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A diversity in climate, geologic parent material, and soil

characteristics exist in Jackson, Josephine, Coos, and Douglas

Counties of southwest Oregon. Previous field trials and soil testing

results have revealed uncertainties as to the phosphorus (P) status

of the soils in this area. Twenty-four sites from nine agriculturally

significant soil series in southwest Oregon were studied. Soils were

selected on the basis of the parent material from which they were

derived, either granitic, basaltic, or sedimentary. A greenhouse

pot study with Yamhill wheat as the indicator plant was used in con-

junction with a modified Change and Jackson P fractionation procedure

to determine the forms of soil P which were most available to plants.

The organic-P content of each soil was also determined. The

aluminum P (Al-P) and iron P (Fe-P) fractions were the most highly

correlated plant available P on most soils, although the

organic P fraction of the Coos County soils appeared to be an important source of plant P. The Bray P_1 dilute acid-fluoride, Olsen 0.5 M NaHCO$_3$, and Morgan's NaOAc P soil tests were used to estimate plant available P. The Bray P_1 and Olsen soil test values were more highly correlated to P uptake by wheat and yield response to P fertilizer than the NaOAc soil test values. The Bray P_1 test was more sensitive than the Olsen test at relatively low soil test values. Also only the Bray P_1 soil test values were significantly correlated to the organic-P content of the Coos County soils. These results indicate that of the three procedures studied, the Bray P_1 method is probably best suited for the estimation of plant available P in the mineral soils of southwestern Oregon.

Relationships Among Phosphorus Soil Tests,
Forms of Soil Phosphorus, and Plant Uptake of
Phosphorus for Selected Southwestern Oregon Soils

by

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INTRODUCTION

In Jackson, Josephine, Douglas, and Coos Counties of south-western Oregon, climate, geology and soil characteristics vary considerably over relatively short distances. Soil pH in this region ranges from near neutral to strongly acidic and annual precipitation ranges from 18 inches near Ashland to over 100 inches in parts of Coos County (U. S. Weather Bureau, 1964). The geology of the area is also quite variable and includes extensive areas of granitic, basaltic, sedimentary, and alluvial parent material (Wells, 1961).

These variations in climate, parent material, and soil types could affect the relationships between phosphorus (P) soil test values and the uptake of P by plants. Optimum crop production requires a sufficient supply of P, either from the soil or applied P fertilizer. There are extensive areas in southwest Oregon that are deficient in P and have proven to be very responsive to P fertilization. Unfortunately, previous field trials and soil testing results have revealed uncertainties as to the P requirements on some of the soils in this region and there has been some doubt concerning the relevance of the soil testing method currently used in this area to estimate P

availability to plants.

In this investigation, a total of 24 soils from nine agriculturally significant soil series in southwest Oregon which were derived from specific types of geologic parent material were studied. A series of chemical soil tests were performed on the various soils, including fractionation of inorganic-P, determination of soil organic-P, and estimation of the P availability in each soil by using three P soil tests currently used in the Pacific Northwest. Phosphorus uptake and yield response to P fertilizer were measured in a greenhouse pot experiment using Yamhill wheat as the indicator plant. The relationships among P soil tests, forms of soil P, and plant uptake of P were examined in order to see which if any of the currently used P soil tests would accurately predict P availability to plants on these soils.

The objectives of this research were:

1. To characterize the P status of soils derived from different parent materials in southwest Oregon,

2. to evaluate the effectiveness of commonly used P soil tests in assessing plant available P in these soils, and

3. to recommend the use of a suitable soil test or tests for predicting the P supplying power of these soils.

REVIEW OF LITERATURE

Phosphorus Soil Testing

Forms of Soil Phosphorus

Fractionation of soil phosphorus (P), first by Chang and Jackson (1957) and later by many others, has established the existence of different forms of P in the soil, each showing a wide range in plant availability depending on soil characteristics and the crop. The major forms of soil P which have been studied are summaried in Table 1.

TABLE 1. Forms of soil P and their extraction

Form of Soil P	Extraction[1]
Al-P	NH_4F pH 8.5
Fe-P	NaOH
Ca-P	H_2SO_4
occluded-P	Na-citrate, Na-dithionite
soluble P	NH_4Cl
organic P	NaOH, NH_4OH

[1] Organic P from Mehta et al. (1954), all other P forms are from Chang and Jackson (1957).

