
Nicollet P563 Aquic Hapludolls	LeSueur P489 Aquic Argiudolls	Luther P565 Aeric Ochraqualfs	Minimal	Somewhat poor
Webster P137 Typic Haplaquolls	Dundas P567 Mollic Ochraqualfs	Ames P568 Typic Albaqualfs	Minimal	Poor
Loess biosequences				
Otley P712 Typic Argiudolls	Ladoga P612 Mollic Hapludalfs	Clinton P126 Typic Hapudalfs	Medial	Moderately well to well
Mahaska P715 Aquic Argiudolls	Givin 54-75 Udollic Ochraqualfs	Keomah P613 Aeric Ochraqualfs	Medial	Somewhat poor

[a]Series name.

[b]Identification number.

[c]Subgroup classification.

Table 3. (Continued)

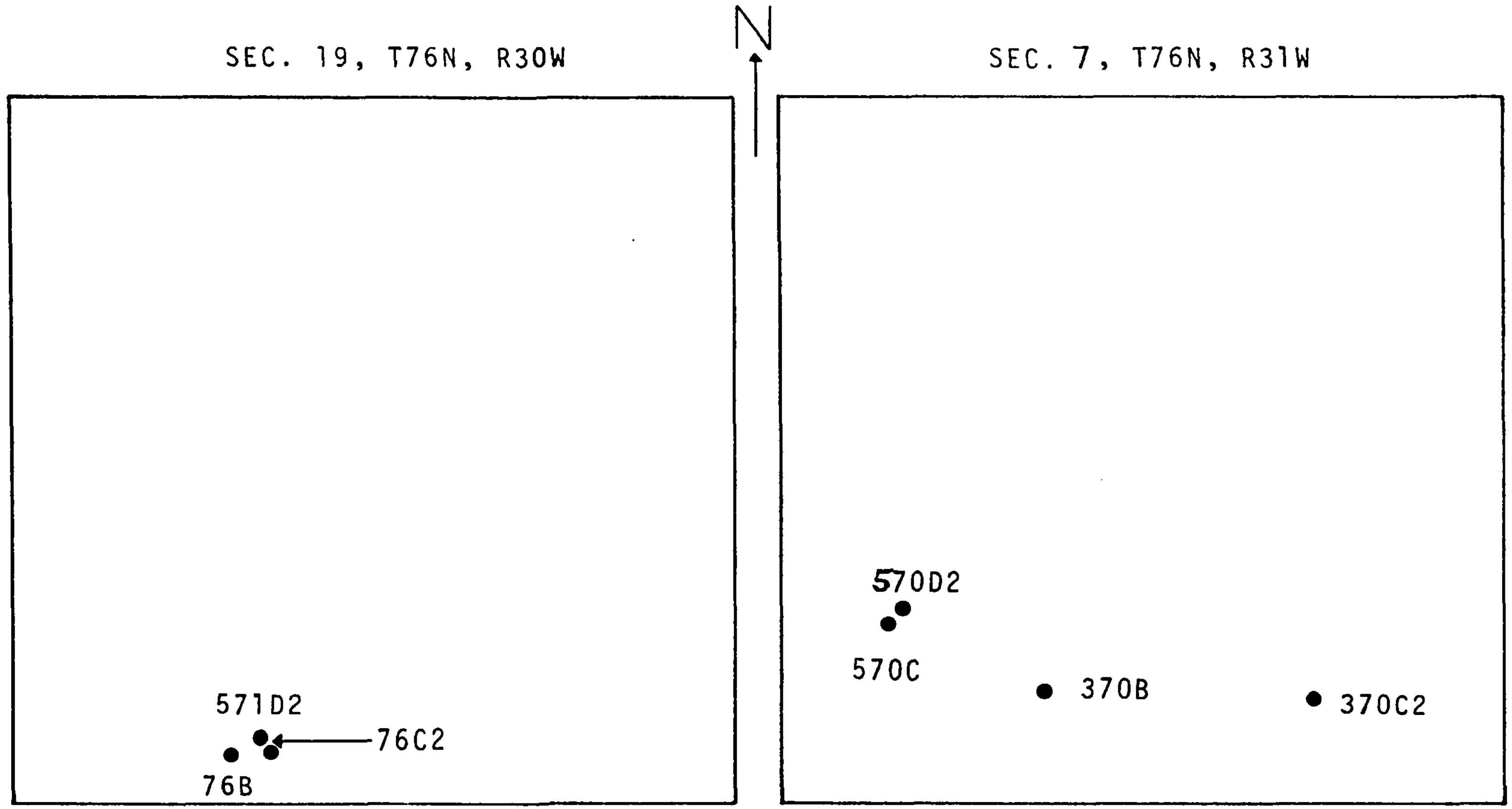
Prairie soils	Transition	Forest soils	Stage of profile development	Natural drainage
Taintor P714 Typic Argiaquolls	Rubio P610 Mollic Albaqualfs	Rushville P423 Typic Albaqualfs	Medial	Poor
Grundy P3 Aquic Argiudolls	Pershing P911 Udollic Ochraqualfs	Weller P910 Aquic Hapludalfs	Maximal	Somewhat poor
Seymour P780 Aquic Argiudolls	Kniffin P903 Udollic Ochraqualfs	Rathbun P906 Aeric Ochraqualfs	Maximal	Somewhat poor
Haig P220 Typic Argiaquolls	Belinda P614 Mollic Albaqualfs	Beckwith P421 Typic Albaqualfs	Maximal	Poor
Edina P223 Typic Argialbolls	Appanoose P908 Mollic Albaqualfs	--	Maximal	Poor
Putnam P186 Mollic Albaqualfs	--	Marion P424 Albaquic Hapludalfs	Maximal	Poor

field and laboratory observations by several workers and represent a gradual change in soil properties due to vegetation, but no data are available for Bray 1 P distribution for most of these profiles. Stored samples were used which were collected by the previous investigators. The choice of biosequences was based on availability of soil samples for the profiles, completeness of data (on particle size, pH and organic carbon) and morphological descriptions for the profiles and the judgment of the modality of profiles representing kind of vegetation and class of drainage.

Study of soil mapping units

The soil mapping unit symbol used is a part of a three factor symbol showing soil type, slope group and erosion class (i.e., 76C2). The first number represents the soil type, the second is the slope group and the third is the erosion class. The slope of the sites represents overall slope, the erosion classes are based on definitions in the soil survey manual (1951, pp. 261-266). Profiles representing Ladoga, Hedrick, Sharpsburg and Nira series were sampled in Adair County with the help of L. D. Lockridge, M. Sherwood and Brian Peterson, on the 31st of August, 1972. The profiles were sampled by horizons to a depth of 3 feet. The morphological descriptions of the profiles are in Appendix II. Figure 2 shows the locations of soil mapping units and the detail information is given in Table 4. The main objective was to determine the difference

Figure 2. Site locations of soil mapping units in Adair County, Iowa



SCALE 4"=1 MILE

Table 4. Native vegetation and series name for different mapping units sampled in Adair County, Iowa

Vegetation	Series	Mapping unit
F/P transition	Ladoga	76B (2-5% slope)
	Ladoga	76C2 (5-9% slope, moderately eroded)
	Hedrick	571D2 (9-14% slope, moderately eroded)
Prairie	Sharpsburg	370B (2-5% slope
	Sharpsburg	370C2 (5-9% slope, moderately eroded)
	Nira	570C (5-9% slope, moderately eroded)
	Nira	570D2 (9-14% slope, moderately eroded)

in available phosphorus content due to landscape position, erosion and natural vegetation. The subgroup classification of each series included in this study is as follows: Ladoga, Mollic Hapludalfs; Hedrick, Mollic Hapludalfs; Sharpsburg, Typic Argiudolls; Nira, Typic Hapludolls. Ladoga and Hedrick soils are of forest-prairie origin, and Sharpsburg and Nira soils are prairie origin.

Laboratory Methods

The air dried samples collected by the author were ground to pass through a 2 mm sieve. A subsample of the sample was taken and reground to pass a 60 mech sieve for phosphorus fractionation.

Particle size analysis

The particle size analysis was made by the method of Kilmer and Alexander (1949). Calgon was employed as dispensing agent. The sand fraction was separated by wet sieving, whereas silt and clay fractions were determined by the pipette method. Coarse silt was calculated by difference.

Soil pH

The pH was measured by a glass electrode and reading was done on a Beckman pH meter using a 1:1 soil-water and a 1:2 soil:0.1 M $CaCl_2$ ratios.

Total carbon analysis

Total carbon was determined by the Leco 70 second carbon analyzer for total carbon of soils (Tabatabai and Bremner, 1970). The procedure was as follows:

1. A soil sample (passed through 60 mesh sieve) weighing between 0.2-0.3 g was placed in a Leco #528-035 crucible and covered with one scoop of iron chips (Leco #301-077), one scoop of tin (Leco #301-076) and one scoop of tin-coated copper (Leco #501-263). A Leco #503-032 scoop was used to add the accelerators.

2. The analyzer was calibrated previously by burning known amounts contained in the Leco standards.

3. The soil and added accelerators were inserted into the calibrated Leco and total carbon recorded. To convert this number to percent total carbon in the soil, it was multiplied

by the factor calculated for the weight of soil sample taken.

Available phosphorus

1. Available phosphorus (Bray 1) was determined by a modification of the Bray and Kurtz (1945) method used in the Iowa State University Soil Testing Laboratory. By the modified Bray 1 method phosphorus was extracted with a solution containing 0.025 N HCl and 0.03 N NH_4F using a 1:10 soil: extractant ratio. The phosphorus was determined by the molybdenum blue method using a Bausch and Lomb spectronic 20 colorimeter.

2. For some soils available phosphorus (Olsen) was extracted using 0.5 M $NaHCO_3$ adjusted to pH 8.5, according to Olsen et al. (1954), with a soil:extractant ratio of 1:20. The phosphorus was determined by the Dickman and Bray method modified to include extra hydrochloric acid to neutralize the sodium bicarbonate.

Inorganic phosphorus fractions

The procedure of Chang and Jackson (1957), as modified by Petersen and Corey (1966), was followed for fractionation of soil phosphorus. Aluminum, iron, calcium and reductant soluble phosphorus were determined. The extractions were made in the following sequence from the single sample of soil which passed through a 60 mesh sieve. The soil to extractant ratio was 1:50. Extractions were in sequence:

Al-P extracted by 0.5 N NH_4F buffered at pH 8.2.

Fe-P extracted by 0.1 N NaOH.

Red-P extracted by 0.3 N sodium citrate plus 1 g sodium dithionite.

Ca-P extracted by 0.5 N H_2SO_4.

The extracted phosphates were measured by the molybdophosphoric blue color method on a Bausch and Lomb spectronic 20 spectrophotometer at 660 mu.

The author analyzed all samples for inorganic P fractions and available phosphorus content, except the available phosphorus content of the Pershing P429 and Tama 16M1. The particle size data for the soils outside of Iowa were obtained through various sources referred to in Table 1, except the Gwalior and Podua soils, for which the particle size was determined by the author. Mr. G. A. Miller provided the particle size data for the soils of the Boone County Traverse. The percentage clay, pH and organic carbon data for all the biosequence soils were taken from various sources referred to in Table 2. Other data reported in the Appendixes were determined by the author.

RESULTS

This section is divided into two subsections. The first section presents the inorganic phosphorus fractions data and the second the available phosphorus data. Sixteen soil profiles representing six suborders were analyzed for the inorganic P (IP) forms. The results are presented by suborders, and within the suborder by individual soil series. The purpose of presenting results according to the suborders in which soil series have been placed is for convenience as well as for comparison purposes.

The soils vary considerably with respect to location, parent material, and/or natural vegetation. General information about some soil profiles analyzed for inorganic P fractions is given in Table 1.

The available phosphorus (AP) was determined in all the profiles on which inorganic P fractions were obtained. In addition, available P was determined on soil profiles representing different soil sequences. Eleven biosequences and 31 soils were studied. These soils are classified in the Alfisol and Mollisol orders and include several suborders. The general location of the individual profiles is given in Table 2. The soils have been arrayed according to the biosequence, drainage class and degree of development in Table 3. The soils of the traverse study and mapping unit study of Alfisols and Mollisols as mentioned in a previous section were also analyzed for available phosphorus.

The results of particle size analysis, pH and total carbon in the soils are also presented to provide additional information. The pH was determined also by the $CaCl_2$ method for some profiles to compare the results. The results of pH (H_2O) will be referred to unless otherwise specified. The total carbon values are assumed to be organic carbon as long as there is no indication that the pH values of the HCl field test that the profiles contained free carbonates within the solum.

Inorganic Phosphorus Fractions

The fractionation of inorganic phosphorus was made by the successive extraction of a single soil sample with a series of reagents according to the method of Chang and Jackson (1957). The four fractions extracted in a sequence are the aluminum phosphate (Al-P), iron phosphate (Fe-P), reductant soluble phosphate (Red-P) and the calcium phosphate (Ca-P). The distribution of various IP fractions and their relative amounts in the soils is given in subsequent pages. The data are presented by suborders.

Aqualfs

Two soils are Aqualfs. Their classification is as follows:

Cisne: Fine, montmorillonitic, mesic family of Mollic Albaqualfs.

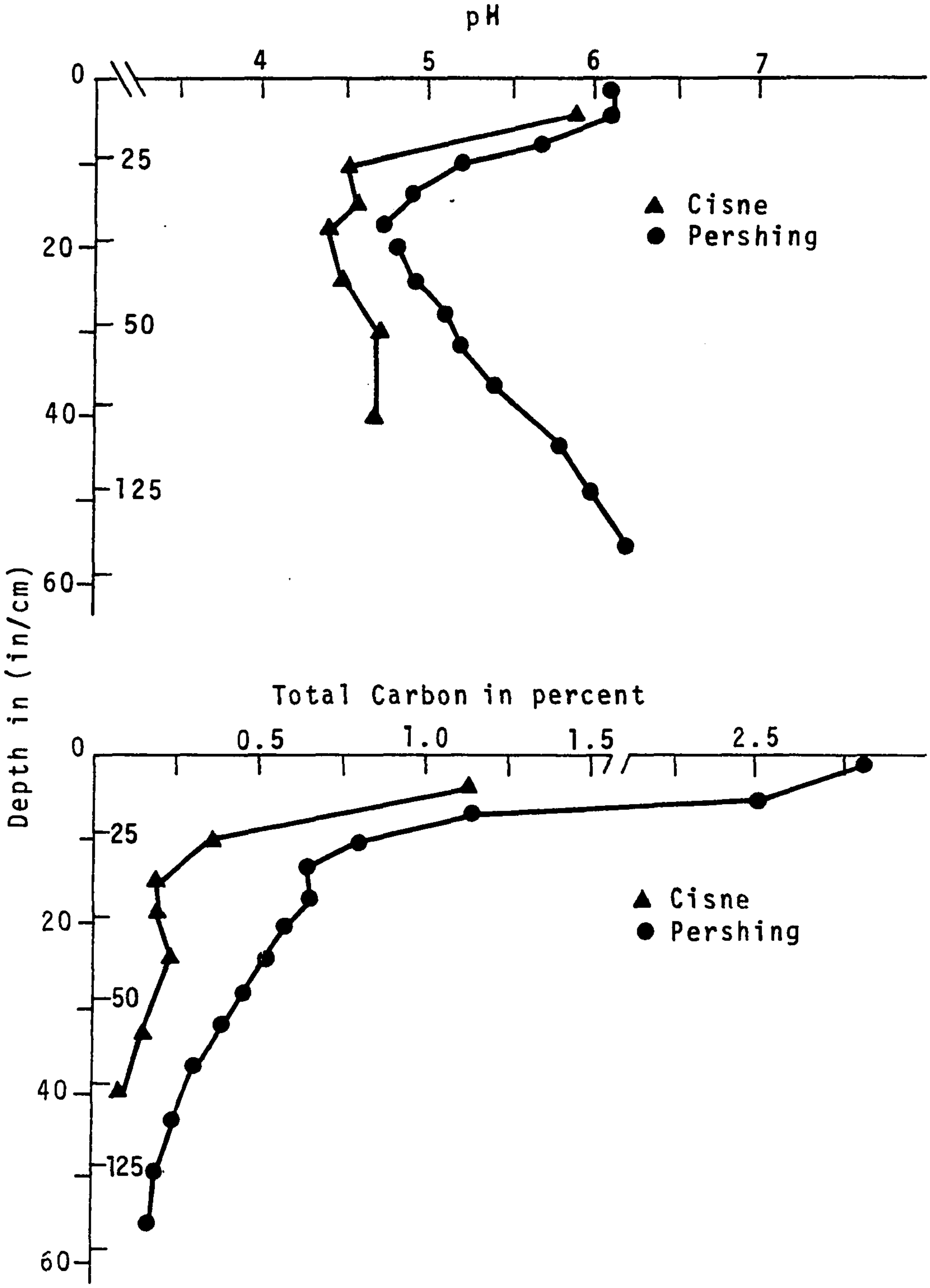
Pershing: Fine, montmorillonitic, mesic family of Udollic Ochraqualfs.

The soil profile of the Cisne series is from Jasper County, Illinois. It formed in thin loess over a till paleosol. The Pershing profile, P429, was collected by White (1953) in Lucas County, Iowa.

The particle size analysis, pH and total carbon data are given in Appendix III. The sand content in the Cisne profile ranges from 12.5 to 18.7 percent, showing a slight decrease with depth. Most of the sand size particles in the Cisne soils consist of iron concretions. There is a sharp increase in clay in the B horizon with a maximum of 36.2 percent in the B21 horizon which is in the 19 to 28 inch zone. The silt fraction is dominant in the Cisne and Pershing profiles. The sand content ranges from 1.1 to 3.0 percent in the Pershing profile. The clay content is high in the Pershing profile. It increases gradually with depth to a maximum of 48.5 percent in the B21 horizon which is in the 15 to 22 inch zone. The pH and total carbon are plotted in Figures 3 and 4, respectively. The Cisne is, in general, strongly acid throughout the profile. The pH range is from 4.4 to 5.9. It is more or less constant except in the uppermost layer. The pH values measured in 0.1 $\underline{M}$ $CaCl_2$ (1:2, soil and $CaCl_2$ soln.) are consistently lower than H_2O pH values. In the Pershing profile, the pH (H_2O) is high (6.1) in the surface, it decreases with depth to the zone of maximum clay. It is most acid in the B horizon where

Figure 3. Distribution of pH in the Cisne and Pershing soils (Aqualfs)

Figure 4. Distribution of total carbon in the Cisne and Pershing soils (Aqualfs)


pH
4
5
6
7
0
25
20
50
40
125
60
▲ Cisne
● Pershing
Depth in (in/cm)
Total Carbon in percent
0.5
1.0
1.5
2.5
0
25
20
50
40
125
60
▲ Cisne
● Pershing

the pH is as low as 4.7. The pH then increases gradually with depth.

The total carbon in the profiles of the Cisne and the Pershing series decreases sharply with depth to the A2 horizon. Then there is a slow decrease to the bottom of the profile (Figure 4). This Pershing soil has more carbon than the Cisne soil.

The data for the inorganic P fractions are given in Table 5. The range (excluding the A1 or the plow layer) of the total IP fractions in the A horizons of the two profiles is from 145 to 207 ppm in the Cisne and from 135 to 190 ppm in the Pershing soil. The total IP fractions in the B and C horizons increase with depth to a maximum of 348 ppm in the Cisne and 479 ppm in the Pershing.

The relative proportions of the IP fractions vary considerably in the two profiles (Figure 5). The Fe-P forms a large proportion (28 to 61 percent) of the IP fractions in the Cisne profile. The Red-P makes a high proportion (39 to 70 percent) in the Pershing profile. The percent Ca-P is higher in the solum of the Cisne profile than in the solum of the Pershing profile. The Red-P is a small fraction (varying from 3 to 30 percent) in the solum of Cisne. The distribution of all the four forms in the individual profiles is described below.

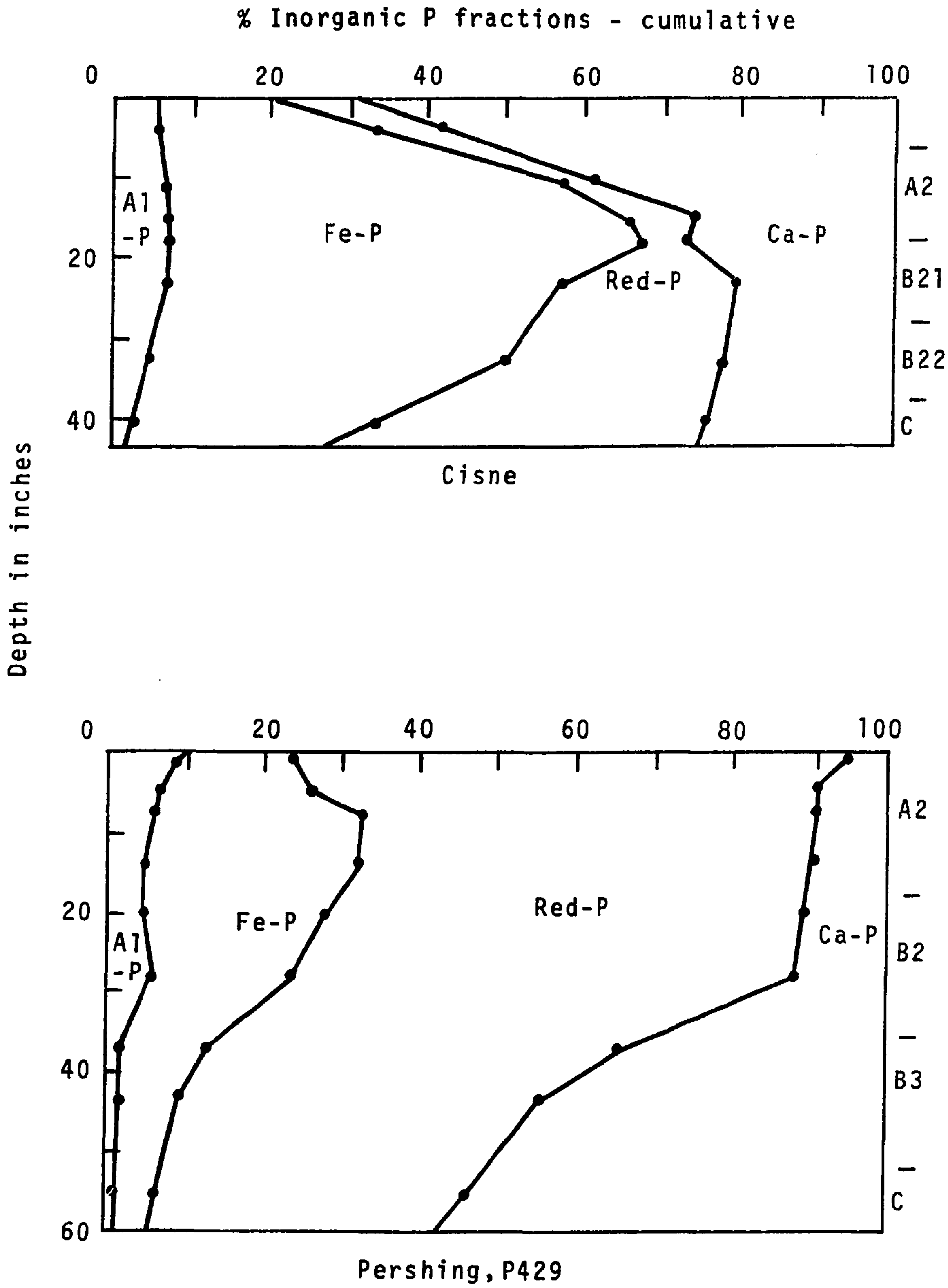
<u>Cisne</u> The Ca-P content is very high (233 ppm) in the Alp or plow layer. In the lower A and B horizons (23 to 28

Table 5. Available P and inorganic P fractions in Cisne and Pershing soils classified under Aqualf suborder

Horizon	Depth	AP in ppm		IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Olsen	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Cisne, Jasper County, Illinois												
Alp	0-8	25	15	25	111	32	233	401	6	28	8	58
A21	8-13	7	5	15	105	7	80	207	7	51	3	39
A22	13-17	6	2	10	70	12	34	135	7	59	9	25
Ab	17-19	4	0	10	89	9	37	145	7	61	6	26
B21	19-28	3	0	10	75	35	31	151	7	50	23	20
B22	28-37	7	1	13	98	70	50	231	5	43	30	22
C1D1	37-43	9	4	13	105	147	83	348	3	31	42	24
Pershing P429, Lucas County, Iowa												
A1	0-3	51[a]		21	34	161	15	231	9	15	70	6
	3-6	37		13	37	123	17	190	7	19	65	9
A2	6-9	25		8	36	78	13	135	6	27	58	9
A3B1	12-15	16		8	45	95	17	165	5	27	58	10
B21	18-22	21		13	60	156	27	256	5	23	61	11
B22	26-30	35		22	64	230	45	361	6	18	64	12
B31	34-40	24		10	45	213	137	405	2	11	53	34
B32	40-46	15		9	34	203	205	451	2	7	45	46
C1	52-58	10		4	33	194	266	497	1	6	39	54

[a]Source - T. E. Fenton, personal communication.

Figure 5. Cumulative plots of the percentage inorganic P fractions for the Cisne and Pershing soils (Aqualfs)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
A1
-P
Fe-P
Red-P
Ca-P
A2
B21
B22
C
20
40
Cisne
Depth in inches
0
20
40
60
80
100
A2
Fe-P
Red-P
Ca-P
A1
-P
B2
B3
C
20
40
60
Pershing, P429

inch zone) the Ca-P fraction comprises about 20 to 25 percent of the total inorganic P fractions. In the lower B and C horizons the maximum value is 83 ppm.

The Al-P fraction is high (25 ppm) in the surface layer. It decreases sharply in the next lower layer, then the values remain almost constant at about 10 ppm throughout the profile.

The Fe-P fraction is high in the surface and decreases slowly with depth to the depth of 28 inches (B21 horizon). The content of Fe-P increases in the lower part of the profile to the maximum value of 105 ppm.

In the A horizon, the Red-P content is low. The Red-P fraction increases sharply reaching the highest value of 147 ppm in the C horizon. Red-P dominates in the C horizon.

<u>Pershing, P429</u> The Al-P, Fe-P and Red-P fractions follow the same pattern of distribution within the profile. The amounts of these fractions are high in the surface then decrease with depth to the depth of 15 inches (the upper B horizon). The Al-P, Fe-P and Red-P show an increase in the zone of maximum clay accumulation. The highest value of these forms occurs in the B22 horizon (Table 5). The solum of the Pershing profile is low in the Ca-P fractions; however, an abrupt increase occurs in the bottom of the profile reaching the value of 266 ppm.

Argids

The Forrest and Tubac soil series are Argids and their classification is as follows:

Forrest: Fine, mixed, thermic family of Ustollic Haplargids.

Tubac: Fine, mixed, thermic family of Typic Paleargids.

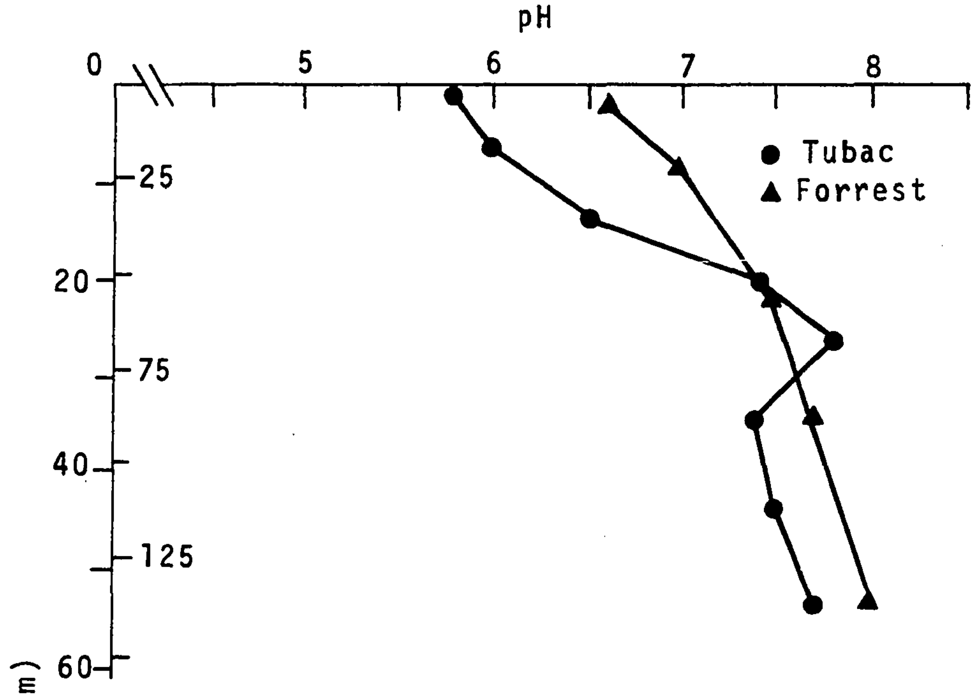
One soil profile represents each series. They are from Cochise County, Arizona. These soils were formerly classified in the Reddish Brown Great Soil Group.

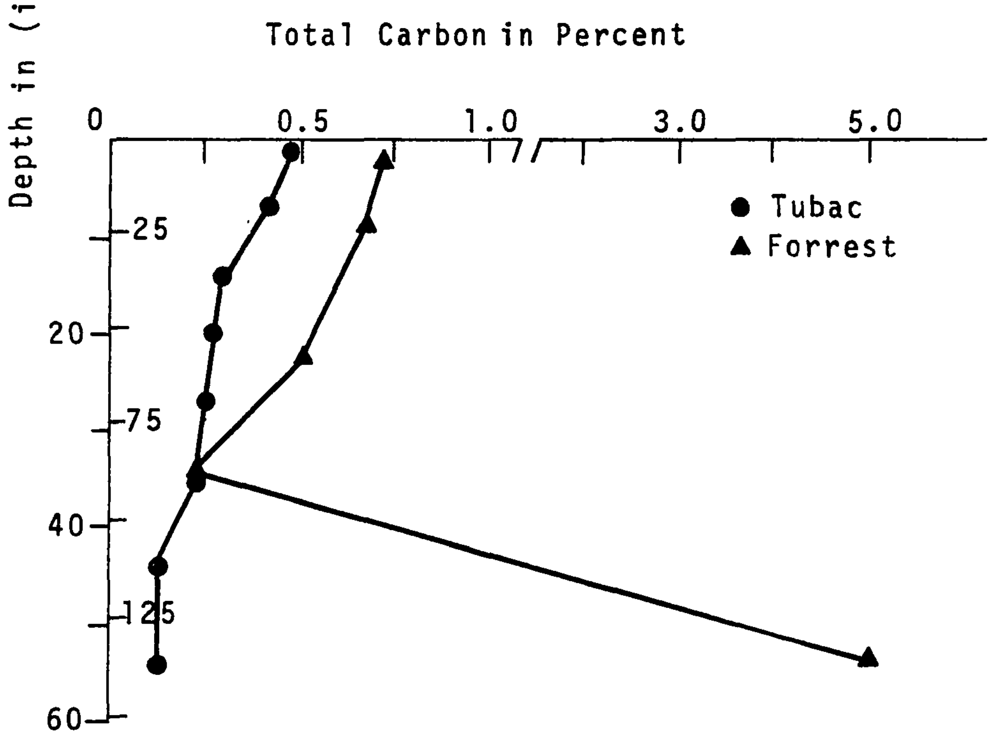
The particle size analysis, pH and total carbon data are given in Appendix III. The textural phase of the Forrest profile is loam and that of the Tubac profile is sandy loam. The sand fraction is the dominant size fraction in both the profiles. The sand fraction ranges from 30.4 to 52.1 percent in the Forrest and from 51.5 to 81.4 percent in the Tubac soil. The clay content increases with depth in both the profiles. The clay maximum occurs in the B22 horizon of the Forrest profile which is in the 16 to 24 inch zone where the clay content is 51.5 percent. The zone of clay maximum in the Tubac profile is the B21 horizon which is in the 16 to 24 inch zone. The clay at this depth is 37 percent.

The pH values are presented in Figure 6. The pH ranges from 6.6 to 8.0 in the Forrest profile showing a gradual increase with depth. The pH also increases with depth from 5.8 in the surface to 7.7 in the C horizon of the Tubac soil. This trend is also similar for pH ($CaCl_2$) values except that the

Figure 6. Distribution of pH in the Forrest and Tubac soils (Argids)

Figure 7. Distribution of total carbon in the Forrest and Tubac soils (Argids)


pH
0
5
6
7
8
25
75
125
20
40
60
Tubac
Forrest
Depth in (in/cm)


Total Carbon in Percent
0
0.5
1.0
3.0
5.0
25
75
125
20
40
60
Tubac
Forrest

values are lower than pH (H_2O values).

The total carbon decreases with depth (Figure 7) in Forrest and Tubac profiles; however, a sharp increase of total carbon occurs in the C2Ca horizon of the Forrest profile.

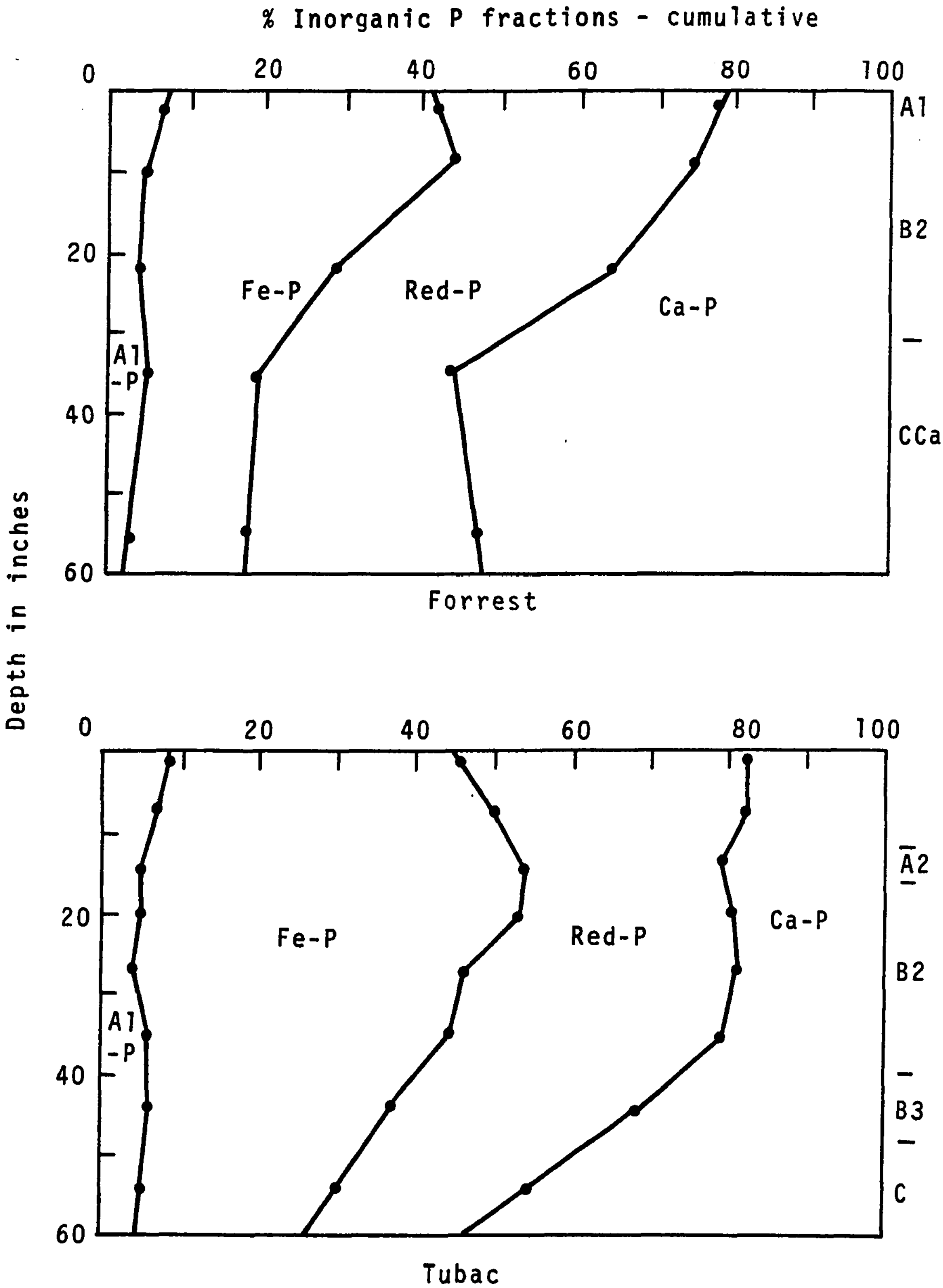
The values of the inorganic P fractions are given in Table 6 and the relative percentages are shown in Figure 8. The sum of the IP fractions ranges from 177 to 266 ppm in the Forrest and from 150 to 245 ppm in the Tubac profile. The sum of inorganic P fractions is 186 ppm in the surface layer of the Forrest profile. It decreases in the B horizon where the values are almost constant. The content of total inorganic P is higher in the C horizons than the values of the B horizon. In the Tubac soil total inorganic P is high in the surface (186 ppm), remains constant in the subhorizons in the depth of 2 to 16 inches. The IP fractions (sum) show a slight accumulation in the zone of maximum clay. The highest amount of total inorganic P is in the C horizon.

The relative proportions of the various inorganic P fractions, expressed as a percentage of sum of the IP forms, are shown in Figure 8. There is a greater proportion of Fe-P in the A and upper B horizon of the Forrest soil. In the lower B and C horizons of this soil the Ca-P form is the largest fraction. The Fe-P fraction is dominant in the solum of the Tubac soil, and comprises from 31 to 49 percent of the inorganic P fractions. The relative abundance of the P forms in the Forrest soil is as follows: Fe-P > Red-P > Ca-P > Al-P

Table 6. Available P and inorganic P fractions in Forrest and Tubac soils classified under Argid suborder

Horizon	Depth	AP in ppm	IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Forrest, Cochise County, Arizona											
A1	0-4	29	18	89	90	54	251	7	35	36	22
B21t	4-13	5	8	69	55	45	177	5	39	31	25
B22t	13-31	4	8	45	62	64	179	4	25	35	36
C1Ca	31-40	6	13	34	62	142	251	5	14	25	56
C2Ca	40-70	7	8	38	78	142	266	3	15	29	53
Tubac, Cochise County, Arizona											
A11	0-2	12	15	70	67	34	186	8	38	36	18
A12	2-12	5	10	63	48	28	149	7	43	32	18
A2	12-16	4	7	74	37	32	150	5	49	25	21
B21t	16-24	2	7	78	44	32	161	5	48	27	20
B22t	24-30	4	8	82	66	37	193	4	43	34	19
B23t	30-40	3	10	67	63	37	177	6	38	35	21
B3t	40-48	4	12	60	60	64	196	6	31	31	32
C	48-60	7	13	60	58	114	245	5	25	24	46

Figure 8. Cumulative plots of the percentage inorganic P fractions for the Forrest and Tubac soils (Argids)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
A1
B2
CCa
Fe-P
Red-P
Ca-P
A1
-P
Forrest
Depth in inches
A2
B2
B3
C
Fe-P
Red-P
Ca-P
A1
-P
Tubac

in the A and upper B horizon, and Ca-P > Red-P > Fe-P > Al-P in the lower B and C horizons. The relative abundance of the P fractions in the solum of the Tubac soils is as follows: Fe-P > Red-P > Ca-P > Al-P. The distribution of various fractions in the Forrest and Tubac profiles is described below.

Forrest In the solum the content of all the four fractions is highest in the surface (A1 horizon) and decreases in the next lower layer. The Al-P fraction ranges from 18 ppm in the surface to 8 ppm in the B horizon. The Fe-P form decreases with depth from 89 ppm in the surface to 34 ppm in the C horizon. The Red-P and Ca-P forms show the same distribution pattern. The high contents in the surface decrease to the upper B horizon then increase with depth. The A1 horizon has the highest value (90 ppm) of Red-P while the highest values of Ca-P (142 ppm) are in the C horizons. The content of Ca-P is about 2.5 times higher in the C horizons than in the solum.

Tubac The Al-P fraction ranges from 7 to 15 ppm. It is highest in the surface layer. Below the surface horizon, it decreases to 10 ppm continuing at about this value to the C horizon. The Fe-P fraction ranges from 60 to 82 ppm showing a slight accumulation in the zone of clay illuviation. The maximum value of Fe-P (82 ppm) occurs in the B22t horizon. The minimum values (60 ppm) are in the C horizon. The Red-P fraction is highest in the surface layer, 67 ppm, decreasing to 37 ppm, in the lower A horizon. Then it increases slowly with depth. The lower part of the profile contains more or less the same amount of Red-P as the surface layer. The Ca-P range is narrow (from 28 to 37 ppm) in the solum of the Tubac soil. In the B3t and C horizons there is a sharp increase in the Ca-P form, 64 and 114 ppm, respectively.

Udalfs

Inorganic P fractions were determined on four profiles of Udalfs. The soil series represented and their classification are given below.

Grantsburg:	Fine-silty, mixed, mesic family of Typic Fragiudalfs.
Hayden:	Fine-loamy, mixed, mesic family of Typic Hapludalfs.
Lester:	Fine-loamy, mixed, mesic family of Mollic Hapludalfs.
Weller:	Fine, montmorillonitic, mesic family of Aquic Hapludalfs.

The Grantsburg was formerly classified as a Gray Brown Podzolic soil with a fragipan. It is from Saline County, Illinois. The Hayden-1 and Lester-2 profiles were collected in Boone County, Iowa. These soil profiles formed in Cary till. The Weller and Grantsburg formed in loess parent material. The profile of Weller, P909, is from Monroe County, Iowa.

The data for particle size, pH and total carbon for the Grantsburg and Weller soils are given in Appendix III, and in Appendix IV for the Hayden-1 and Lester-2 soil profiles. Silt is the dominant size fraction throughout the profiles of

Grantsburg and Weller. The clay content in the Grantsburg soil ranges from 14 to 29 percent showing an accumulation in the fragipan horizon which is in the zone of 21 to 41 inches. In this zone clay content ranges from 23 to 29 percent. The profile of the Weller series is high in clay content which ranges from 19.5 to 47.5 percent. The clay content increases with depth and the maximum clay occurs in the 23 to 33 inch zone (B21 and B22 horizons).

The pH range is from 4.7 to 5.7 in the Grantsburg profile and from 4.3 to 6.7 in the Weller profile. A perusal of Figure 9 indicates that both profiles are more acid in the B horizons than in the A or C horizons. The pH is as high as 6.7 in the uppermost layer of the Weller soil while it is as low as 4.3 in the zone of maximum clay accumulation.