Susuki et al. (1963) noted that Ca-P and secondarily, Al-P

were important in supplying P to plants in 17 Michigan soils ranging

in pH from 4.8 to 7.8. Al-abbas and Barber (1964a) found that Fe-P

and, to a lesser extent Al-P were important on central Indiana soils.

A study of alluvial soils of northwestern India showed that only Al-P

was significantly correlated to P uptake by plants (Talati et al.,

1975), while Pinto (1974) concluded that NH_4Cl extractable P was the

most important P fraction for plants in 24 Venezuelan soils. The

plant availability of the organic P fraction in some soils is well

documented and will be discussed later in this literature review.

Occluded P refers to that fraction which is coated with iron oxides.

This P fraction is not correlated with plant uptake of P (Al-Abbas

and Barber, 1964a; John and Gardner, 1971). Clearly then, there

are several different forms of P in the soil that may be important to

soil testing and plant nutrition.

Plant Available Phosphorus

The question of estimating the plant available P or P supplying

power of a soil is a very complex one which has been studied since

the middle 1800's (Daubney, 1845). Although a complete review of

P-soil-plant relationships is beyond the scope of this thesis, the

major principles of P release by soils and P uptake by plant roots

will be examined in light of their usefulness in understanding the

characteristics and requirements of a good P soil test.

Mattingly (1965) was the first of many to set forth the principles of P release from soils. In these principles, P release is characterized by three parameters: capacity (buffering characteristics), intensity (concentration), and kinetics (rate). According to this scheme, intensity characteristics relate to the initial concentration of P in the soil solution while the capacity characteristics reflect the ability to maintain this concentration of P in the soil solution by buffering against the removal of P by plant roots. Work by Fried (1956), Fried et al. (1957), and Olsen and Watanabe (1966) showed that the release of P from soils with adequate supplies of P was much more rapid than uptake by plants, so that the kinetic or rate factor is generally not as critical in predicting P release from soils as are the intensity and capacity factors.

When testing soils for available P the intensity or concentration factor is probably most directly measured by the P extracted with water or very dilute acid at a low soil to solution ratio. The capacity factor of a soil may be stressed in a P soil test by: increasing the concentration of the P extracting ion(s), decreasing the soil-to-solution ratio, and increasing the time of extraction. Soil tests designed for field conditions where extensive cropping is practiced must, therefore measure both the intensity and capacity characteristics of the soil from the form or forms of soil P which contribute most to plant growth.

The Use of Phosphorus Soil Tests

The complex nature of soil P and variable contribution of the various P fractions to uptake of P by plants from an extremely broad range of soils has led to a proliferation of P soil test methods. Anderson (1960) presents a review of the history and development of P soil tests and Bingham (1962) lists most of the commonly used P soil tests and some of their specific applications. New P soil tests have been introduced mostly to serve local conditions and preferences and do not constitute fundamental changes in P soil testing. Most, but not all P soil tests involve the extraction of a soil sample by a given volume of solution for a specified length of time with the P supplying power of the soil being equated to the P content of the soil extract. Table 2 summarizes the main P soil testing methods. Of these, two extraction methods, namely those of Olsen et al. (1954) and Bray and Kurtz (1945) have been widely adopted. Three other extractions which have been widely used are NaOAc (Morgan, 1939), Bray and Kurtz' P_2 solution (0.3 $\underline{N}$ HCl - 0.03 $\underline{N}$ NH_4F), and Mehliches' solution (0.25 N H_2SO_4 - 0.05 $\underline{N}$ HCl) (Mehlich, 1953). These five extractants which have been widely researched and widely used in soil testing laboratories, address nearly the full range of soil chemical characteristics, and account for well over half of all of the P soil testing done in the United States (Bingham, 1962). A

TABLE 2. Summary of some P soil testing categories

Type	Example	Reference
Extraction Methods		
mineral acids	$0.25 \underline{N} H_2SO_4 - 0.05 \underline{N}$ HCl	Mehlich (1953)
buffered weak acids	NaOAc - HOAc, pH 4.8	Morgan (1932)
buffered bases	$0.5 \underline{M}$ NaHCO$_3$, pH 8.5	Olsen et al. (1954)
neutral salts or water	0.01 M CaCl$_2$	Soltanpour et al. (1974)
dilute salts and acids	0.03 N NH$_4$F - 0.025 N HCl	Bray & Kurtz (1945)
complexone solutions	0.0025 M Na$_2$EDTA	Ahmed & Islam (1975)
anion exchange resins	Dowex-2, Cl$^-$ form	Amer et al. (1955)
Equilibration Methods		
buffered inorganic salts	K$_2$HPO$_4$, Super-Floc 127	Baker (1973)
isotopic dilution	P^{32} + 0 to 400 ppm P^{31}	Baker (1964)
sorption	from 2 ppm P solution	Beckwith (1964)
Mathmatical Indecies	P Index	Sacheti & Saxena (1974)
Miscellaneous Techniques	electroultrafiltration	Schüller et al. (1975)