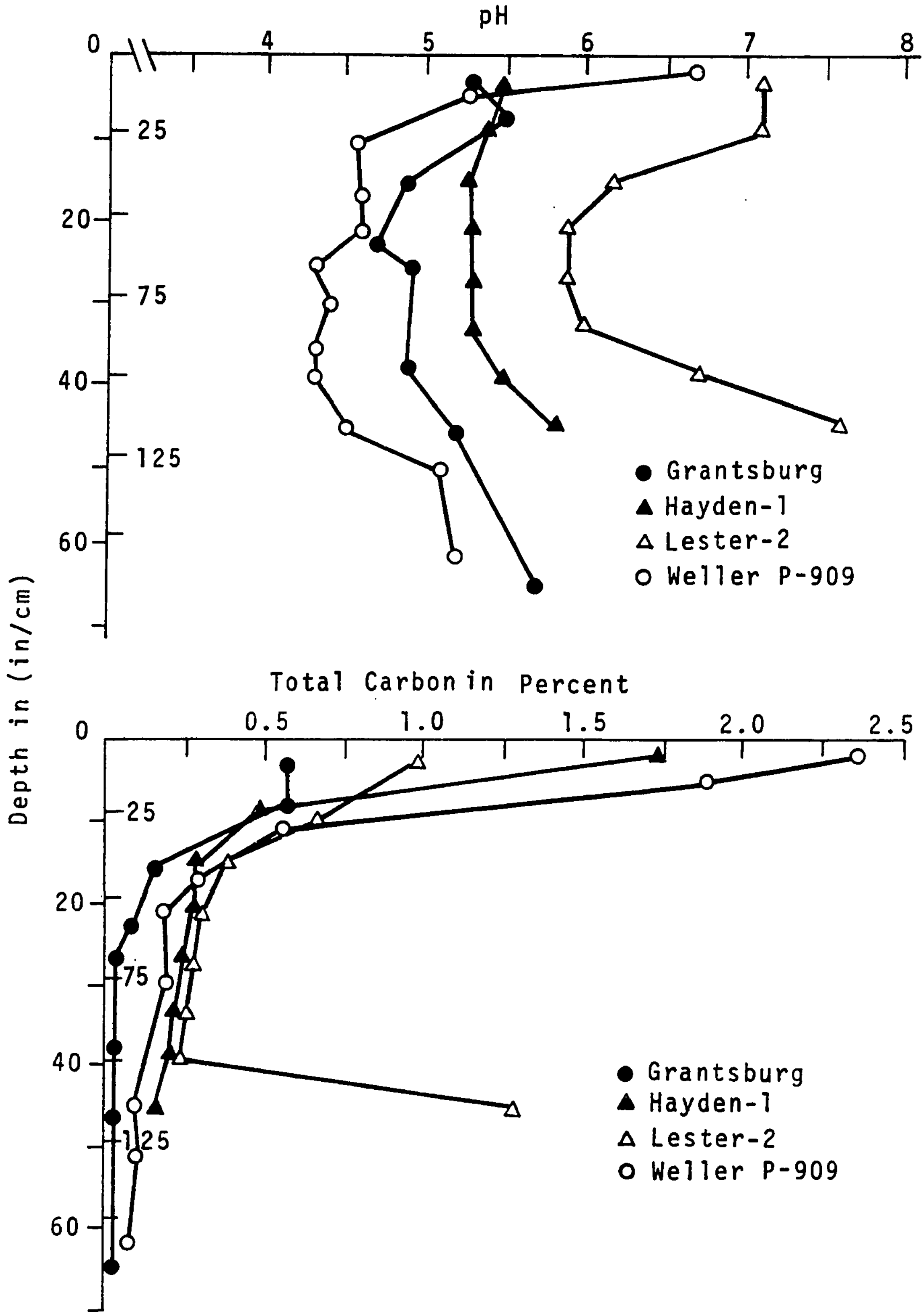
The total carbon in both the Grantsburg and Weller profiles decreases with depth (Figure 10). In general, Grantsburg soil is lower in total carbon than the Weller soil. The content of total carbon is 2.3 percent in the upper 4 inches of the Weller profile but decreases to 0.55 percent at 7 inches.

The detailed account of the particle size, pH and total carbon data in the Hayden and Lester soils are given where the results are presented of the available P in Udalfs and Udolls in a Cary till biosequence. However, a brief account is made here.

The sand fraction is the dominant particle size fraction

Figure 9. Distribution of pH in the Grantsburg, Hayden, Lester and Weller soils (Udalfs)

Figure 10. Distribution of total carbon in the Grantsburg, Hayden, Lester and Weller soils (Udalfs)


pH
0
4
5
6
7
8
25
20
75
40
125
60
Grantsburg
Hayden-1
Lester-2
Weller P-909
Depth in (in/cm)
Total Carbon in Percent
0
0.5
1.0
1.5
2.0
2.5
25
20
75
40
125
60
Grantsburg
Hayden-1
Lester-2
Weller P-909

in the Hayden-1 and Lester-2 profiles. The maximum clay in these profiles occurs in the zone of 18 to 30 inches. The maximum content of clay is about equal in these Hayden and Lester soils, 28 and 26.4 percent, respectively. The pH values in the Hayden soil profiles are quite uniform, about 5.5 (Figure 9). But in the Lester-2 profile the pH values are more variable. There is a decrease of total carbon content with depth in both the profiles (Figure 10).

The data for the inorganic P fractions of the four Udalfs are in Table 7. The sum of all four IP fractions is 223 ppm in the surface of the Grantsburg profile. The values increase with depth showing an accumulation (highest value being 456 ppm) in the zone of maximum clay. Then the content of total IP fractions decreases to the C horizon. In the Weller profile the value of total inorganic P forms is also high (265 ppm) in the surface layer. It decreases sharply below the surface layer, then the values increase with depth to the lower B and C horizons. The highest value of total IP fractions is 597 ppm in the B32 horizon.

The different IP forms vary in their dominance in the various horizons of the Grantsburg and Weller soils. The Fe-P is the dominant form throughout the profile of the Grantsburg soil. The Red-P is the next dominant P form. The range of the Fe-P is from 35 to 49 percent and of the Red-P is from 19 to 44 percent. The Ca-P comprises 37 percent of the total inorganic P forms in the surface layer. The percentage of Ca-P

Table 7. Available P and inorganic P fractions in Grantsburg, Hayden, Lester and Weller soils classified under Udalf suborder

Hori- zon	Depth	AP in ppm		IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Olsen	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Grantsburg, Saline County, Iowa												
Ap	0-6	9	9	17	79	44	83	223	8	35	20	37
A2	6-10	10	5	15	110	77	75	277	5	40	28	27
B2	10-21	7	11	12	184	130	68	394	3	47	33	17
A'2	21-24	5	5	17	173	147	64	401	4	43	37	16
B'2	24-34	9	9	21	173	203	59	456	5	38	44	13
B'31	34-41	10	15	23	224	158	54	459	5	49	34	12
B'32	41-51	18	23	25	158	130	118	431	6	37	30	27
C1	51-80	16	18	20	150	74	142	386	5	39	19	37
Hayden, Profile no. 1, Boone County, 8, site 1, Iowa												
	0-6	14	8	6	39	65	27	137	4	28	48	20
	6-12	6	1	2	32	49	27	110	2	29	44	25
	12-18	5	4	4	49	55	14	122	3	41	45	11
	18-24	17	12	8	54	58	17	137	6	39	43	12
	24-30	25	20	15	64	107	24	210	7	30	51	12
	30-36	23	20	15	83	74	62	234	6	36	31	27
	36-42	16	16	8	45	72	117	242	3	19	30	48
	42-48	7	9	6	30	70	182	288	2	11	24	63

Table 7. (Continued)

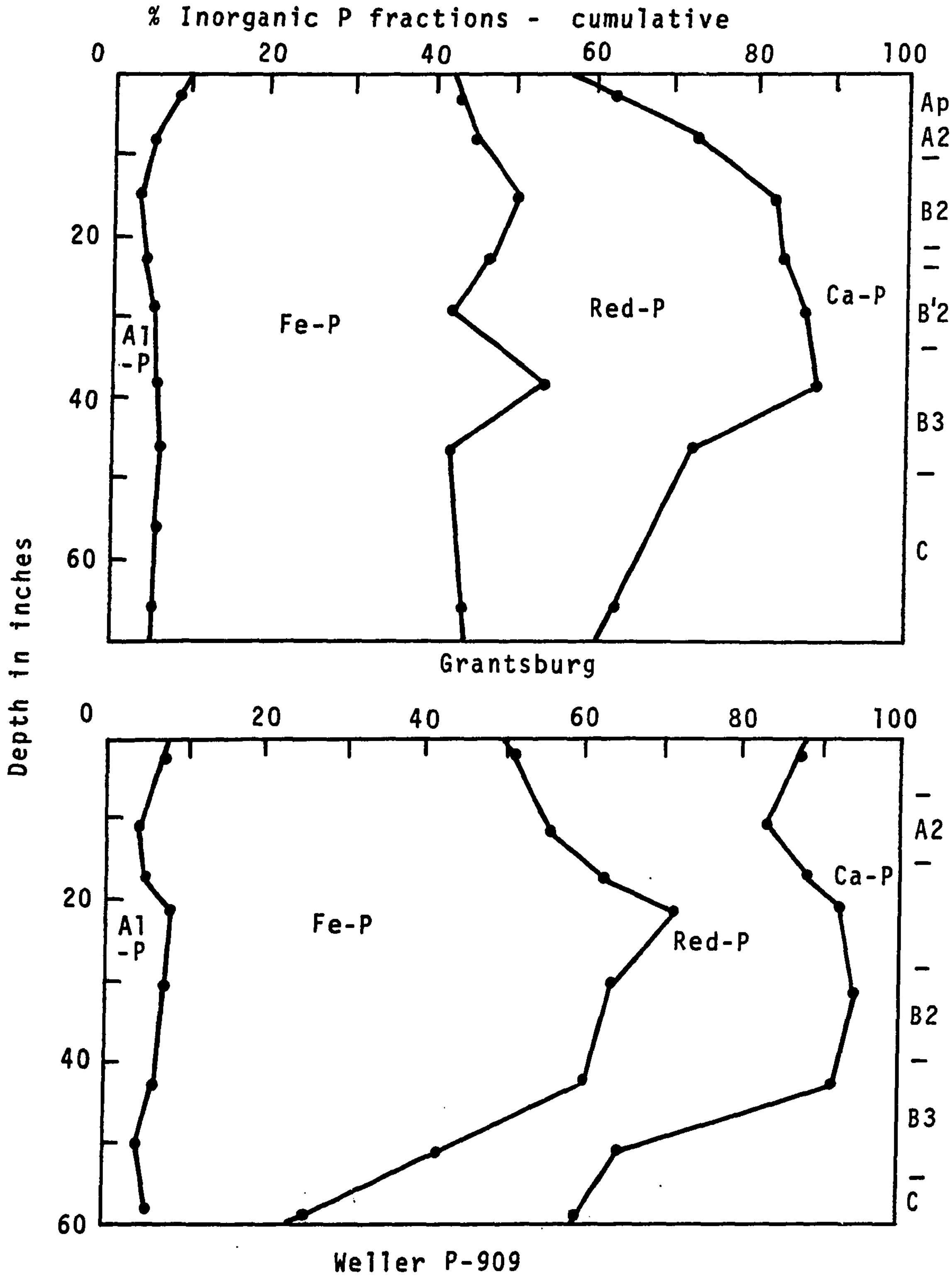
Hori-zon	Depth	AP in ppm: Bray 1	AP in ppm: Olsen	IP fractions in ppm: Al-P	Fe-P	Red-P	Ca-P	Sum	Percentage of sum of IP fractions: Al-P	Fe-P	Red-P	Ca-P
Lester, Profile no. 1, Boone County, 8, site 5, Iowa												
	0-6	15		8	34	74	19	135	6	25	55	14
	6-12	10		6	29	51	24	110	5	26	47	22
	12-18	7		4	29	72	15	120	3	24	60	13
	18-24	12		6	32	112	17	167	4	19	67	10
	24-30	15		8	39	45	62	154	5	25	29	41
	30-36	11		6	34	60	87	187	3	18	32	47
	36-42	1		2	32	70	205	309	1	10	23	66
	42-48	4		2	33	45	267	347	1	9	13	77
Weller, P909, Monroe County, Iowa												
A1	0-4	20	15	18	117	96	34	265	7	44	36	13
A22	7-15	15	7	8	93	48	30	179	4	52	27	17
AB	15-19	8	7	13	132	58	27	230	5	57	26	12
B1	19-23	13	10	30	222	73	28	353	8	63	21	8
B22t	28-33	22	22	35	258	147	30	470	7	56	31	6
B31t	38-47	55	34	33	275	159	45	512	6	54	31	9
B32	47-54	42	30	27	225	130	215	597	4	38	22	36
C	57-60	23	18	28	116	95	341	580	5	20	16	59

then decreases with depth to the lower B horizon where the value is as low as 12 percent. The Al-P is a small fraction making only 3 to 8 percent of the total inorganic P fractions. In the Weller soil the Al-P is also a small fraction of the IP forms. As in the Grantsburg profile, the Fe-P is the largest IP fraction in the Weller profile (Figure 11). The range is from 20 to 63 percent. The Red-P is the next dominant form in the solum ranging from 16 to 36 percent. The Ca-P makes a very small percentage of total IP forms in the solum. The range within the solum is about 6 to 17 percent. The value of 6 percent Ca-P is in the B22t horizon and is also the lowest Ca-P value of the sixteen profiles analyzed for the IP forms. In the C horizon of the Weller soil Ca-P is the dominant form in which it constitutes 59 percent of total inorganic P forms.

The sum of the IP fractions is low in Hayden-1 and Lester-2 soils (Table 7). The sum of the IP fractions is 137 ppm in the surface of the Hayden soil and 135 ppm in the Lester soil. The IP fractions decrease in the next layer, and then gradually increase with depth. The total amounts of inorganic P forms extracted in the upper three layers are the same in the profiles of Hayden and Lester. There is a sharp increase of the IP forms in the C horizon of the Lester soil while the increase in the lower B and C horizons is gradual in the Hayden soil.

There is a considerable variation in the relative percentages of the inorganic P forms in the Hayden and Lester soils (Figure 22). The Red-P fraction is the dominant

Figure 11. Cumulative plots of the percentage inorganic P fractions for the Grantsburg and Weller soils (Udalfs)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
Depth in inches
20
40
60
Ap
A2
B2
B'2
B3
C
Al
-P
Fe-P
Red-P
Ca-P
Grantsburg
0
20
40
60
80
100
20
40
60
A2
B2
B3
C
Al
-P
Fe-P
Red-P
Ca-P
Weller P-909

IP fraction in the 30 inch depth in the Hayden profile and in the 24 inch depth in the profile of the Lester soil. The Ca-P fraction is dominant below these depths in each profile.

In the solum of the Hayden-1 soil, the Fe-P fraction comprises 28 to 39 percent of the total inorganic P fractions. In contrast, the Ca-P fraction makes up only 11 to 26 percent in the solum of this soil. The percentage of the Al-P increases in the zone of clay illuviation of the Hayden-1 soil.

In the Lester profile the percentages of the Al-P and Fe-P fractions increase slightly in the B horizon. The Ca-P makes up only 10 to 22 percent of the fractions to a depth of 2 feet, but below this depth it increases sharply and is the dominant form. The Ca-P ranges from 41 to 77 percent in the lower part of the profile.

A more detailed account of the profile distribution of the inorganic P forms in the individual soils is given below.

Grantsburg The content of each of the Al-P, Fe-P and Red-P fractions is higher in the B horizon than in the A and C horizons. The Al-P content is low and the values vary from 12 to 25 ppm. The Fe-P and Red-P have the same pattern of distribution in the solum. The content of these fractions increases with depth showing a distinct accumulation in the zone of clay maximum. The lowest value of Fe-P (79 ppm) and Red-P (44 ppm) are in the Ap horizon. The highest values of the Fe-P and Red-P, 224 ppm and 203 ppm, respectively, are in the B horizon. The Ca-P content is 83 ppm in the plow layer and then decreases with depth to the lower B horizon. A sharp increase of the Ca-P occurs in the B32 and C horizons reaching a maximum value of 142 ppm.

Hayden-1 There is a distinct zone of accumulation of Al-P, Fe-P and Red-P in the 24 to 36 inch zone (Table 7), which is also the zone of maximum clay content. The contents of these fractions are highest in this zone.

In the Hayden profile, the range of values of Al-P is from 2 to 15 ppm, of Fe-P from 32 to 83 ppm, and of Red-P from 49 to 107 ppm. The lowest content of Al-P, Fe-P and Red-P is in the 6 to 12 inch depth. The Ca-P is high in the A horizon, it decreases in the upper B horizon and then increases with depth. The highest amount (182 ppm) of the Ca-P is in the C horizon.

Lester-2 In this Lester profile (Table 7), the Al-P content is low, varying from 2 to 8 ppm. The Al-P and Fe-P show a slight accumulation in the zone of 24 to 39 inches. The Fe-P does not vary greatly throughout the profile ranging from 29 to 39 ppm. The Red-P ranges from 45 to 112 ppm. The content of Red-P is highest at the depth of 18 to 24 inches. The distribution of the Red-P appears to be erratic, but it is the dominant fraction in the solum. The Ca-P content is low in the upper 2 feet of the profile in which the values range from 15 to 24 ppm. Below the depth of 2 feet, the Ca-P increase is sharp, and the values range from 62 to 267 ppm.

Weller, P909 There is a distinct zone of accumulation of Al-P, Fe-P and Red-P in the B22 and B31 horizons (Table 7). The Red-P and Fe-P content is high in these horizons. In the A horizon the contents of Al-P, Fe-P and Red-P are highest in the surface layer and decrease to a minimum for the profile in the A2 horizon. The values of these fractions then increase with depth to the maximum values in the zone of highest clay content. The Ca-P is slightly higher in the A1 surface layer, than in the A2 layer. In the A and B2 layers, the Ca-P values are quite constant (around 30 ppm). The Ca-P increases sharply in the B3 and C horizons. The highest value of the Ca-P is 341 ppm in the C horizon. In the profile, the ranges of the Al-P, Fe-P and Red-P are from 8 to 35 ppm, from 93 to 275 ppm, and from 48 to 159 ppm, respectively.

Udolls

The Clarion and Tama soil series studied are classified as follows:

Clarion: Fine loamy, mixed, mesic family of Typic Hapludolls.

Tama: Fine silty, mixed, mesic family of Typic Argiudolls.

The Clarion-1 soil profile formed in Cary till and is from Boone County, Iowa. The profile of Tama series is from Cedar County, Iowa. It formed in loess. The inorganic P data are in Table 8. The particle size analysis, pH and total carbon data for the Tama profile are given in Appendix III, and for the Clarion-1 soil (site 6) in Appendix IV.

The particle size, pH and total carbon results for the Clarion profile are discussed in more detail later under the heading "Available P in Udalfs and Udolls in a Cary till biosequence". The pH and total carbon distribution in the Clarion soil are given in Figures 12 and 13, respectively.

The silt fraction is dominant in the profile of the Tama series. The clay content ranges from 24.7 to 34.3 percent, showing a gradual increase from the surface to the lower B horizon. As shown in Figure 12, the pH values are quite constant throughout the Tama profile. However, there is a gradual increase of pH from the A12 horizon to the C horizon. As shown in Figure 13, total carbon in Tama profile decreases rapidly from the surface and then gradually with depth. In this profile, total carbon is presumed to be equivalent to organic carbon.

The sum of the inorganic P fractions ranges from 106 to 339 ppm in the Clarion profile, and in the Tama profile the range is from 108 to 433 ppm (Table 8). In the Clarion solum, the total IP fraction is highest in the surface layer then decreases with depth to a minimum in the zone of 18 to 24 inches. The values then increase in the C horizon. In the Tama profile the minimum value of the sum of the IP fractions is in the zone of 12 to 16 inches, the A13 horizon. Below this depth there is a gradual increase to the lower B horizon. The sum of the IP fractions is lower in the C horizon than

Figure 12. Distribution of pH in the Clarion and Tama soils (Udolls)

Figure 13. Distribution of total carbon in the Clarion and Tama soils (Udolls)

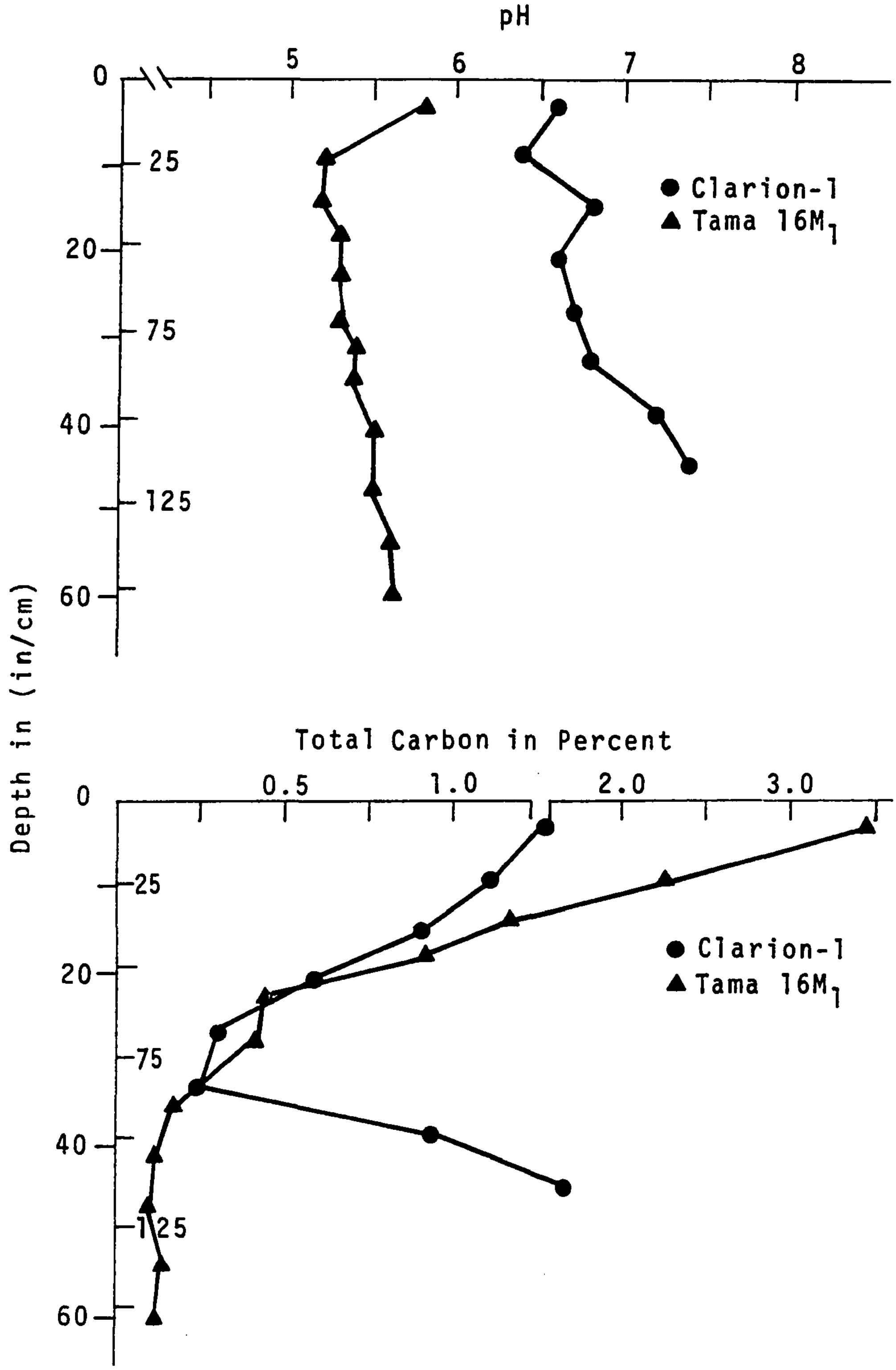

pH
5
6
7
8
0
25
20
75
40
125
60
● Clarion-1
▲ Tama 16M1
Depth in (in/cm)
Total Carbon in Percent
0.5
1.0
2.0
3.0
0
25
20
75
40
125
60
● Clarion-1
▲ Tama 16M1

Table 8. Available P and inorganic P fractions in Clarion and Tama soils classified under Udoll suborder

Horizon	Depth	AP in ppm	IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Clarion, Profile no. 1, Boone County, 8, site 6, Iowa											
	0-6	20	10	53	84	28	175	6	30	48	16
	6-12	15	6	33	83	17	139	4	24	60	12
	12-18	4	2	33	82	15	132	2	25	62	11
	18-24	4	2	25	45	34	106	2	24	42	32
	24-30	4	2	37	84	22	145	1	26	58	15
	30-36	2	2	27	70	132	240	1	15	29	55
	36-42	3	2	20	67	250	339	1	6	20	73
	42-48	4	2	25	62	232	321	1	8	19	72
Tama, 16 Ml, Cedar County, Iowa											
Ap	0-7	68[a]	34	79	67	63	233	15	34	39	28
A12	7-12	20	8	57	28	24	117	6	49	24	21
A13	12-16	9	4	36	30	38	108	4	33	28	35
B1	16-20	5	2	33	45	45	125	2	26	36	36
B21	20-26	3	1	34	103	45	183	1	18	56	25
B22	26-30	7	4	45	109	33	191	2	23	58	17
B22	30-33	6	4	60	169	42	275	2	22	61	15
B23	33-38	11	7	58	178	43	276	3	20	62	15
B24t	38-44	25	17	102	204	86	409	4	25	50	21
B24t	44-51	39	21	131	164	117	433	5	30	38	27
B31	51-57	43	19	49	130	123	321	6	15	41	38
C	57-63	40	18	77	119	157	371	5	21	32	42

[a]Source - G. A. Miller (personal communication).

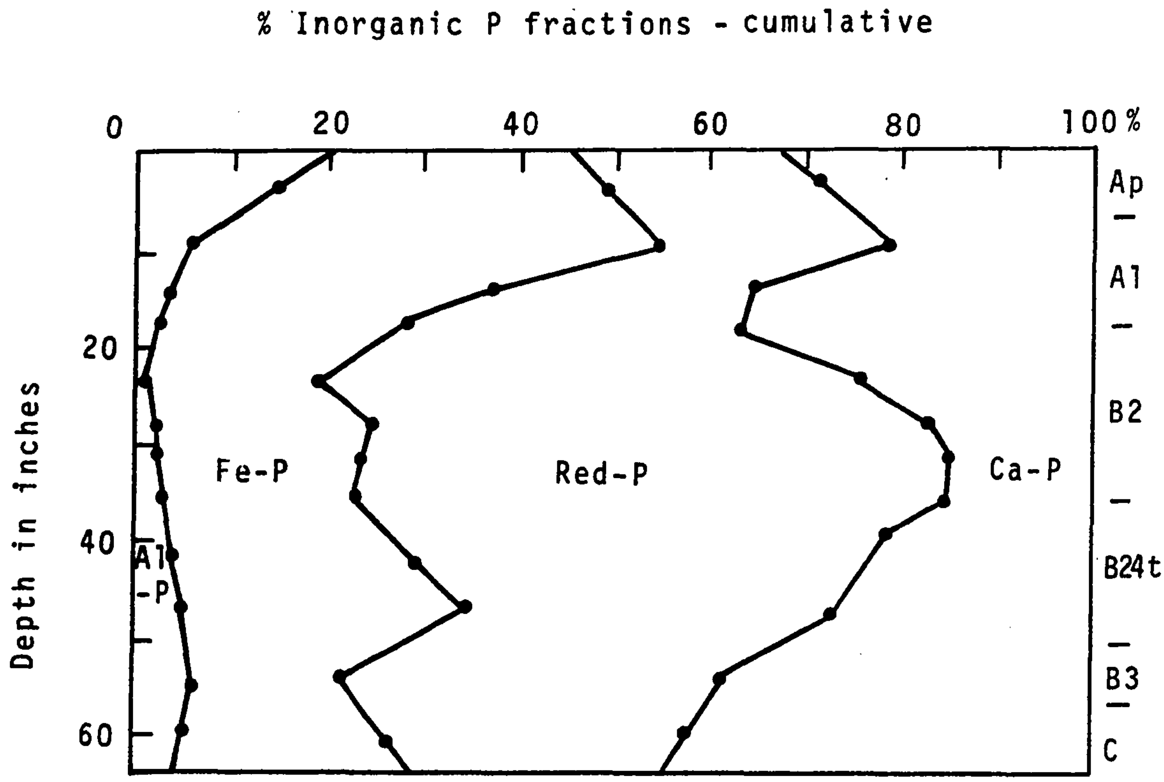
in the B23 and B24 horizons.

In the Clarion profile above about 30 inches the Red-P is the major fraction (Figure 22). Below this depth the Ca-P is the dominant form. The percentage of Fe-P is constant in the zone of 6 to 30 inches. It is the second largest fraction in the solum, the 0 to 30 inch layer. The Al-P is an insignificant fraction below one foot depth where its percentage range is only 1 to 2 percent.

The Red-P is a major fraction also in the B horizon of the Tama soil (Figure 14). In the A horizon Fe-P makes up a large proportion while in the C horizon the Ca-P constitutes the largest portion of the total inorganic P fractions. The Al-P comprises 15 percent of the inorganic P forms in the plow layer. Below this layer it only constitutes 1 to 6 percent.

Clarion-1 The Al-P content is 6 to 10 ppm in the upper one foot depth (Table 7). Below this depth its amount is only 1 or 2 ppm. The Fe-P is 53 ppm in the surface layer, and then the values remain constant (around 35 ppm) within the solum to about 30 inches. The content of Fe-P is lowest in the C horizon, about 25 ppm. The Red-P content in the various horizons is greater than the Fe-P fraction. Except for the 18-24 inch zone the Red-P content averages about 80 ppm to 20 inches. The Red-P is the major form extracted in the Clarion solum. The Ca-P content is lowest in the upper 30 inch depth where the values are from 15 to 34 ppm. There is a large increase of Ca-P below 30 inches with values of 132 to 232 ppm.

Figure 14. Cumulative plots of the percentage inorganic P fractions for the Tama soil (Udoll)


% Inorganic P fractions - cumulative
0
20
40
60
80
100%
Depth in inches
20
40
60
Fe-P
Red-P
Ca-P
Al
-P
Ap
A1
B2
B24t
B3
C

Tama 16M1

Tama The sum of the Al-P, Fe-P and Red-P fractions is 233 ppm in the surface layer (Table 8). There is a decrease to 108 ppm in the lower A13 horizon in the 7 to 12 inch zone. The contents of these P forms increase with depth to a maximum value of 433 ppm in the lower B horizon at a depth of 44 to 51 inches. There are 63 ppm of Ca-P in the surface layer, and it decreases to a minimum of 24 ppm in the next lower A12 horizon. The content of Ca-P then increases with depth to a maximum value of 157 ppm in the C horizon at a depth of 57 to 63 inches. The range in the values of the four IP forms is as follows: Al-P, 1 to 34 ppm; Fe-P, 33 to 131 ppm; Red-P, 24 to 204 ppm; and Ca-P, 24 to 157 ppm. The low content of Red-P is apparent in the 7 to 20 inch zone. The Al-P content is very low, about 1 to 4 ppm, in the lower A horizon and in most parts of the B horizon. In the lower B and C horizons there are 18 to 20 ppm of the Ca-P fraction.

Ustalfs

Four Ustalfs, Amarillo, Arvana, Gwalior and Podua, were studied. These soils are classified as follows:

Amarillo: Fine-loamy, mixed, thermic family of Aridic Paleustalfs.

Arvana: Fine-loamy, mixed, thermic family of Petrocalcic Paleustalfs.

Gwalior: Fine-loamy, mixed, thermic family of Typic Haplustalfs.

Podua: Fine-loamy, mixed, thermic family of Aquic Natrustalfs.

The Amarillo and Arvana soils were formerly classified in the Reddish Chestnut Great Soil Group. The Amarillo profile was collected in Hockley County, Texas and the Arvana soil profile was collected in Andrews County, Texas. The calcium carbonate accumulation is at about 37 inches in the Amarillo soil profile. In the Arvana soil profile indurated caliche (Petrocalcic horizon) was present at about 26 inches.

The profiles of Gwalior and Podua soils are from Gwalior district, Madhya Pradesh, India. As the series status of these soils has not been determined, the names used here are for identification purposes only.

The results of the inorganic P fractionation are given in Table 9. Profile distribution of these fractions are also plotted in Figures 17 and 18.

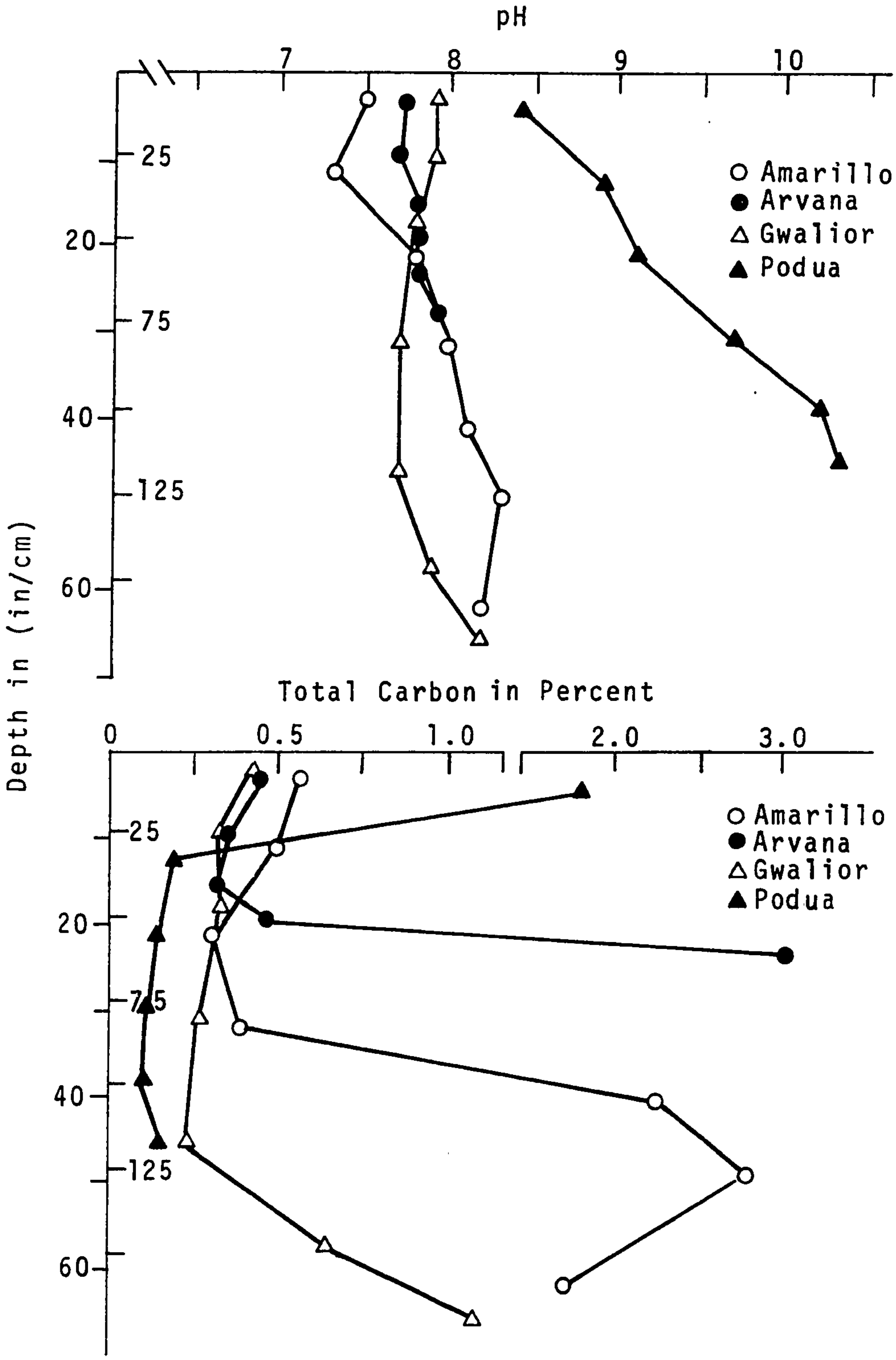
The particle size, pH, and total carbon data of these four soils are given in Appendix III. The pH and total carbon content are plotted in Figures 15 and 16. A brief account of the data is given below.

In the Amarillo soil, sand is the major particle size fraction. The sand content ranges from 57.6 to 71.4 percent. The clay content ranges from 15.1 to 29 percent and it is the next largest fraction. The silt content is lower than the clay content throughout the profile. The clay content increases with depth and the depth of maximum clay zone is from 16 to 43 inches.

The sand content in the profile of Arvana series varies

Figure 15. Distribution of pH in the Amarillo, Arvana, Gwalior and Podua soils (Ustalfs)

Figure 16. Distribution of total carbon in the Amarillo, Arvana, Gwalior and Podua soils (Ustalfs)


pH
7
8
9
10
25
75
125
20
40
60
Amarillo
Arvana
Gwalior
Podua
Depth in (in/cm)
Total Carbon in Percent
0
0.5
1.0
2.0
3.0
25
75
125
20
40
60
Amarillo
Arvana
Gwalior
Podua

from 65.7 to 84.8 percent. The percentage of sand decreases with depth while that of silt and clay increases. The range of the silt and clay content is from 6.8 to 13.9 percent and from 8.4 to 20.4 percent, respectively. The maximum clay occurs in the lower B horizon.

The silt fraction is dominant throughout the profiles of the Gwalior and Podua soils. The sand content varies from 14.4 to 27.5 percent in the Gwalior soil while in the Podua soil it varies from 29.7 to 43 percent. The clay accumulation is in the B2 horizon and in the B3 horizon of Gwalior and Podua soils, respectively. The clay content range is from 21.6 to 36.1 percent in the Gwalior soil and from 18.6 to 28.4 percent in the Podua soil.

The pH values in Gwalior, Amarillo and Arvana soils as shown in Figure 15 are between 7.5 and 8.0. In the Podua soil profile the pH is 8.5 in the surface and increases to 10.3 at 40 inches.

Figure 16 shows the distribution of total carbon in the four Ustalfs. In the Amarillo profile the total carbon increases sharply at the 37 inch depth and the values remain around 2.5 percent in the rest of the B horizon. There is a sharp increase of total carbon due to carbonates in the lower B horizons of the Arvana and Gwalior soils. The total carbon content is high in the plow layer of the Podua profile, but it decreases sharply in the A12 horizon. Below this horizon the values are about constant.

Table 9. Available P and inorganic P fractions in Amarillo, Arvana, Gwalior and Podua soils classified under Ustalf suborder

Horizon	Depth	AP in ppm		IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Olsen	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Amarillo, Eastern Hockley County, Texas												
A1	1-7	7	3	13	74	32	45	164	8	45	20	27
B21t	7-16	4	2	7	54	28	42	131	5	41	21	32
B22t	16-27	4	1	7	69	25	34	135	5	51	19	25
B23t	27-37	4	2	6	63	30	54	153	4	41	20	35
B24tCa	37-45	4	4	6	34	30	69	138	4	25	22	49
B25tCa	34-54	2	2	6	34	25	59	124	5	28	20	47
B26tCa	54-70	3	1	8	38	27	50	124	6	31	23	40
B27tCa	70-100	5	2	6	22	25	54	107	6	21	23	50
B28tCa	100-112	4	1	2	27	23	59	111	2	24	21	53
Arvana, Andrews County, Texas												
A1	1-7	7	2	10	57	34	30	131	8	43	26	23
B2t	7-12	6	1	5	53	25	34	117	4	46	21	29
B2t	12-18	7	1	5	53	28	54	140	4	38	20	38
B3t	18-21	7	2	9	70	28	59	166	6	42	17	35
B3tCa	21-26	5	4	4	34	32	65	135	3	25	24	48
	26+	-	-	8	27	60	68	163	5	16	37	42

Table 9. (Continued)

Hori-zon	Depth	AP in ppm		IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Olsen	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Gwalior (no established series), Gwalior District (M.P.), India												
Ap	0-6	63	25	36	93	150	147	426	8	22	35	35
A12	6-13	11	7	8	79	95	107	289	3	27	33	27
B1	13-22	3	2	7	72	90	44	213	3	34	42	21
B2	22-40	4	1	11	85	130	75	301	4	28	43	25
B31	40-52	3	0	4	70	118	155	347	1	20	34	45
B32	52-62	3	1	2	54	70	367	493	0	11	14	75
CCa	62+	4	1	4	39	75	334	452	1	9	16	74
Podua (local name), Gwalior District (M.P.), India												
Ap	0-11	3	7	10	49	32	160	251	4	19	13	64
A12	11-15	1	0	8	50	30	205	293	3	17	10	70
B2	15-27	3	0	6	57	39	173	275	2	21	14	63
B31	27-34	12	0	7	53	55	142	257	3	21	21	55
B32	34-42	16	5	10	75	48	137	270	4	28	18	50
CCa	42+	24	8	15	79	74	155	323	5	24	23	48

The total inorganic P fraction (Al-P + Fe-P + Red-P + Ca-P) is high in the surface of Amarillo, Arvana and Gwalior soil profiles (Table 9) ranging from 131 to 426 ppm. It decreases to a minimum in the lower A or upper B horizons, then increases with depth. The highest content of the sum of the inorganic P forms is in the lower B horizons of the Arvana and Gwalior soils but in the case of Amarillo it is in the B23t horizon. Below the B23t horizon the sum of IP fractions decreases with depth. The content of the IP fractions increase with depth in the Podua profile. Considering the profiles as a whole, the relative amount of the sum of the IP forms is in the order of Gwalior > Podua > Arvana > Amarillo.

The relative contents of the different forms of inorganic phosphorus (in percent of the sum of inorganic P fractions) in the Amarillo and Arvana profiles are shown in Figure 17. It is evident that Al-P constitutes a small proportion of the total IP forms. The Fe-P is the dominant form in the A and upper B2 horizons of the two soils. The Ca-P then becomes a major fraction in the BCa horizons. It comprises from 47 to 53 percent below the 37 inch depth in the Amarillo profile. In the Arvana profile the Ca-P varies from 42 to 48 percent below the depth of 21 inches. The relative proportion of Red-P is about 20 percent throughout the profile of Amarillo soil. The Red-P is quite uniform in the Arvana profile comprising about 20 percent of the total inorganic P forms.

The relative proportions of each of the four IP fractions

Figure 17. Cumulative plots of the percentage inorganic P fractions for the Amarillo and Arvana soils (Ustalfs)

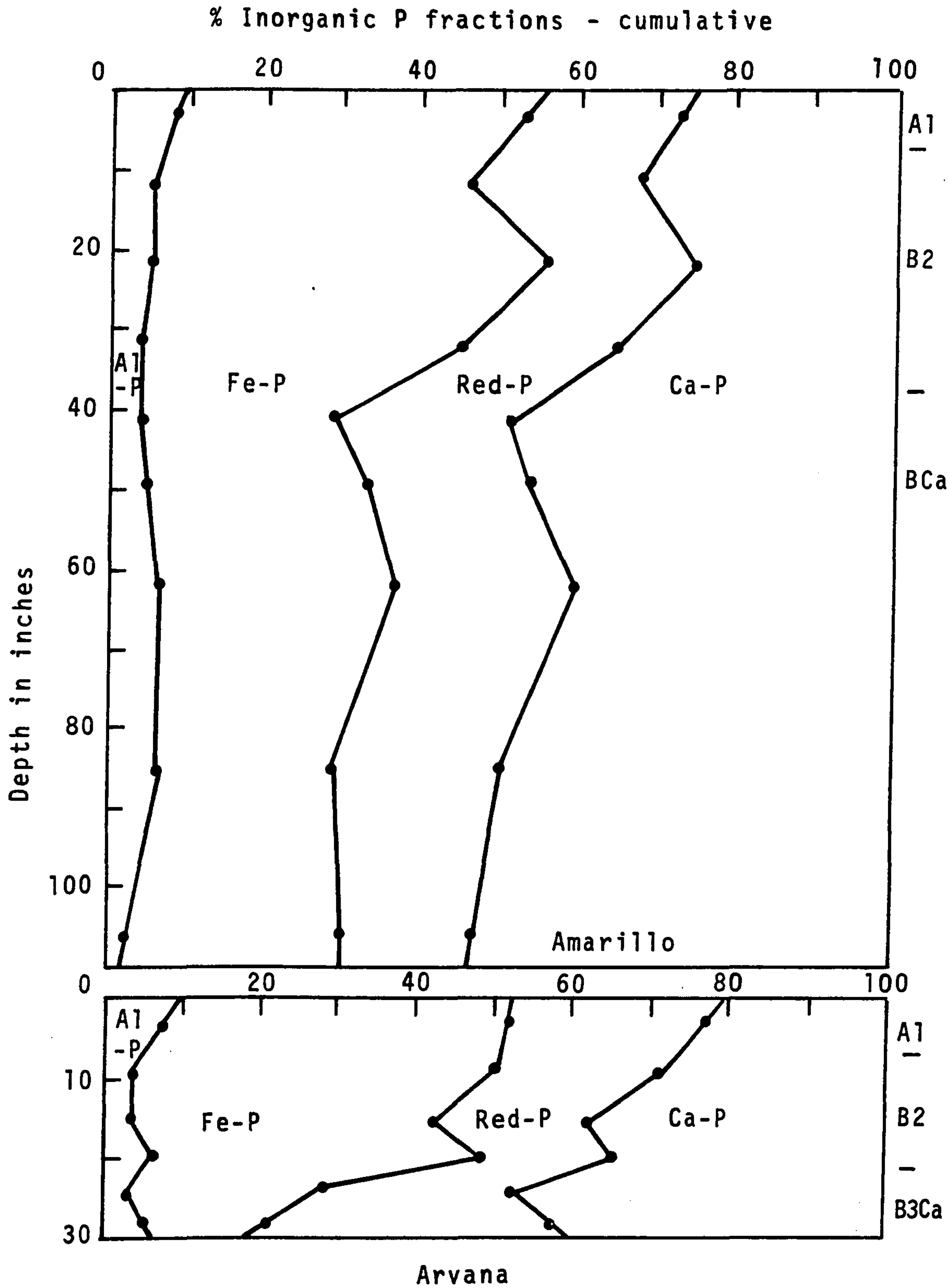
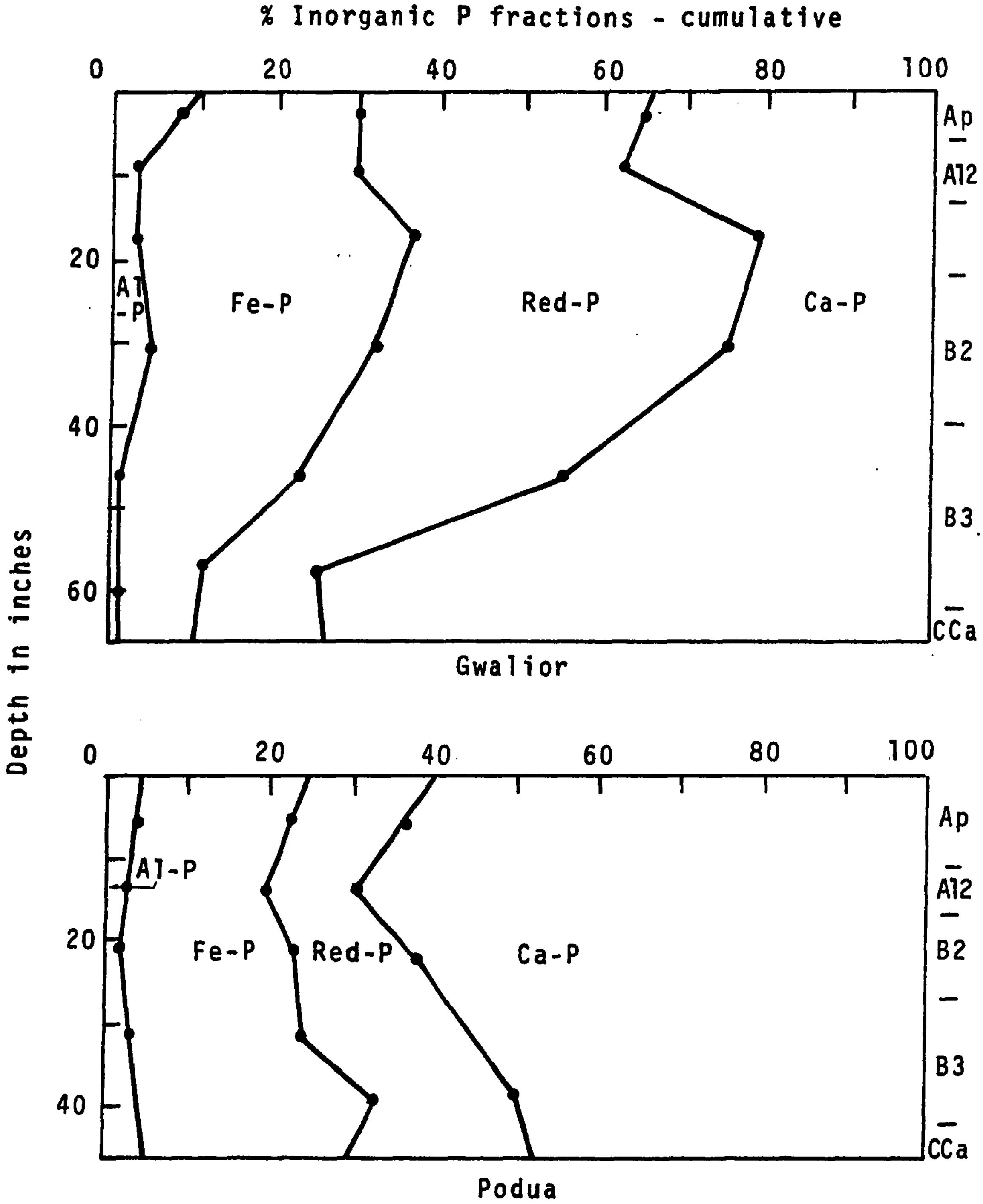

% Inorganic P fractions - cumulative
0
20
40
60
80
100
Depth in inches
A1
-P
Fe-P
Red-P
Ca-P
A1
B2
BCa
Amarillo
10
30
A1
-P
Fe-P
Red-P
Ca-P
A1
B2
B3Ca
Arvana

Figure 18. Cumulative plots of the percentage inorganic P fractions for the Gwalior and Podua soils (Ustalfs)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
Depth in inches
Ap
A12
B2
B3
CCa
Al-P
Fe-P
Red-P
Ca-P
Gwalior
Podua

in the Gwalior profile show a considerable variation (Figure 18). In the A horizon which is in the depth of 0 to 13 inches the Red-P and Ca-P are equal and are the dominant forms, comprising 70 percent of the total inorganic P forms. The Red-P is the dominant form in the 13 to 40 inch zone, the upper B horizon. The Ca-P form is then the major fraction below this depth. The Fe-P form is slightly greater in amount in the lower A and upper B horizon. The Ca-P form is then the major fraction below this depth. The Fe-P form is slightly greater in amount in the lower A and upper B horizons than in the Ap and lower B and C horizons. The Al-P form makes up 8 percent of the sum of the total inorganic P forms in the Ap horizon. Below the depth of 6 inches the percentage Al-P decreases rapidly with depth.

In the Podua soil profile the Ca-P is the dominant form throughout the profile. The Ca-P ranges from 48 to 70 percent, its percentage decreasing slightly with depth. The percentage of Al-P, Fe-P and Red-P shows a slight increase with depth with the maximum value in the C horizon. The Al-P form is a uniformly low proportion, about 3 percent, throughout the solum.

<u>Amarillo</u> The Al-P is highest, 13 ppm, in the surface layer. Below this layer the values range from 6 to 8 ppm. The highest content of Fe-P (74 ppm) and Red-P (32 ppm) is also in the uppermost layer. The values of Fe-P decrease below the 37 inch depth, where the values range from 22 to 38

ppm. The Red-P content is nearly constant (from 23 to 30 ppm) below the surface layer. The content of Ca-P ranges from 34 to 69 ppm. The lowest values of Ca-P (from 34 to 45 ppm) are in the upper B horizon which occurs in the zone of 7 to 27 inches. The Ca-P shows little variation within the zone of 37 to 112 inches.

Arvana The Al-P and Fe-P range from 4 to 10 ppm and from 27 to 70 ppm, respectively. There is a slight accumulation of the Al-P and Fe-P in the zone of B3 horizon which is at the 18 to 21 inch depth. In the lower B horizon the Fe-P content is low (27 to 34 ppm). The content of Red-P ranges from 25 to 60 ppm, and is highest in the petrocalcic horizon beginning at 21 inches. The variation in values of Red-P within the solum is small, that is, from 25 to 34 ppm. The Ca-P form is low in the one foot depth in the B and C horizons. The values of Ca-P range from 30 to 68 ppm. The highest value is in the petrocalcic horizon.

Gwalior The highest values of Al-P, Fe-P and Red-P are in the surface (Ap) layer. The amount of these fractions decreases sharply in the next lower horizon. There is a slight accumulation of the Al-P and Fe-P fractions in the horizon of maximum clay at the 22 to 40 inch depth (Appendix III), and there is a distinct accumulation of Red-P in this zone. The minimum values of the Al-P, Fe-P and Red-P forms are in the C horizon. There is 147 ppm of the Ca-P form in the surface layer. It decreases to 44 ppm in the B1 horizon and then increases with depth to a maximum value of 367 ppm in the lower B horizon. The content of Ca-P in the various horizons ranges from 44 to 367 ppm.

Podua The Al-P is a small fraction ranging from 6 ppm in the B2 horizon to 15 ppm in the CCa horizon. The values of Al-P are quite constant in the middle part of the profile. The Fe-P content increases with depth from 49 to 79 ppm from the surface down to the C horizon. The depth distribution pattern of Red-P is similar to that of the Fe-P fraction. Generally, the values increase with depth. The Red-P ranges from 30 to 74 ppm. The Ca-P form generally decreases with depth and its values range from 137 to 205 ppm. Thus, the Ca-P is a major form extracted in all the horizons of the Podua soil profile.

Ustolls

Two profiles of the Pullman series were studied. The Pullman series is classified as follows:

Pullman: Fine, mixed, thermic family of Torrertic Paleustolls.

The Pullman soils were formerly classified as Reddish Chestnut soils. The profiles are from Curry County, New Mexico. The layer of calcium carbonate accumulation begins at 32 inches in profile No. 1.

The data on the inorganic phosphorus fractions are given in Table 10 and in Figure 21.

The particle size, pH and total carbon data are given in

Appendix III. The sand, silt and clay are about in equal proportions in both the profiles. The clay content in profile no. 1 ranges from 25.6 to 35.6 percent, and in profile no. 2 it ranges from 20.7 to 36.2 percent. There is an increase in clay content immediately below the plow layer. The highest clay content in profile no. 2 is in the C horizon.

The pH range of the Pullman soils studied is from 6.8 to 8.1. In profile no. 1 the pH decreases slightly below the surface layer and then it increases (Figure 19). In profile no. 2, the pH increases with depth. The distribution of total carbon in the two profiles is shown in Figure 20. The content of total carbon is lower in the profile no. 2 than in the profile no. 1. However, there is a sharp increase of total carbon in the calcareous C horizon of the Pullman-2.

The data for inorganic P fractions in the two Pullman soils is presented in Table 10 and Figure 21. The two profiles of this soil vary with respect to P forms. The sum of the four fractions is higher in profile no. 1 than in profile no. 2. In both profiles the total IP fraction is high in the surface, decreases to a minimum in the next lower layer and then increases with depth to a maximum value in the C horizon. The range is from 229 to 385 ppm in the profile no. 2 and from 166 to 240 ppm in the profile no. 1.

The Fe-P form is the major fraction in the Ap and B2 horizons of both Pullman soil profiles in which it comprises 37 to 47 percent of the sum of the P fractions (Figure 21).

Figure 19. Distribution of pH in the two Pullman soils Ustolls)

Figure 20. Distribution of total carbon in the two Pullman soils (Ustolls)

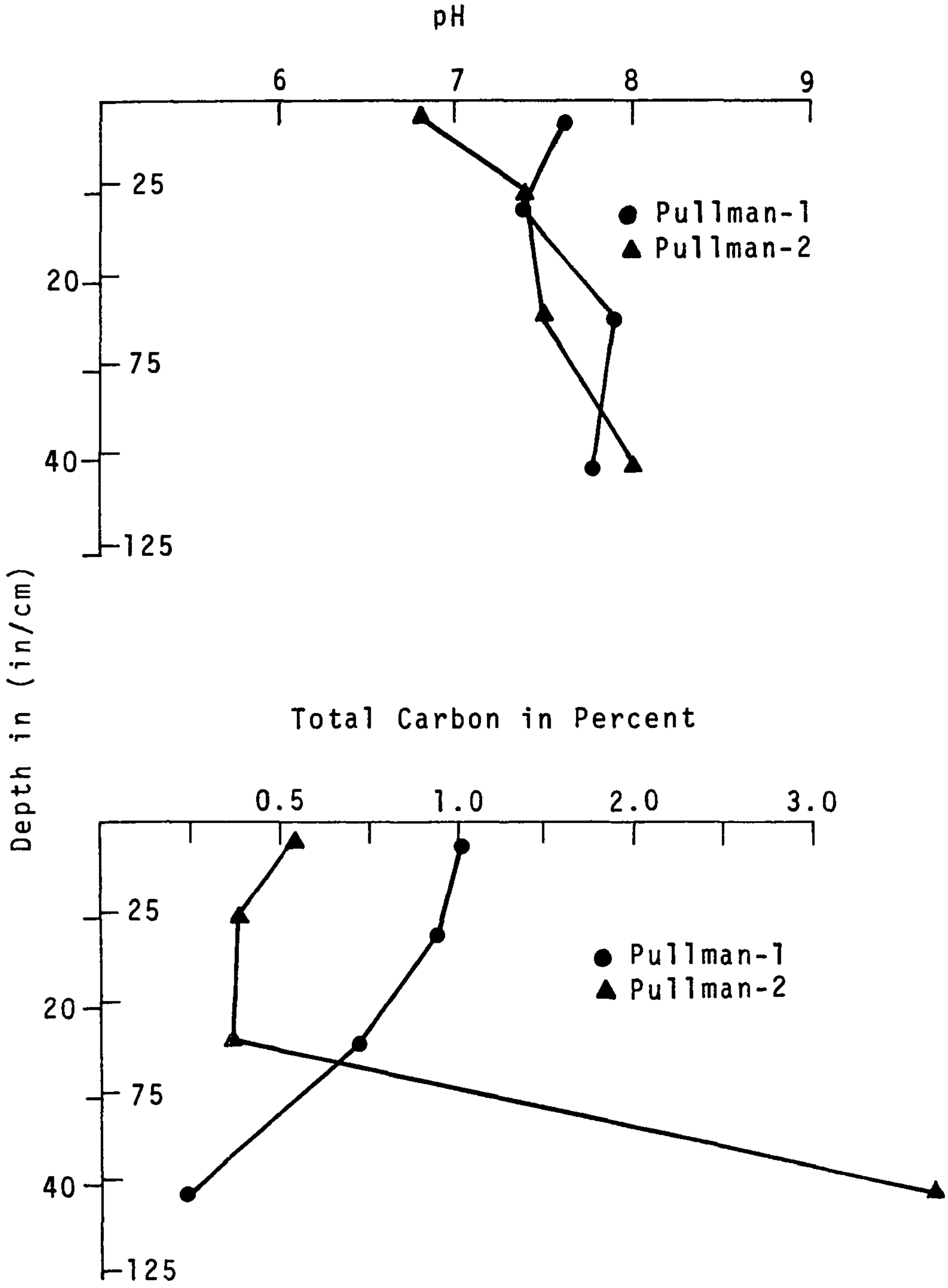
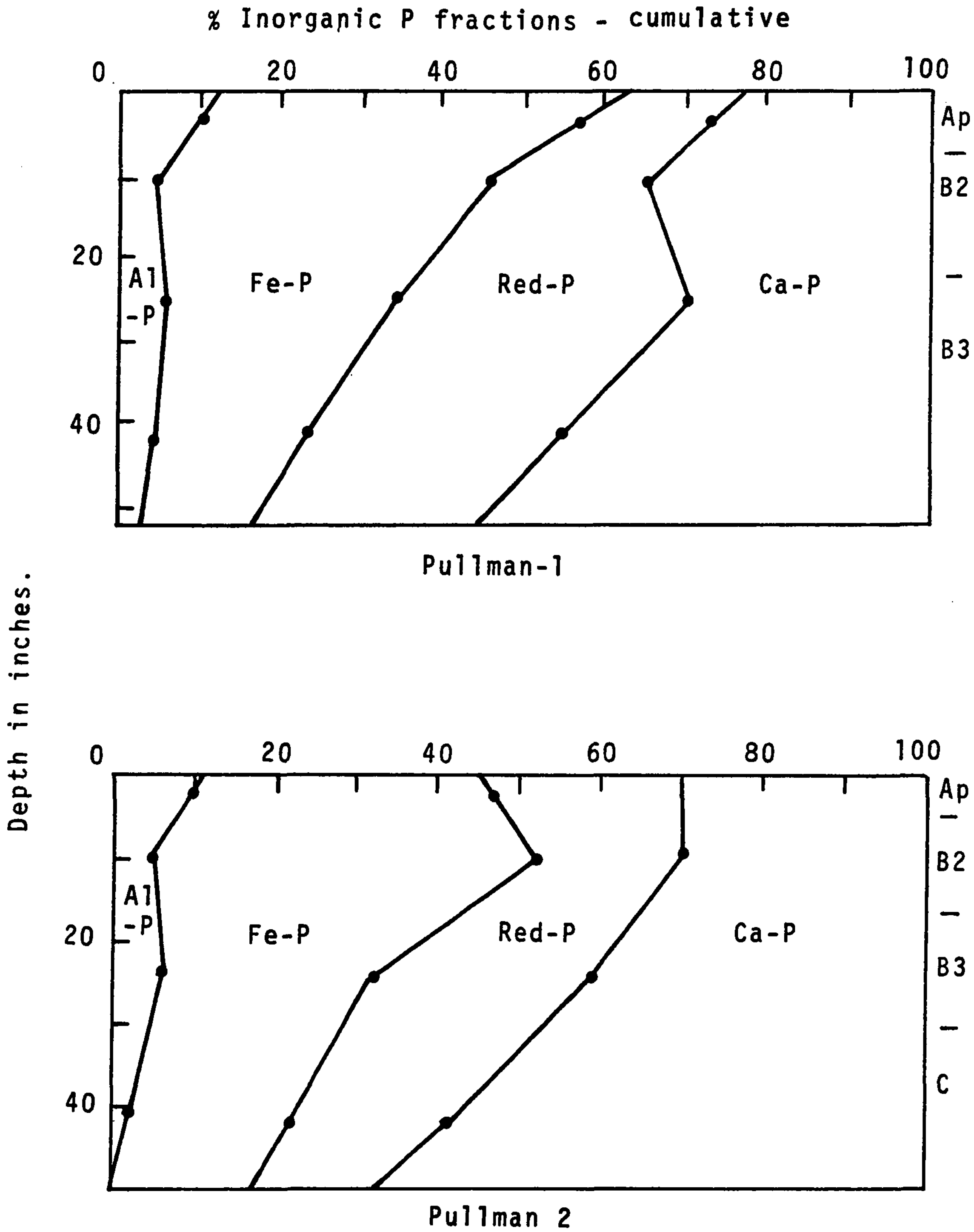

pH
6
7
8
9
25
20
75
40
125
● Pullman-1
▲ Pullman-2
Depth in (in/cm)
Total Carbon in Percent
0.5
1.0
2.0
3.0
25
20
75
40
125
● Pullman-1
▲ Pullman-2

Table 10. Available P and inorganic P fractions in Pullman soils classified under Ustoll suborder

Hori-zon	Depth	AP in ppm		IP fractions in ppm					Percentage of sum of IP fractions			
		Bray 1	Olsen	Al-P	Fe-P	Red-P	Ca-P	Sum	Al-P	Fe-P	Red-P	Ca-P
Pullman, Profile no. 1, Curry County, New Mexico												
Ap	0-6	48	27	33	158	53	89	333	10	47	16	27
B2	6-19	11	5	13	93	43	80	229	5	41	19	35
B31	19-30	16	4	21	106	130	107	364	6	29	36	29
B32	30-52	37	14	16	77	118	174	385	4	20	31	45
Pullman, Profile no. 2, Curry County, New Mexico												
Ap	0-4	30	15	18	67	42	53	180	10	37	23	30
B22	4-16	11	6	8	78	30	50	166	5	47	18	30
B31	16-32	7	2	12	53	54	84	203	6	26	27	41
C1	32-50	4	17	4	45	49	142	240	2	19	20	59

Figure 21. Cumulative plots of the percentage inorganic P fractions for the two Pullman soils (Ustolls)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
Ap
B2
B3
20
40
Al
-P
Fe-P
Red-P
Ca-P
Pullman-1
Depth in inches.
0
20
40
60
80
100
Ap
B2
B3
C
20
40
Al
-P
Fe-P
Red-P
Ca-P
Pullman 2

The Ca-P is the next largest fraction in these horizons. This form of phosphorus dominates in the lower B and C horizons in both of the profiles. The range of Ca-P is from 27 to 45 percent in profile no. 1, and from 30 to 59 percent in profile no. 2. The proportion of Red-P is larger in the lower B horizon of the profile-1 than in the upper part of the profile. The Red-P makes up 18 to 27 percent of the sum of the P fractions in the profile-2. The percentage of Red-P is highest in the B31 horizons of both profiles. The Al-P comprises a small proportion of the inorganic P fractions and its percentage decreases with depth in the Pullman soil profiles. The proportion of Al-P is the same in each horizon of the two profiles. A more detailed account of the distribution of the inorganic P forms in individual profiles is given below.

Pullman-1 The Al-P and Fe-P are distributed with depth in the same pattern. The highest content of these forms is present in the surface layer, then decrease in the next lower layer (B2 horizon). The contents of these forms increase in the B31 horizon, and again decrease in the B32 horizon. The values of Al-P range from 13 to 33 ppm and of Fe-P from 77 to 158 ppm. The Red-P value is 53 ppm in the Ap horizon, decreases slightly in the B2 horizon and then increases sharply in the lower B horizons. The Ca-P form has the same pattern of distribution with depth as the Red-P. The Ca-P content ranges from 80 to 174 ppm. It is highest in the B32 horizon and the lowest content is in the B2 horizon.

Pullman-2 The distribution of Al-P and Red-P in this profile is the same as in Pullman profile no. 1. From the surface there is a decrease in the next lower horizon, with an increase in the lower B and C horizons. The values for Al-P range from 4 to 18 ppm and the Red-P from 30 to 54 ppm. The Fe-P is low in the Ap horizon, increases in the B2 horizon, and then decreases with depth. The content of Fe-P ranges from 45 to 78 ppm. The amounts of Ca-P are about constant in the zone of 0 to 16 inches with values of about 50 ppm. The Ca-P fraction increases sharply in the B3 horizon and the highest content (142 ppm) is in the C horizon.

Udalfs and a Udoll in a biosequence

To study the influence of natural vegetation on the content of inorganic P, three profiles of a well-drained biosequence from Cary till were collected in Boone County, Iowa. These profiles are of the Hayden, Lester and Clarion soil series. The Hayden soil formed under forest and the Clarion under prairie. The Lester is considered to have formed partly under prairie and partly under forest. On this soil, presumably, forest encroached on the prairie, and soils of such a natural vegetative history are sometimes referred to as "transition" soils.

The data of the inorganic P fractions of these Hayden and Lester profiles are given in Table 7, and have been discussed previously. The data on this Clarion profile are presented in Table 8 and have been discussed previously. In Figure 22 the distribution of the IP forms in these profiles is also plotted, expressed cumulatively in percentages of the sum of the IP fractions.

In general, the relative abundance of the various IP forms is as follows:

Al-P: Hayden > Lester > Clarion

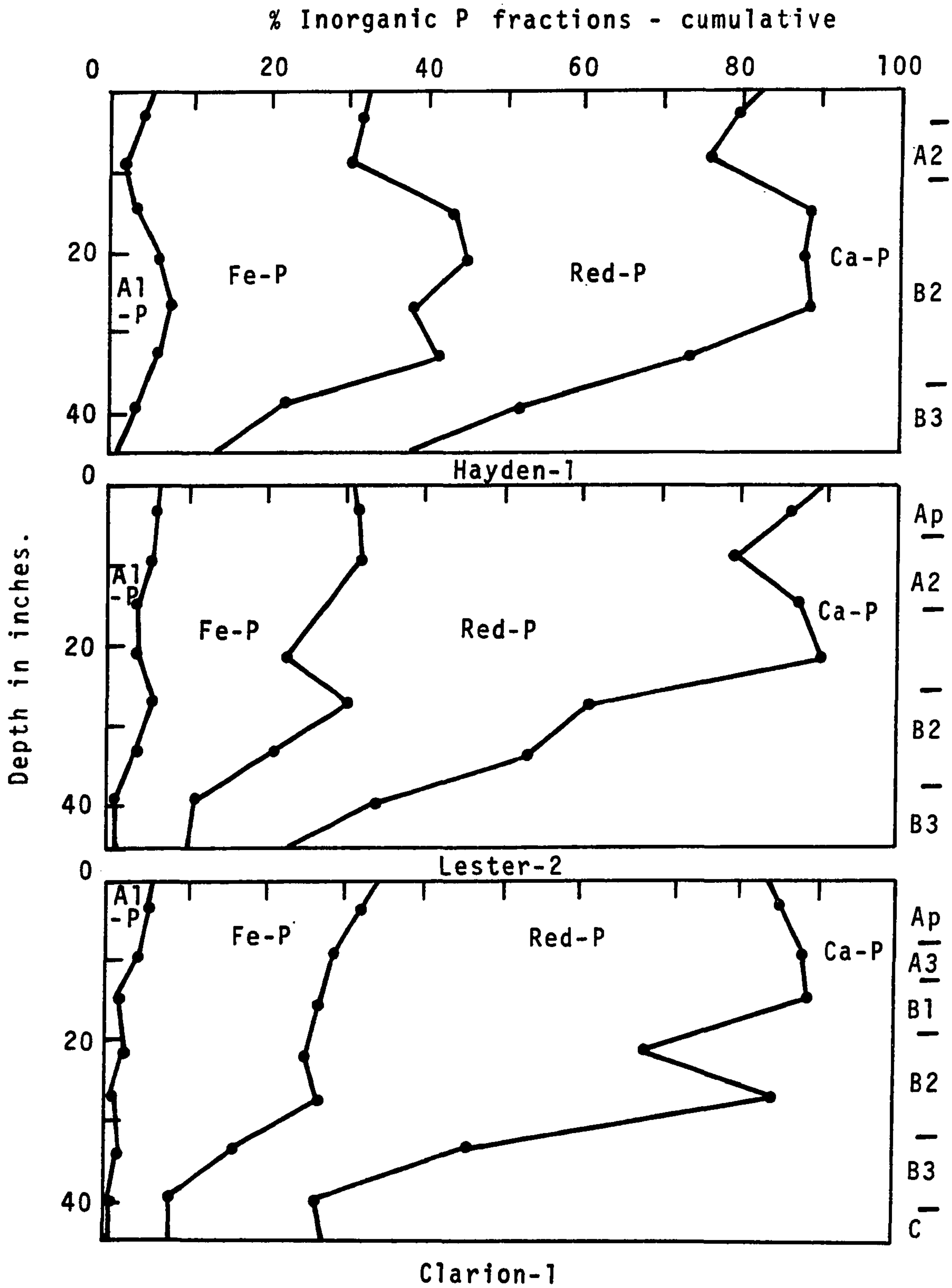
Fe-P: Hayden > Lester > Clarion

Red-P: Clarion > Lester > Hayden

Ca-P: Lester > Clarion > Hayden

The accumulation of Al-P, Fe-P and Red-P is evident in the B horizon of the forest formed Hayden profile. The accumulation of these P fractions is less pronounced in the transition Lester soil. In the prairie Clarion soil profile there is no apparent accumulation of the Al-P, Fe-P and Red-P in the B horizon. The percentages of Al-P and Fe-P are high in the surface layer, decrease in the lower A horizon in the Hayden and in the upper B horizon in the Lester soil. In the Clarion soil, Al-P decreases gradually with depth to the lower B horizon. In the Hayden and Lester soils, the Red-P follows the same trend as those of Al-P and Fe-P but in the Clarion soil the distribution of Red-P is more or less erratic. The highest proportion of Al-P, Fe-P and Red-P is in the zone of 18 to 30 inches of the Hayden profile. The difference due to vegetation is also well expressed in the distribution of the

Figure 22. Cumulative plots of the percentage inorganic P fractions for the Hayden, Lester and Clarion soils (Udalfs and a Udoll in a biosequence)


% Inorganic P fractions - cumulative
0
20
40
60
80
100
Depth in inches.
Al -P
Fe-P
Red-P
Ca-P
A2
B2
B3
Hayden-1
Ap
Lester-2
A3
B1
C
Clarion-1

Ca-P. The abrupt increase of Ca-P occurs at the 36 to 42 inch depth in the Hayden profile while in the Clarion profile it occurs in the zone of 30 to 36 inches.

Available Phosphorus

The available phosphorus (AP) was determined in all the soil samples on which inorganic P fraction data were obtained. The AP was determined in these soil samples by the Bray-1 method. In addition ten of these soil profiles were also analyzed for AP content by the Olsen method to compare the results of AP obtained by the Bray-1 method with those obtained by the Olsen method.

The AP by the Bray-1 method was determined also in a number of Alfisols and Mollisols on which no inorganic P fractionations were made. Thus the various studies on AP are as follows: (1) available phosphorus in Udalfs and Udolls in a Cary till biosequence (a traverse study); (2) available phosphorus in Alfisols and Mollisols in Cary till biosequences; and (3) available phosphorus in Alfisols and Mollisols in loess biosequences and (4) available phosphorus in Udalfs and Udolls sampled by mapping units in Adair County.

In this subsection the results of AP are arranged under the suitable headings in subsequent pages.

Comparison of Bray and Olsen extractants

The AP was extracted by Bray-1 and Olsen's reagents on ten profiles. These are the Cisne, Grantsburg, Hayden, Weller, Amarillo, Arvana, Gwalior, Podua and Pullman soil profiles. The data are given along with the inorganic P fractions in Tables 5, 7, 9, and 10. A perusal of the data in these tables indicates that the trend of change in values of the AP within each profile extracted by the two methods appears to be the same. In Figures 23 to 26 the AP values by the two methods are plotted for Cisne, Hayden, Amarillo and Podua soils. In general, the values obtained by the Olsen method are lower than those obtained by the Bray-1 method.

In the Cisne profile, the Bray-1 AP ranges from 3 to 25 ppm, and the Olsen AP ranges from 0 to 15 ppm (Figure 23). The values are high in the surface, decrease gradually to a minimum in the B horizon at about 20 inches and then increase in the lower B and C horizons below about 30 inches. The values of AP obtained by the Olsen method are slightly higher than the Bray-1 AP values in the lower B and C horizons of the Grantsburg soil (Table 7). However, in the A and B horizons the amount of AP extracted by both methods is about the same. In the Hayden soil (Figure 24), the differences between the Bray-1 AP and the Olsen AP values range from 3 to 6 ppm, the Bray-1 AP values being higher in the depth of 0 to 36 inches. Below the depth of 36 inches the AP values obtained by both methods are about the same. Throughout the profile of

Figure 23. Distribution of available phosphorus (Bray 1 and Olsen) in the Cisne soil

Figure 24. Distribution of available phosphorus (Bray 1 and Olsen) in the Hayden soil

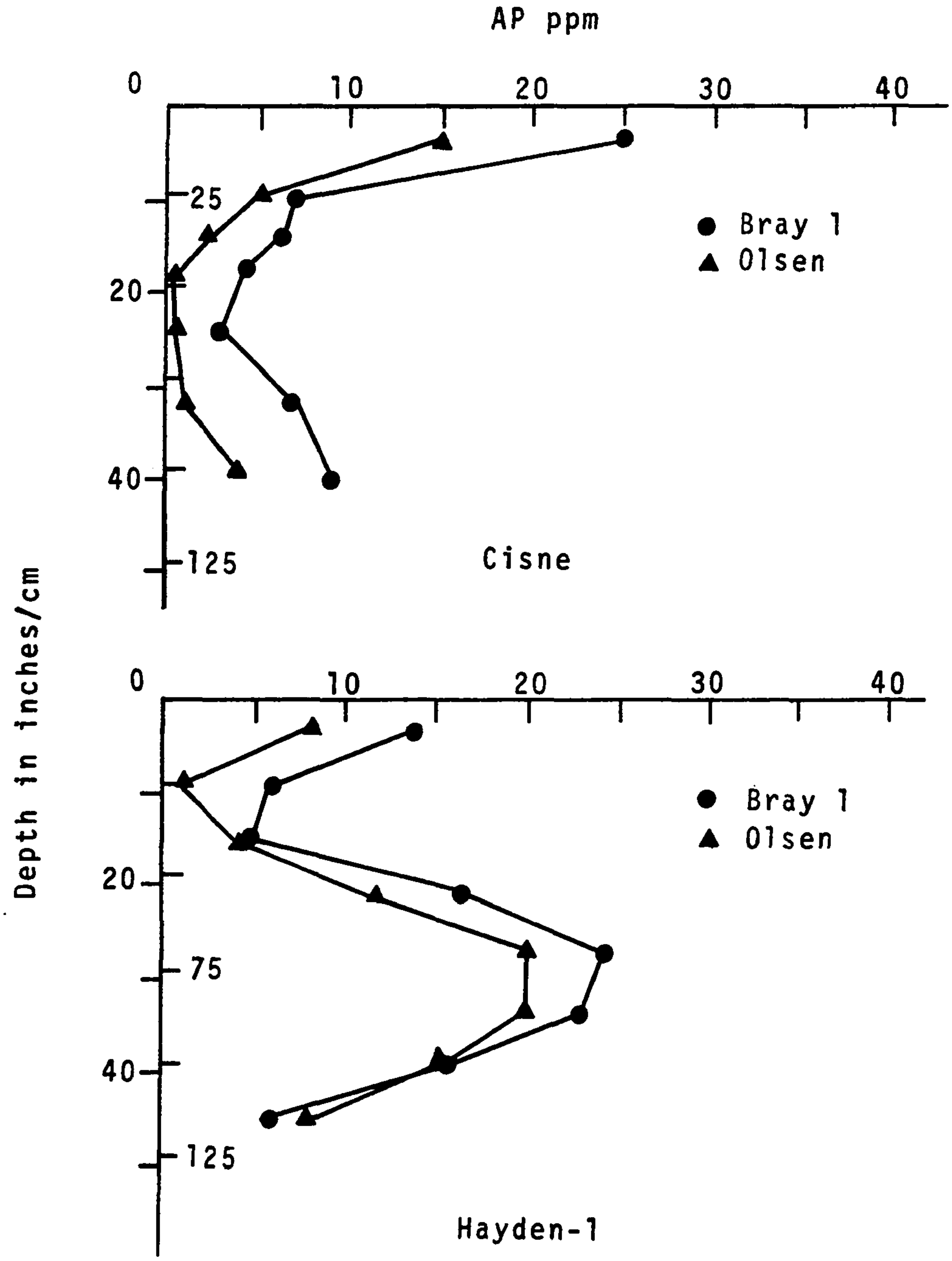
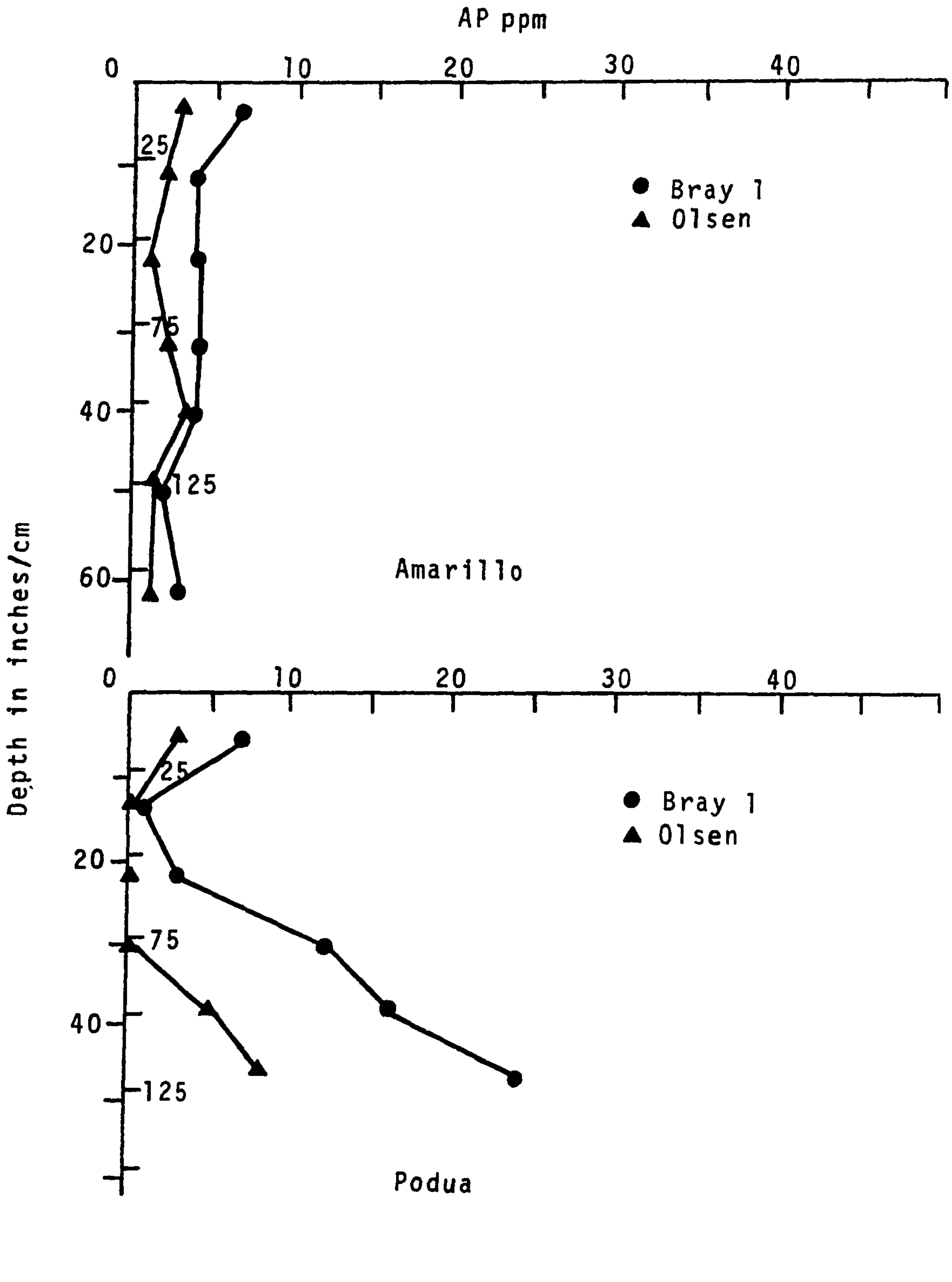

AP ppm
0
10
20
30
40
25
20
40
125
Bray 1
Olsen
Cisne
Depth in inches/cm
0
10
20
30
40
20
75
40
125
Bray 1
Olsen
Hayden-1

Figure 25. Distribution of available phosphorus (Bray 1 and Olsen) in the Amarillo soil

Figure 26. Distribution of available phosphorus (Bray 1 and Olsen) in the Podua soil


AP ppm
0
10
20
30
40
25
75
125
20
40
60
Bray 1
Olsen
Amarillo
Depth in inches/cm
0
10
20
30
40
25
75
125
20
40
Bray 1
Olsen
Podua

the Weller soil, the Olsen AP values are lower by 1 to 19 ppm than by the Bray-1 method (Table 7). The maximum difference is in the lower B horizon.

In the Ustalfs, the Amarillo, Arvana, Gwalior and Podua soils, the Olsen AP values are lower than Bray-1 AP values throughout the soil profiles (Table 9). In the Podua soil the Olsen AP values are quite low in the lower B and C horizons (Figure 26).

The AP contents extracted by both the methods determined on soil samples of the two Pullman profiles differ in the same way as in other soils. The difference in values range from 5 to 23 ppm, the Olsen AP values being lower (Table 10). However, in the C horizon of the Pullman-2 soil the Olsen method extracted more AP than the Bray-1 method.