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detailed treatment of the different forms of soil P extracted by these

various soil test methods is found in Thomas and Peaslee (1975) and

is summarized in Table 3.

The Olsen test has proven to be more effective for soils having

medium-to-high cation exchange capacity (C.E.C.), high degrees of

base saturation and moderate-to-high amounts of Ca-P and free

$CaCO_3$ (Tripathi et al., 1970; Bhan and Shanker, 1973). This test

has also proven desirable on noncalcareous soils. Dubey et al. (1973)

found that the Olsen test was superior to five others in predicting P

availability on the organic soils os Hoshangabad, India, while Gattani

and Seth (1973) had similar results with 24 non-calcic alfisols in

Rajasthan, India. A survey of both acidic and calcareous Welsh soils

indicated that the Olsen method gave the best correlation with P up-

take over a wide range of soil types.

The Bray P_1 test is most often the best method for soils having

low-to-medium C.E.C. that are typically acidic and have been

moderately to highly weathered (Oko and Agboola, 1974; Kumaras-

wamy et al., 1973). In some cases this method has even proven

more successful than Olsen's on calcareous soils. Smith et al.

(1957) found the Bray P_1 soil test to be much more correlated to

wheat yields than the Olsen test on 17 calcareous soils from western

Kansas. This example is an exception but in many cases the Olsen

and Bray P_1 soil test values are highly correlated and often give

TABLE 3. Forms of soil P extracted by five common P soil tests.

Soil Test Method	Extracting Ion	Soil P Form Extracted
Olsen	HCO_3^-	Al-P > Fe-P > Ca-P
Bray P_1	F^-	Al-P
	H^+ (0.025 $\underline{N}$)	Fe-P, Ca-P
Bray P_2	F^-	Al-P
	H^+ (0.3 $\underline{N}$)	Ca-P > Fe-P
Morgan's NaOAc	OAc^-	prevents P readsorption
	H^+	Ca-P > Al-P > Fe-P
Mehlich	H^+	Ca-P > Al-P > Fe-P

equally satisfactory results. Independent studies from a wide variety of soils in Central America, Turkey, Tunisia, and India (Balerdi et al., 1968; Ozbek, 1969; Tnani and Kannenberg, 1971; and Dubey et al., 1974, respectively) have shown that the Bray P_1 and Olsen methods give comparable and reliable results.

It is appropriate at this point to note that the relative distribution of the soil P fractions can change with repeated application of phosphate fertilizer. Work on acid soils by Volk and McLean (1963), Grigg (1966), Tandon (1969), Peck et al. (1971) and Ballard and Pritchett (1976) all indicated a nearly linear increase in the Al-P fraction following fertilizer P application. Grigg (1966) recommended the Olsen test to monitor these fluctuations in Al-P while Tandon (1969), Peck et al. (1971) and Ballard and Pritchett (1976) all found the Bray P_1 test most accurately predicted the changes in plant available P coming from the Al-P fraction.

In many alluvial soils Ca-P accounts for the bulk of plant available P and a soil test which extracts proportionately more Ca-P is desirable. The higher concentration of H^+ in the Bray P_2 soil test does extract more of the Ca-P fraction than does the Bray P_1 test. Studies of alluvial rice growing soils in Iran (Kacar et al., 1967), Japan (Shiga, 1973), Thailand (Kanapathy et al., 1973), and Nigeria (Enwezor, 1977) all found the Bray P_2 test to give the best

estimation of plant available P, compared to the Bray P_1 and Olsen

methods.

Morgan's NaOAc P soil test is not used as extensively as the

Bray and Olsen methods. The Morgan solution is used to extract

other nutrients in addition to P. It is currently used in parts of

Washington[1] and has proven effective in predicting P availability in

some acid soils (Lathwell et al., 1958; Griffin and Lorton, 1970).