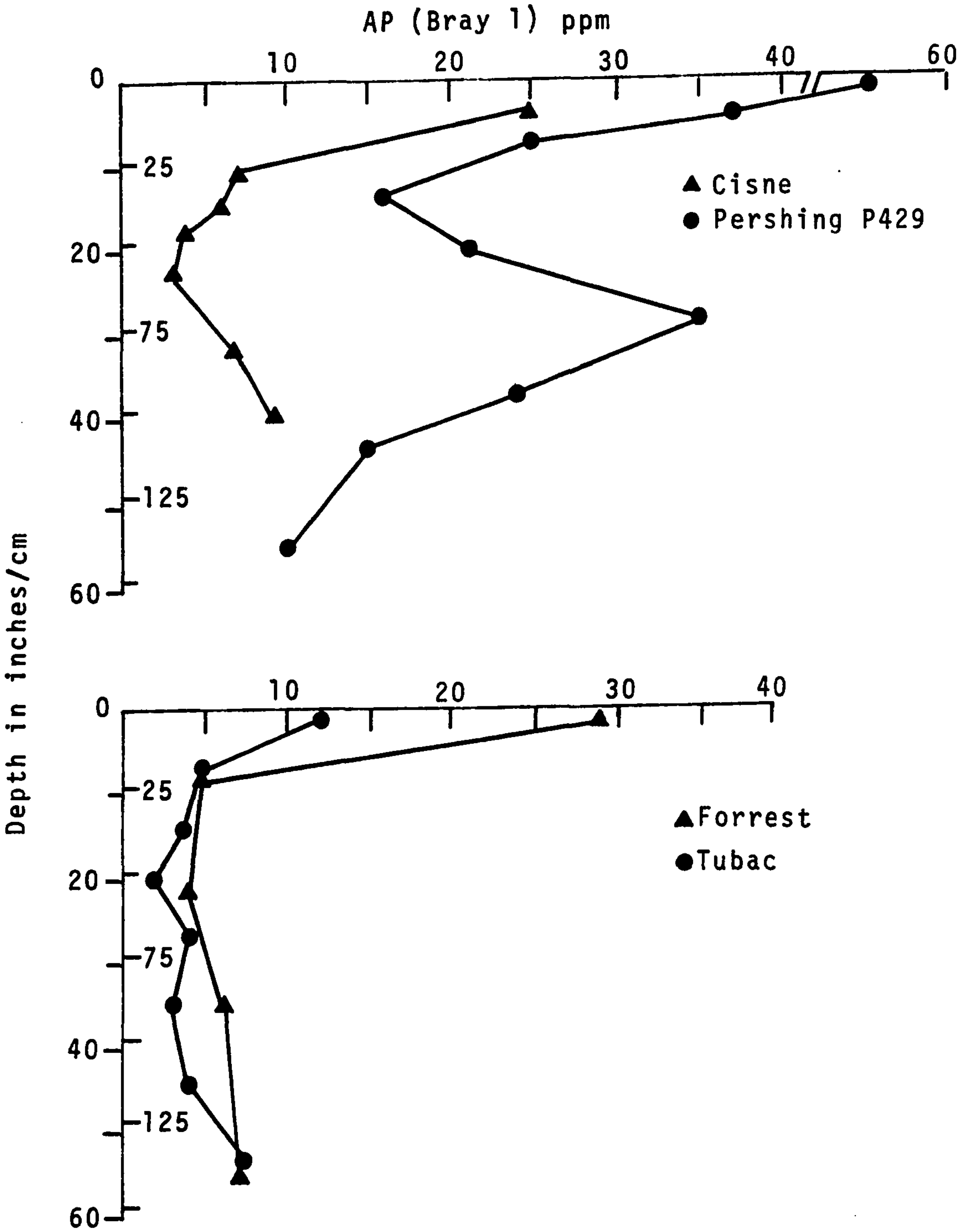
Available phosphorus in soils on which inorganic P fractions are reported

All the soils on which inorganic P fractions are reported in previous subsections were analyzed for available phosphorus (AP) by the Bray-1 method. These AP results are reported here by suborders, and soils within the suborders.

Aqualfs The data on AP of the Cisne and Pershing soils of this suborder are given in Table 5 and the values with depth are shown in Figure 27. The highest content of AP is in the surface layers of the Cisne and Pershing soils. The AP range is from 3 to 25 ppm and from 10 to 51 ppm in the Cisne and Pershing soil profiles, respectively. The AP

Figure 27. Distribution of available phosphorus (AP) in the Cisne and Pershing soils (Aqualfs)

Figure 28. Distribution of available phosphorus (AP) in the Forrest and Tubac soils (Argids)


AP (Bray 1) ppm
0
10
20
30
40
60
25
20
75
40
125
60
Cisne
Pershing P429
Depth in inches/cm
0
10
20
30
40
25
20
75
40
125
60
Forrest
Tubac

decreases below the surface layer to a minimum value in the upper B horizon of the Cisne soil, then the values increase gradually in the lower B and C horizons. In the Pershing soil, AP shows an accumulation at about 30 inches which is also the zone of clay enrichment (Appendix III). Below this depth zone the contents of AP decrease with depth.

The Pershing soil has a larger amount of AP than the Cisne soil.

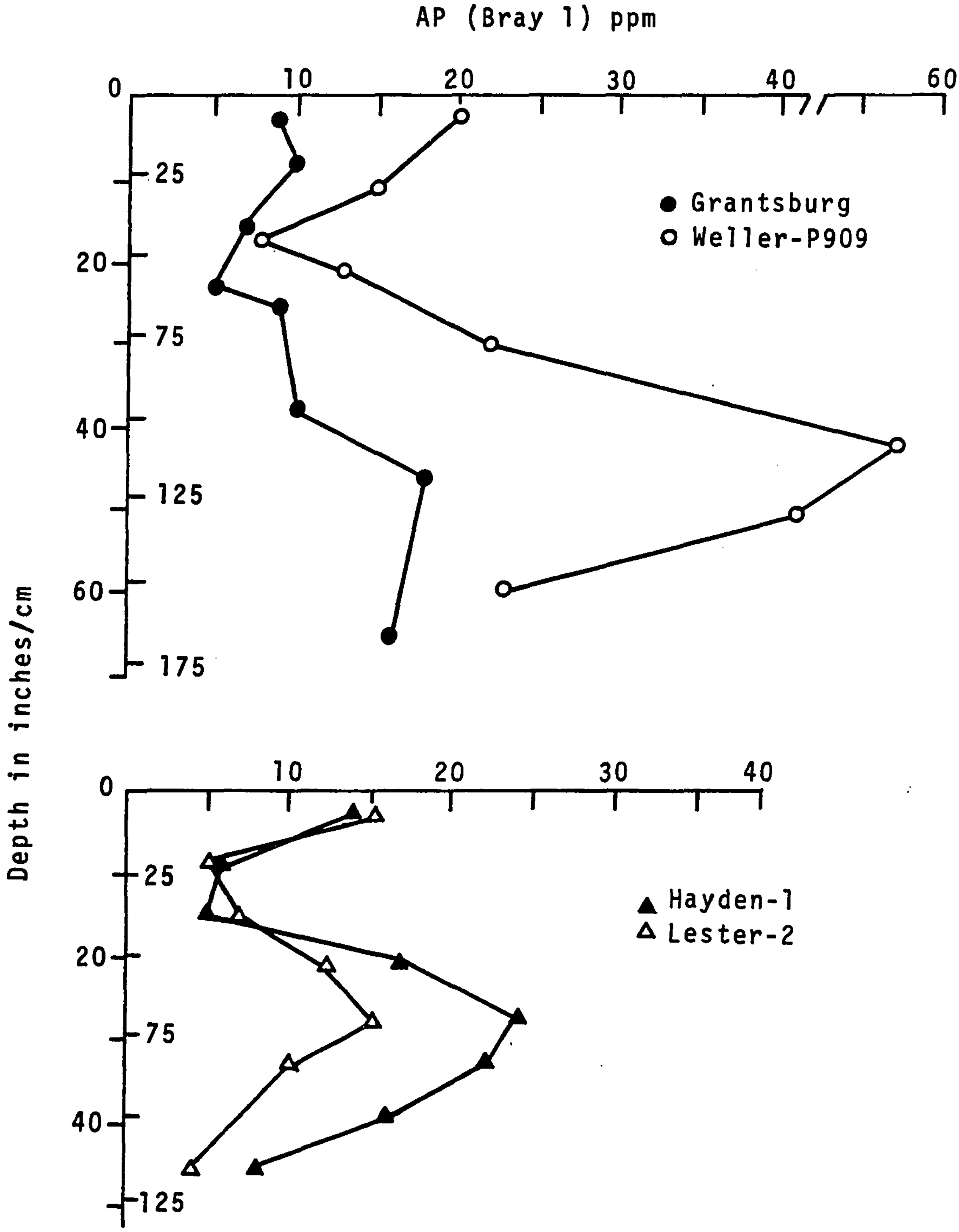
Argids The values of AP in Forrest and Tubac soils are given in Table 6 and the changes with depth in the profiles are shown in Figure 28. The Forrest and Tubac soils are low in AP. There is about the same and constant amount of AP in both the soil profiles except in the surface layer. The AP is highest in the surface layer, it decreases rapidly in the next lower layer and then the values remain constant in the profiles. The AP is slightly lower in the Tubac soil than in the Forrest soil. Its range in the Forrest soil is from 4 to 29 ppm and in the Tubac soil from 2 to 12 ppm. The minimum AP values are in the upper B horizons of the two soils.

Udalfs Four soils are in this suborder, namely Grantsburg, Hayden, Lester and Weller. The AP data for these soils are presented in Table 7, and the AP distribution for these soils is plotted in Figures 29 and 30.

The Grantsburg is low in AP content and the values range from 5 to 18 ppm. The Weller is high in AP content in which the values of AP range from 8 to 55 ppm. The lower B horizons

Figure 29. Distribution of available phosphorus (AP) in the Grantsburg and Weller soils (Udalfs)

Figure 30. Distribution of available phosphorus (AP) in the Hayden and Lester soils (Udalfs)

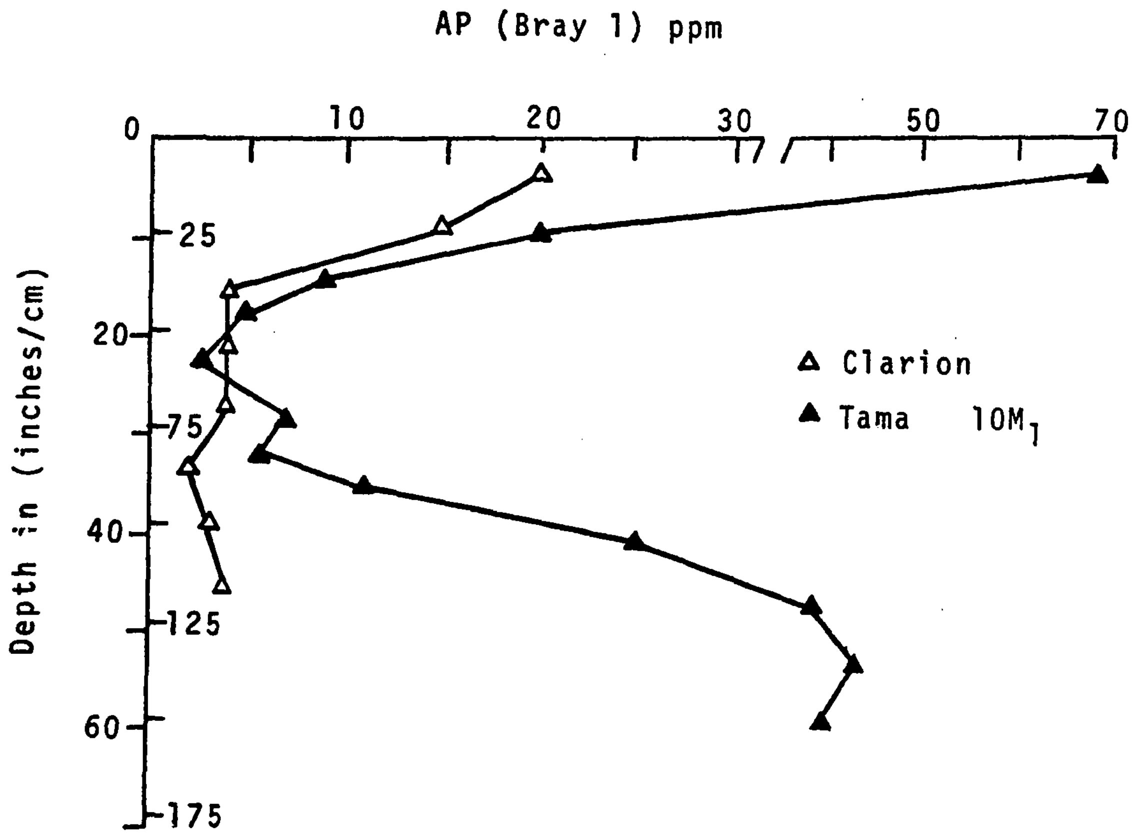

AP (Bray 1) ppm
0
10
20
30
40
60
25
20
75
40
125
60
175
Grantsburg
Weller-P909
Depth in inches/cm
0
10
20
30
40
25
20
75
40
125
Hayden-1
Lester-2

of these soils contain the highest amount of AP. The distribution pattern of AP is the same in the Grantsburg and Weller soils showing an accumulation of AP in the lower B horizons. However, the accumulation of AP is much more pronounced in the Weller soil. The minimum values of AP is in the zone of 21 to 24 inches and 15 to 19 inches of the Grantsburg and Weller soil profiles, respectively.

The AP distribution pattern in the Hayden-1 and Lester-2 soils is the same. However, there is more AP in the middle part of the Hayden profile than in the Lester profile. The surface layers contain high amounts of AP and then the AP contents decrease to minimum values in the lower A horizons (12 to 18 inch depth). The AP increases in the B horizons to the maximum values for the individual profile. The increase is less pronounced in the Lester soil as compared to the Hayden soil profile. Both soils contain about the same amount of AP in the upper 18 inches zone. The range of AP in the Lester soil is from 4 to 15 ppm and in the Hayden soil is from 5 to 25 ppm.

Udolls The Clarion and Tama soils were studied. The AP values are plotted in Figure 31 and the data are given in Table 8. The range of AP in the Clarion and Tama soils is from 2 to 20 ppm and from 3 to 68 ppm, respectively. The highest values are in the surface layers of these soils. The AP decreases in the lower A horizon and then remains about constant in the remainder of the profile of Clarion soil. In

Figure 31. Distribution of available phosphorus (AP) in the Clarion and Tama soils (Udolls)


AP (Bray 1) ppm
0
10
20
30
50
70
25
20
75
40
125
60
175
Depth in (inches/cm)
Δ Clarion
▲ Tama 10M1

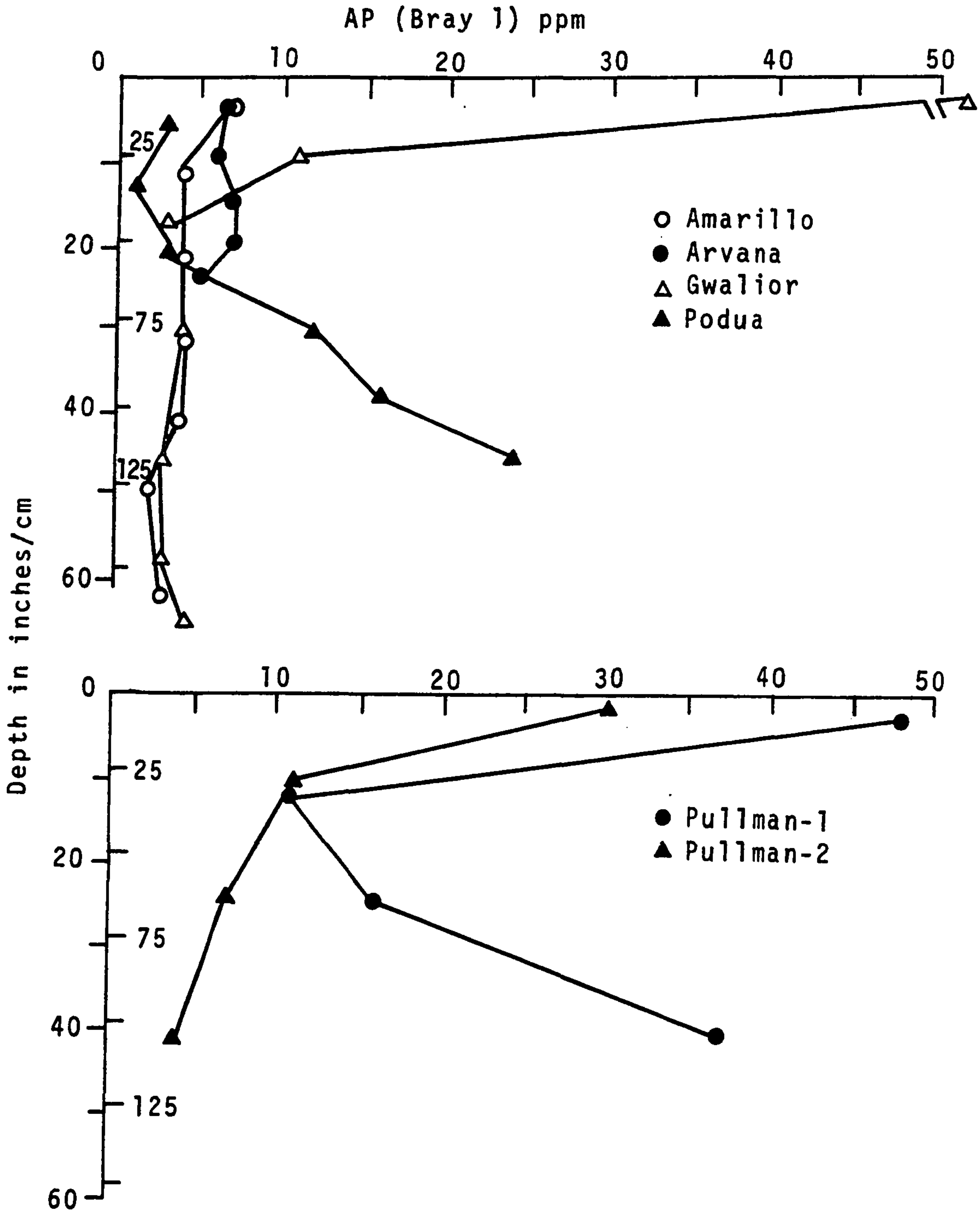
the Tama soil the distribution of AP is different. The AP decreases sharply from the surface to the upper B horizon then increases in the lower B and C horizons. The AP content is much lower (3 to 11 ppm) in the zone of 12 to 38 inches than in the upper and lower layers of the profile.

<u>Ustalfs</u> Available P was determined on the Amarillo, Arvana, Gwalior and Podua soils (Table 9). In the profiles of Amarillo and Gwalior soils the AP content is about the same and constant except in the surface layers (Figure 32). The values of AP in these profiles (excluding A horizon) range from 2 to 5 ppm. The AP is quite high (63 ppm) in the surface layer of the Gwalior soil. The range of AP is from 5 to 7 ppm in the Arvana soil profile. There is a very slight accumulation of AP in the B horizon at about 20 inches of the Arvana soil. In the Podua soil the AP is low in the 0 to 27 inch zone where the range is from 1 to 3 ppm. Below the depth of 27 inches the AP increases rapidly with depth (Figure 32). The lower B and C horizons of the Podua soil contain 12 to 24 ppm of AP.

<u>Ustolls</u> The AP data for the two Pullman profiles are given in Table 9 and are plotted in Figure 33. In the Pullman-1 profile the AP is high in the surface, it decreases to a minimum value in the upper B horizon in the 6 to 19 inch zone then increases rapidly with depth. The AP values range from 11 to 48 ppm and from 4 to 30 ppm in the profile no. 1 and no. 2, respectively. The AP is high in the surface layer of

Figure 32. Distribution of available phosphorus (AP) in the Amarillo, Arvana, Gwalior and Podua soils (Ustalfs)

Figure 33. Distribution of available phosphorus (AP) in the two Pullman soils (Ustolls)


AP (Bray 1) ppm
0
10
20
30
40
50
25
20
75
40
125
60
Amarillo
Arvana
Gwalior
Podua
Depth in inches/cm
0
10
20
30
40
50
25
20
75
40
125
60
Pullman-1
Pullman-2

Pullman-2, decreases sharply in the next lower layer, then the decrease is gradual with depth. The minimum value of AP is in the C horizon of Pullman-2.

Available phosphorus in Udalfs and Udolls in a Cary till biosequence

The details of this traverse study along with location of sites (Figure 1) are given in a previous section. The purpose of this study was to evaluate the influence of natural vegetation on AP in the soil profile. Two profiles of each of the Hayden, Lester and Clarion soil series were analyzed for AP. In addition, particle size, pH and total carbon were determined. The data are given in Appendix IV.

The distribution of AP in Hayden-1, Lester-2 and Clarion-1 profiles is plotted in Figures 30 and 31. In Figure 34, the AP values for the other Hayden, Lester and Clarion profiles are plotted. The AP is high in the surface of Hayden and Lester soils, decreases to a minimum value in the 12 to 18 inch zone, increases to its maximum value in the B horizon and then decreases in the C horizon. The surface layers of Clarion contain the highest amount of AP, and the values tend to be higher than in surface layers of the Hayden and Lester soils. In the Clarion profiles, the AP then decreases to the upper B horizon and it remains more or less constant throughout the solum of the Clarion soil.

The range of AP in the Hayden, Lester and Clarion soils is from 2 to 25 ppm, 1 to 15 ppm and 2 to 20 ppm, respectively.

The order of maximum to minimum amount of AP in the B horizons of the six profiles analyzed is as follows: Hayden-1 > Hayden-2 > Lester-2 > Lester-1 > Clarion-2 > Clarion-1. The order of maximum to minimum amount of AP in the A horizon is as follows: Clarion-1 > Hayden-2 > Lester-2 > Hayden-1 > Clarion-2 > Lester-1.

The effect of natural vegetation is expressed more clearly in the AP content of the B horizon. The order of increasing content of AP is prairie < transition < forest.

The results of the several other properties of the Clarion, Lester, and Hayden soils studied are discussed briefly below.

Particle size distribution The sand fraction is the dominant size fraction in all the site samples. The sand and fine silt fractions are variable, ranging from 24.4 to 64.2 and 7.9 to 29.8 percent, respectively. The coarse silt and clay fractions are relatively less variable ranging from 10.5 to 26.5 and from 11.9 to 28.8 percent, respectively. The clay distribution within the profiles generally increases with depth down to the B horizon, then decreases within the C horizon. This trend is less pronounced in the two Clarion profiles comprising sites 6 and 7. Thus the zone of clay enrichment is distinct in the Hayden and Lester soils. The data for clay content are summarized in Table 11.

A perusal of Table 11 indicates the following trends. The order of decreasing maximum clay in the B horizon and B/A clay ratio is forest > transition > prairie. This order

Figure 34. Distribution of available phosphorus (AP in the Hayden, Lester and Clarion soils (Udalfs and a Udoll in a biosequence)

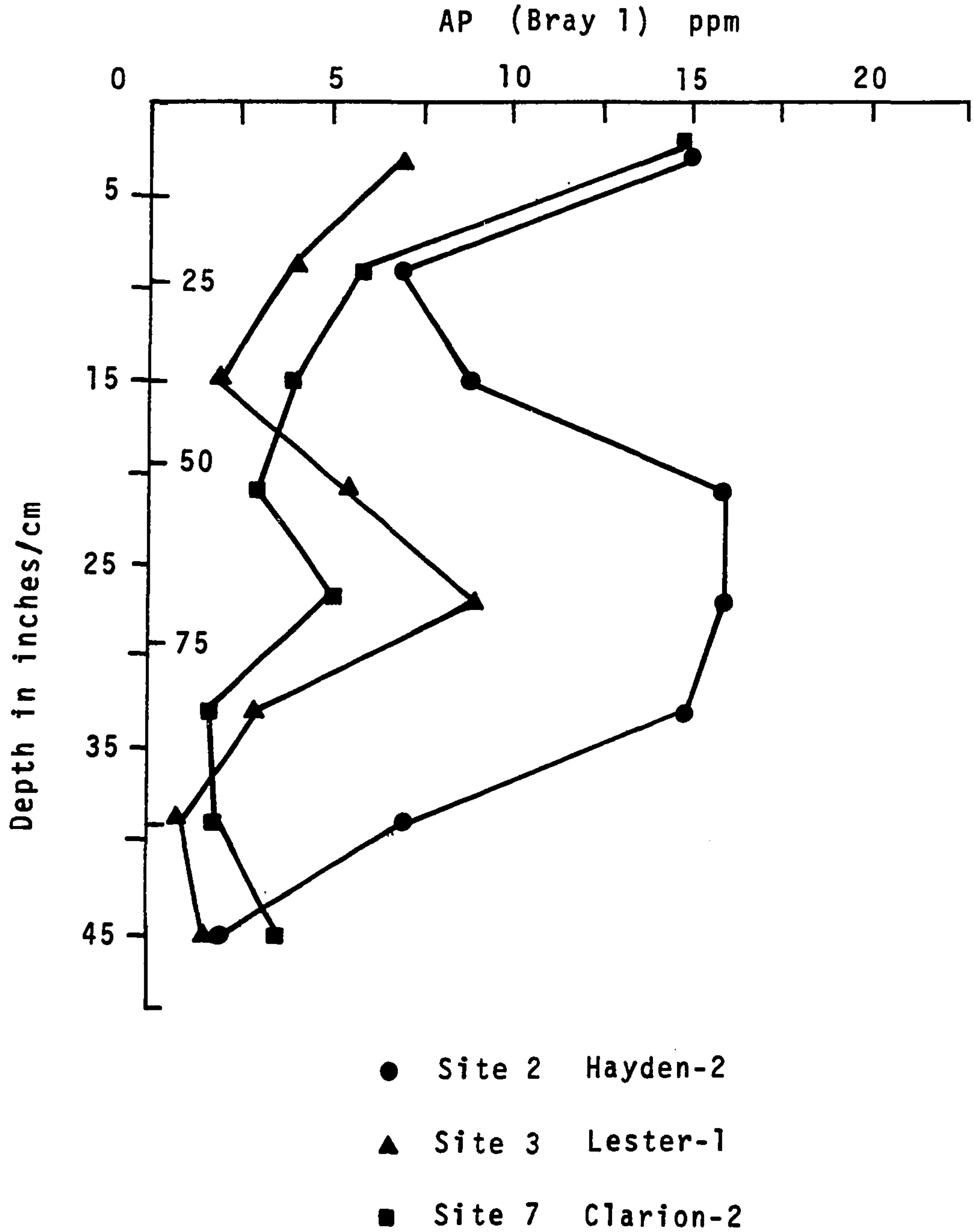

AP (Bray 1) ppm
0
5
10
15
20
Depth in inches/cm
5
25
15
50
25
75
35
45
Site 2 Hayden-2
Site 3 Lester-1
Site 7 Clarion-2

Table 11. Clay minimum and clay maximum, B/A clay ratio, depth of clay maximum and depth to 1% total carbon

Natural vegetation	Site no.	Series	% clay		Max. B / Min. A clay ratio	Depth (in.) to	
			Min. in A horizon	Max. in B horizon		Clay max.	1% TC carbon
Forest	1	Hayden-1	15.3	28.0	1.83	21	6
	2	Hayden-2	11.9	28.8	2.42	27	6
Transition	3	Lester-1	15.0	27.7	1.84	27	7
	5	Lester-2	14.3	26.4	1.84	21	7
Prairie	6	Clarion-1	22.3	23.0	1.03	21	14
	7	Clarion-2	22.2	24.7	1.11	21	16

corresponds to the decreasing order of AP in the B horizons of forest-transition and prairie soils.

<u>pH</u> The pH was determined by the 1:1, soil-water, and by 1:2, soil-$CaCl_2$ methods. The pH ranges from 5.1 to 7.9 (H_2O) and 4.3 to 7.4 ($CaCl_2$). The pH ($CaCl_2$) is lower for all soil samples than the corresponding pH (H_2O) and the differences range from 0.1 to 1.4 pH units. Only the pH (H_2O) will be discussed. The Hayden-1 in general has the lowest pH values. It is around 5.3 throughout most of the profile, except for the lower B horizon where the pH increases a little. The Hayden and Lester soils as a group have lower pH values in the B horizons than in other parts of the profile. The Clarion soils show only a slight variation in reaction within the profiles. The pH is as high as 7.9 in the C horizons of all profiles except the Hayden-1. The acidity throughout the sola tends to decrease towards the Clarion end of the transect corresponding to the decrease of AP in the B horizons of soils.

<u>Total carbon</u> The percentage total carbon in the surface sample of site 1 through 7 is 1.74, 1.84, 1.52, 0.98, 1.54, and 1.68, respectively. The total carbon decreases with depth in all the profiles but the rate of decline is more rapid in Hayden and Lester profiles. The total carbon content in Clarion soils is higher than in Hayden and Lester soils. The depth to 1 percent carbon for all sites is given in Table 11. The depth to 1 percent carbon in Clarion profiles is about

twice as great as in Hayden and Lester profiles. The order of maximum to minimum thickness of >1% organic carbon is as follows: prairie > transition > forest which is the same order of AP in the A horizon according to natural vegetation.

<u>Available phosphorus in Alfisols and Mollisols in a Cary till biosequence</u>

The nine soils studied are arranged according to biosequence, degree of profile development and drainage class in Table 3. The subgroup level of classification of soils is also presented in Table 3. The data for the soils are given in Appendix V. The vegetation-drainage relationship of the nine series is given in Table 12.

Table 12. The vegetation-drainage relationship of the nine series formed in a Cary till

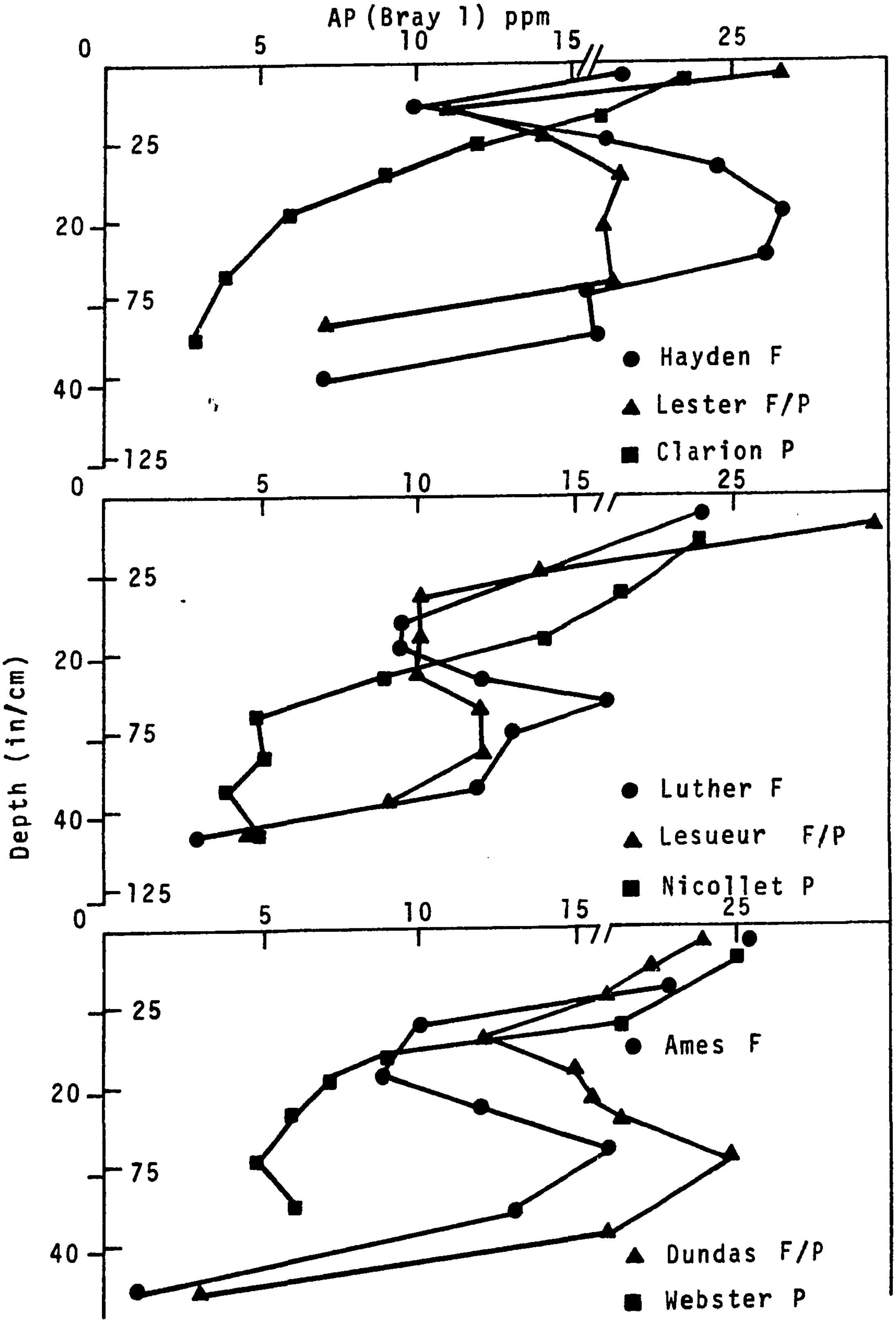
	Drainage class		
Vegetation	Well	Somewhat poor	Poor
Forest	Hayden	Luther	Ames
F/P transition	Lester	LeSueur	Dundas
Prairie	Clarion	Nicollet	Webster

The AP distribution in the soils is presented in Figure 35. In the forest soils (Hayden, Luther, Ames) and in the transition Prairie-forest soils (Lester, LeSueur, Dundas), the AP is high in the surface layer, decreases in the next lower A or upper B horizons, then increases in the zone of maximum clay content and then again decreases in the lowest layers, the C horizon. Thus in these six soils, which are Alfisols, there are two maxima and two minima AP zones. In contrast, the prairie soils (Clarion, Nicollet, Webster) contain a high amount of AP in the surface layer, with a gradual decrease with depth and to constant values in the lower B and C horizons.

Hayden-Lester-Clarion biosequence The AP content in the Hayden profile ranges from 7 to 28 ppm (Table 7 and Figure 35. In the solum, the lowest AP content is in the A2 horizon. The B horizon contains the highest amount of AP. The range of AP in the Lester soil is from 7 to 28 ppm, and the A2 horizon contains the minimum value of AP within the solum. The highest content of AP in the Lester soil is at the surface. There is a slight accumulation of AP in the B horizon of Lester soil. The values of AP range from 3 to 22 ppm in the Clarion P97. The A horizon is highest in AP content. The AP content in the Clarion soil decreases rapidly from the surface to the lower A horizon and then the values remain almost constant.

Luther-LeSueur-Nicollet biosequence In the somewhat poorly drained Luther biosequence the pattern of AP distribution is the same as in the well drained Hayden-Lester-Clarion biosequence. The AP range is from 3 to 23, 5 to 34 and 4 to 23 ppm in the Luther, LeSueur, and Nicollet soil profiles, respectively. The highest value of AP in all these three

Figure 35. Distribution of available phosphorus (AP) in Cary till biosequences of minimal development (well drained Hayden-Lester-Clarion sequence; somewhat poorly drained Luther-LeSueur-Nicollet sequence and poorly drained Ames-Dundas-Webster sequence)


AP (Bray 1) ppm
0
5
10
15
25
25
20
75
40
125
Depth (in/cm)
Hayden F
Lester F/P
Clarion P
Luther F
Lesueur F/P
Nicollet P
Ames F
Dundas F/P
Webster P

soils is at the surface. There is a slight accumulation of AP in the B horizons of Luther and LeSueur soils. However, the accumulation is more pronounced in the forest formed Luther soil than in the transition LeSueur soil. The trend of AP distribution in the Nicollet soil is the same as that in the Clarion soil, namely, highest AP values are in the surface and there is a gradual decrease with depth.

Ames-Dundas-Webster biosequence In the poorly drained biosequence, there is a similar pattern of AP distribution as in the Hayden and Luther biosequences. In the surface layers the AP values are similar. In the Ames and Dundas soils there is a minimum value of AP in the upper B horizons in the 10 to 15 inch zone. Then there is an increase in AP in the B horizon in the 20 to 40 inch depth. The Dundas soil has more AP in this zone than does the Ames soil. This is followed by a decrease in AP in the lowest layer analyzed. In the poorly drained prairie Webster soil the highest AP values are in the surface. Then there is a gradual decrease of AP with depth.

The nine soils (Table 11) can also be viewed as topo-hydro sequences, with vegetation constant but drainage differing. In the prairie derived Clarion-Nicollet-Webster sequence, the A horizon of the somewhat poorly drained Nicollet soil contains more AP than the poorly drained Webster soil followed by the well drained Clarion soil. In the Hayden-Luther-Ames sequence of forest soils, the order of maximum to minimum AP content in the B horizon is as follows: Hayden > Ames >

Luther. The AP content of the B horizons of the transition soils is higher in the poorly drained Dundas than in the well drained Lester soil.

Available phosphorus in Alfisols and Mollisols in loess biosequences

The soils of the several loess biosequences are arrayed according to biosequence, degree of profile development and drainage class in Table 3. In the same table the subgroup classification of each soil is given also. The AP data as well as other data are given in Appendix V. The AP values by the Bray-1 method of the various sequences are plotted in Figures 36 to 38. The sequence members of the same development stage are plotted together. Thus in Figure 36, Clinton, Ladoga and Otley soils are the forest, transition and prairie soils, respectively, of the well drained Clinton biosequence. After the soil name the letters F, F/P and P indicate forest, transition and prairie, respectively.

In general, from Figures 36 to 38 loess soils of the same drainage class and vegetation origin are higher in AP than the similar member of the Cary till biosequences, Figure 35.

In each biosequence regardless of drainage class and stage of profile development, the prairie soil differs from the transition and forest derived soils in the pattern of AP distribution with depth. In the prairie formed soils, indicated by the letter P after the soil name, the uppermost layer contains the highest amount of AP (Figures 36 to 38). The AP decreases to a minimum in the upper B horizons, then there is a tendency for AP to increase slightly in the B horizons. However, the amount in the B horizons is not higher than the amount in the uppermost layer, except in the Mahaska soil. In this soil the amount in the B horizon exceeds the amount present in the surface horizon.

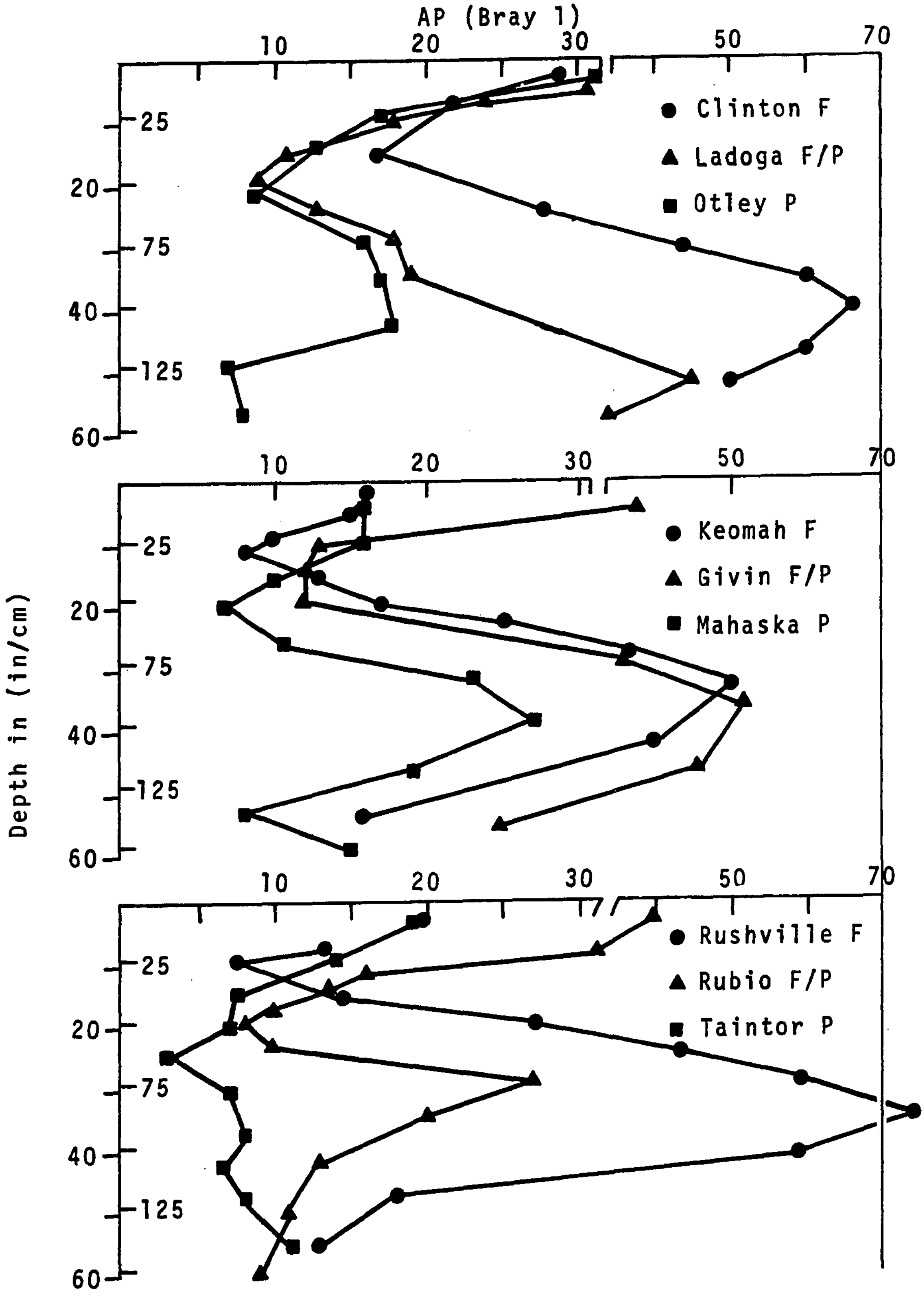
In most biosequences, in the transition soils, indicated by F/P after the soil name in Figures 36 to 38, AP is highest in the uppermost layer, then decreases sharply to a minimum value in the lower A or upper B horizons. In the next lower layer the AP increases gradually to a maximum in the middle to lower B horizon followed by a gradual decrease in the C or deepest horizon. In the forest formed member in each biosequence the highest amount of AP is in the B horizon. The forest soils have a similar pattern of AP distribution as in the case of the transition soils, though the increase of AP in the B horizons is more pronounced than in the associated transition soil. The minimum values of AP in forest soils occur at relatively shallow depths compared to transition soils.

Considerable variability exists in the amount of AP within the profiles of the various soils and between the biosequences. But all the prairie, transition and forest soils have the characteristic distribution of AP as described in the preceding paragraphs. The increase of AP in the B horizon is not evident in the prairie soils formed in Cary till, while the prairie soils formed in loess show a slight increase, except the Grundy soil profile. Some of the prairie loess soils, as the Otley and Mahaska soils, show an increase of AP in the middle B horizons, but the amount is less than in associated sequence members. The AP distribution pattern is about the same in the Seymour, Taintor and Haig soils showing a slight increase in the B horizons.

Among the transition soils, Givin has the highest AP value in the B horizon. In Givin, the AP is slightly higher than in its associated forest soil, Keomah. The AP content in the B horizons of Pershing, Belinda and Appanoose soils is quite high with values around 50 ppm. The increase of AP occurs in the lower B and upper C horizons of the Ladoga soil. The rest of the transition soils studied also show a distribution pattern of AP characteristic of the forest soils. Among the loess derived forest soils, the order of maximum to minimum accumulation of AP in B horizons is as follows: Rushville > Clinton > Rathbun > Weller > Keomah > Beckwith > Marion. The detailed account of the distribution of AP in various soil sequences follows.

<u>Biosequences of medial development</u> The medially developed biosequences studied are the well drained Clinton-Ladoga-Otley sequence, the somewhat poorly drained Keomah-Givin-Mahaska sequence, and the poorly drained Rushville-Rubio-Taintor sequence. The AP data are plotted in Figure 36. In all these soils there is more clay in the B horizon than in the A horizon (Appendix V).

Figure 36. Distribution of available phosphorus (AP) in loess biosequences of medial development (well drained Clinton-Ladoga-Otley sequence; somewhat poorly drained Keomah-Givin-Mahaska sequence and poorly drained Rushville-Rubio-Taintor sequence)


AP (Bray 1)
10
20
30
50
70
Depth in (in/cm)
25
20
75
40
125
60
Clinton F
Ladoga F/P
Otley P
Keomah F
Givin F/P
Mahaska P
Rushville F
Rubio F/P
Taintor P

Clinton-Ladoga-Otley biosequence All the three soils are grouped in the well drained class of natural drainage. The AP content is about the same (around 30 ppm) in the surface layer of these soils (Figure 36). The range of AP in Clinton is 17 to 66 ppm, in Ladoga 9 to 44 ppm, and in Otley 9 to 33 ppm. The minimum value of AP is in the zone of 9 to 21 inches in the Clinton profile while in the Ladoga soil the minimum AP is in the zone of 16 to 21 inches. The upper and lower B horizons of Otley soil contain the minimum amount of AP. The increase of AP in the B horizons of Clinton and Otley soils corresponds to the increase of clay content but is slightly deeper than the maximum clay content. In Ladoga the highest AP is in the lower B and C horizons.

Keomah-Givin-Mahaska biosequence These soils are classed as somewhat poorly drained. The AP in the Keomah (forest soil) ranges from 8 to 50 ppm. The values vary from 8 to 17 ppm in the A and upper B horizons, that is, in the zone of 0 to 21 inches. Below this depth the AP content increases sharply reaching a maximum value of 50 ppm in the lower B horizon at about 30 inches. The AP values are uniform, 12 to 13 ppm, in the zone of 9 to 23 inches in the Givin (transition soil) profile. Below this depth the AP is slightly higher than in the Keomah soil. The values of AP in the Givin soil range from 12 to 52 ppm. The increase of AP content in the B horizon of the Mahaska (prairie soil) is not as pronounced as in the transition and forest soil. However, distinct zones of AP minima and maxima occur in the Mahaska soil.

Rushville-Rubio-Taintor biosequence In this poorly drained biosequence, Rushville is the forest soil, Rubio the transition soil, and Taintor is the prairie derived soil. The AP range is from 8 to 74 ppm, from 8 to 40 ppm and from 3 to 19 ppm in the Rushville, Rubio and Taintor soils, respectively. The AP minima is in the A2 horizon of the Rushville soil, that is, in the zone of 8 to 14 inches. The zone of maximum AP is in the lower B horizon and is slightly below the zone of clay enrichment (Appendix V). In the Rubio soil, the minimum values of AP are in the zone of 16 to 26 inches (upper B horizon). The highest AP occurs slightly below the zone of maximum clay content. The AP content in the Taintor soil profile remains about constant below the depth of 1 foot. The range of AP in the profile is from 3 to 19 ppm.

Biosequences of maximal development The biosequences studied are as follows:

Somewhat poorly drained Weller-Pershing-Grundy

Somewhat poorly drained Rathbun-Kniffin-Seymour

Poorly drained Beckwith-Belinda-Haig

Poorly drained Appanoose-Edina

Poorly drained Marion-Putnam.

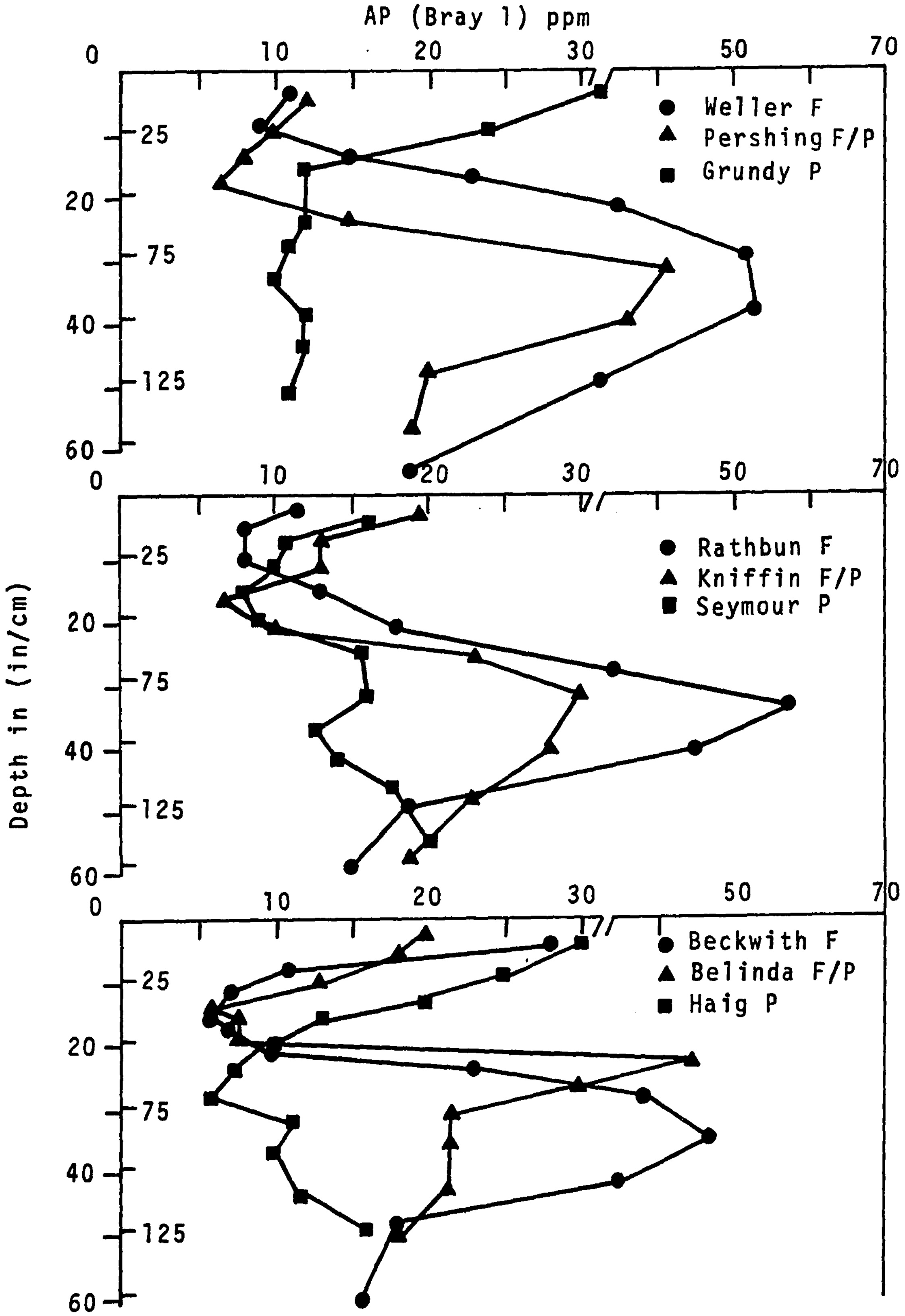
The B horizons of these soils are considerably finer in texture than the A horizons. The AP distribution with depth is presented in Figures 37 and 38. The results of AP in the individual biosequences are described below.

Weller-Pershing-Grundy biosequence The AP minima is in the zone of 7 to 12 inches and 11 to 21 inches in the profiles of Weller (forest soil) and Pershing (transition soil), respectively (Figure 37). The sharp increase of AP is in the middle to lower part of the B horizons at 30 to 40 inches. The surface layers of Weller and Pershing soil contain about the same amount of AP. The AP content in the Grundy (prairie) soil is high at the surface, decreases to the upper B horizon at about 30 inches, then it remains almost constant throughout the rest of the profile. The values of AP range from 10 to 33 ppm in the Grundy profile, from 7 to 42 ppm in the Pershing and from 9 to 53 ppm in the Weller profile.

In the B horizon the content of AP is Weller > Pershing > Grundy.

Rathbun-Kniffin-Seymour biosequence The surface layer of Kniffin (transition soil) contains more AP than the surface layers of Seymour (prairie soil) followed by Rathbun (Figure 37). The AP minima is at the same depth in the profiles of Seymour and Kniffin soil while it is at a shallower depth in the Rathbun profile. All the three soils show high values of AP in the B horizons. The values of AP in the B horizon of the Seymour soil are as high as at the surface. The AP contents range from 8 to 57 ppm, from 7 to 30 ppm, and from 8 to 20 ppm in the Rathbun, Kniffin, and Seymour soils, respectively.

Figure 37. Distribution of available phosphorus (AP) in loess biosequences of maximal development (moderately well drained Weller-Pershing-Grundy sequence; somewhat poorly drained Rathbun-Kniffin-Seymour sequence and poorly drained Beckwith-Belinda-Haig sequence)


AP (Bray 1) ppm
0
10
20
30
50
70
Weller F
Pershing F/P
Grundy P
Rathbun F
Kniffin F/P
Seymour P
Beckwith F
Belinda F/P
Haig P
Depth in (in/cm)
25
20
75
40
125
60

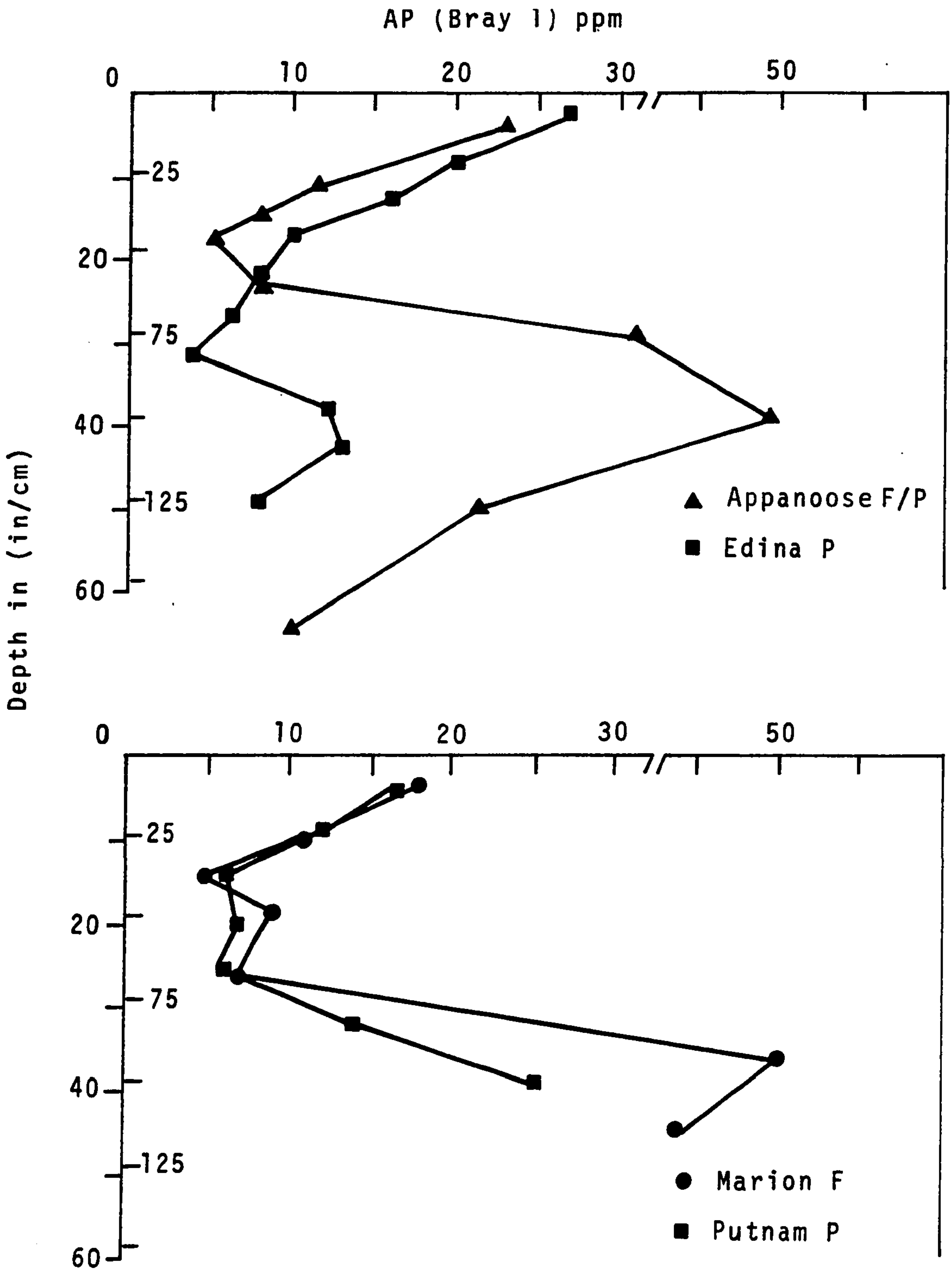
In the B horizon the content of AP is forest > transition > prairie.

<u>Beckwith-Belinda-Haig biosequence</u> The order of maximum to minimum AP content in the A horizon is as follows: Haig (prairie soil) > Belinda (transition soil) > Beckwith (forest soil). The AP minima is at the same depth in the Beckwith and Belinda soil profiles (Figure 37). The AP increases sharply in the zone of 19 to 24 inches in the Belinda profile, then the AP drops sharply to about 20 ppm and remains constant within the 28 to 46 inch depth. The AP content in the Haig soil decreases with depth from the surface to the B2 horizon then increases slightly with depth. The distribution of AP in the Beckwith follows the same pattern as in other forest soils. There is an AP minimum in the 10 to 20 inch zone and an AP maximum in the 30 to 40 inch zone. The range of AP in the Beckwith, Belinda and Haig is from 6 to 47 ppm, 6 to 47 ppm, and 6 to 30 ppm, respectively.

The content of AP is forest > transition > prairie.

<u>Appanoose-Edina partial biosequence</u> The AP content ranges from 4 to 27 ppm and from 5 to 49 ppm in the Edina (prairie soil) and Appanoose (transition) soils, respectively. The AP content in the Edina soil is high in the surface, decreases with depth to B2 horizon, then there is a slight increase of AP in the lower B and C horizons (Figure 38). The A horizon of Edina contains slightly more AP than the A horizon of Appanoose soil. But in the B horizons the AP is 3 to

Figure 38. Distribution of available phosphorus (AP) in loess partial biosequences of maximal development (poorly drained Appanoose-Edina sequence, poorly drained Marion-Putnam sequence)


AP (Bray 1) ppm
0
10
20
30
50
25
20
75
40
125
60
Depth in (in/cm)
Appanoose F/P
Edina P
Marion F
Putnam P

4 times more in the Appanoose soil than in the Edina soil. Thus the order of AP content is transition > prairie. The values of AP in the C horizons of both the soils are close to each other.

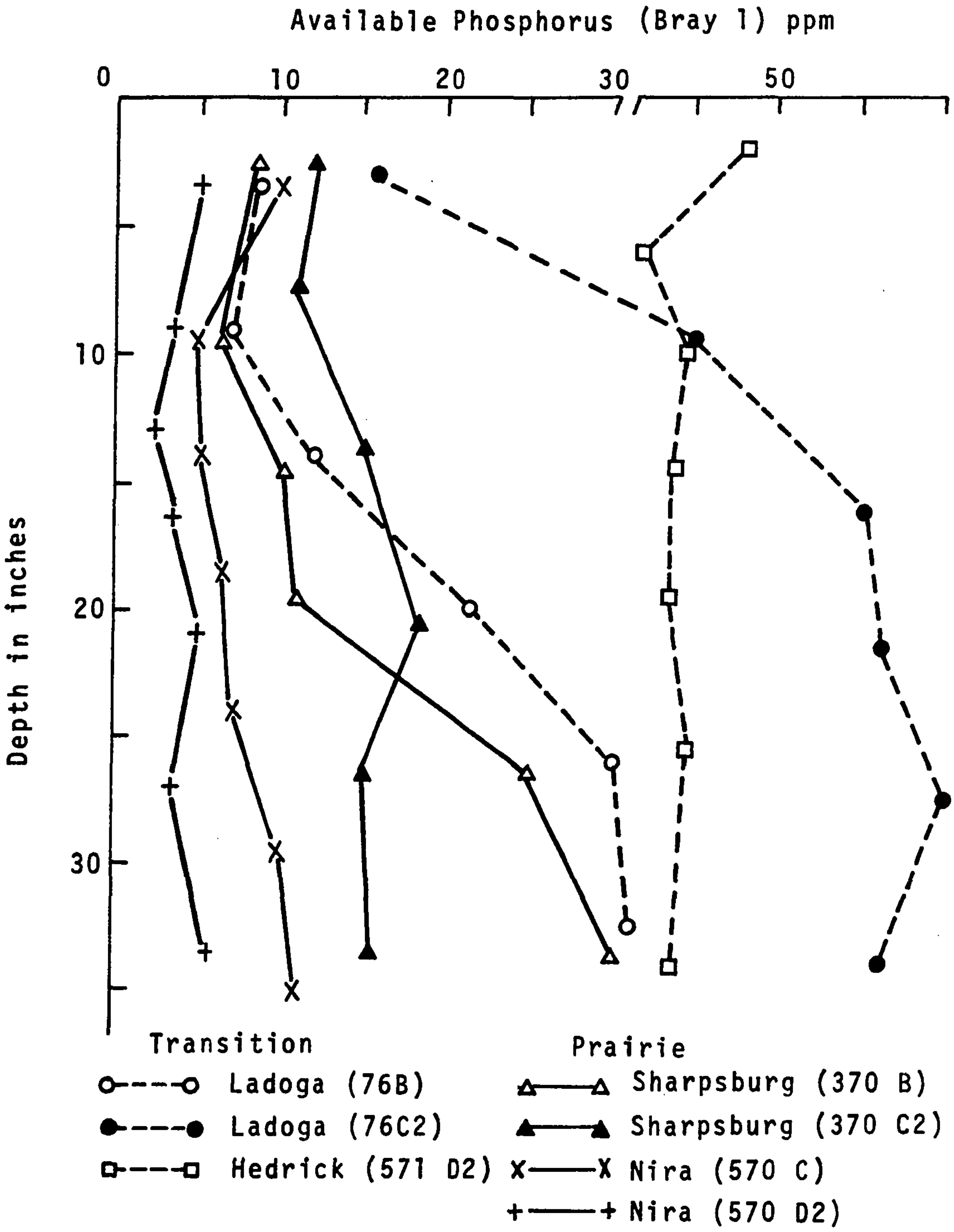
Marion-Putnam partial biosequence Of all the loess soils studied, Putnam and Marion soils have the highest clay content in the B horizon (Appendix V). The values of AP are high in the surface of both soils and decrease to the lower A horizons and upper B horizon. Below 30 inches there is more AP in Marion than in Putnam, or in the order of forest > prairie.

Available phosphorus in Udalfs and Udolls sampled by mapping units in Adair County

The subgroup classification, location and details of the soils sampled in Adair County, Iowa, are presented in the methods of analysis section (Figure 2 and Table 4). The soils studied are of the Ladoga, Hedrick, Sharpsburg and Nira series. Some of the soils are of different slope and/or erosion phases. The soils were analyzed for particle size, pH, total carbon and available phosphorus. These data as well as the AP data are presented in Appendix VI. The AP distribution with depth in the profiles studied is shown in Figure 39.

In the Ladoga profiles, the AP values are quite different but the shape of the distribution curve is the same. The AP ranges from 7 to 33 ppm and from 16 to 70 ppm in the Ladoga soils on B slope and on C slope, respectively. The values

Figure 39. Distribution of available phosphorus (AP) for different mapping unit sites in Adair County


Available Phosphorus (Bray 1) ppm
0
10
20
30
50
Depth in inches
10
20
30
Transition
Ladoga (76B)
Ladoga (76C2)
Hedrick (571 D2)
Prairie
Sharpsburg (370 B)
Sharpsburg (370 C2)
Nira (570 C)
Nira (570 D2)

in both cases increase with depth. The AP distribution in the profiles of Sharpsburg soils follows the same pattern except the profile on C slope in which the values of AP decrease a little below the 2 foot depth. The AP content of the Sharpsburg soil on C slope is higher in the zone of 2 feet than in the soil profile on B slope. Below this depth the AP content is lower in the profile on C slope than in the profile on B slope. The range of AP in the Sharpsburg on B slope is from 7 to 31 ppm and in the Sharpsburg soil on C slope it is from 11 to 16 ppm.

The distribution pattern of AP is about the same in the Nira and Hedrick soils. The values of AP in these soil profiles remain about constant, showing no significant variation between the horizons. The AP content in the transition Hedrick soil is much higher than in the Nira soils. The AP values in the Hedrick soil range from 34 to 47 ppm and in the Nira soils from 3 to 11 ppm. The content of AP in the Nira soil on C slope is higher in all the horizons than in the soil profile on D slope.

To evaluate the significance of AP in differentiating soil series, the data of clay, total carbon, pH and AP are plotted for Ladoga and Sharpsburg in Figure 40 and for Hedrick and Nira in Figure 41. These two figures make it clear that there are wide differences in the AP contents of soil series but other soil properties like clay content and pH show a very little difference. There are differences in the total carbon

Figure 40. Distribution of clay, total carbon, pH and available phosphorus (AP) in the Ladoga and Sharpsburg soils

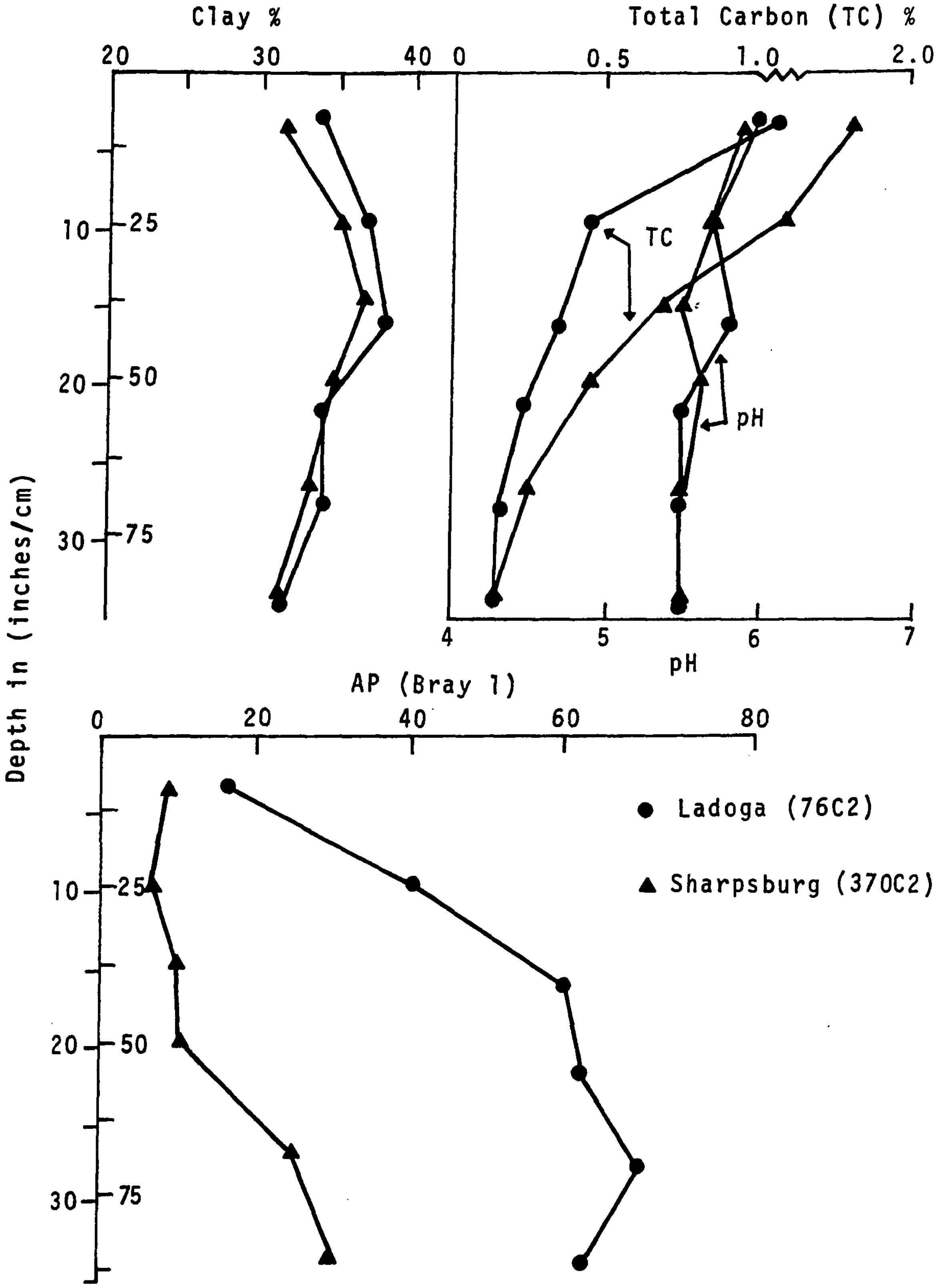
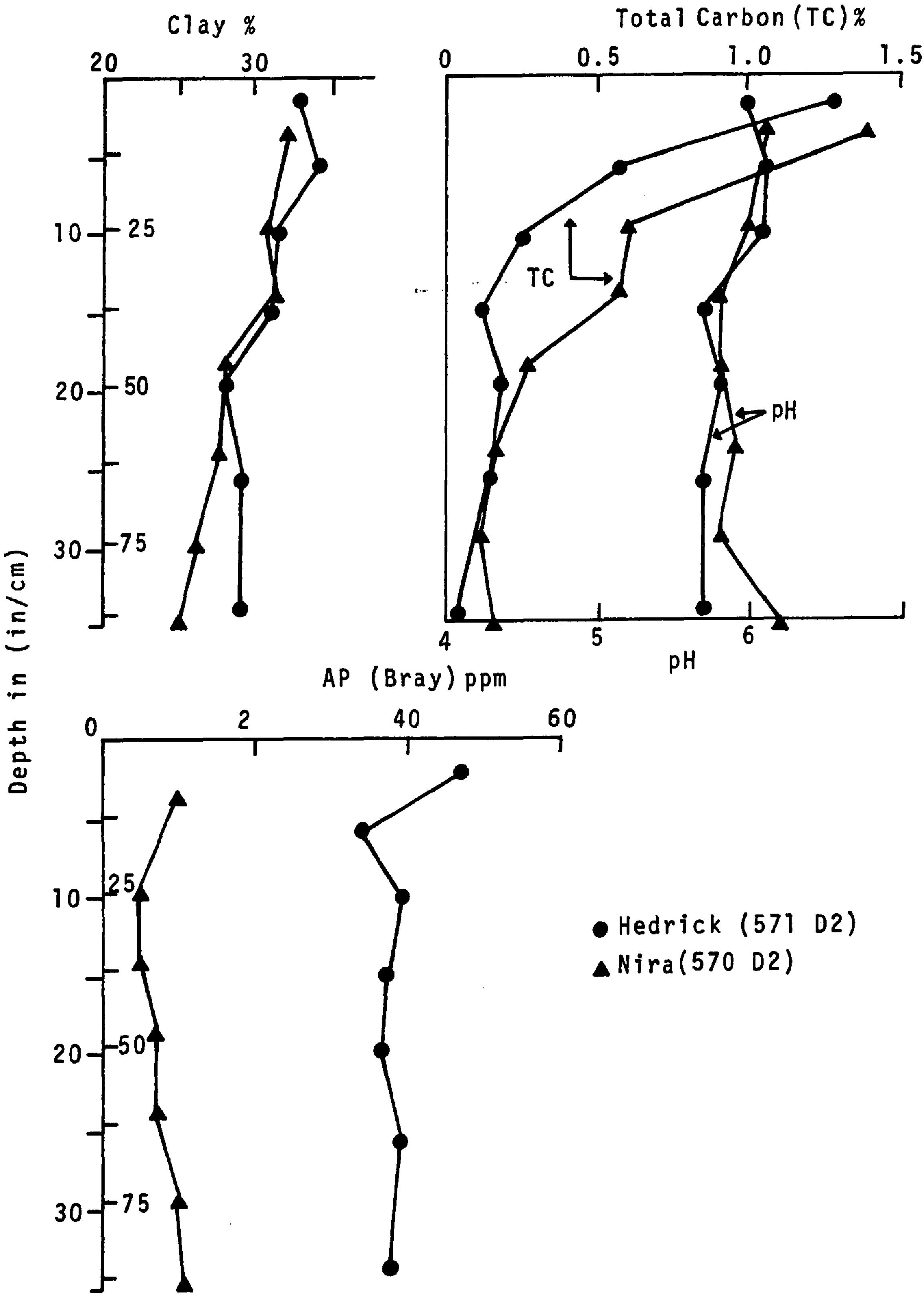

Clay %
20
30
40
Total Carbon (TC) %
0
0.5
1.0
2.0
TC
pH
4
5
6
7
pH
Depth in (inches/cm)
10
25
20
50
30
75
AP (Bray 1)
0
20
40
60
80
Ladoga (76C2)
Sharpsburg (370C2)

Figure 41. Distribution of clay, total carbon, pH and available phosphorus in the Hedrick and Nira soils



Clay %
20
30
Total Carbon (TC)%
0
0.5
1.0
1.5
TC
pH
4
5
6
pH
Depth in (in/cm)
10
25
20
50
30
75
AP (Bray) ppm
0
2
40
60
● Hedrick (571 D2)
▲ Nira (570 D2)

contents on the surface but the differences become insignificant at lower depths.

The clay content in the Ladoga and Sharpsburg soils increases with depth to the depth of 12 to 18 inches then decreases slowly with depth (Figure 40). The Ladoga soil contains slightly higher clay than the Sharpsburg soil. The pH values for the two soils are almost the same except in the zone of 12 to 18 inches where the pH values differ slightly. The Sharpsburg soil contains more total carbon throughout the profile than the Ladoga soil; however, the total carbon values come close in the lower part of the profiles. The differences in the amounts of AP are more in the lower solum, that is, below the depth of 1 foot.

The Nira and Hedrick soils show the same distribution of clay content with depth, decreasing gradually with depth (Figure 41). The pH decreases with depth to 15 inches and then values remain about constant in the remainder of the profiles. The total carbon content is higher in the A horizon of the Nira soil than in the Hedrick soil. Below the depth of 18 inches the total carbon values are about the same in both profiles. The AP values are about 3 to 4 times higher throughout the profile of Hedrick than in the Nira soil profile.

DISCUSSION

This study was initiated to test if the inorganic P fractions and available phosphorus could aid in characterizing the taxonomic categories studied, including soil series, and to obtain a better understanding of soil genesis. In the following subsections the inorganic P fractions and available phosphorus will be discussed by taxonomic categories. Characterization and comparison of IP and AP by various categories will be made during the discussion. Also discussed is the relationship of IP fractions and AP to soil forming factors, weathering status of soils and several other soil properties.

Inorganic Phosphorus Fractions

Sixteen soils varying rather widely in profile characteristics were studied. Since the parent materials in which soils formed are not homogenous with respect to phosphorus mineralogy, the percentage of IP fractions is used in characterization and comparison purposes. The percentages of IP forms are also used for graphical plots in the results section. First, a general discussion of the IP fractions in various horizons of the profile is given and then the inorganic forms according to taxonomic categories are discussed. Finally, the P fractions are related to weathering stages of soils and soil forming conditions.

General distribution of IP fractions in genetic horizons

In general, the Ca-P is a dominant inorganic P fraction in the lower B and C horizons of the soils studied. Westin and Buntley (1967), Hawkins and Kunze (1965) and Smeck and Runge (1971) also reported Ca-P as the major fraction in the C horizons of the different soils studied.

The Ca-P is no longer a dominant IP form in the more weathered A and B horizons in the sixteen soils of this study. Its relative abundance by horizons is as follows: C > A > B. The Ca-P has been transformed to a considerable degree into Al-P, Fe-P and Red-P. Within each solum the percentage of Ca-P does not vary much.

The Red-P and Fe-P are the dominant forms in the A and B horizons. Generally, the order of abundance of these forms in the various horizons is as follows: B > A > C. Considering all the soils analyzed for the inorganic P forms, the Red-P constitutes a relatively large portion of the sum of the four IP forms. These results are in agreement with those of Westin and DeBrito (1969) and Smeck and Runge (1971) who also found a high percentage of Red-P in soils.

The Al-P fraction is low (under 10 percent of the sum of P fractions) in many soils and is relatively constant with depth. This shows that the Al-P never accumulates in the soil environment but may serve primarily as a transition phase for decreasing Ca-P and increasing Fe-P. A constant Al-P fraction was also found by Hawkins and Kunze (1965) and Juo and Ellis

(1968). Competition between clay and P for Al ions may also explain the low Al-P fraction. Though Al-P is a small fraction there is a range of 1 to 8 percent in the B horizons of the different soils. This will be discussed later.

The transformations of Ca-P to other IP forms presumably are the result of weathering and leaching processes. The degree of these transformations are likely affected by the duration and intensity of these processes. The variations in the relative amounts of forms of phosphorus in various horizons are also expected since the distribution of the various inorganic P fractions tend to be pH dependent (Hsu and Jackson, 1960). The Ca-P is usually dominant in the neutral to alkaline pH (usually the pH of C horizons) range and it decreases as the pH drops (Chang and Jackson, 1958). Mausbach (1969) indicated that the Ca-P changed to sesquioxide bound P (Al-P + Fe-P + Red-P) as a result of increased acidity during soil development. Hsu and Jackson (1960) mentioned that the Al-P and Fe-P are largely of secondary origin formed in the course of geologic and pedological weathering.

Relationship of P fractions to taxonomic categories

The sixteen soils studied provide a comparison of taxonomic categories with respect to IP fractions. The number of taxonomic cagories represented in this study are as follows: orders - 3, suborders - 6, great groups - 11, subgroups - 15, and series - 15. Thus, this study represents only 3 orders and only a small number of the classes in the respective categories. The current classification of the soils studied according to various taxonomic categories is given in Table 13.

The weighted average values of the percentage of IP fractions for the control section were calculated for each soil and the values are given in Table 14. The values are plotted in Figure 42. In soil survey work an arbitrary control section (the layer of soil) of 10 to 40 inches is defined for use in classification of certain soils. The author used the depth to 40 inches, excluding the uppermost layer of the soil because the surface layer may have had P added. The values are average (per inch) over the 40 inch zone. As the control section centers the attention on genetic horizons, namely A and B horizons, the control section was chosen because it reflects best the soil forming conditions and soil weathering processes. The average values of IP fractions for different soils were used to calculate average values for taxonomic categories in which the soils are grouped. These values are presented at appropriate places in tabular form.

Order   Of the sixteen profiles studied, ten were classified as Alfisols, two as Aridisols and four as Mollisols. The average percentage of IP fractions for the control sections of the soil orders is given in Table 15.

There are no clearcut differences with respect to the IP fractions between the soil orders. However, the Fe-P value is higher in Alfisols than in Mollisols. The reverse is the

Table 13. Taxonomy of soils on which the inorganic P fractions were determined

Order	Suborder	Great group	Subgroup[a]	Series
Alfisols	Aqualfs	Albaqualf	Mollic	Cisne
	Udalfs	Ochraqualf	Udollic	Pershing
		Fragiudalf	Typic	Grantsburg
		Hapludalfs	Aquic	Weller
			Mollic	Lester
			Typic	Hayden
	Ustalfs	Paleustalf	Aridic	Amarillo
			Petrocalcic	Arvana
		Haplustalf	Typic	Gwalior
		Natrustalf	Natric	Podua
Aridisols	Argids	Haplargid	Ustollic	Forrest
		Paleargid	Typic	Tubac
Mollisols	Udolls	Argiudoll	Typic	Tama
		Hapludoll	Typic	Clarion
	Ustoll	Paleustoll	Torrertic	Pullman

[a]Technically, subgroup name consists of prefix + great group, i.e., Mollic Albaqualf.

case for Ca-P. The Red-P is higher in Mollisols than in Alfisols. The Al-P fraction is low in all the orders. The Alfisols have slightly higher amounts of the Al-P than the Mollisols. The Aridisols studied have less Ca-P than Mollisols. One explanation may be that both Aridisols have argillic horizons but both Millisols have a weak argillic or a cambic horizon only.

Table 14. Weighted average percentage of IP fractions, ratios of P fractions and B/A clay ratios for 16 soils

Series name	Weighted average % of IP fractions in the control section/inch				Inorganic P ratios			B max/ A min clay ratio
	Al-P	Fe-P	Red-P	Ca-P	Al-P + Fr-P + Red-P/Ca-P	Red-P/ Fe-P	Fe-P/ Ca-P	
Cisne	6	46	23	25	3.00	0.50	1.84	2.85
Pershing	5	21	56	18	4.56	2.66	1.16	1.99
Grantsburg	4	44	37	15	5.67	0.84	2.93	2.05
Hayden	5	29	40	26	2.84	1.37	1.11	1.83
Lester	4	20	43	33	2.03	2.15	0.60	1.84
Weller	6	55	28	11	8.09	0.51	5.00	2.42
Amarillo	4	46	20	30	2.34	0.43	1.53	1.87
Arvana	4	32	22	42	1.38	0.69	0.76	2.53
Gwalior	3	27	39	31	2.22	1.44	0.87	1.67
Podua	3	22	16	59	0.69	0.73	0.37	1.52
Forrest	5	26	31	38	1.63	1.19	0.68	3.06
Tubac	5	41	29	25	3.00	0.70	1.64	4.02
Clarion	2	20	45	33	2.03	2.25	0.60	1.03
Tama	3	28	45	24	3.16	1.60	1.16	1.38
Pullman-1	4	28	29	39	1.56	1.03	0.72	1.39
Pullman-2	4	28	26	42	1.38	0.92	0.67	1.43

Figure 42. Weighted average percentage of IP fractions (per inch) in the control section of 16 soils

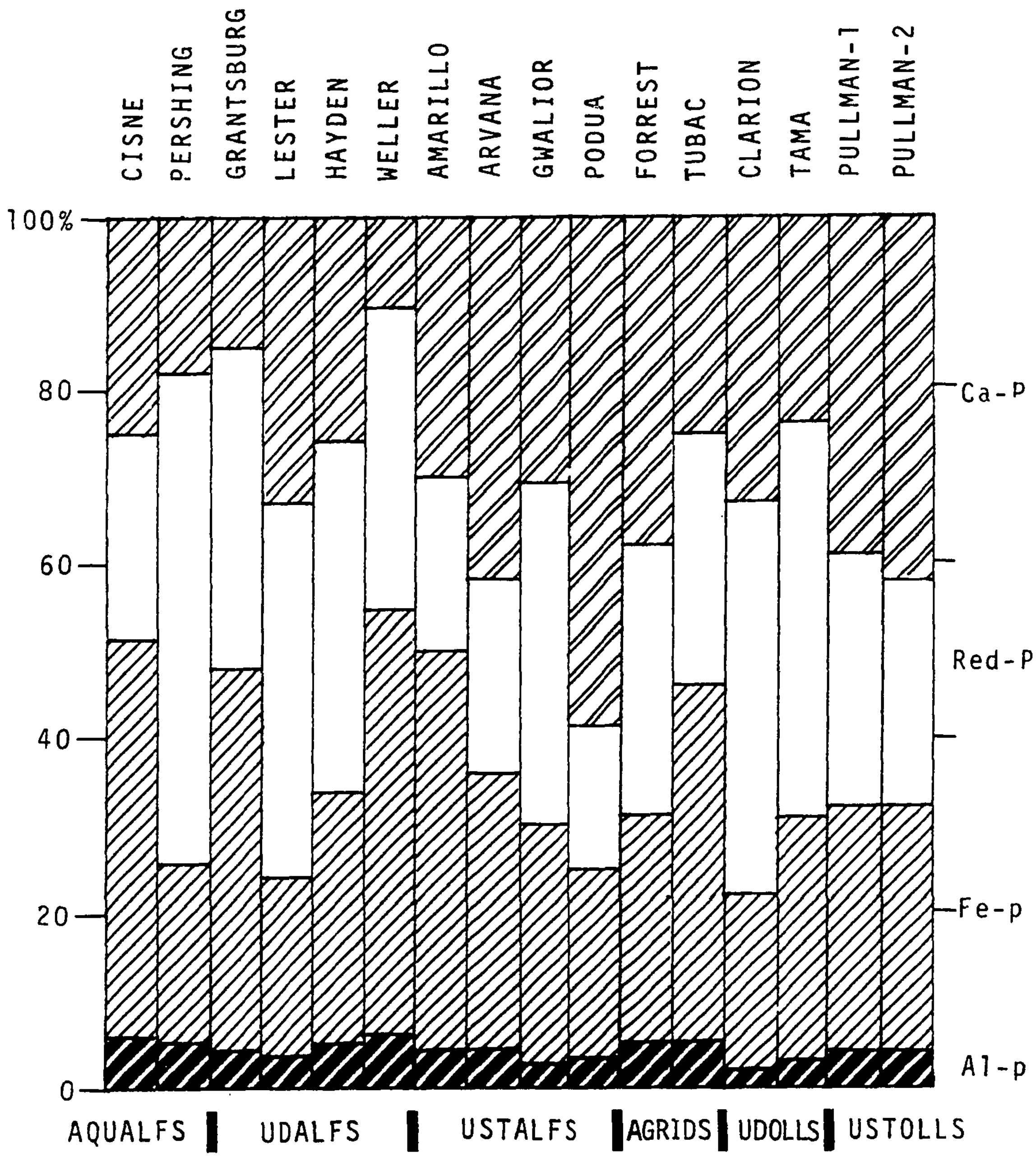

CISNE
PERSHING
GRANTSBURG
LESTER
HAYDEN
WELLER
AMARILLO
ARVANA
GWALIOR
PODUA
FORREST
TUBAC
CLARION
TAMA
PULLMAN-1
PULLMAN-2
100%
80
60
40
20
0
Ca-P
Red-P
Fe-p
Al-p
AQUALFS
UDALFS
USTALFS
AGRIDS
UDOLLS
USTOLLS

Table 15. Weighted average percentages of P fractions according to soil orders

Soil order	Weighted average % of IP fractions in the control section/inch			
	Al-P	Fe-P	Red-P	Ca-P
Alfisols	4.5	34	33.5	28
Aridisols	5	33.5	30	31.5
Mollisols	3.25	26	36.25	34.5

<u>Suborder</u> The average percentage values of the inorganic P fractions for the control sections according to the suborders are given in Table 16.

The Ca-P is higher in the Ustalfs and Ustolls than in the Aqualfs, Udalfs, and Udolls. Another IP fraction which differentiates the <u>Udic</u> and <u>Ustic</u> moisture regimes in soils within suborders is the Red-P. The Red-P is lower in the Ustalfs and Ustolls than in Aqualfs, Udalfs, and Udolls.

The Al-P and Fe-P are higher in the Aqualfs and Udalfs than in Udolls. The Udolls contain higher amounts of the Red-P and Ca-P than the Aqualfs and Udalfs. The difference between the Ustalfs and Ustolls is less apparent with respect to the IP forms. However, the Fe-P is slightly higher in the Ustalfs than in the Ustolls. The reverse is true for the Red-P.

The inorganic P fractions seem to differentiate the soils more clearly at the suborder level than at the order level.

Table 16. Weighted average percentage of IP fractions according to suborders

	Weighted average % of IP fractions in the control section/inch			
Suborders[a]	Al-P	Fe-P	Red-P	Ca-P
Aqualfs (1)	5.5	33.5	39.5	21.5
Udalfs (5)	4.75	37	37	21.75
Ustalfs (4)	3.5	32	24	40.5
Argids (2)	5	33.5	30	31.5
Udolls (2)	2.5	24	45	28.5
Ustolls (2)	4	28	27.5	40.5

[a]Number in parentheses indicates the number of profiles studied.

Probably, the climate has significant influence on the transformations and distribution of phosphorus. The Ca-P and Red-P fractions seem to have possibilities as differentiating criteria at the suborder level.