McIntosh (1969) and Griffin and Lorton (1970) found that modification

of the Morgan's NaOAc solution with 0.03 $\underline{N}$ F$^-$ improved the accur-

acy of the test. Tolchard and Dight (1972) obtained erroneous

results using the Morgan procedure on some acid Welsh soils.

The inability of the Mehlich double acid soil test to extract

sufficient amounts of Al-P has severely restricted its range of

application. Stephen and Lin (1974) found it to be satisfactory for

predicting available P in 24 Hong Kong soils, but many other

researchers have found the Bray P_1 and Olsen tests superior to the

Mehlich procedure.

Other extractants for P soil tests have been developed. Some

of these are $(NH_4)_2 SO_4$ (Amer et al., 1976; Bruce, 1966), Na_2CO_3

(Dalal, 1973), $Na_2C_2O_4$ (Al-Abbas and Barber, 1964b), and E. D. T. A.

(Borlan and Bordeiasu, 1968; Nnadi et al., 1975). Many of these

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[1] Personal communication from A. R. Halvorson, W. S. U.,
  Pullman, Washington.

P soil tests are highly correlated to P uptake by plants, but have not
gained wide acceptance because their usefulness is limited either to
a small geographical area or an inextensive soil type. In most cases
a well established soil test method gave equally satisfactory results
(Al-Abbas and Barber, 1964b).

A technique which has shown some promise is based on anion
exchange resins. The work of Amer et al. (1955), in which P from
a soil suspension is adsorbed by an anion exchange resin, stimulated
some interest in this method, however, it has been plagued by a
number of analytical and practical problems which have prevented its
adoption for routine laboratory use. The procedure is long and
involved and often requires shaking periods of up to 16 hours (Hislop
and Cooke, 1968). Cook and Hislop (1963) report significant inter-
ference from soil salts as well as temperature effects which change
P adsorption by the resin by up to 4% per 1°C. In a study of 3 Chilean
soils derived from volcanic ash, Zunino et al. (1973) found that resin
extractable P decreased drastically during the 180 day period
following P fertilization, and that meaningful predictions of P
availability from these soils required a precise knowledge of pre-
vious P fertilizer applications.

Various equilibration methods for determining the P needs of
crops have been discussed in the literature. The simplest method
involves equilibration of a soil sample with a standard P solution of

about 0.2 ppm P (Beckwith, 1964). The amount of P sorbed was found to parallel the P fertilizer requirements of plants. Baker (1964, 1973) refined this technique and had success in predicting plant availability of P, but improved the correlation with P uptake of a test crop by using the Bray P_1 soil test.

P soil tests such as those of Sacheti and Saxena (1974) and Schüller (1975) do not have practical application in soil testing laboratories.

In summary, because of the great variability of soils and the forms of soil P which constitute the reservoir of plant available P, it is not likely that a satisfactory single P soil test can be developed for all soils. The Bray P_1 soil test for most acid soils and the Olsen soil test for most calcareous soils give satisfactory results because they have been specifically designed to extract the most important forms of soil P which are available to plants.

Phosphorus Fractionation

Different Sequential Extraction Methods

In 1938, Dean discussed several soil P compounds. Chang and Jackson (1957) published a method for P fractionation in soils which with several modifications has served as a standard precedure for P fractionation. This method and its modifications have done

much to determine the forms of both native and applied P in soils.

The method uses a sequence of extractants which selectively remove

different forms of soil P one at a time (Table 1). First, soluble P

(primarily $Ca\ HPO_4$) is removed with NH_4Cl. Then a neutral NH_4F

solution is added to remove Al-P followed by NaOH solution for

removal of Fe-P. Sulfuric acid is added to remove apatite and other

forms of insoluble Ca-P. Finally, Al-P and Fe-P compounds which

are coated with Fe oxides and are referred to as occluded P, are

removed by reducing the Fe in the soil and repeating the NH_4F and/or

NaOH extractions.

While this method, in its original form, was useful in defining

some definite fractions of soil P, several analytical problems were

encountered (Aung-Khin and Leeper, 1960). It was discovered that

neutral NH_4F was not a selective extractant of Al-P but also extracted

a significant amount of Fe-P (Aung-Khin and Leeper, 1960). Bromfield

(1967) found that the amount of soil P extracted by NH_4F decreased

drastically in the presence of iron and aluminum oxides and concluded

that NH_4F extractable P does not equal the Al-P fraction. Fife

(1959, 1962) examined the selectivity of NH_4F as an extractant for

Al-P and found that at pH 8.5, NH_4F was a suitable extractant of

Al-P and did not remove significant amounts of the Fe-P fraction.