Great group The Fe-P, Red-P and Ca-P proportions vary considerably according to the great groups (Table 17). The Fe-P is the largest IP fraction in the Albaqualf, Fragiudalf, Paleustalfs and Paleargid. In the Ochraqualfs, Haplustalf, Argiudoll and Hapludoll the Red-P is the largest proportion of the sum of IP fractions. The Ca-P occurs as a major fraction in the Natrustalf, Haplargid and Paleustolls occurring in moderately dry regions.

Table 17. Weighted average percentage of IP fractions according to great groups

Great group[a]	Weighted average % of IP fractions in the control section/inch			
	Al-P	Fe-P	Red-P	Ca-P
Albaqualf (1)	6	46	23	25
Ochraqualf (1)	5	21	56	18
Fragiudalf (1)	4	44	37	15
Hapludalfs (3)	5	35	37	23
Paleustalfs (2)	4	39	21	36
Haplustalf (1)	3	27	39	31
Natrustalf (1)	3	22	16	59
Haplargid (1)	5	26	31	38
Paleargid (1)	5	41	29	25
Argiudoll (1)	3	28	45	24
Hapludoll (1)	2	20	45	33
Paleustolls (2)	4	28	29	39

[a]Number in parentheses indicates the number of profiles studied.

Among the moist Aqualfs and Udalfs, the Fe-P and Red-P appear to differentiate the great groups. The Albaqualf and Ochraqualf differ in the relative amounts of all the four fractions. The Albaqualf contains considerably higher amount of the Fe-P than the Ochraqualf. The reverse is true for the Red-P form. The variation of the P fractions is less in the

Fragiudalf and Hapludalfs. The values of the Red-P for both the great groups are the same. The Fe-P in the Fragiudalf is higher than the Hapludalfs.

The Argiudoll and Hapludoll differ from each other in the relative amounts of the Fe-P and Ca-P. The Fe-P is higher accompanied with a lower amount of Ca-P in the Argiudoll than in the Hapludoll.

The Paleargid is characterized by having about twice the amount of the Fe-P than in the Haplargid. The Paleustalfs also contain considerably higher amount of the Fe-P than the Haplustalf and Natrustalf.

Subgroup Only two great groups have more than one representative. These are the Hapludalfs and Paleustalfs. The weighted average values of the percentages of IP fractions of these subgroups are given in Table 18.

Among the Hapludalfs, the Aquic Hapludalf has a high proportion (>50 percent) of the Fe-P fraction. It has the lowest proportion of Ca-P. The Red-P is the largest proportion in the Typic Hapludalf and the Mollic Hapludalfs. The order of Ca-P proportion is as follows: Mollic > Typic > Aquic. This order corresponds to the pH values in the profiles of the soils representing the subgroups. The previously discussed relationship of pH and the Ca-P fraction holds true here.

The Fe-P and Ca-P are different in the Aridic and Petrocalcic subgroups of the Paleustalfs. The Petrocalcic Paleustalf contains a higher proportion of the Ca-P in its control

Table 18. Weighted average percentage of IP fractions according to subgroups

Subgroup	Weighted average % of IP fractions in the control section/inch			
	Al-P	Fe-P	Red-P	Ca-P
	Hapludalfs			
Typic Hapludalf	5	29	40	26
Mollic Hapludalf	4	20	43	33
Aquic Hapludalf	6	55	28	11
	Paleustalfs			
Aridic Paleustalf	4	46	20	30
Petrocalcic Paleustalf	4	32	22	42

section than the Aridic Paleustalf. Conversely, the Fe-P is a larger proportion of the IP fractions in the Aridic Paleustalf than in the Petrocalcic Paleustalf. The presence of a caliche layer (Petrocalcic horizon) within the 40 inch depth appears to be the factor for the high proportion of the Ca-P form.

Series The two profiles of the Pullman (Torrertic Paleustolls) series provide a limited comparison of the P fractions within the series. Both the profiles are uniform with respect to the weighted average percentages of IP forms within the control section. The proportions of each of the four inorganic P fractions is about the same in both the profiles although the absolute amount of P forms vary in the profiles.

The sum of the P fractions is higher in the Pullman-1 than Pullman-2 profile. The similar kind of difference was also reflected in the AP contents (Table 10). The differences can be attributed to variations in both the nature of parent materials and the conditions under which the profile developed. This is indicated by the higher clay and organic carbon contents in the Pullman-1 profile than in the Pullman-2. The higher clay and organic matter contents in the Pullman-1 profile may be involved in the higher contents of the inorganic P fractions than in the Pullman-2.

Relationships of IP fractions to soil forming factors and weathering

In general, the inorganic P fractions tend to vary with climate, natural vegetation and with other soil properties such as pH, clay and organic carbon. Therefore, the distribution of IP fractions probably would indicate the influence of the soil forming factors and the conditions under which the soil is formed. The P forms thus would be most useful as an additional criterion for classifying certain soils. First a brief look at variations of the P fraction according to the soil forming factors.

Climate Table 16 shows that the distribution of P fractions is related to climate. The Ca-P form is more prevalent in soils of moderately dry climates (Ustalfs and Ustolls). The Red-P makes up a proportionally larger fraction in soils of humid climate (Aqualfs, Udalfs and Udoll). Koyumdjisky and Dan (1969) analyzed the soils of the various Great Soil Groups of Israel for the inorganic P fractions and they concluded that the distribution of the P forms is controlled by climate. These workers also reported that the higher Ca-P proportions were accompanied by lower proportions of the Fe-P in the soils of semi-arid areas.

The Ustalfs and Ustolls generally have higher pH than the Aqualfs, Udalfs and Udolls. Due to less leaching involved in soils of <u>ustic</u> climate, the pH of the soils is generally within the neutral to alkaline pH range. Dean (1938) suggested that the acid soluble P (Ca-P) increased in the soils of neutral to alkaline pH and the alkali soluble P (Fe-P in acid soils.

<u>Vegetation</u> Within the same climatic region, the percentage of Red-P is higher in the soils (Udolls and Ustolls) formed under grass vegetation than in the corresponding soils (Aqualfs and Udalfs and Ustalfs) formed under the woody plants. The relative proportion of the Red-P appears to be the indicator of the natural vegetation. The relative proportions of the Al-P, Fe-P and Ca-P also appear to be an indicator of the natural vegetation.

The Hayden, Lester and Clarion soils were analyzed for the inorganic P fractions. These soils are similar with respect to climate, parent material, topography (drainage) and time of development. These soils form a biosequence and thus serve as a good example to investigate the effect of vegetation (the only one soil forming factor which differs) on the IP fractions. The Hayden is a forest formed soil, the Lester formed under forest encroachment on prairie and the Clarion is a prairie formed soil.

The differences in the distribution of IP fractions are clearly expressed in Figure 22. In this example, vegetation seems to have an effect on the inorganic P forms through its influence on the degree of leaching and weathering. In the Lester and Hayden profiles with the increasing forest influence, progressive increases in the clay contents of the B horizons are to be expected (Cardoso, 1957). This is reflected in the more pronounced accumulation of the Al-P, Fe-P and Red-P (the sesquioxide P fractions) in the B horizon of Hayden soil, and less accumulation of these IP forms in the Lester soil. In the Clarion soil there is less Al-P, Fe-P and Red-P in the B horizon than is present in the A horizon.

These results are in agreement with those of Bauwin and Tyner (1957) who reported that the total phosphorus and extractable phosphorus contents of the B horizons of the Gray-Brown Podzolic soils (Udalfs) as a whole exceeded that of the Brunizems (Udolls). With respect to the inorganic P fractions in the profile as a whole, Mausbach (1969) reported the Ca-P decreases, and Al-P and Fe-P increase with forest influence.

By data in Table 13, the Ca-P is lower and the Fe-P is higher in the control section of the Hayden soil than in the Lester and Clarion soils. The increased weathering and leaching under the forest type of vegetation might have caused a shift from the Ca-P to form more Al-P and Fe-P in the Hayden soil. This also resulted in the difference of the depth at which the Ca-P increases. The increase of the Ca-P fraction occurs at deeper depth (36 to 42 inch zone) in the forest soil, Hayden, and at shallower depth (18 to 24 inch zone) in the prairie soil, Clarion.

The Al-P is high in the A horizon of the Clarion but it is low in the remainder of the profile. The concentration of the Al-P in the A horizon of the Clarion has probably taken place as the result of accumulation of organic matter. Kaila (1961) has shown that the mineralized organic P accumulates in the NH_4-F extractable fraction (Al-P).

The Weller and Pershing form a partial biosequence, the Weller being a forest soil and the Pershing is the transition soil. The higher average value of the Al-P and Fe-P accompanied with the lower value of the Ca-P (Table 14) in the Weller soil than in the Pershing soil further confirms that the Ca-P is more transformed to the Al-P and Fe-P under the forest influence.

Parent material The amounts of IP fractions in soils depend considerably on its parent material. Within the same climatic region and under the influence of the same natural vegetation, the soils formed in loess (Weller, Pershing and Tama) show higher values of the total IP fractions than the soils formed in Cary till (Hayden, Lester and Clarion). This is expected since the loess soils have higher amounts of total and dilute acid soluble P than till soils (Pearson et al., 1940). The loess derived soils contained an average of about 500 to 700 ppm of total phosphorus as compared to about 300 ppm in the till derived soils. Westin and Buntley (1966a) also reported higher contents of the inorganic P fractions in loess soils than in till soils of South Dakota.

Weathering and the inorganic P fractions Several investigators have utilized the inorganic P fractions to characterize the soils in terms of weathering and profile development. According to Chang and Jackson (1958) the weathering sequence of the IP fractions in decreasing weathering order is as follows: Ca-P $\longrightarrow$ Al-P $\longrightarrow$ Fe-P $\longrightarrow$ Occluded-P (reductant soluble Al-P and Fe-P + Al-P and Fe-P occluded in the iron oxide). Smeck (1970) found a decrease of the Ca-P and an increase of Al-P + Fe-P + Red-P with increasing textural profile development of the soils.

The Ca-P attains a minimum in the lower A or the upper B horizons which implies that they are the most intensively leached and weathered horizons. As Ca-P is prevalent in the C horizons, one can conclude that the least weathered horizon is the C horizon. This is in accord with the commonly accepted soil genesis theory that the C is less weathered than superjacent B and A horizons.

According to the generalization of Chang and Jackson (1958) the higher the proportion of the Red-P the more the soil is weathered. This has not been substantiated in recent investigations. Mausbach (1969) and Smeck (1970) found high proportions of Red-P in lightly to moderately weathered soils. The Red-P appears to be related to the natural vegetation together with the humid environments rather than to the weathering status of the soil. In the present investigations, the Red-P comprises 40 to 56 percent in the Tama, Clarion, Pershing, Lester and Hayden soils.

To assist in evaluating the profile development and the weathering stage of soils, the max B/min A clay ratios and various IP fraction ratios were calculated and are given in Table 14. The ratios vary considerably in the soils. There seems to be no consistent relationships with the clay ratios and either of the IP fraction ratios. However, the Al-P + Fe-P + Red-P (sesquioxide bound P)/Ca-P will be referred to during the discussion because this ratio includes all the IP fractions and probably is a better indication of IP transformations.

The highest ratio (8.09) of sesquioxide P/Ca-P (Ox-P/Ca-P) is in the Weller soil followed by the Grantsburg (5.67) soil. The B/A clay ratio shows that Weller is more developed and since the pH values are low, the Weller is also more weathered than the Grantsburg soil. The Weller is moderately well drained and the Grantsburg is considered as having slightly poorer drainage condition than the Weller. The Fe-P comprises a larger proportion of the inorganic P fractions in Weller than in Grantsburg. The lower pH of the Weller may account for a larger proportion of the Fe-P. The Ca-P makes a lower proportion of the sum of IP forms in the Grantsburg than in Weller soil. Mausbach (1969) found that the poorly drained soils have more Ca-P and less Ox-P, than the well drained soil. This may correspond to a higher pH in the poorly drained soil. However, the data for another Grantsburg soil indicate that it may be more weathered than Weller. Grantsburg has a fragic horizon and seems to have a lower exchangeable Ca-Mg ratio, slightly lower pH and base saturation than Weller.

If the Weller and Hayden are compared, then higher B/A clay ratios correspond to higher Ox-P/Ca-P ratios.

The ratios of the Ox-P/Ca-P for the Pershing and Cisne are 4.56 and 3.00, respectively. The B/A clay ratios are 1.99 and 2.85, respectively. Thus an increased B/A clay ratio is not accompanied by a higher Ox-P/Ca-P ratio. The Red-P is low in the solum of the Cisne soil and some IP may be in occluded form in iron concretions. The Cisne contains higher proportions of Fe-P throughout the profile. Thus the lower pH of the Cisne may account for the higher proportion of the Fe-P. If the Pershing and Lester, both transition, soils are compared, the Pershing soil is more weathered than Lester, by the criterion of B/A clay ratios and by criterion of Ox-P/Ca-P ratios.

The Ox-P/Ca-P ratios for the Hayden, Lester and Clarion are 2.84, 2.03 and 2.03, respectively. According to these ratios, Hayden is more developed and weathered than the Lester and Clarion soils.

Tama and Clarion soils, both Udolls, have B/A clay ratios of 1.38 and 1.03, respectively. The Ox-P/Ca-P ratios are 3.16 and 2.03, respectively. Thus, there is good correspondence.

The Amarillo and Arvana soils are Paleustalfs. The major difference between these soils is the presence of Petrocalcic horizon in the Arvana soil. This horizon seems to have inhibited transformation of Ca-P to other IP forms. The ratio of the Ox-P/Ca-P is 2.34 in the Amarillo and 1.38 in the Arvana soil.

The Podua soil, a Natrustalf, has the lowest (0.69) Ox-P/Ca-P ratio of all the soils studied for IP fractions, indicating that the phosphorus has transformed to a low degree. The Ca-P dominates throughout the profile relating to high pH values and the aquic conditions prevailing in the soil. In the Gwalior soil, a typic Haplustalf, the Red-P is the largest IP fraction resulting in a Ox-P/Ca-P ratio of 2.22. Thus Gwalior soil is more developed than Podua by either the B/A clay ratio or the Ox-P/Ca-P ratio.

The two Argids studied are the Forrest and Tubac soils. The Tubac soil has a B/A clay ratio of 4.02 and the Forrest soil, a Ustollic Haplargid, has a B/A clay ratio of 3.06. The Tubac soil also has a higher Ox-P/Ca-P ratio than the Forrest soil. Thus Tubac is more developed by both ratios than Forrest, or Typic Paleargids are more strongly developed than Ustollic Haplargids.

As two profiles of the Pullman series were analyzed for IP fractions some test of the Ox-P/Ca-P ratio can be made at the series level. The B/A clay ratios were 1.39 and 1.43. The Ox-P/Ca-P ratios were 1.56 and 1.38. These values can be considered acceptable for a series, and both profiles are of similar development.

Available Phosphorus

The results of available phosphorus (AP) determinations in a number of soil profiles were presented in a previous section under different headings. These data provide an opportunity to compare AP distribution by several taxonomic categories and to evaluate the possible use of AP as a differentiating criteria and for characterization. For this evaluation the weighted average AP for the A horizon, B horizon and control section is used. These values and the taxonomic class of each soil are given in Table 19. The discussion is primarily by order, suborder, great group, subgroup and series.

Although the weighted average values of the AP are used for the characterization and differentiation of taxonomic categories, there are varieties of AP distribution in the

Table 19. Subgroup classification, weighted average of available phosphorus in the A horizon, B horizon and control section and B/A clay ratio for different soils

		Weighted average of AP in ppm/inch			
Subgroup classification	Series	A horizon	B horizon	Control section	B/A clay ratio
Mollic Albaqualfs	Appanoose	18	24	23	2.77
	Belinda	14	24	22	2.89
	Cisne	14	5	6	2.85
	Putnam	11	14	12	4.37
	Rubio	29	14	18	2.29
Typic Albaqualfs	Ames	18	13	14	2.20
	Beckwith	16	28	21	3.05
	Rushville	12	48	40	3.56
Aeric Ochraqualfs	Keomah	13	33	27	2.59
	Luther	0	12	12	1.96
	Rathbun	9	27	28	2.27
Mollic Ochraqualf	Dundas	20	17	17	1.58
Udollic Ochraqualfs	Givin	29	35	29	1.94
	Kniffin	17	20	20	1.49
	Pershing P311	11	24	24	2.06
	Pershing P429	37	22	26	2.00
Typic Fragiudalf	Grantsburg	9	10	8	2.05
Albaquic Hapludalf	Marion	14	23	20	3.77
Aquic Hapludalfs	Weller P909	14	32	16	2.37
	Weller P910	10	35	37	2.37
	LeSueur	24	11	11	1.53
Mollic Hapludalfs	Ladoga	52	22	15	1.60
	Lester-1	5	4	4	1.84
	Lester-2	12	9	9	1.84
	Lester P561	21	17	14	1.32

Table 19. (Continued)

Subgroup classi- fication	Series	Weighted average of AP in ppm/inch			
		A horizon	B horizon	Control section	B/A clay ratio
Typic Hapludalfs	Clinton	26	41	36	1.97
	Hayden-1	10	14	15	1.83
	Hayden-2	11	13	12	2.42
	Hayden P401	15	22	18	1.98
Typic Haplustalf	Gwalior	35	3	5	1.67
Aquic Natrustalf	Podua	2	9	8	1.52
Aridic Paleustalf	Amarillo	7	4	4	1.87
Petrocalcic Paleustalf	Arvana	7	6	6	2.53
Ustollic Haplargid	Forrest	29	4	5	3.06
Typic Paleargid	Tubac	6	3	3	4.02
Typic Argialboll	Edina	20	8	11	2.52
Typic Argiaquolls	Haig	23	9	12	1.94
	Taintor	14	8	8	1.16
Typic Haplaquoll	Webster	19	6	8	1.03
Aquic Argiudolls	Grundy	29	11	14	1.35
	Mahaska	15	17	16	1.26
	Seymour	13	13	12	2.07
Typic Argiudolls	Otley	22	12	14	1.25
	Tama	38	20	9	1.38

Table 19. (Continued)

Subgroup classi- fication	Series	Weighted average of AP in ppm/inch			
		A horizon	B horizon	Control section	B/A clay ratio
Aquic Hapludolls	Nicollet	22	17	9	1.04
Typic Hapludolls	Clarion P97	15	5	6	1.05
	Clarion-1	13	3	5	1.03
	Clarion-2	8	3	4	1.11
Torrertic Paleustolls	Pullman-1	48	24	24	1.39
	Pullman-2	30	9	7	1.43

profiles. In general, the AP is high in the surface layers, then it decreases gradually and/or abruptly to a minimum in the lower A or upper B horizons. In some soils, the AP increases greatly in the B horizon while in other soils the AP values remain about constant after an initial decrease. In some soils the AP increases slightly in the lower B and the C horizons. These kinds of AP distribution in soil profiles were also reported by Runge (1963) and Smeck and Runge (1971).

Runge and Riecken (1966) interpreted that the high amount of phosphorus in the surface layers of Mollisols is due to inorganic and easily mineralized organic phosphorus from plant residues, the decrease in the lower A and upper B horizons is caused by constant removal of phosphorus by the plant roots and the increase in the lower B and upper C horizons is due to weathering of parent material and illuviation from upper layers.

Relationship of available phosphorus to taxonomic categories

The weighted average values of AP for the A horizon, B horizon and control section for all the soils were calculated. These values are given in Table 19 along with the subgroup name for each soil. To evaluate whether the AP bears any consistent relationship with soil taxonomy, the average AP values of each soil were used to obtain an average value for a particular class of the category. The soils studied are placed in 3 orders, 8 suborders, 15 great groups and 24 subgroups. In the following discussion the characterization of the taxonomic categories with respect to the available phosphorus content has been attempted.

Order In Table 20 the weighted average values of AP are given according to orders. The content of AP in the A horizons appears to be a criterion for distinguishing the Alfisols and Mollisols. The AP content of the A horizons of the Mollisols is higher than in Alfisols. This is in agreement with the general notion that the surface layer of Mollisols are more fertile than that of Alfisols. The high content of the AP in the B horizons of the Alfisols distinguishes them from the Mollisols. This indicates that the subsoils of the Alfisols are more fertile with respect to AP than the Mollisols.

Table 20. Weighted averages of available phosphorus according to orders

	Weighted average of AP in ppm/inch					
	A horizon		B horizon		Control sec.	
Order[a]	Ave.	Range	Ave.	Range	Ave.	Range
Alfisols (33)	15	2-52	15	3-48	13	4-40
Aridisols (2)	18	6-29	4	3-4	4	3-5
Mollisols (15)	25	8-48	11	3-24	11	4-24

[a]Numbers in parentheses indicate number of profiles studied.

The higher amounts of AP in the A horizons of the Mollisols seem to be related to the greater amount of organic matter accumulation in Mollisols. This may result in release of soluble nutrient ions through the decay of plant and other biota remains.

The Aridisols have low amounts of AP in the B horizons suggesting that the AP is only concentrated in the surface layers. The average values of AP for the control sections are 13 ppm, 11 ppm, and 4 ppm in the Alfisols, Mollisols, and Aridisols, respectively.

Suborder The average values of AP differentiate the classes of the suborders more clearly (Table 21) than the classes at the order level. The Aqualfs and Udalfs have higher amounts of AP in the A and B horizons and consequently in the control sections than any of the other suborder classes.

Table 21. Weighted averages of available phosphorus according to suborders

	Weighted average of AP in ppm/inch					
	A horizon		B horizon		Control sec.	
Suborder[a]	Ave.	Range	Ave.	Range	Ave.	Range
Aqualfs (16)	17	9-37	23	5-48	21	6-40
Udalfs (13)	13	5-52	16	4-41	13	4-37
Ustalfs (4)	15	2-35	6	3-9	6	4-8
Argids (2)	18	6-29	4	3-4	4	3-5
Alboll (1)	20	-	8	-	11	-
Aquolls (3)	19	14-23	8	6-9	9	8-12
Udolls (9)	21	8-38	13	3-20	10	4-16
Ustolls (2)	39	30-48	17	9-24	16	7-24

[a]Number in parentheses indicates number of profiles studied.

On the average, soils of these two suborders contain higher amounts of AP in the B horizons than in the A horizons. The Udalfs have higher amounts of AP in the B horizons than do the Ustalfs.

The Albolls, Aquolls and Udolls are characterized by having more AP in the A horizons than in the B horizons. However, there is little or no difference between the Albolls, Aquolls and Udolls with respect to the average AP values in the A horizons and control sections. The AP content in the B horizons of the Udolls is slightly higher than associated

Albolls and Aquolls. The better drainage conditions in Udolls may cause more leaching of the AP resulting in the higher amounts of the AP in the B horizons of the Udolls than in Aquolls.

The weighted average AP values for the control sections of the Ustalfs, Argids, Aquolls, Udolls, and Ustolls range only from 4 to 10 ppm whereas the values for the Aqualfs and Udalfs range from 13 to 21 ppm. Thus AP has possibilities as a differentiating criterion. According to Table 21, soils developed under forest in moist (aquic and udic) areas have more AP than soils developed under prairie in similar moisture areas.

Great group The weighted average values of AP of the soils studied arranged by great groups are given in Table 22. The values for the Albaqualfs, Ochraqualfs and Hapludalfs are very close to each other and thus AP does not differentiate the soils having albic and ochric horizons. The reason may be that the soils of these great groups are developed under the same climatic region and under the forest and/or forest encroached on prairie. The soils are considered to have about the same extent of leaching and weathering. But the Fragiudalf has low amounts of AP in the A and B horizons. The only representative of this great group studied is the Grantsburg soil. The strong acid nature of the profile may account for the low values of the AP. Thus soils with fragipan possibly may be characterized as having low AP in the solum.

Table 22. Weighted averages of available phosphorus according to great groups

	Weighted average of AP in ppm/inch					
	A horizon		B horizon		Control sec.	
Great group[a]	Ave.	Range	Ave.	Range	Ave.	Range
Albaqualfs (8)	16	11-29	23	5-48	21	6-40
Ochraqualfs (8)	18	9-37	22	12-35	21	12-29
Fragiudalf (1)	9	-	10	-	8	-
Hapludalfs (12)	17	5-52	21	4-41	18	4-37
Haplustalf (1)	35	-	3	-	5	-
Natrustalf (1)	2	-	9	-	8	-
Paleustalfs (2)	7	7	5	4-6	5	4-6
Haplargid (1)	29	-	4	-	3	-
Paleargid (1)	6	-	3	-	3	-
Argialboll (1)	20	-	8	-	11	-
Argiaquolls (2)	19	14-23	9	8-9	10	8-12
Haplaquoll (1)	19	-	6	-	8	-
Argiudolls (5)	25	13-38	15	11-20	13	9-16
Hapludolls (4)	17	8-22	11	3-17	7	4-9
Paleustolls (2)	39	30-48	17	9-24	16	7-24

[a]Number in parentheses indicates number of profiles studied.

There is little variation in the average values of the AP in the Argialboll, Argiaquolls and Haplaquoll. The AP thus does not aid in differentiating the soils of these great groups. The more or less similar conditions of the natural drainage in the soils seem to have a uniform effect on the AP contents of these soils. The role of prairie in their formation may also be a factor in similar AP values. The Argiudolls and Hapludolls contain higher amounts of AP in the B horizons than the other great groups of the Mollisol order. The Argiudolls contain the higher amounts of the AP in the A horizons and B horizons than the Hapludolls. The Argiudolls studied are the loess soils while the Hapludolls studied are the till derived soils, and the different kind of parent material may be the cause for the higher amounts of the AP in the Argiudolls than Hapludolls. Till parent materials are usually lower in total phosphorus than loess parent material (Mausbach, 1969).

The Natrustalf contains higher amount of AP than the Haplustalf and the Paleustalfs. The only representative of the Natrustalf is the Podua soil. The Podua soil contains a high proportion of the Ca-P which may account for the higher AP values in the profile of this soil.

The AP contents in the B horizons of the strongly developed Paleustalfs are slightly higher than the Haplustalf. The great groups of the Ustalf suborder seem to differ in the amounts of AP in the B horizons.

The Paleargid (Tubac) contains lower values of AP in the B horizon and control section than the Haplargid (Forrest). The lower clay and total carbon content of the Tubac soil than the Forrest soil seems to be a reason for the lower AP content.

Subgroup The subgroups of only those great groups which have more than one representative of the subgroup are discussed here. The effect of subgroup diagnostic criteria on AP can be evaluated.

The mollic subgroup of the Albaqualfs, Ochraqualfs and Hapludalfs great groups is characterized by having a higher amount of the AP in the A horizons and lower amount in the B horizons than the other subgroup of the corresponding great groups (Table 23). The soils of the mollic subgroup are the intergrades towards the Mollisols, and the AP results show that the AP content is higher in the A horizon than in the B horizons, which is true also of the Mollisols.

The average AP content in the B horizons of the Typic Albaqualfs is almost twice the amount of AP in the B horizon of the Mollic Albaqualfs. In the Ochraqualfs, the soils of the Udollic subgroup have higher values of AP throughout the profiles. The moist nature of these soils may account for the higher values of the AP than the soils of Aeric and Mollic subgroup. However, the average AP values in the B horizons of the Udollic and Aeric subgroups of the Ochraqualf great group are very similar and there is no clear effect of Udollic, Aeric and Mollic criteria on AP. The weighted average values

Table 23. Weighted averages of available phosphorus according to subgroups

Subgroup[a]	Weighted average of AP in ppm/inch					
	A horizon		B horizon		Control sec.	
	Ave.	Range	Ave.	Range	Ave.	Range
Mollic Albaqualfs (5)	17	11-29	16	5-24	16	6-23
Typic Albaqualfs (3)	15	12-18	30	13-48	25	14-40
Aeric Ochraqualfs (3)	11	9-13	24	12-33	22	12-28
Mollic Ochraqualf (1)	20	-	17	-	17	-
Udollic Ochraqualfs (4)	24	11-37	25	20-35	25	20-29
Albaquic Hapludalf (1)	14	-	23	-	20	-
Aquic Hapludalfs (3)	16	10-24	26	11-35	21	11-37
Mollic Hapludalfs (4)	23	5-52	13	4-22	11	4-15
Typic Hapludalfs (4)	16	10-26	23	13-41	20	12-36
Aridic Paleustalf (1)	7	-	4	-	4	-
Petrocalcic Paleustalf (1)	7	-	6	-	6	-
Typic Argiaquolls (2)	19	14-23	9	8-9	10	8-12
Aquic Argiudolls (3)	19	13-29	14	11-17	14	12-16
Typic Argiudolls (2)	30	22-38	16	12-20	12	9-14
Aquic Hapludoll (1)	22	-	17	-	9	-
Typic Hapludolls (3)	12	8-15	4	3-5	5	4-6

[a]No. in parentheses indicates number of profiles studied.

of the AP in the soils of Albaquic, Aquic and Typic subgroups of the Hapludalf great group are also close to each other and available phosphorus does not differentiate these soils at the subgroup level.

The Petrocalcic Paleustalf (Arvana) has more AP in the B horizon than the Aridic Paleustalf (Amarillo). This may be accounted for by the calcareous nature of the B horizon of the Arvana soil.

The Argiudolls differ only slightly among themselves. The aquic subgroup shows slightly lower values of AP in the A and B horizons than the typic subgroup. But in the case of Hapludolls, the soil (Nicollet) of the aquic subgroup contains the higher amounts of AP in the profile than the Typic Hapludoll (Clarion). The higher organic matter and clay content of the Aquic Hapludoll may be the cause of higher AP than in the Typic Hapludolls. But this relationship does not hold true for the Argiudolls.

In general, there seems to be less clear effect of AP at the subgroup level than at the great group level. Perhaps this is because differentiation of subgroups of great groups is dependent on minor morphological criterion.

<u>Series</u> The range of the available phosphorus in and between series are expected since a soil series has certain range of color, subsoil character, slope, etc. and the series differ from each other in terms of origin. Here the discussion is centered around the variation of AP amounts and distribution

in various profiles of certain series.

For some series more than one profile was analyzed for AP. These are the profiles of Weller, Pershing, Hayden, Lester, Clarion and Pullman series. The weighted average values of AP in ppm per inch for the profiles of these series are given in Table 9. The average values of AP in the horizons of the two Weller profiles are similar. Likewise, the two Pershing are alike in the content of AP in the B horizon. All three Clarion profiles have low AP in the B. However, the values of AP in the surface layers are quite variable in each series, perhaps the result of past soil treatment.

However, the B horizon AP value ranges from 13 to 22 ppm per inch in the Hayden series. The profile with the lowest AP value has slightly higher pH value than the other two Hayden values (Appendix IV and V). The AP values in the Lester series range from 4 to 17 ppm per inch in the B horizon. As the Lester series is transition to the Hayden and Clarion series perhaps its AP values will range more widely than either the Clarion and Hayden series.

To examine the distribution of AP in the different profiles of the Weller series the AP data are plotted in Figure 43 and for the profiles of the Hayden, Lester and Clarion series in Figure 44. The pattern of the distribution of AP in these profiles is the same but the amounts of AP differ by depth. The maximum values of AP is about the same in each profile of the Weller series. But in the Hayden and Lester

Figure 43. Distribution of available phosphorus and clay in the Weller P909 and Weller P910 profiles

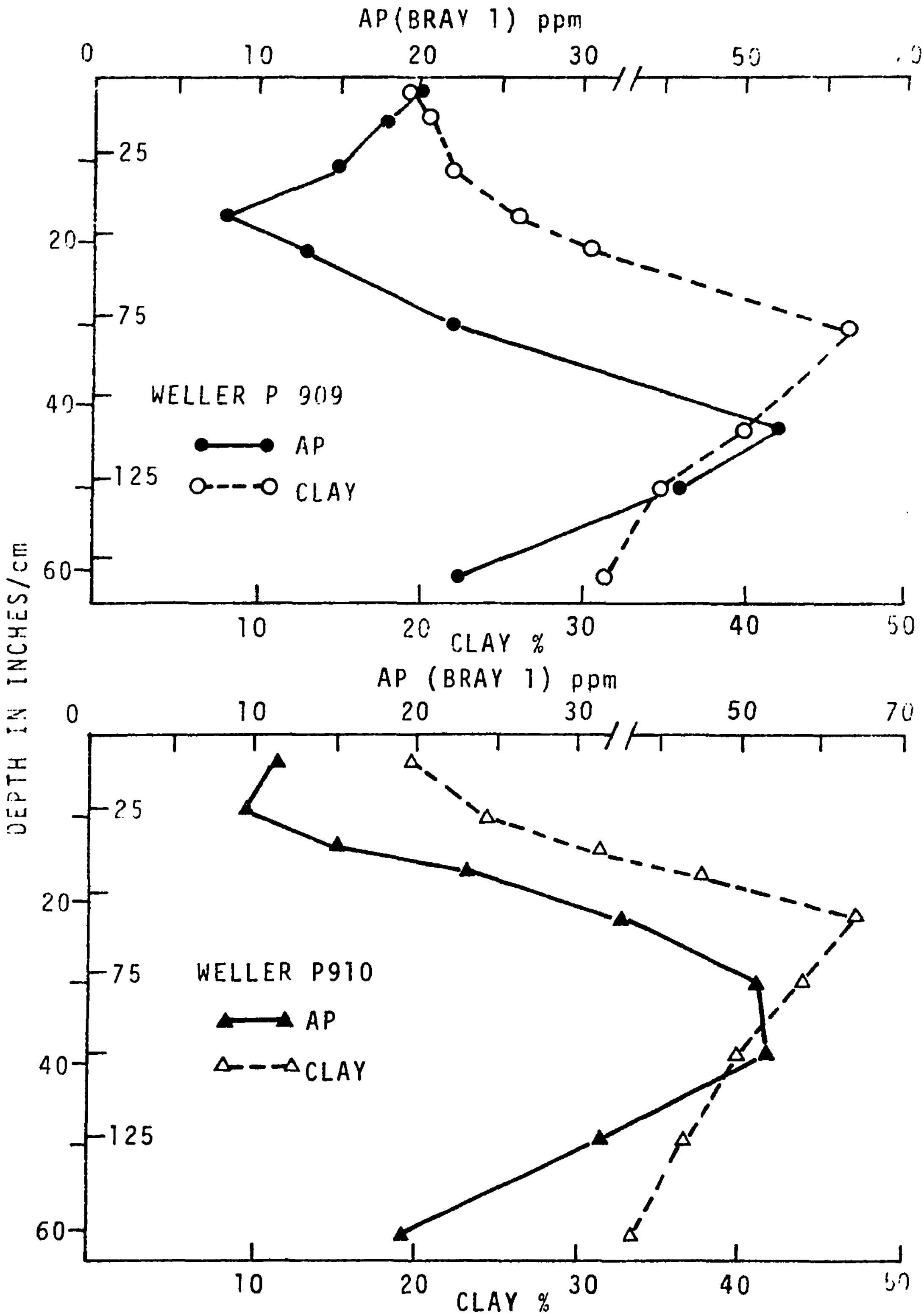
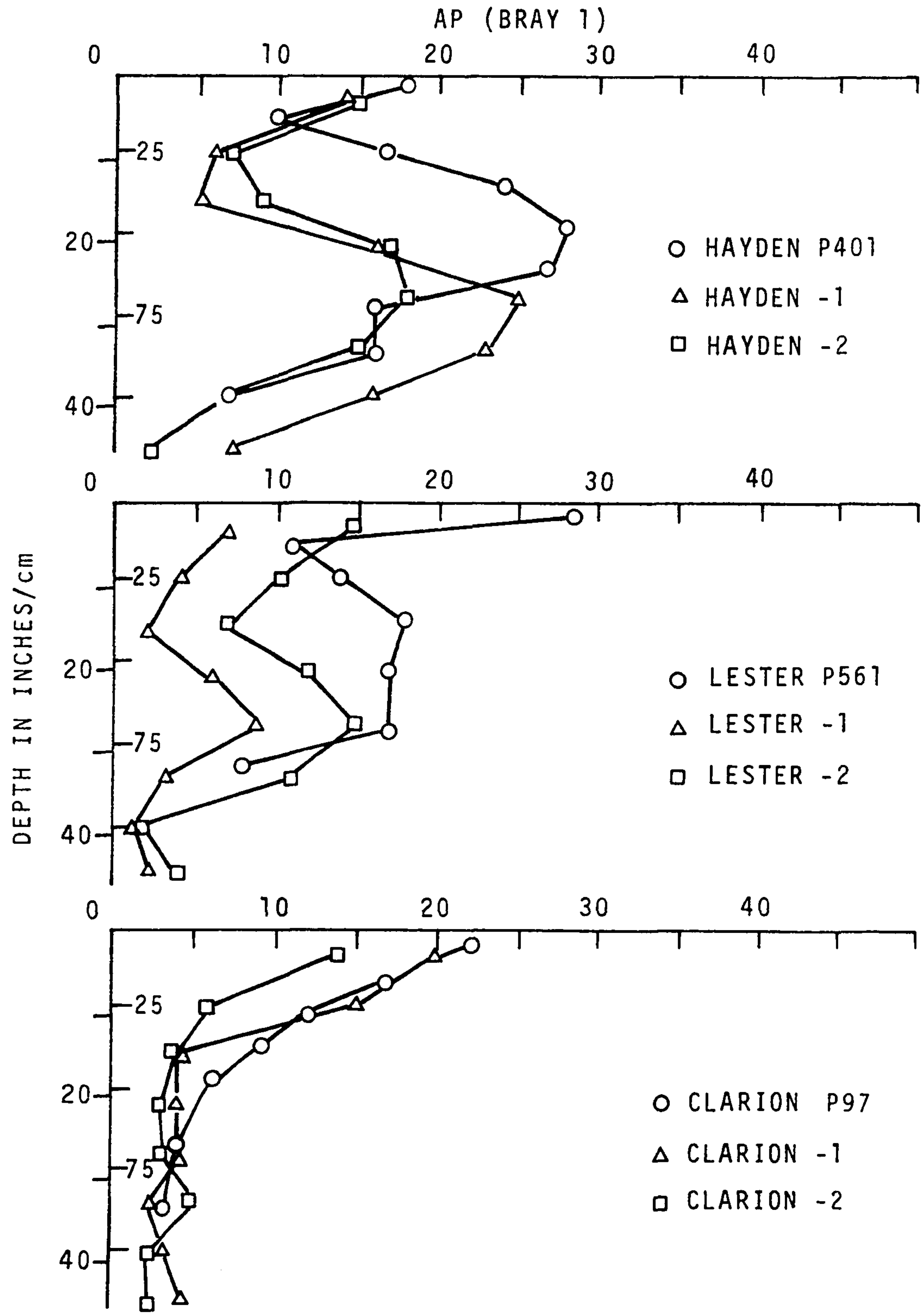

AP(BRAY 1) ppm
0
10
20
30
50
70
WELLER P 909
AP
CLAY
CLAY %
DEPTH IN INCHES/cm
25
20
75
40
125
60
AP (BRAY 1) ppm
WELLER P910
AP
CLAY
CLAY %

Figure 44. Distribution of available phosphorus in different profiles of the Hayden, Lester and Clarion series


AP (BRAY 1)
0
10
20
30
40
25
20
75
40
HAYDEN P401
HAYDEN -1
HAYDEN -2
DEPTH IN INCHES/cm
LESTER P561
LESTER -1
LESTER -2
CLARION P97
CLARION -1
CLARION -2

series, the maximum AP values in the profile are different. The AP contents in the different profiles of the Clarion series are about the same.

All the factors responsible for these differences are not obvious. However, the different amounts of AP at different depths in the profiles seem to be affected by the clay contents and the depth of occurrence of the maximum clay in the profiles. For each series, if the depth of the maximum clay zone is shallow, the depth of the maximum AP zone is also shallow (Figure 43). This relationship holds true for the profiles of the Weller, Pershing, Hayden and Lester series. This suggests that the distribution of AP is related to the degree of development of the profile and the position of the maximum clay zone in the profile. However, the maximum AP value is usually in the layer immediately below the zone of maximum clay content in these profiles.

The profiles of the Clarion soil series show about the same values of AP indicating more homogeneity as regards AP in the prairie formed Clarion soil than in either the Hayden and Lester series. The reason for a low AP in the subsoil of the Clarion soil may be due to the presence of considerable organic P in many prairie formed soils (Kosse, 1966; Runge, 1963). Immobilization of P in organic phosphorus form would make less P available for IP forms and transfer of P from the A to the B horizon.

It is to be mentioned here that the AP values for the profile samples taken 20-25 years ago and for the profile samples recently sampled do not vary for a particular series. The profiles, Hayden P401, Lester P561, Clarion P97, and Pershing P429 were sampled in the 1940's and 1950's. The AP profile values show the same distribution pattern and maximum AP values as those of recently sampled profiles.

Relationship of AP to B/A clay ratio The profile distribution of the AP values vary widely between the series. There are several factors which can be used to explain the amounts and distribution of AP in a series. Since much of the discussion on profile AP values centers on weathering examination is warranted of the AP distribution in soil series according to their degree of profile development, a measure of weathering. Several investigators (Allaway and Rhoades, 1951; Chang and Jackson, 1958; Smeck and Runge, 1971) have concluded that there is a definite relationship between the amounts and distribution of P in soils and degree of profile development. This conclusion was supported in the previous subsection. The B/A clay ratio is often used as a measure of profile development. This ratio of a number of the soils of this study is given in Table 19. This ratio seems to bear a relationship with the average value of AP in the B horizon and control section. And in general, although a few exceptions exist, the higher the B/A clay ratio the larger the average AP content of the soil. The relationship appears to be more consistent in the Alfisols than in Mollisols. Furthermore, it is more consistent among the soils in a class of a subgroup.

Although the B/A clay ratio in the Cisne profile is high (2.85), the AP content is low. The Grantsburg also has a high ratio, but the availability of phosphorus is low. The increased leaching as indicated by low pH and advanced stage of development seems to account for the low AP content. The strong acid nature of these soils also suggests that the soluble P might be fixed by iron and aluminium compounds which generally prevail in acid soils. Perhaps occluded Al-P and Fe-P forms are important in these soils. Chang and Jackson (1958) mentioned that the formation of iron and aluminium phosphate compounds account for high phosphate fixation in acid soils.

But this is not always true. For example, the Weller profile is more acid than the Grantsburg profile studied. The B/A clay ratio of the Weller is also higher (2.37) than in Grantsburg. But the availability of phosphorus is considerably higher in the Weller soil. The Grantsburg has a "fragic" horizon and soil forming processes causing a fragic horizon may be responsible for low AP in this soil.

Considering the prairie derived soils, the B/A clay ratio in the Haig is higher than Taintor soil. The AP content in the control section of the Haig is also higher than Taintor. Another example is that of the Tama and Otley soils, the AP content in the B horizon of the Tama is higher and it also has higher B/A clay ratio than Otley.

However, the relationship between the B/A clay ratio and the AP content seems to be confounded by other soil factors and soil properties. Some of these are discussed later.

Relationship of AP to soil sequences Since most of the results of AP were presented according to sequences, AP amounts and distribution in soils should be examined in relation to profile development and drainage class. The discussion is centered on the biosequence soils to evaluate whether or not they bear consistent relationship with other soil factors such as drainage and landscape position.

All the till derived biosequence soils (Figure 35) represent the minimal degree of profile development for their subgroup. However, the degree of development increases towards the forest end of the biosequence and so the AP content in the B horizon increases. The Hayden, Luther and Ames biosequences also form a hydro-toposequence. The well drained Hayden is higher in AP content than the somewhat poorly drained Luther and poorly drained Ames. The better drained conditions in the Hayden soil may account for more leaching and lower pH resulting in higher values of AP. Considering the Clarion-Nicollet-Webster as a hydro-toposequence, the Webster soil contains higher amounts of AP than the Nicollet and Clarion soils. The erosion might move some material to the lower landscape position, thus shortening the AP rich zone in Clarion and lengthening the zone in the Webster soil. The less apparent difference between the transition LeSueur and the forest soil Luther in a biosequence is possibly due to less forest influence in the Luther profile.

The Clinton, Keomah and Rushville biosequences are of medial degree of profile development. These sequences also form a drainage sequence consisting of well drained, somewhat poorly drained and poorly drained members. Comparing the prairie members, the poorly drained Taintor is low in AP, the somewhat poorly drained Mahaska is high and the well drained Otley is intermediate in the AP contents (Figure 36). Comparing the forest soils, the poorly drained Rushville is high in AP content followed by the Clinton and Keomah. In this case, the AP data show no trend according to the drainage class because it appears to be confounded with other soil properties as pH, clay and organic carbon.

The Weller, Rathbun, Beckwith, Appanoose and Marion biosequences form a sequence of increasing degree of the profile development. All the soils represent maximal profile development. The Weller and Rathbun biosequence soils are moderately well drained and somewhat poorly drained, respectively. The soils of the rest of the biosequences are poorly drained. The effect of vegetation on the profile distribution of AP is very well expressed in the somewhat poorly to moderately well drained Weller, Pershing and Grundy soils.

The distribution pattern of AP in the poorly drained prairie Seymour, Haig and Edina soils is similar showing an increase in the B horizons and again in the C horizons. The reason for replenishment of AP at increasing depth may be the additional moisture in impeded drainage condition. The Belinda soil shows a characteristic abrupt increase of AP in the zone of 19 to 24 inches which corresponds to the abrupt increase of the clay content. The transition soil Appanoose contains considerable amount of the AP like the forest soils.

In terms of the profile development, the Putnam and Marion soils can be considered to be highly leached and weathered as indicated by the acid pH throughout the profile. The low AP contents of these soils are likely due to their intense weathering to which they have been subjected. It should also be mentioned that Godfrey and Riecken (1954) noted low amounts of total phosphorus in these soils.

Soil mapping units   Soil mapping units include information about percent slope and degree of erosion. It has been recognized that slope class and often erosion class are essential parts of a soil for its classification, mapping and interpretation. In Iowa, soil scientists are confronted with the problem of placing the "eroded" prairie derived soils in the Mollisol or the Alfisol order. Often slope and erosion phases of soil series differ mainly in the thickness of the A horizon, clay content of the A horizon and organic carbon content. The depth to 0.58 percent organic carbon is shallow in the eroded prairie derived profiles and these soils do not meet the mollic epipedon requirement of Mollisols. Then, soil scientists are tempted to place such soils in the Alfisol order on the basis of organic carbon distribution.

A perusal of Figures 40 and 41 indicate that with respect to the AP distribution the eroded Sharpsburg (Typic Argiudolls) and Nira (Typic Hapludolls) are quite different in AP from the Ladoga (Mollic Hapludalfs) and Hedrick (Mollic Hapludalfs) soils, respectively. The depth to 0.58 percent organic carbon of these eroded mapping units are given in Table 24 and the values are close to each other. The weighted average AP values (Table 24) for the eroded Sharpsburg and Nira soils are lower than for the Ladoga and Hedrick soils. This supports the view that eroded phases of the Sharpsburg and Nira soils should be classified as Mollisols. This would recognize their genetic origin.

Relationship of available phosphorus to soil forming factors

The AP data of individual profiles will be briefly contrasted according to parent material, vegetation and climatic factors of soil formation.

Parent material   The amount of AP in soils depends also on its parent material. The Cary till and loess derived soils of Iowa provide a comparison of AP according to parent materials. These soils are developed under the same climate. The soils formed in Cary till contain lower AP values than the loess soils formed under the same kind of natural vegetation (Table 25). For example, the forest soils Hayden, Luther and Ames formed in Cary till have about half the amount of AP than

Table 24. Slope class, erosion class, the weighted averages of AP per inch and depth to 0.58% organic carbon for soils from Adair County

Series	Slope	Erosion	AP in 0-36" ppm/inch	Depth to 0.58% OC
Ladoga	B	1	20	17
Ladoga	C	2	52	6
Sharpsburg	B	1	16	17
Sharpsburg	C	2	15	5
Hedrick	D	1	38	8
Nira	C	2	7	12
Nira	D	2	5	11

is present in the forest-loess soils, the Clinton, Keomah and Weller.

This kind of relationship with respect to total phosphorus and dilute acid soluble P was also found by Pearson et al. (1940), Fenton et al. (1967) and Mausbach (1969). They reported lower values of total P in till soils than in loess soils. The higher values of AP in loess soils than in till soils apparently are due to higher content of total P in loess soils. The loess is a sorted material, and it seems that the P rich material might have blown up and deposited leaving the P deficient coarse particles at the source sites.

Table 25. Weighted averages of AP per inch in the control section of till and loess derived soils arranged in biosequences

Forest soils		Transition soils		Prairie soils	
Series name	AP	Series name	AP	Series name	AP
Till derived soils in biosequences					
Hayden-1	15	Lester-1	4	Clarion-1	5
Hayden-2	12	Lester-2	9	Clarion-2	4
Hayden P401	18	Lester P561	14	Clarion P97	6
Luther	12	LeSueur	11	Nicollet	8
Ames	14	Dundas	17	Webster	8
Loess derived soils in biosequences					
Clinton	36	Ladoga	15	Otley	14
Keomah	27	Givin	29	Mahaska	16
Rushville	40	Rubio	18	Taintor	8
Weller P910	37	Pershing P911	24	Grundy	14
Weller P909	16	Pershing P429	26		
Rathbun	28	Kniffin	20	Seymour	15
Beckwith	21	Belinda	22	Haig	12
		Appanoose	23	Edina	11
Marion	20			Putnam	12

<u>Vegetation</u> The relative distribution and amounts of AP for the biosequence soils formed in both kinds of parent materials is the same (Figures 34 through 38 and Table 25). It is apparent from the Figures 35 and 38 that the prairie and forest soils fit into clearly defined trends of AP distribution with depth. In general, the surface layers of the soils contain high amounts of the AP, it decreases in the lower A or upper B horizons. The AP decreases rather sharply in the lower A horizons of the forest soils compared to

prairie soils indicating that the AP leached out to the B horizons. A noticeable increase in the B horizons of the forest and transition soils supports this view. In the prairie formed soils the increase of AP in the B horizon generally does not occur. However, a slight increase of AP in the lower B and C horizons of some prairie soils was noticed. The explanations for the patterns of distribution of AP characteristic of forest and prairie soils have been discussed previously. Table 25 shows that the average AP values are the least for prairie soils, greatest for forest soils and intermediate for the transition soils.

In a recent study, Hinkley, Runge and Pedersen (1970) also found the same kind of profile distribution of AP in biosequence soils. Consequently, the profile distribution of AP may be useful in differentiating soils formed under forest from those formed under prairie. The depth of occurrence of TP minima was also found to be useful in differentiating forest, transition and prairie soils (Fenton et al., 1967). According to these investigators depth to TP minimum was greatest in the prairie soil, least in the forest soil and intermediate in the transition soil.

Climate The Ustalfs, Argids and Ustolls occurring in regions of semiarid to arid climates contain on an average 5 ppm of the AP in the control section. The parent material and the natural vegetation for these soils is not the same but they contain low amounts of AP within the control section. It seems that the effect of climate overshadows the effect of the parent material, vegetation and other conditions of soil formation.

Relationship of Available and Inorganic Forms of Phosphorus to Some Other Soil Properties

The amounts and distribution of available phosphorus and inorganic P fractions in relation to soil properties such as clay, pH and organic carbon have been discussed by Westin and Buntley (1966b) and Hawkins and Kunze (1965). Hawkins and Kunze also discussed AP (Olsen) relating it to the IP fractions. Westin and Buntley and Mausbach (1969) computed various correlations also. No consistent relationships were reported by these investigators, the relationship varied due to position of sample and the kind of soil. In this subsection, the relationship between IP and AP, pH and organic carbon are briefly discussed. In the previous discussions the relationship between the clay content and IP and AP has already been evaluated using the B/A clay ratios.

Inorganic P fractions and available phosphorus

It is known that available soil phosphorus determined by a chemical method includes all the forms of phosphorus but mainly is related to calcium, aluminium and iron phosphates. The relative amounts of phosphorus dissolved from the various forms of phosphates in soils depends on the relative amounts of Ca-P, Al-P and Fe-P in a soil and the relative solubilities of these phosphates in the extractant.

The data presented in Tables 5 through 10 indicate that, in general, the distribution of AP follows the pattern of distribution of Al-P, Fe-P and in some cases Red-P also. In the Cisne soil only, the AP distribution pattern resembles the pattern of Ca-P distribution within the profile. The Ca-P and the sum of IP fractions follow the same trend in the profile and the trend is different than that of AP, Al-P, Fe-P and Red-P. Mausbach (1969) found a nonsignificant negative correlation with Ca-P and AP.

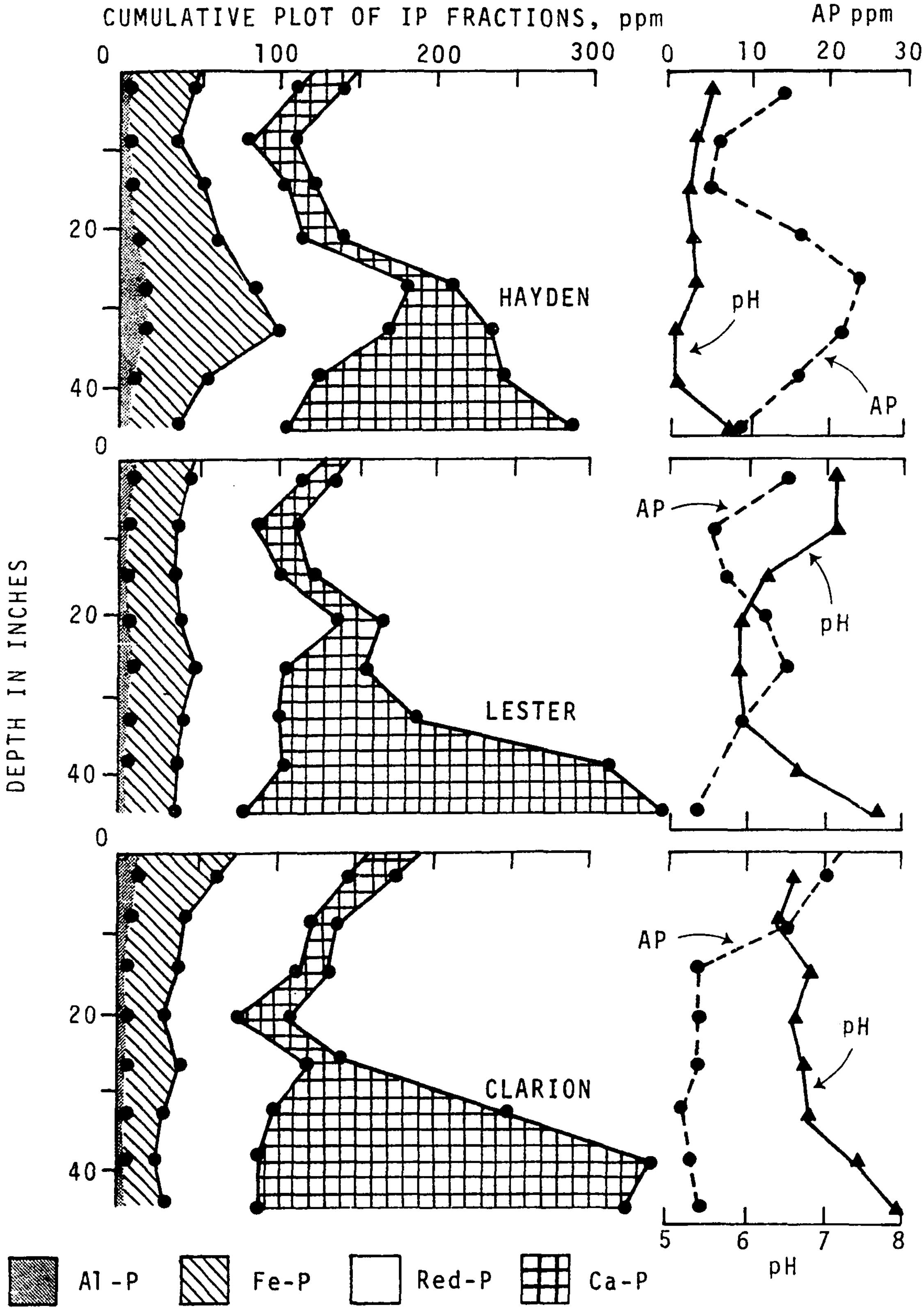
Mausbach (1969) indicated that AP was correlated to Al-P, Fe-P, Red-P and NH_4Cl soluble P showing that as these fractions increase in concentration there is a corresponding increase in AP. The correlation of AP to Al-P seems due to NH_4F used in the Bray reagent. Chang and Juo (1963) reported equally large amounts of AP from all the three groups of soils, soils dominant in Fe-P, Ca-P and Fe-P + Ca-P. Fife (1959) also indicated that the Bray reagent extracted some Fe-P and Ca-P.

The high amounts of AP extracted from the B horizons of Udic and Aquic Alfisols are related to the increase of Al-P, Fe-P and Red-P suggesting that these are the forms involved in the AP extracted by either Bray or Olsen methods. As Ca-P is low in the B horizons of these soils, it would seem that for the samples of the B horizons of the Aqualfs and Udalfs the Ca-P is not positively involved in the AP extracted. The Ca-P increases in the C horizon of these soils but the AP does not increase correspondingly. Westin and Buntley (1966b) found that the higher the AP results by Bray and Olsen tests, the lower the Ca-P, or the higher the Ca-P the lower the AP for both the Bray and Olsen method.

In Figure 45 is shown the relationship of AP to IP fractions. The relationships discussed above become apparent. The similar distribution of Al-P and Fe-P is expected since they both tend to form under similar pH conditions. The Fe-P and Red-P fractions are thought to be related to the iron status of the soil and therefore vary together. As the Ca-P and the sum of IP fractions distributions are the same, this indicates that the Ca-P is an important fraction. Mausbach (1969) reported high correlations between Ca-P and IP, and between IP and TP (total phosphorus). The same reasoning can be given for IP and TP.

The Olsen reagent extracted lower amounts of AP than the Bray 1 reagent but the distribution of AP within the profile remains the same (Figures 23 through 26). This suggests that for soil genesis and classification studies both methods will serve. Breland and Sierra (1962) studied the relative effects of 8 extractants on the removal of P from 7 major soil types of Florida. They found the HCl and NH_4F, and H_2SO_4 solutions extracted more P than the other extractants (0.5 M $NaHCO_3$ was one of them).

Figure 45. Comulative plot of the IP fractions and AP and pH distribution in the Hayden, Lester and Clarion series


CUMULATIVE PLOT OF IP FRACTIONS, ppm
0
100
200
300
AP ppm
0
10
20
30
DEPTH IN INCHES
20
40
HAYDEN
pH
AP
LESTER
CLARION
5
6
7
8
pH
Al-P
Fe-P
Red-P
Ca-P

Forms of phosphorus and pH

The pH values are plotted in Figure 45 along with the AP and IP fractions. The acid nature of the B horizons of Hayden and Lester soils corresponds to the accumulation of Al-P, Fe-P, Red-P and AP. Several other forest and transition soils have shown the same kind of relationship. Mausbach (1969) and Smeck (1970) also found the same relationship, in fact, Mausbach found a negative correlation with pH and Al-P and Fe-P. The relationship between pH and forms of phosphorus in prairie soils and soils from dry climate does not seem to be consistent.

Forms of phosphorus and total carbon

The distribution of AP and Al-P in the prairie formed soils is about the same as that of total carbon. This suggests that the mineralized organic phosphorus contributes to AP and Al-P. The transition and forest soils do not show such relationship; however, the amount of AP in the A horizon seems to be related to total carbon content. Soils from drier regions fail to show a consistent relation and pH seems to be the dominant factor.

Some Implications

The author hopes that he has added impetus to the interest in soil phosphorus in relation to soil genesis and classification. The phosphorus status of a soil reflects climate, vegetation, parent material and possibly some other soil forming processes and agents. Hence available phosphorus with different fractions may prove to be a useful criterion for classifying soils.

The depth distribution of AP varies greatly in different soils. Soil testing which involves only surface soil samples cannot give an adequate estimate of phosphorus fertilizer needs. Runge and Peck (private communication, 1968) concluded that the variable response of added P was attributed to the subsoil AP differences between soils. The implication of this research for soil fertility also is obvious.

The IP fractions will provide more understanding of soil genesis through the relative transformation of Ca-P to other forms, thus suggesting the weathering status of a soil. The paleosols can be detected on the basis of the relatively lower proportion of the Ca-P and higher proportion of Fe-P than the associated soil.

Further Research

The basic objective of this study was to compare the distribution of IP fractions and AP between individual soils and taxonomic categories. This study indicated that the IP fractions and AP could be helpful in characterizing certain taxonomic categories and soil phases. For further testing, an intensive profile sampling would be needed. This should include the typical representatives of the taxonomic categories.

There is a conflict with respect to Red-P. According to Chang and Jackson (1958), the Red-P proportion is high in the more weathered soils. But this study and other studies (Smeck, 1970 and Mausbach, 1969) indicate that the Red-P proportion is quite high even in the slightly weathered soils, as Tama and Clarion. Further research is needed to test whether the Red-P is related to the natural vegetation or to some other soil properties like iron content. The relation of oxalate and diothionite soluble forms of iron to Red-P should be investigated. Runge (1963) indicated that the segregation of iron and phosphorus go together.

The sequence of transformation of Ca-P under prairie and forest vegetation needs to be verified. It seems that under prairie vegetation most of the Ca-P would go to organic phosphorus and then to inorganic P fractions, while under the forest vegetation Ca-P goes chiefly to IP.

The Bray 1 and Olsen methods of available phosphorus seem to pick up different amounts of IP fractions. Which of the 3 most active IP forms (Al-P, Fe-P and Ca-P) is most soluble in Bray 1 reagent or in Olsen reagent needs to be tested further.

A detailed study to establish the variation of AP according to landscape position of the soil series is needed to solve the problem of classifying eroded soils.

Another area of fruitful research would be to include soils of less development than Clarion and Hayden in order to obtain more information on the various IP forms. Traverses and stages of development from Clarion and Hayden to the calcareous Storden series should provide better information on Ca-P transformations to OP and the several IP forms.

SUMMARY AND CONCLUSIONS

In an effort to search for more and better criteria for soil characterization and classification, the inorganic P fractions (Al-P, Fe-P, Red-P and Ca-P) and available phosphorus contents and their distribution were determined on a variety of soil profiles. This study was limited to the Alfisols and Mollisols. The possibility of using IP and AP forms in differentiating the Alfisols and Mollisols at various taxonomic category levels was assessed.

Ten soil profiles outside of Iowa were studied. The soils of Iowa studied include soils of a biosequence traverse study in Boone County, soils of 11 different biosequences, and soil mapping units of Adair County. The results are presented and discussed in two subsections, inorganic P fractions and available phosphorus. The results are presented under several headings using the suborder names.

The inorganic P was fractionated on 16 soils by the Chang and Jackson method. The relative amounts of IP fractions varied within the soil profiles. The Ca-P is a dominant fraction in the lower B and C horizons. The Red-P and Fe-P are the dominant forms in the A and B horizons. The Red-P constitutes a relatively large proportion of the sum of the four IP forms. The Al-P fraction is low and is relatively constant with depth.

The IP fractions also vary as to climate, vegetation, and parent material. The Ca-P is more prevalent in soils of moderately dry climate. The Red-P makes up a considerably larger proportion in soils of humid climate. Within the same climatic region the percentage of Red-P is higher in soils formed under prairie vegetation than the corresponding soils formed under the woody plants. The native forest vegetation also reflected in the more pronounced accumulation of the Al-P, Fe-P and Red-P (the sesquioxide P fractions) in the B horizons. There is less Al-P, Fe-P and Red-P in the B horizon than is present in the A horizons of the prairie soils. The soils formed in loess show higher values of the sum of IP fractions than the soils formed in Cary till.

The IP fractions proved to be useful for characterizing certain taxonomic categories, particularly at the suborder levels through the effects of climate and vegetation. The Ca-P fraction is larger in the Ustalfs and Ustolls than in Aqualfs, Udalfs and Udolls. The Udolls contain higher amounts of the Red-P and Ca-P than the Aqualfs and Udalfs. The difference between the Ustalfs and Ustolls is less apparent with respect to the IP fractions; however, the Fe-P is slightly higher in the Ustalfs than in Ustolls. The reverse is true for the Red-P. The Paleosols contain considerable amounts of the Fe-P.

The relation between the Max B/Min A clay ratio and sesquioxide P/Ca-P ratio was evaluated in order to characterize the soils in terms of weathering and profile development. The higher clay ratio corresponds to the higher Oxide-P/Ca-P ratio in certain group of soils.

The available phosphorus was determined in 57 soil profiles by the Bray-1 method. The AP was extracted by the Bray-1 and Olsen reagents on 10 profiles to compare the results. The trend of change in values of the AP within each profile extracted by both the methods is the same. The AP values obtained by the Olsen method are slightly lower, however, than those obtained by the Bray-1 method. This suggests that for soil genesis and classification studies both methods will serve.

In general, the available phosphorus is high in the surface layers, then it decreases gradually and/or abruptly to a minimum in the lower A or upper B horizons. In Aqualfs and Udalfs, the AP increases greatly in the B horizons while in many Mollisols the AP values remain about constant after an initial decrease. In some Mollisols the AP increases slightly in the lower B and the C horizons. The AP distribution for the Alfisols and Mollisols is a result of soil genesis processes. The high AP in the surface are due to addition of P fertilizers, manures, accumulation of mineralized P and inorganic phosphorus. The minimum in the lower A and upper B horizons are due to eluviation and plant recycling. The increase in the B horizons and upper C horizons are due to pH, illuviation and lack of removal of weathered compounds by plants.

The soils formed in Cary till also contain lower AP values than the loess soils formed under the same kind of natural vegetation. The profile distribution of AP proved to be useful in differentiating forest, transition and prairie soils. The increase of AP in the B horizon is greatest for forest soils, least for prairie soils and intermediate for transition soils. The soils of moderately dry climate contain low amounts of AP within the control section.

The weighted average values of AP for the A horizon, B horizon and control section of soils were used to characterize the taxonomic categories. The high content of AP in the B horizons of the Alfisols distinguishes them from the Mollisols. The mollic subgroup of the Alfisols is characterized by having a higher amount of AP in the A horizons and lower amounts in the B horizons than the other subgroups.

The pattern of distribution of AP in the different profiles of a particular series is the same but the amounts of AP at depths differ. This was found to be related to the clay contents and depth of the maximum clay zone in the profile. If the depth of the maximum clay zone is shallow, the depth of maximum AP zone is also shallow. The AP maximum lies below the maximum clay zone.

A relationship between B/A clay ratio and AP content in the B horizon or control section was evaluated. Although a few exceptions exist, the higher the B/A clay ratio the larger the average AP value of the soil. The AP data show no consistent trend according to drainage class, except for some prairie sequences.

The erosion and slope phases of some series were studied. The AP results differentiated the series more clearly than the other soil properties. The AP results also recognized the genetic origin of these soils.

In Aqualfs and Udalfs, the AP distribution follows the pattern of distribution of Al-P, Fe-P and Red-P. In Aquolls and Udolls the AP generally follows the pattern of Al-P.

The natural vegetation has had a pronounced effect on the AP content of the B horizons of the profiles.

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APPENDIX I: PROFILE DESCRIPTIONS FOR SOILS OUTSIDE OF IOWA

Series: Cisne

Location: Jasper County, Illinois, T6N, R9E Sec 3 NE160, NW40 Newton soil experimental field, S½ of plot 309, 9 ft N and 25 ft E of SW corner stake of plot 309

Slope: < .25%

Described by: J. B. Fehrenbacher, P. R. Johnson, AHB.

Horizon	Depth inches	Description
A1p	0-8	10YR3/2 with some 3/1 friable silt loam with moderate, fine crumb structure and abrupt, smooth boundary.
A21	8-13	10YR 4.5/a with hole fillings of 5/1 and common, fine distinct 10 YR 5/8 Fe mottlings. Friable silt loam with weak, medium platy structure and clear, smooth boundary.
A22	13-17	10YR 7/2 and some 6/2 friable silt with weak, medium platy structure and abrupt, smooth boundary.
A-B	17-19	10YR 6/1 with common, medium prominent 5YR 4/6 mottlings and heavy 10YR 7/1 silt coatings. Friable to firm, light silty clay loam with moderate, medium to fine angular blocky structure and clear, smooth boundary.
B21	19-28	10YR 5/2 with common, medium, prominent 5YR 4/6 mottles and heavy 10YR 5.5/1 clay skins. Firm, heavy silty clay loam with strong, fine prismatic breaking to strong, fine to medium angular blocky structure. Clear, smooth boundary.
B22	28-37	10YR 5/1.5 with common, medium, distinct 10YR 4/4 mottlings and a few 10YR 5/1 clay coatings. Firm, heavy silty clay loam with moderate, medium angular blocky structure and clear smooth boundary.
C1-D1	37-43	2.5Y 6/2 with common, medium to coarse, prominent 10YR 4/4 mottlings and occa-

		sional 10YR 5/1 clay skin. Firm silty clay loam with some grit and weak, coarse angular blocky structure and gradual, smooth boundary.
D11	43-51	2.5Y 6/2 with common, coarse, prominent 10YR 4/4 mottles. Firm, heavy silty clay loam with some grit and weak, coarse, angular blocky to massive structure.

Series: Forrest

Location: Cochise County, Arizona, 2200'N and 2150'E of SW corner Sec 6, T16S, R24E

Topography: Nearly level to gently sloping valley plains and old fans

Sampled and described by: Richmond and Havens

Horizon	Depth inches	Description
A1	0-4	Brown (7.5YR 5/4) heavy loam, dark reddish brown (5YR 3/4) moist; moderaté coarse platy structure; slightly hard, friable, sticky, slightly plastic; many fine and medium roots; few medium and coarse tubular pores; noneffervescent; slightly acid (pH 6.5); clear smooth boundary.
B21t	4-13	Reddish brown (5YR 4/4) light clay, dark reddish brown (5YR 3/4) moist; moderate medium and coarse subangular and angular blocky structure; very hard, friable, sticky, plastic; many very fine and fine roots; few fine and coarse tubular pores; common pressure faces; noneffervescent; neutral (pH 7.0); clear wavy boundary.
B22t	13-31	Dark reddish brown (2.5YR 3/4) clay, dark reddish brown (2.5YR 3/4) moist; strong, medium prismatic structure; very hard, fr friable, sticky, very plastic; common very fine and fine roots; many pressure faces; noneffervescent; mildly alkaline (pH 7.5); clear wavy boundary.

C1Ca	31-40	Mottled reddish yellow (5YR 6/6) and pinkish white (7.5YR 8/2) gravelly clay loam, yellowish red (5YR 5/6) and pink (7.5YR 8/4) moist; massive breaking to weak medium subangular blocky structure; very hard, friable, sticky, plastic; few very fine and fine roots; common medium and coarse tubular pores; few thin clay films in pores; violently effervescent; moderately alkaline (pH 8.0); gradual wavy boundary.
C2Ca	40-70	Pinkish white (7.5YR 8/2) loam or sandy clay loam, light brown (7.5YR 6/4) moist, with common medium distinct pink (7.5YR 7.4) mottles, yellowish red (5YR 5/6) moist; massive; hard to very hard, friable, slightly sticky, alightly plastic; few fine and medium tubular pores; few gravel; violently effervescent; moderately alkaline (pH 8.2).

Series: Tubac

Location: Cochise County, Arizona, 1850'N and 1650'W of SE corner Sec 23, T17S, R24E

Topography: Nearly level to gently sloping fans and valley slopes

Collected and described by: Richmond and Havens

Horizon	Depth inches	Description
A11	0-2	Yellowish red (5YR 5/6) sandy loam, reddish brown (5YR 4/4) moist; weak thin platy and weak fine granular structure; slightly hard, very friable, nonsticky, nonplastic; many fine and medium roots; common fine vesicular and tubular pores; few fine gravel; noneffervescent; medium acid (pH 6.0); abrupt smooth boundary.
A12	2-12	Yellowish red (5YR 5/6) sandy loam, reddish brown (5YR 4/4) moist; massive; slightly hard, very friable, nonsticky, nonplastic; common fine and medium roots; many very fine, fine and few coarse

		tubular pores; noneffervescent; slightly acid (pH 6.5); clear wavy boundary.
A2	12-16	Light brown (2.5YR 6/4) gravelly sandy loam, dark brown (7.5YR 4/4) moist; massive; hard, very friable, nonsticky, nonplastic; few very fine and fine roots; many fine vesicular and few fine tubular pores; noneffervescent; neutral (pH 7.0); abrupt wavy boundary.
B21t	16-24	Red (2.5YR 4/6) clay, dark red (2.5YR 3/6) moist; strong medium prismatic structure; very hard, friable, sticky, very plastic; common very fine and fine roots; few thin clay films on ped faces; common pressure faces; common dark coatings on ped faces; noneffervescent; moderately alkaline (pH 8.0); gradual wavy boundary.
B22t	24-29	Red (2.5YR 4/6) clay, dark red (2.5YR 3/6) moist; strong medium prismatic structure; very hard, friable, sticky, very plastic; common very fine and fine roots; few thin clay films on ped faces; common pressure faces; common dark coatings on ped faces; approximately 12 to 15 percent gravel; slightly effervescent; moderately alkaline (pH 8.0); clear wavy boundary.
B23tca	29-40	Red (2.5YR 4/6) clay loam, dark red (2.5 YR 3/6) moist; weak coarse prismatic structure; very hard, friable, sticky, plastic; common very fine and fine roots; few fine tubular pores; common pressure faces and dark coatings on ped faces; few gravel; slightly to strongly effervescent, moderately alkaline (pH 8.0); clear wavy boundary.
B3tca	40-48	Yellowish red (5YR 5/6) sandy loam, yellowish red (5YR 4/6) moist; massive; very hard, friable, nonsticky, slightly plastic; few fine roots; few fine tubular pores; many clay coatings and bridges on sand grains; 10 percent fine gravel; slightly effervescent; moderately alkaline (pH 8.0); clear wavy boundary.

C	48-60	Reddish yellow (5YR 6/6) gravelly sandy loam, yellowish red (5YR 5/6) moist; massive; slightly hard, very friable, nonsticky, nonplastic; common thin clay coatings and bridges on sand grains; slightly effervescent; moderately alkaline (pH 8.0).

Series: Grantsburg

Location: Saline County, Illinois, R10S, R5E Sec 30, NE160, NW160, NW40, NE10 on west side of deep side of railroad cut

Slope: 2 to 5%

Sampled and described by: A. H. Beavers, J. B. Fehrenbacher, RBG, PRJ

Horizon	Depth inches	Description
Ap	0-6	10YR 4/2-4/3 friable silt loam with weak fine crumb structure and abrupt smooth boundary.
A2	6-10	10YR 4/3 friable silt loam with moderate, medium platy structure, and abrupt smooth boundary.
B2	10-21	7.5YR 4/4 firm, fine silt loam with moderate, medium subangular blocky structure and clear smooth boundary.
A'2	21-24	Mixed 10YR 5/4 and 7.5YR 4/4 with 7.5YR 4/4 being clay skins at least in part; heavy 10YR 7/2 coatings and seams of fine sand or silt; few, fine 10YR 3/2 Fe-Mn concretionary mottles; firm light silty clay loam with strong medium subangular blocky to blocky structure and clear smooth boundary.
B'2	24-34	10YR 5/4 with thick 5YR 3.5/4 clay skins; common medium distinct 5YR 5/2 mottles and also 10YR 6/3 coatings on aggregate surfaces; very firm light silty clay loam with moderate, coarse prismatic structure breaking to moderate, medium to coarse

		blocky to subangular blocky aggregates; gradual smooth boundary.
B'31	34-41	10YR 5/4 with 7.5YR 4/4 clay skins less pronounced than in horizon above; common, medium, distinct 10YR 4/2 mottles and streaks with some fine 10YR 5/4 Fe-Mn concretionary mottles also present; very firm, fine silt loam with weak coarse blocky aggregates weakly arranged in prisms; vesicular nature of aggregates more pronounced than in horizon above; gradual smooth boundary.
B'32	41-51	10YR 5/4 with thin discontinuous 7.5YR 4/4 clay skins; 10YR 6/3 mottles and streaks less pronounced than in horizon above; some fine 10YR 3/2 Fe-Mn concretionary mottles also present; firm silt loam with little structure except for vesicular condition; gradual smooth boundary.
C1	51-80	5YR 3.5/4 massive firm silt loam; 10YR 6/2-7/2 planes or crack fillings ¼" to 1" wide separate vesicular 1 ft to 2 ft wide polygonal blocks next to 10YR 6/2 silt and clay crack fillings. This horizon appears to be Farmdale loess.

Series: Amarillo

Location: Hockley County, Texas, Spade Ranch, 3.3 miles north on highway 168 from the intersection with highway 116, thence west on ranch road for 1 mile, thence north 0.9 mile thence west for 2 miles

Topography: Nearly level upland

Collected and described by: B. L. Allen and B. R. Tembhare

Horizon	Depth inches	Description
A1	0-7	Brown (7.5YR 4/4) fine sandy loam, dark brown (7.5YR 3/2) when moist; weak, mixed subangular blocky and granular structure; hard when dry, friable when moist; non-calcareous; many roots; smooth, clear

		boundary.
B21t	7-16	Reddish brown (5YR 4/4) sandy clay loam, dark reddish brown (5YR 3/4) when moist; compound, weak prismatic and weak subangular blocky structure; very hard when dry, friable when moist; noncalcareous; many roots; smooth, gradual boundary.
B22t	16-27	Yellowish red (5YR 4/6) sandy clay loam, yellowish red (5YR 4/6) when moist; compound, moderate prismatic and moderate subangular blocky structure; very hard when dry, friable when moist; noncalcareous; common roots; smooth, clear boundary.
B23t	27-37	Yellowish red (5YR 4/8) sandy clay loam, yellowish red (5YR 4/6) when moist; compound, weak prismatic and moderate subangular blocky structure; very hard when dry, friable when moist; noncalcareous; few roots; irregular, clear boundary.
B24tca	37-45	Yellowish red (5YR 4/8) sandy clay loam, yellowish red (5YR 4/8) when moist, weak prismatic and very weak subangular blocky structure; very hard when dry, driable when moist; $CaCO_3$ occurs mostly as films and threads and as masses forming weakly cemented areas; few roots; irregular, clear boundary.
B25tca	45-54	Reddish yellow (5YR 6/8) sandy clay loam, yellowish red (5YR 5/8) when moist; weak subangular blocky structure, approaching massive; very hard when dry, friable when moist; estimated 40% $CaCO_3$ masses; few roots; diffuse boundary.
B26tca	54-70	Reddish yellow (5YR 6/8) sandy clay loam, yellowish red (5YR 5/8) when moist; very weak subangular blocky structure; very hard when dry, friable when moist; approximately 30% $CaCO_3$; few roots; diffuse boundary.
B27tca	70-100	Reddish yellow (5YR 6/8) sandy clay loam, reddish yellow (5YR 6/8) when moist; very hard when dry, friable when moist; calcareous.

B28tca	100-112	Reddish yellow (5YR 7/6) fine sandy loam, reddish yellow (5YR 6/6) when moist; very hard when dry, friable when moist; calcareous.
Cca	112+	Pink (5YR 7/4) sandy clay loam, light reddish brown (5YR 6/4) when moist; very hard when dry, friable when moist; calcareous.

Remarks: Below the B23t horizon dry colors vary from yellowish red (5YR 4/8) and reddish yellow (5YR 6/8) to pink (5YR 8/3 and 8/4).

Series: Arvana

Location: Andrews County, Texas, 9.1 miles east of Andrews, highway 176 thence approximately 0.3 mile north

Topography: Flat

Collected and described by: B. L. Allen and B. R. Tembhare

Horizon	Depth inches	Description
A1	0-7	Dark brown (7.5YR 4/4) loamy sand, dark reddish brown (5YR 3/4) moist; weak to medium subangular blocky structure; slightly hard, very friable; common very fine roots and pores; noncalcareous; clear wavy boundary.
B2t	7-18	Yellowish red (5YR 4/6) loamy sand, dark reddish brown (5YR 3/4) moist; moderate coarse prismatic and moderate subangular blocky structure; slightly hard, very friable; few fine roots and common fine pores; noncalcareous; patchy clay films on ped faces; gradual boundary.
B3t	18-21	Sandy loam; weak medium prismatic and weak subangular blocky structure; slightly hard, friable; few fine roots; common very fine pores; calcareous; abrupt wavy boundary.
B1ca + B3t	21-26	Very pale brown (10YR 8/4) sandy clay loam, very pale brown (10YR 7/4) moist; common large (two to three inches in diameter)

		strongly cemented caliche fragments; structure of noncarbonate masses is mixed weak granular and weak subangular blocky.
C2cam	26-37	Very pale brown (10YR 8/4) sandy clay loam, very pale brown (10YR 7/4) moist; indurated caliche with a smooth laminar upper surface; lower surfaces of plates have nodular development.

Soil Type: Gwalior (no established series)

Location: Gwalior District, Madhya Pradesh, India, about 150 yards NW of Agricultural Chemistry Building

Described by: J. D. Alexander, J. B. Fahrenbacher

Horizon	Depth inches	Description
Ap	0-6	Brown to dark yellowish brown (10YR 4/3/5 moist) fine sandy loam; massive to cloddy; friable to firm; clear smooth boundary.
A12	6-13	Brown (9YR 4/3 moist) fine sandy loam; weak medium subangular blocky structure with a few angular blocky peds evident; friable; clear smooth boundary.
B1	13-22	Brown (9YR 4/3 moist) clay loam; weak to moderate medium subangular blocky structure, friable; clear smooth boundary.
B2	22-39	Dark brown (10YR 3/3 moist) heavy clay loam; weak fine prismatic structure breaking to moderate medium subangular and angular blocky structure; a few fine Fe-Mn concretions; firm; clear smooth boundary.
B31	39-51	Brown (10YR 4/3 moist) clay loam; weak medium subangular blocky structure; common Fe-Mn concretions; friable; clear smooth boundary.
B32	51-61	Dark yellowish brown (10YR 4/4 moist) sandy clay loam to clay loam; weak medium to coarse subangular blocky structure; few Fe-Mn concretions; friable, clear

Horizon	Depth inches	Description
		smooth boundary.
Cca	61+	Yellowish brown (10YR 5/4 moist) to dark yellowish brown (10YR 4/4 moist) sandy loam; massive, many $CaCO_3$ concretions; friable.

Soil Type: Podua (local name for high clay)

Location: Rairu, Gwalior District, Madhya Pradesh, India

Described by: J. D. Alexander, J. B. Fehrenbacher

Horizon	Depth inches	Description
Ap	0-8	Yellowish brown (10YR 5/4 moist) fine sandy loam; weak fine subangular blocky structure; friable; calcareous; clear smooth boundary.
A12	8-15	Brown (10YR 4.5/3 moist) sandy clay loam; weak moderate to fine subangular blocky structure; friable; calcareous; clear smooth boundary.
B2	15-27	Brown (10YR 4/3 moist) clay loam; weak medium subangular and angular blocky structure; many fine Fe-Mn concretions; calcareous; clear smooth boundary; a few fine carbonate concretions.
B31	27-33	Dark grayish brown (2.5Y 4/2-4/3 moist) clay loam; weak medium to coarse subangular and angular blocky structure; few fine Fe-Mn concretions; some carbonate concretions; calcareous; firm to friable; clear smooth boundary.
B32	33-41	Dark grayish brown (2.5Y 4/3 moist) sandy clay loam to clay loam; weak coarse angular blocky structure; many carbonate concretions; friable; calcareous; clear smooth boundary.
Cca	41+	Grayish brown (2.5Y 5/2 moist) loam to sandy loam; massive; friable; calcareous; many carbonate concretions.

Series: Pullman No. 1

Location: Curry County, New Mexico, approx. 400'S and 300'E of NW corner, S-6 T4N R36E

Slope: 1%

Sampled and described by: A. D. Buchanan, D. G. Harper and others

Horizon	Depth inches	Description
Ap	0-6	Brown (10YR 4/3 dry) to very dark gray dark gray brown (3/2 moist) loam; strong, medium granular structure; dry, slightly hard; moist, friable; noncalcareous; abrupt, smooth boundary.
B2	6-19	Brown (10YR 4/3 dry) to very dark gray brown (3/2 moist) clay loam; strong, medium to fine prismatic and blocky structure (some clay stains on outside of aggregates); dry, very hard; moist, firm; noncalcarous; abrupt, smooth boundary.
B31	19-30	Brown (7.5YR 5/2 dry) to dark brown (3/2 moist) clay loam; moderately defined, medium granular structure; dry, hard; moist, firm; slightly calcareous; clear, smooth boundary.
B32	30-52	Light brown (7.5YR 6/4 dry) to brown (4/2 moist) clay loam; dry, slightly hard; strongly calcareous; otherwise similar to B31.

Series: Pullman No. 2

Location: Curry County, New Mexico, approx. 1440'N and 660' E of S½ S-1, T4N, R36E

Slope: 1%

Collected and described by: A. D. Buchanan, D. G. Harper and others

Horizon	Depth inches	Description
Ap	0-4	Dark yellowish brown (10YR 4/4 dry) to dark brown (3/3 moist) loam; weak to moderate, fine granular structure; slightly hard; friable; noncalcareous; abrupt, smooth boundary.
B21	4-6	Dark brown (7.5YR 4/4; 3/2 moist) loam; well defined, medium blocky structure (plow pan); hard; firm; noncalcareous; abrupt, smooth boundary.
B22	6-16	Dark brown (7.5YR 4/4; 3/2 moist) clay loam; weak, coarse prismatic and well defined, medium blocky structure (faint glazing on aggregates); hard; friable; noncalcareous; abrupt, smooth boundary.
B31	16-32	Brown (7.5YR 5/4 dry) to dark brown (3/2 moist) clay loam; moderately well defined coarse to medium blocky structure; hard; friable; moderate to strongly calcareous (many fine prominent lime mycelia); clear, smooth boundary.
C1	32-50	Pink (5YR 7/3 dry) to reddish brown (5/4 moist) clay loam; weak, medium to fine granular structure; hard; friable; strongly calcareous (many medium prominent lime mottlings and soft nodules); clear, smooth boundary.