Aung-Khin and Leeper (1960) also pointed out that a significant

amount of reductant soluble P, also called occluded P, was liberated

during the extraction of Ca-P by H_2SO_4. Petersen and Corey (1966)

suggested that reductant soluble P should be removed before the Ca-P.

This method also calls for the use of alkaline NH_4F (pH 8.2) as the

extractant for Al-P. Petersen and Corey's (1966) method of P

fractionation has given quite satisfactory results (Uzu et al., 1975)

and has needed no further modifications.

Several other P fractionation schemes have appeared in the

literature, although none have received the attention or acceptance

of the modified Chang and Jackson (1957) method. Bhangoo and Smith

(1957) and Bishop and Barber (1958) both devised schemes in which

soil P was divided into three fractions: 1) adsorbed P, 2) acid

soluble P, and 3) alkali soluble P. Their aim was to extract P

fractions that would be correlated to P uptake by plants. Unfor-

tunately both procedures failed to define a discrete Al-P fraction

which in many cases is the most important form of soil P for plants.

Williams et al. (1971) pointed out that the CaF_2 formed during

extraction with NH_4F adsorbed some soil P, thereby underestimating

Al-P and Fe-P while overestimating reductant soluble P. They sug-

gested a procedure for P fractionation using successive single

extractions with a NaOH solution, a citrate-dithionite-bicarbonate

reductant solution, and a HCl solution. Again, this system fails to

define an Al-P fraction and hence has not been widely adopted. In an

interesting approach, Gachon (1972) used the Chang and Jackson

(1957) procedure of soil P fractionation in conjunction with equili-

bration of the soil sample with radioactively labelled P^{32}. After

examining the fate of the applied P^{32} on both acid and calcareous

soils he concluded that labile P as determined by isotopic dilution is

superior to the fractionation procedure of Chang and Jackson (1957)

in assessing the P fertility of soils.

Application of Phosphorus Fractionation Information

Information from P fractionation of soils has been used in a

number of different ways. Four major uses appear repeatedly in the

literature; they are, 1) fractionation data in conjunction with field or

greenhouse results to indicate which forms of soil P are most plant

available, 2) relative distribution of forms of soil P can be used to

predict which P soil test might be most useful in predicting plant

available P for a given soil type, 3) P fractionation can clearly deter-

mine the fate of applied P in soil and aid in evaluation of the residual

effectiveness of P fertilization, and 4) the relative proportions of

soil P are a very sensitive index of chemical weathering in soils.

Research has shown that, depending on soil conditions, each of

the forms of inorganic P, excepting occluded P, can be an important

source of P for plants. Using sudangrass (Sorghum vulgare sudanese)

Juo and Ellis (1968) examined the availability of P from synthetic

phosphate minerals. They found that colloidal ferric and aluminum

phosphates were much more plant available than their crystalline analogs, with crytalline variscite ($AlPO_4 \cdot 2H_2O$) being about twice as available to plants as crystalline strengite ($FePO_4 \cdot 2H_2O$).

There are many examples in the literature where P fractionation and greenhouse studies have led to the correct prediction of which P soil test would be most suited in assessing the P status of a given soil (Jackson et al., 1964; Kurtz and Quirk, 1965; Chang, 1965; Datta and Khera, 1969; and Bisen and Ramamoorthy, 1973). P fractionation was used in a study of 24 Indiana soils by Al-Abbas and Barber (1964a, b), who found that the Fe-P fraction was important to the yield of millet. Knowing this they devised a soil test designed specifically for extracting Fe-P and found that it was more highly correlated to crop yields than six of the most commonly used P soil tests, including the Bray P_1 and Olsen methods.

The fate of applied P to soils has been elucidated by P fractionation studies on a wide variety of soils (Chang and Jackson, 1958; Chiang, 1963; Robertson et al., 1966; Appelt and Schalscha, 1970; and Weaver et al., 1975). In nearly all cases, except with calcareous soils, applied P is initially converted to Al-P with a slower conversion to Fe-P with time. In calcareous soils, especially in alluvial soils of clay-slate origin, Ca-P is likely to form following P additions (Chiang, 1963).