APPENDIX II: PROFILE DESCRIPTIONS FOR SOIL MAPPING UNITS SAMPLED IN ADAIR COUNTY, IOWA

Site: 1 Series: Ladoga, 76B

Location: 372'N and 39'E of SW corner of SE$\frac{1}{4}$ of SW sec 19, T76N, R30W

Horizon	Depth inches	Description
Ap	0-7	Very dark grayish brown (10YR 3/2), light silty clay loam, moderate fine granular structure, friable, abrupt smooth boundary.
A2	7-11	Dark grayish brown (10YR 4/2), light silty clay loam, weak medium platy structure breaks to very fine subangular blocky structure, friable, few very dark gray (10YR 3/1) and very dark grayish brown (10YR 3/2) peds, abrupt smooth boundary.
B1	11-17	Dark brown (10YR 4/3) light silty clay loam, weak fine subangular blocky structure, friable, gradual smooth boundary.
B21t	17-23	Dark yellowish brown (10YR 4/4), medium silty clay loam, medium subangular blocky structure, thin discontinuous clay films, dark grayish brown grainy silt coats (10YR 4/2), smooth boundary.
B22t	23-29	Brown (10YR 4/3), medium silty clay loam, moderate medium subangular blocky structure, firm, thin clay films, few dark grayish brown grainy silt coats, gradual smooth boundary.
B23t	29-36	Yellowish brown (10YR 5/4), medium silty clay loam, moderate medium subangular blocky and angular blocky structure, firm, continuous clay films, few grayish brown (5Y 6/2) mottles.

Site: 3 Series: Ladoga, 76C2

Location: 507'N, 109'E of SW corner of SE¼ of SW sec 19, T76N, R30W

Horizon	Depth inches	Description
Ap	0-6	Very dark grayish brown (10YR 3/2) silt loam, weak fine granular structure, friable, clear smooth boundary.
B21t	6-13	Brown (10YR 4/3) silty clay loam, weak fine subangular blocky structure, firm, smooth boundary.
B22t	13-19	Brown (10YR 4/5) medium silty clay loam, weak medium subangular blocky structure, firm, smooth boundary.
B31	19-24	Brown (10YR 5/3) medium silty clay loam, fine olive gray (5Y 5/2) mottles, moderate medium subangular blocky structure, firm gradual smooth boundary.
B32	24-31	Yellowish brown (10YR 5/4), light silty clay loam, common fine and medium light olive gray (5Y 6/2) mottles, coarse angular blocky structure, firm, thin discontinuous clay films, gradual smooth boundary.
C	31-37	Mottled yellowish brown (10YR 5/4) and light olive gray (5Y 6/2), light silty clay loam, strong brown mottles (7.5YR 5/6), massive structure but some vertical cleavage.

Site: 2 Series: Hedrick, 571D2

Location: 405'N and 227'E of SW corner of SE¼ of SW sec 19, T76N, R30W

Horizon	Depth inches	Description
Ap	0-4	Very dark grayish brown (10YR 4/2) silt loam, weak fine granular structure, friable, dark grayish brown (10YR 4/2) s silt coatings, abrupt smooth boundary.
B21	4-8	Brown (10YR 4/3) and grayish brown (10YR 4/2) mixed silty clay loam, fine subangular blocky structure, friable, smooth boundary.
B22	8-12	Brown (10YR 4/3), silty clay loam, medium subangular blocky structure, friable, smooth boundary.
B3	12-22	Olive gray (5Y 5/2) some yellowish brown (10YR 5/6) mottles, silty clay loam, medium subangular blocky structure, friable, gradual smooth boundary.
C	22+	Light olive gray (5Y 6/2) light silty clay loam, common prominent yellowish brown (10YR 5/6) mottles, massive, friable.

Site: 4 Series: Sharpsburg, 370B

Location: 1440'N, 1400'W of SE corner of sec 7, T76N, R31W

Horizon	Depth inches	Description
A12	0-5	Dark brown (10YR 3/3) light silty clay loam, weak medium granular structure, friable, abrupt smooth boundary.
A3	5-10	Brown (10YR 4/3), medium silty clay loam, moderate very fine subangular blocky structure, friable gradual smooth boundary.
B1t	10-18	Brown (10YR 4/3) medium silty clay loam, fine angular blocky structure, friable, gradual smooth boundary.
B21t	18-23	Brown (10YR 4/3), medium silty clay loam, weak medium prismatic structure parting to moderate fine and very fine subangular blocky structure, firm, gradual smooth boundary.
B22t	23-37	Dark yellowish brown (10YR 4/4), medium silty clay loam, fine and medium olive gray (5Y 6/2) mottles, moderate medium prismatic structure parting to moderate fine subangular blocky structure, clay film, firm.

Site: 5 Series: Sharpsburg, 370C2

Location: 675'N, 1400'W of SE¼ of sec 7, T76N, R31W

Horizon	Depth inches	Description
Ap	0-6	Very dark brown (10YR 2/2), light silty clay loam, very fine granular structure, friable, abrupt smooth boundary.
A12	7-12	Dark brown (10YR 3/3), light silty clay loam, moderate fine granular structure, friable, gradual smooth boundary.
A3	12-17	Very dark grayish brown (10YR 3/2), light silty clay loam, some brown (10YR 4/5) peds, moderate very fine subangular blocky structure, friable, gradual amooth boundary.
B21t	17-22	Dark brown (10YR 3/3), medium silty clay loam, weak medium prismatic structure parting to moderate fine and very fine subangular blocky structure, smooth boundary.
B22t	22-31	Brown (10YR 4/3), medium silty clay loam, few mottles strong brown (7.5YR 5/6), moderate prismatic structure parting to moderate fine subangular blocky structure, firm, continuous clay films, gradual smooth boundary.
B23t	31-36	Dark yellowish brown (10YR 4/4), medium silty clay loam, few fine strong brown (7.5YR 5/6) mottles, moderate medium prismatic structure, parting to moderate fine subangular blocky structure, friable, discontinuous clay films.

Site: 6 Series: Nira, 570C

Location: 1350'N and 141'E of SE corner of sec 7, T76N, R31W

Horizon	Depth inches	Description
Ap	0-7	Very dark grayish brown (10YR 3/2) light silty clay loam, weak fine granular structure, friable, abrupt smooth boundary.
A3	7-12	Very dark grayish brown (10YR 3/2) and dark brown to brown (10YR 4/3) mixed peds, medium silty clay loam, weak, coarse granular structure, friable, clear smooth boundary.
B21	12-16	Dark brown (10YR 4/3), medium silty clay loam, moderate fine subangular blocky structure, friable, smooth boundary.
B22	16-21	Mottled yellowish brown (10YR 5/4), heavy silty clay loam, very few strong brown (7.5YR 5/6) mottles, moderate medium subangular blocky structure, friable, smooth boundary.
B31	21-27	Light olive gray (5Y 6/2), medium silty clay loam, few strong brown (7.5YR 5/6) mottles, medium and coarse subangular blocky structure, friable, gradual smooth boundary.
B32	27-38	Light olive gray (5Y 6/2), light silty clay loam, common medium strong brown (7.5YR 5/6) mottles, weak coarse prismatic structure, friable.

Site: 7 Series: Nira, 570D2

Location: 1350'N and 1195'E of SW corner of sec 7, T76N, R31W

Horizon	Depth inches	Description
Ap	0-7	Very dark grayish brown (10YR 3/2), light silty clay loam, fine granular structure, friable, clear smooth boundary.
B1	7-11	Dark brown (10YR 4/3), medium silty clay loam, weak fine subangular blocky structure, friable, smooth boundary.
B21	11-15	Dark brown (10YR 4/3), heavy silty clay loam, weak medium subangular blocky structure, friable, smooth boundary.
B22	15-18	Brown (10YR 5/3), heavy silty clay loam, moderate medium subangular blocky structure, friable, smooth boundary.
B31	18-24	Light olive gray (5Y 6/2) medium silty clay loam, moderate coarse subangular blocky structure, friable, gradual smooth boundary.
B32	24-30	Gray (5Y 6/1), light silty clay loam, weak coarse prismatic structure, friable, gradual smooth boundary.
C	30+	Gray (5Y 6/1), light silty clay loam, massive structure, friable.

APPENDIX III: PARTICLE SIZE ANALYSIS, pH AND TOTAL CARBON (TC) CONTENT IN SOIL PROFILES ON WHICH INORGANIC P FRACTIONS ARE REPORTED

Horizon	Depth inches	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay	pH Water	pH $CaCl_2$	TC %
Cisne, Jasper County, Illinois								
Alp	0-8	17.3	26.7	40.3	13.7	5.9	5.4	1.13
A21	8-13	18.4	24.3	42.4	13.1	4.5	4.1	0.35
A22	13-17	18.7	24.2	41.1	12.7	4.6	3.9	0.18
Ab	17-19	14.0	21.0	38.4	24.8	4.4	3.8	0.19
B21	19-28	12.5	17.7	30.3	36.2	4.5	3.8	0.22
B22	28-37	13.6	16.7	31.5	35.0	4.7	3.9	0.16
C1D1	37-43	14.0	18.8	33.3	30.0	4.7	4.0	0.11
Pershing, P421, Lucas County, Iowa								OC %
A1	0-3	2.8	61.8		24.3	6.1		3.28
	3-6	3.0	61.7		24.3	6.1		2.05
A2	6-9	3.0	64.8		25.8	5.7		1.16
	9-12	2.6	66.1		28.2	5.2		0.80
AcB1	12-15	2.0	70.9		34.6	4.9		0.66
B21	15-18	1.2	74.2		46.0	4.7		0.66
	18-22	1.1	74.9		48.5	4.8		0.57
B22	22-26	1.2	73.7		45.8	4.9		0.52
	26-30	1.4	73.4		44.6	5.1		0.46
B31	30-34	1.4	69.4		41.5	5.2		0.40
	34-40	1.6	68.6		37.5	5.4		0.31
B32	40-46	1.3	62.5		36.5	5.8		0.24
	46-52	1.6	66.4		34.2	6.0		0.19
C1	52-58	1.9	67.9		33.2	6.2		0.17

Horizon	Depth inches	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay	pH Water	CaCl$_2$	TC %
Forrest, Cochise County, Arizona								
A1	0-4	48.7	15.2	19.3	16.8	6.6	5.7	0.72
B21t	4-13	42.4	9.6	13.7	34.3	7.0	6.7	0.69
B22t	13-31	30.4	8.6	9.9	51.5	7.5	7.3	0.51
C1Ca	31-40	41.1	9.3	15.2	34.4	7.7	7.7	0.24
C2Ca	40-70	52.1	9.0	23.4	15.3	8.0	7.7	5.42
Tubac, Chochise County, Arizona								
A11	0-2	69.9	12.7	8.2	9.2	5.8	4.3	0.47
A12	2-12	66.2	12.8	9.3	11.7	6.0	5.2	0.42
A2	12-16	63.8	14.0	11.4	10.8	6.5	5.9	0.31
B21t	16-24	51.5	6.1	5.4	37.0	7.4	7.0	0.28
B22t	24-30	52.6	7.3	4.4	35.7	7.8	7.4	0.26
B23t	30-40	66.6	7.8	5.7	19.9	7.4	7.1	0.24
B3	40-48	81.4	5.6	1.7	11.3	7.5	7.3	0.14
C	48-60	80.2	6.2	2.7	10.9	7.7	7.3	0.13
Grantsburg, Saline County, Illinois								
Ap	0-6	5.4	36.9	46.6	14.0	5.3	4.9	0.57
A2	6-10	1.8	30.7	49.0	18.3	5.5	5.0	0.57
B2	10-21	2.4	26.3	47.2	23.1	4.9	4.0	0.16
A'2	21-24	1.0	24.2	45.5	28.6	4.7	3.8	0.09
B'2	24-30	1.0	25.3	43.9	28.8	4.9	3.8	0.03
B'31	34-41	1.3	26.1	46.5	25.1	4.9	3.9	0.08
B'32	41-51	3.0	30.2	46.3	19.6	5.2	4.1	0.03
C1	51-80	6.5	31.9	41.4	18.4	5.7	4.9	0.01

Horizon	Depth inches	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay	pH Water	$CaCl_2$	TC %
Weller P909, Monroe County, Iowa								
A1	0-4	2.9	31.6	45.9	19.6	6.7	6.4	2.37
A21	4-7	2.1	31.3	46.0	20.6	5.3	4.9	1.89
A22	7-15	1.7	30.1	46.4	21.8	4.6	3.9	0.55
AB	15-19	2.1	28.6	43.4	25.9	4.6	3.8	0.30
B1	19-23	1.7	26.2	41.5	30.6	4.6	3.7	0.20
B21t	23-28	1.2	20.4	30.9	47.5	4.3	3.9	
B22t	28-33	1.1	19.2	33.1	46.6	4.4	3.9	0.19
B23t	33-38	0.7	20.4	35.2	43.7	4.3	4.0	
B31t	38-47	0.7	23.2	36.2	39.9	4.5	4.1	0.09
B32	47-54	1.1	24.9	39.1	34.9	5.1	4.5	0.11
C	57-66	0.8	27.0	41.0	31.2	5.3	5.3	0.07
Tama[a], 16 Ml, Cedar County, Iowa								
Ap	0-7	2.2	72.8		25.0	5.8	5.5	3.44
A12	7-12	2.1	73.0		24.9	5.2	4.7	2.26
A13	12-16	2.7	72.6		24.7	5.2	4.7	1.35
B1	16-20	2.9	70.7		26.4	5.3	4.8	0.82
B21	20-26	2.5	68.8		28.7	5.3	4.8	0.44
B22	26-30	2.4	68.0		29.6	5.3	4.8	0.41
	30-33	2.3	68.3		29.4	5.4	4.8	0.28
B23	33-38	1.9	64.9		33.2	5.4	4.9	0.17
B24t	38-44	1.5	64.2		34.3	5.5	5.0	0.11
	44-51	0.9	65.2		33.9	5.5	5.0	0.12
B31	51-57	0.8	65.3		33.9	5.6	5.2	0.14
C	57-63	1.1	70.0		28.9	5.6	5.2	0.08

[a]Collected and analyzed by G. A. Miller as a variation of Tama series.

Horizon	Depth inches	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay	pH Water	pH $CaCl_2$	TC %
Amarillo, Eastern Hockley County, Texas								
A1	1-7	68.6		16.3	15.1	7.5		0.57
B21t	7-16	65.2		11.7	23.1	7.3		0.50
B22t	16-27	60.8		12.8	26.4	7.8		0.32
B23t	27-37	60.7		12.8	26.5	8.0		0.40
B24tCa	37-45	58.5		14.0	27.5	8.1		2.25
B25tCa	45-54	57.6		13.4	29.0	8.3		2.81
B26tCa	54-70	64.2		12.3	23.5	8.2		1.93
B27Ca	70-100	65.6		14.4	20.1	8.1		2.60
B28tCa	100-112	71.4		11.4	17.2	8.1		2.37
Arvana, Andrews County, Texas								
A1	1-7	84.8		6.8	8.4	7.7		0.45
B2t	7-12	81.3		7.1	11.6	7.7		0.35
B2t	12-18					7.8		0.34
B3t	18-21	78.0		7.6	14.3	7.8		0.48
B3tCa	21-26	66.3		12.9	21.3	7.8		3.04
	26+	65.7		13.9	20.4	7.9		8.07
Gwalior (no established series) Govt. Agri. Res. Farm, Gwalior (M.P.) India								
Ap	0-6	26.3	20.8	31.3	21.6	7.9		0.44
A12	6-13	21.2	20.3	30.7	27.8	7.9		0.28
B1	13-22	16.3	20.1	30.9	32.7	7.8		0.28
B2	22-40	14.4	20.8	28.7	36.1	7.7		0.27
B31	40-52	16.7	24.9	24.7	33.7	7.7		0.24
B32	52-62	18.9	23.9	31.1	26.1	7.9		0.66
CCa	62+	27.5	23.2	29.8	19.5	8.2		1.21

Horizon	Depth inches	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay	pH Water	pH $CaCl_2$	TC %
Podua (local name) Rairu Tahsil, Gwalior (M.P.) India								
Ap	0-11	31.9	22.1	27.4	18.6	8.4		1.80
A12	11-15	34.0	15.0	27.9	23.1	8.9		0.19
B2	15-27	33.0	16.2	26.5	24.3	9.1		0.14
B31	27-34	32.1	16.8	23.7	27.4	9.7		0.11
B32	34-42	29.7	17.1	24.8	29.4	10.2		0.09
CCa	42+	43.05	17.73	20.40	18.82	10.3		0.15
Pullman-1, Curry County, New Mexico								
Ap	0-6	40.3	34.1		25.6	7.6		1.04
B2	6-19	32.5	31.0		35.6	7.4		0.95
B31	19-30	32.9	35.0		32.1	7.9		0.72
B32	30-52	35.5	31.2		33.3	7.8		0.24
Pullman-2, Curry County, New Mexico								
Ap	0-4	47.6	31.7		20.7	6.8		0.54
B22	4-16	39.2	30.5		29.8	7.4		0.39
B31	16-32	35.9	34.4		29.7	7.5		0.36
C1	32-50	32.2	31.6		36.2	8.0		3.67

APPENDIX IV: AP (BRAY 1), pH, TOTAL CARBON (TC) AND PARTICLE SIZE ANALYSIS FOR BIOSEQUENCE SOILS TRAVERSED IN BOONE COUNTY, IOWA

Depth inches	AP Bray 1 ppm	pH H_2O	pH $CaCl_2$	TC %	Particle size analysis (%) >2 mm	Sand	Coarse silt	Fine silt	Clay
Hayden-1, Site 1									
0-6	14	5.5	4.8	1.74	0.1	28.6	26.3	29.8	15.3
6-12	6	5.4	4.3	0.47	0.4	30.9	24.8	25.5	18.8
12-18	5	5.3	4.4	0.29	1.0	33.1	20.6	22.1	24.2
18-24	17	5.3	4.5	0.27	3.9	40.5	16.3	15.2	28.0
24-30	25	5.3	4.6	0.24	3.8	46.6	14.6	11.5	27.3
30-36	23	5.4	4.7	0.21	0.8	46.3	15.3	12.7	25.6
36-42	16	5.6	5.0	0.21	1.0	47.5	15.5	11.9	25.1
42-48	7	5.8	5.6	0.15	8.0	53.3	15.0	11.5	20.2
Hayden-2, Site 2									
0-6	15	7.6	6.4	1.84	2.0	42.3	24.6	21.2	11.9
6-12	7	6.6	6.0	0.58	7.5	43.8	21.7	20.7	13.8
12-18	9	6.1	5.8	0.19	3.7	43.6	16.9	16.6	22.9
18-24	16	5.6	5.2	0.20	4.8	44.7	15.2	14.4	25.7
24-30	16	5.9	5.3	0.21	2.2	46.2	13.6	11.4	28.8
30-36	15	6.0	5.5	0.17	2.8	50.6	13.1	10.7	25.6
36-42	7	6.5	5.8	0.12	2.3	50.4	17.3	9.9	22.4
42-48	2	7.5	6.1	0.99	3.3	55.0	16.0	7.9	21.1
Lester-1, Site 3									
0-6	7	6.5	5.9	1.52	0.1	36.7	26.5	21.8	15.0
6-12	4	6.6	5.8	0.79	0.2	35.2	24.7	23.6	16.5
12-18	2	6.6	5.3	0.26	4.9	30.1	20.8	25.8	23.3
18-24	6	6.0	5.0	0.26	0.4	29.5	20.1	23.0	27.4
24-30	9	5.9	5.1	0.17	0.5	31.8	18.6	31.9	27.7
30-36	3	6.5	5.7	0.18	2.2	44.3	14.1	14.4	27.2

Depth inches	AP Bray 1 ppm	pH		TC %	Particle size analysis (%)				
		H_2O	$CaCl_2$		>2 mm	Sand	Coarse silt	Fine silt	Clay
36-42	1	7.4	6.9	0.57	0.1	24.4	24.6	28.8	22.2
42-48	2	7.9	7.1	2.13	7.3	48.2	20.2	18.7	13.0
Lester-2, Site 5									
0-6	15	7.1	6.3	0.98	3.3	50.4	18.8	16.5	14.3
6-12	10	7.1	6.3	0.65	3.2	44.4	17.5	18.7	19.3
12-18	7	6.2	5.3	0.38	1.1	36.0	17.9	20.1	26.0
18-24	12	5.9	5.0	0.27	1.4	38.6	16.2	18.8	26.4
24-30	15	5.9	5.1	0.23	2.5	42.1	16.9	16.9	24.1
30-36	11	6.0	5.2	0.24	6.9	64.2	10.5	7.9	17.4
36-42	1	6.7	5.9	0.20	0.8	38.5	18.5	17.0	26.0
42-48	4	7.6	7.1	1.28	0.0	34.1	15.4	23.9	26.6
Clarion-1, Site 6									
0-6	20	6.6	6.0	1.54	0.6	39.2	21.7	16.8	22.3
6-12	15	6.4	5.9	1.26	1.7	41.0	20.1	16.2	22.7
12-18	4	6.8	6.2	0.86	1.9	48.5	16.5	12.7	22.3
18-24	4	6.6	6.2	0.59	2.0	49.0	14.9	13.1	23.0
24-30	4	6.7	6.2	0.32	2.5	47.6	15.8	13.8	22.8
30-36	2	6.8	6.3	0.25	3.3	47.5	15.7	14.6	22.2
36-42	3	7.4	7.2	0.87	6.8	48.4	18.0	14.3	19.3
42-48	4	7.9	7.4	1.67					

Depth inches	AP Bray 1 ppm	pH		TC %	Particle size analysis (%)				
		H_2O	$CaCl_2$		>2 mm	Sand	Coarse silt	Fine silt	Clay
Clarion-2, Site 7									
0-6	14	6.4	5.1	1.68	0.1	42.2	20.4	15.2	22.2
6-12	6	6.2	5.2	1.55	0.0	37.9	21.1	17.5	23.5
12-18	4	6.0	5.2	1.31	1.2	37.4	20.1	18.1	24.4
18-24	3	5.9	5.3	1.00	0.3	35.6	20.5	19.1	24.7
24-30	3	6.0	5.6	0.67	1.1	40.9	18.9	16.9	23.2
30-36	5	6.3	5.9	0.38	3.5	47.2	19.0	13.2	20.6
36-42	2	6.5	6.1	0.26	2.4	48.6	15.2	16.4	19.8
42-48	2	6.9	6.5	0.15	11.0	49.7	16.5	14.6	19.2
48+	4	7.5		0.34	2.4	61.0	12.5	11.2	15.3

APPENDIX V: AP (BRAY 1), pH, CLAY AND ORGANIC CARBON IN SOIL PROFILES REPRESENTING BIOSEQUENCES

Soils under prairie (grass)						Transition		
Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm
Cary till biotoposequence								
Clarion P97						Lester P561		
A1	0-4	22	6.1	24.8	3.00	A1	0-3	28
	4-8	17	5.9	26.2	2.48	A2	3.7	11
A3	8-12	12	5.8	25.5	1.88	B1	7011	14
	12-16	9	5.8	26.2	1.38	B2	11-18	18
B	16-20	6	6.0	25.8	0.92	B3	18-22	17
	24-28	4	7.4	18.0	0.53	C1	22-32	17
C	28-32		7.9	20.9		C2	32+	7
	32-36	3	8.4	17.9				
Nicollet P563						LeSueur P489		
A1	0-11	23	7.0	36.5	3.33	Ap	0-8	34
A3	11-15	18	6.5	38.0	2.48	A2	8-11	14
B1	15-20	14	6.3	37.4	1.88	A3	11-15	10
B21	20-25	9	6.2	36.8	1.41	B1	15-19	10
B22	25-29	5	6.5	37.4	0.94	B21	19-24	10
B3	29-34	5	6.8	33.4	0.66	B22	24-29	12
C1	34-39	4	7.2	31.3	0.40	B3	29-35	12
C2	39+	5	8.5	26.6	2.06	C1	35-41	9
						C2	41+	5
Webster P137						Dundas P567		
A	0-8	25	7.4	34.2	4.12	A1	0-3	23
	8-13	18	7.1	33.7	3.71	A21	3-7	20
	13-17	9	6.5	34.8	1.91	A22	7-10	17
B	17-21	7	6.7	34.0	1.10	B1	10-16	12
	21-26	6	6.8	31.7	0.52	B21	16-19	15
C1	26-31	5	7.7	28.1	0.29	B22	19-22	16
C2	31-37	6	8.0	24.2	0.17	B31	22-26	17
						B32	26-32	25
						C1	32-45	17
						C2	45+	3

soils			Soils under forest					
pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
		TC %						TC %
			Hayden P401					
6.5	22.8	4.49	A1	0-3	18	6.1	17.0	2.71
6.4	21.2	1.75	A2	3-7	10	6.0	17.8	1.00
5.5	24.3	0.79	A3	7-11	17	5.7	24.2	0.59
5.3	26.7	0.59	B1	11-16	24	5.0	31.7	0.34
5.3	28.1	0.49	B2	16-21	28	4.9	33.6	0.40
5.4	26.0	0.26		21-26	27	4.9	33.8	0.39
8.1	25.5	1.76	B3	26-31	16	5.2	32.3	0.39
				31-36	16	6.6	28.2	0.26
			C	36-42	7	7.8	22.3	1.42
		OC %	Luther P565					OC %
5.7	22.9	2.41	A1	0-3	23	6.1	19.5	2.57
5.9	25.5	1.66	A21	3-8	--	5.7	16.5	0.89
6.1	27.8	1.31	A22	8-14	--	5.7	16.1	0.41
5.9	31.6	0.91	B11	14-17	9	5.4	20.0	0.41
5.9	35.2	0.76	B12	17-21	9	5.2	24.4	0.38
5.7	35.0	0.79	B21	21-24	12	5.1	30.2	0.35
5.6	34.4	0.33	B22	24-27	17	5.0	31.6	0.50
6.6	34.0	0.52	B3	27-31	13	5.2	29.9	0.24
7.6	29.2	1.07	C1	31-42	12	5.8	30.4	0.41
			C2	42+	3	8.5	18.9	1.82
			Ames P568					
6.9	22.5	3.21	A1	0-4	26	5.3	20.5	2.76
6.6	22.1	2.12	A21	4-9	21	5.6	18.0	1.46
6.6	22.7	1.26	A22	9-15	10	5.3	20.7	0.78
6.6	27.3	0.85	B21	15-20	9	5.0	35.4	0.59
6.3	31.9	0.83	B22	20-24	12	4.9	39.7	0.60
6.0	34.8	0.87	B3	24-30	17	4.8	34.4	0.38
5.9	35.0	0.67	C1	30-40	13	6.3	31.9	0.26
6.6	34.7	0.36	C2	40+	1	8.4	25.0	2.06
6.1	29.2	0.29						
8.2	23.7	1.78						

Soils under prairie (grass)					
Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
Loess biosequences					
Otley, 54-281					
Ap	0-7	33	6.0	29.8	2.44
A1	7-12	18	5.1	33.3	2.08
A3	12-17	13	5.1	34.9	1.66
B21t	17-26	9	5.0	37.4	1.34
B22t	26-32	16	5.2	36.2	0.56
B23t	32-40	17	5.2	34.0	0.39
B31t	40-46	18	5.2	31.5	0.22
B32t	46-53	7	5.8	29.5	0.16
B33t	53-61	8	6.3	29.6	0.12
Mahaska P715					
A1p	0-8	16	5.5	30.8	2.89
A12	8-13	16	4.9	34.8	2.18
A3	13-17	10	5.0	38.0	1.07
B1	17-23	7	5.0	38.0	1.07
B21	23-30	11	5.0	38.9	0.58
B22	30-35	23	5.2	36.4	0.36
B31	35-42	27	5.5	33.7	0.21
B32	42-51	19	6.0	32.6	0.14
C1	51-55	8	6.7	32.7	0.16
C2	55-62	15	6.8	27.9	0.12
Taintor 54-279					
Ap	0-6	19	6.5	36.6	3.57
A12	6-12	14	5.6	41.1	2.22
A3	12-17	8	5.9	42.8	1.14
B1	17-22	7	6.1	42.8	0.67
B21tg	22-28	3	6.4	41.1	0.46
B22tg	28-34	7	6.7	35.9	0.26
B31tg	34-40	8	7.3	34.7	0.21
B32tg	40-45	7	7.5	31.4	0.12
B32tg	45-50	8	7.5	27.9	0.12
Cg	50-60	11	7.8	26.2	0.12

Transition		
Hori-zon	Depth in.	Bray 1 ppm
Ladoga P612		
Ap	406	32
A2	6-8	24
A2	8-10	18
B1	13-16	11
B2	16-21	9
B2	21-25	13
B2	25-31	18
B3	31-37	19
B3	47-55	44
C1	55-60	34
Givin 54-75		
Ap	0-9	38
A2	9-12	13
B1	12-16	12
B21	16-23	12
B22	23-34	37
B23	34-42	52
B3	42-50	46
C	50-60	25
Rubio P610		
Ap	0-6	40
A2	6-10	33
A2	10-13	16
A3	13-16	14
B2	16-18	10
B2	18-20	8
B2	20-26	10
B2	26-32	27
B3	32-38	20
B3	38-45	13
B3	45-55	11
C1	55-65	9

soils			Soils under forest					
pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
			Clinton P126					
5.5	24.4	2.61		0-5	29	6.9	19.0	1.71
5.5	23.8	1.82		5-9	22	5.9	19.0	1.14
5.4	23.6	1.39		9-21	17	5.7	28.1	0.59
5.2	29.5	0.89		21-27	28	5.1	37.6	0.33
5.1	32.8	0.75		27-33	44	5.2	37.0	0.27
5.4	36.2	0.58		33-37	60	5.3	35.0	0.24
5.2	37.8	0.43		37-43	66	5.3	34.8	0.20
5.5	35.3	0.35		43-49	60	5.4	32.3	
5.4	32.3	0.21		49-54	50	5.5	31.6	0.17
5.5	29.7	0.19						
			Keomah P613					
5.9	19.3	1.67	Ap	0-4	16	5.6	16.3	1.24
5.8	23.3	0.97		4-7	15			
5.4	28.2	0.63	A21	7-10	10	5.8	22.3	0.68
5.2	35.2	0.57	A22	10-12	8	5.6	26.6	0.49
5.1	37.5	0.45	A3	12-14	10		28.3	0.42
5.1	35.5	0.27	B1	14-16	13	5.4	33.5	0.36
5.2	35.3	--	B21t	16-18	12	5.0	36.5	0.31
--	--	--		18-21	17	4.9	40.9	0.38
				21-24	25	5.1	42.3	0.31
			B22t	24-30	37	6.7	42.1	0.28
			B23t	30-37	50	6.1	38.2	0.20
			B3t	37-47	40	6.6	34.6	0.21
			C	47-60	16	6.0	30.0	0.20
			Rushville P423					
6.5	21.0	1.78	Ap	0-6	15	5.8	14.1	1.18
5.6	24.6	1.18	Ap	6-8	14	5.7	14.7	1.11
5.3	30.1	0.86	A2	8-11	8	5.4	17.8	0.43
5.2	39.1	0.88	A2	11-14	10	5.1	23.9	0.30
4.7	45.2	0.85	B1	14-17	15	4.8	38.2	0.24
4.9	48.2	0.72	B2	17-22	27	4.6	40.3	0.30
5.2	47.8	0.49	B2	22-26	44	4.6	46.6	0.24
5.2	44.2	0.38	B2	26-32	59	4.7	44.4	0.20
5.5	38.9	0.32	B3	32-38	74	4.9	39.8	0.16
6.0	35.9	0.29	C	38-44	59	5.1	37.8	0.14
6.6	35.2	0.20						
7.0	31.5	0.15						

Soils under prairie (grass)					
Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
Grundy P3					
Ap	0-7	33	4.6	33.6	2.73
A12	7-13	24	4.7	36.3	2.24
B1	13-19	12	4.8	43.0	1.30
B21	19-25	12	5.2	45.6	0.74
B22	25-30	11	5.7	41.0	0.37
B31	30-36	10	5.9	36.8	0.23
B32	36-42	12	6.1	32.2	0.17
	42-46	12	6.2	31.1	0.11
C1	48-54	11	6.3	25.7	0.10
Seymour P780					
A1p	0-6	16	5.5	25.7	2.41
A1A2	6-9	11	5.4	27.9	1.46
A3	9-13	10	5.4	30.1	0.98
B1	13-17	8	5.4	34.6	0.78
B21	17-22	9	5.4	53.4	0.73
B22	22-29	16	5.6	49.1	0.42
B23	29-35	16	5.9	44.8	0.20
B31	35-39	13	6.3	40.5	0.19
B32	39-45	14	6.4	39.3	0.16
C1	45-50	18	6.4	38.3	0.12
C2	50-60	20	6.6	35.6	0.12
C3	60-70	14	6.4	34.6	0.19
Haig P220					
A1	0-7	30	5.6	25.4	2.71
A11	7-10	25	5.2	26.4	
A3	10-14	20	5.3	27.1	2.24
A3B1	14-18	13	5.3	33.2	
B1	18-22	10	5.5	40.7	1.26
B2	22-26	8	5.4	49.5	
B2	26-30	6	5.6	49.2	0.63
B3	30-34	12	6.0	44.2	
B31	34-40	10	6.1	42.0	
C1	40-46	12	6.3	39.2	0.22
C1	46-52	16	6.4	36.4	

Transition		
Hori-zon	Depth in.	Ap Bray 1 ppm
Pershing P911		
Ap	0-8	12
A21	8-11	10
A22	11-15	8
B1	15-21	7
B21t	21-27	15
B22t	27-36	42
B31t	36-43	37
B32t	43-53	20
B33	53-61	19
Kniffin P903		
A1	0-6	20
A2	6-9	13
B1	9-14	13
B21t	14-18	7
B22t	18-23	10
B23t	23-28	23
B31t	28-35	30
B32t	35-45	28
B33	45-52	23
B34	52-63	19
C	63-71	10
Belinda P614		
Ap	0-4	20
Ap	4-7	18
A2	7-12	13
A2	12-14	6
A2	14-17	8
B1	17-19	8
B2	19-24	44
B2	24-28	30
B3	28-33	22
B3	33-38	22
B3	38-46	22
B3	46-54	18

soils			Soils under forest					
pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
			Weller P910					
5.8	21.5	1.85	Ap	0-7	11	5.0	19.9	1.16
5.3	22.5	1.01	A2	7-12	9	4.7	24.5	0.30
5.2	25.7	0.57	AB	12-15	15	4.6	31.2	0.27
5.0	35.5	0.42	B1	15-18	23	4.5	37.4	0.24
5.0	44.3	0.42	B21t	18-25	35	4.5	47.2	0.20
5.4	41.9	0.28	B22t	25-34	52	4.4	43.4	0.12
5.6	38.0	0.19	B31t	34-43	53	4.6	39.8	0.11
5.7	35.3	0.15	B32t	43-55	33	5.0	36.7	0.12
5.9	32.7	0.12	B33t	55-67	19	5.5	33.4	0.16
			Rathbun P906					
4.9	33.8	3.34	A1	0-4	12	5.4	20.7	3.24
4.6	37.3	0.07	A21	4-7	8	4.7	21.5	1.18
4.7	42.2	1.52	A22	7-13	8	4.5	26.1	0.62
4.8	50.4	0.95	B1	13-17	13	4.5	37.0	0.46
5.4	43.3	0.53	B21t	17-25	18	4.1	42.2	0.44
6.0	36.0	0.22	B22t	25-31	35	4.3	47.1	0.39
6.3	32.6	0.14	B23t	31-36	57	4.4	42.7	0.34
6.3	32.0	0.11	B31t	36-44	45	4.9	38.1	0.15
6.1	30.3	0.15	B32t	44-54	19	5.9	33.7	0.12
6.3	24.5	0.15	B33t	54-63	15	6.5	30.7	0.15
6.3	19.9	0.11						
			Beckwith P421					
7.3	18.1	1.72	Ap	0-6	28	5.1	17.2	2.22
6.9	18.2	1.65	A2	6-9	11	5.0	17.1	0.61
5.6	20.8	0.99	A2	9-14	7	5.1	17.7	0.42
5.5	23.9	0.72	B1	14-16	6	4.5	30.5	0.34
5.4	29.8	0.68	B2	16-19	7	4.2	49.3	0.42
--	--	--	B2	19-22	10	4.4	52.3	0.41
5.3	50.5	0.77	B2	22-25	23	4.4	51.9	0.33
5.3	52.4	0.61	B2	25-31	38	4.6	47.9	0.24
5.5	46.2	0.44	B3	31-38	47	4.8	43.2	0.24
5.9	40.3	0.27	B3	38-45	35	5.2	41.5	0.21
6.1	38.0	0.23	C	45-52	18	5.8	35.4	0.16
6.1	36.8	0.16						

Soils under prairie (grass)						Transition		
Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm
Edina P223						Appanoose P908		
A1	0-6	27	5.1	21.6	1.94	Ap	0-8	23
A11	6-10	20	5.2	21.4		A2	8-14	12
A2	10-15	16	5.3	23.8	1.08	B1	14-15	8
A2B1	15-19	10	5.4	25.7		B21tg	15-20	5
B1	19-24	8	5.4	43.6	0.98	B22tg	20-26	8
B2	24-29	7	5.5	54.6	0.97	B23tg	26-33	32
B21	29-34	4	5.7	51.4		B31tg	33-41	49
B3	34-40	12	6.0	48.3		B32tg	41-59	22
C1	40-46	13	6.1	41.4	0.35	C	59-68	10
C2	46-52	8	6.4					
C21	52-60	15	6.8					
Putnam P186								
A	0-6	17	5.6	13.8	1.73			
A12	6-11	12	5.3	20.2	1.15			
A2	11-17	6	5.5	23.2	0.59			
B2	17-22	7	5.5	60.3	0.96			
B21	22-29	6	5.5	57.3	0.77			
B3	29-35	14	5.7	47.2	0.48			
B31	35-42	25	6.0	37.1	0.26			

soils			Soils under forest					
pH	Clay %	OC %	Hori-zon	Depth in.	AP Bray 1 ppm	pH	Clay %	OC %
6.6	21.5	1.48						
5.1	26.2	0.68						
4.8	32.7	0.64						
4.8	59.6	1.00						
5.2	54.9	0.84						
5.5	45.5	0.34						
6.0	38.5	0.18						
6.4	32.2	0.18						
6.6	39.0	0.11						
			Marion P424					
			Ap	0-6	18	4.8	17.9	
			A2	6-13	11	4.7	17.0	
			B1	13-15	5	4.9	33.7	
			B2	15-21	9	4.6	64.2	
			B2	21-31	7	4.6	56.0	
			B3	31-42	50	4.7	44.8	
			B3	42-48	37	5.0	37.9	

APPENDIX VI: AP (BRAY 1), pH, TOTAL CARBON AND PARTICLE SIZE ANALYSIS FOR SOIL MAPPING UNITS IN ADAIR COUNTY

Hori-zon	Depth in.	AP Bray 1 ppm	pH	TC %	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay
Ladoga (76-B)[a] 1[b]-1[c]								
Ap	0-7	9	6.3	1.43	1.7	34.8	38.4	25.1
A2	7-11	7	6.2	0.85	1.2	33.2	37.4	28.2
B1	11-17	12	6.0	0.57	1.4	30.9	36.6	31.7
B21t	17-23	22	5.6	0.53	2.1	28.2	32.9	36.8
B22t	23-29	31	5.6	0.47	1.2	29.6	33.1	36.1
B23t	29-36	33	5.4	0.30	1.4	31.4	31.7	35.5
Ladoga (76-C2) 1-3								
Ap	0-6	16	6.0	1.14	1.4	26.8	37.6	34.2
B21	6-13	40	5.7	0.45	1.4	26.3	36.2	37.1
B22	13-19	60	5.8	0.33	1.3	26.5	34.2	38.0
B31	19024	63	5.5	0.23	0.8	32.0	33.1	34.1
B32	24-31	70	5.5	0.15	0.6	32.3	33.1	34.0
C	31-37	63	5.5	0.15	0.5	33.6	34.5	31.4
Hedrick (571-D2) 1-2								
Ap	0-4	47	6.0	1.27	1.6	31.8	33.3	33.3
B21	4-8	34	6.1	0.57	1.5	33.6	31.0	34.1
B22	8-12	39	6.1	0.24	1.3	34.1	33.1	31.5
B3	12-17	38	5.7	0.12	1.1	35.7	31.9	31.3
B3	17-22	37	5.8	0.20	0.7	34.1	37.4	27.8
C	22-29	39	5.7	0.16	0.7	31.8	38.6	28.9
	29-39	38	5.7	0.09	0.6	30.7	39.8	28.9
Sharpsburg (370-B) 1-5								
Ap	0-7	9	5.9	1.61	2.1	34.1	32.3	31.5
A12	7-12	7	5.7	1.16	1.4	30.2	33.0	35.4
A3	12-17	10	5.5	0.69	1.6	29.4	33.1	36.9
B21t	17-22	11	5.6	0.43	1.5	31.7	32.0	34.8
B22t	22-31	25	5.5	0.24	2.0	30.5	35.1	33.4
B23t	31-36	31	5.5	0.13	1.6	32.8	34.3	31.3

[a]Mapping unit.

[b]County number for Adair County.

[c]Site number.

Horizon	Depth in.	AP Bray 1 ppm	pH	TC %	Particle size analysis (%) Sand	Coarse silt	Fine silt	Clay
Sharpsburg (370-C2) 1-4								
A12	0-5	12	6.1	1.07	2.3	32.5	34.3	31.3
A3	5-10	11	6.0	0.49	1.0	31.6	35.2	32.2
B1	10-18	15	5.8	0.21	1.0	36.2	33.5	29.3
B21	18-23	18	5.8	0.09	1.0	39.3	31.9	27.8
B22	23-30	15	5.9	0.09	1.3	39.3	34.8	24.6
B22	30-37	16	5.9	0.06	1.4	39.5	34.6	24.5
Nira (570-C) 1-6								
Ap	0-7	10	6.1	1.39	1.1	34.6	31.0	33.3
A3	7-12	5	6.0	0.57	1.0	34.6	33.3	31.1
B21	12-16	5	5.8	0.56	1.1	34.3	33.3	31.3
B22	16-21	7	5.8	0.25	0.9	37.2	33.7	28.2
B31	21-27	7	5.9	0.16	1.0	39.4	32.0	27.6
B32	27-32	10	5.8	0.12	1.5	37.2	35.3	26.0
	32-28	11	6.2	0.14	2.1	37.4	35.4	25.1
Nira (570-C2) 1-7								
Ap	0-7	5	6.1	1.35	1.7	36.4	29.4	32.5
B1	7-11	4	6.1	0.56	1.9	37.2	31.4	29.5
B21	11-15	3	5.9	0.36	1.8	37.5	33.3	27.4
B22	15-18	4	6.1	0.25	1.5	39.8	31.6	27.1
B31	18-24	5	6.4	0.19	1.9	31.1	39.6	27.4
B32	24-30	4	6.4	0.17	4.3	25.8	42.5	27.4
C	30-37	6	6.5	0.11	1.1	25.4	44.8	28.7