The distribution of the forms of soil P can be used to assess

the extent of pedogenesis in soils (Smeck, 1973). Young soils are relatively enriched in Ca-P and organic P, while old soils contain predominately Fe-P, Al-P, and occluded P (Dahnke et al., 1964; Williams and Walker, 1969; Ballard, 1970; and John and Gardner, 1971). Smeck and Runge (1971) also suggest that total soil P, P translocations, and P availability increase with increased profile development.

Organic Phosphorus Fractionation

The organic P fraction in soils has not been considered important to plant growth, thus relatively little effort has been put into characterizing organic P. Batsula and Krisonosova (1973) found that 99% of the soil organic P in three Russian mollisols occurs in side chains in the humus. They also found that the fulvic acid fraction of soil organic matter contains about 10 times more P than the humic acid fraction. These findings were confirmed by Fares et al. (1974).

Several attempts at fractionating soil organic P are recorded in the literature. Martin (1964) used exchange resins with differing percentages of cross linkages and was successful in extracting different organic P fractions. Sommers et al. (1972) performed a sequential extraction of organic P using 1 $\underline{N}$ HCl, cold 0.3 $\underline{N}$ NaOH, and hot 0.3 $\underline{N}$ NaOH. The NaOH extracts were then chromatographically separated into three distinct fractions. In both of these organic

P fractionation procedures, precise chemical characterization and

relative plant availability of the various P fractions were not deter-

mined and at present the fractionation of soil organic P is an item of

academic curiosity only.

Organic Phosphorus

Methods of Determination

Black and Goring (1953) first reviewed the subject of the deter-

mination of soil organic P. All methods involve the oxidation of the

soil organic matter which converts all organic forms of P to in-

organic forms which are easily determined. Oxidation of organic

matter can occur before or after extraction of P from the soil

sample. Oxidation prior to extraction (usually dilute acid) is

accomplished by ignition or treatment with 30% H_2O_2 (Legg and

Black, 1955; Saunders and Williams, 1955; Dickman and De Turk,

1938). These procedures require extraction of duplicate soil

samples, one with and one without oxidation of organic matter.

Organic P is calculated by the difference in P content of these two

soil extracts.

In other procedures, organic forms of P are removed from the

soil by an alkaline extractant of variable concentration and tempera-

ture following an acid pretreatment. One aliquot is either digested

in perchloric acid or ignited to allow measurement of the organic +

mineral P in the extract. Mineral P is determined from a second aliquot in which organic matter has been removed by flocculation and filtration, with the organic P content being determined by difference (Mehta et al., 1954; Pearson, 1940; Harrap, 1963).

There are numerous references in the literature concerning the effectiveness of the various methods of determining soil organic P. In almost all cases, the HCl, NaOH extraction procedure of Mehta et al. (1954) is compared with the ignition, dilute acid extraction procedure of Saunders and Williams (1955). Enwezor and Moore (1965) and Ipinmidum (1973) investigated a total of 27 Nigerian soils and in both cases favored the Mehta procedure, as the ignition method gave results that were too high.

Williams and Walker (1967) and McKercher and Anderson (1968) investigated soil and parent material samples from New Zealand and Canada, respectively, which were relatively low in organic P content and obtained high values for organic P using the ignition method, and attributed this to an increase in the dilute acid soluble P soil fraction following ignition.

Bornemisza and Igue (1967) investigated 11 Costa Rican soils which were relatively high in organic P content. In this case the ignition methods of Legg and Black (1955) and Saunders and Williams (1955) were compared with the Mehta et al. (1954) extraction procedure, with the ignition methods giving consistently lower results.

Their work indicated that aluminum phosphate formation from some

of the organic P fraction during the ignition of these high sesquioxide

soils was responsible for the reduction in dilute acid solubility of

organic P following ignition. Other work suggests that ignition only

partially oxidizes the soil organic matter to inorganic forms, while

some is converted to a lignin-like compound which retains some

organic P in a highly insoluble form (Dormaar and Webster, 1964).

The Mehta et al. extraction procedure is not without its

analytical problems. Harrap (1963) and Bomemisza and Igue (1967)

conducted extensive experiments which demonstrated that a signifi-

cant amount of organic P was hydrolyzed during extraction and hence

gave low values for the organic P fraction. Nonetheless, the Mehta

et al. (1954) extraction method continues to be the reference proce-

dure for determining soil organic P content (Ipinmidun, 1973).

Because of the inherent analytical inaccuracies in each of the

different methods, and because organic-P must be measured in-

directly, there is still no one absolute measure of soil organic P.

Dormaar (1964) concluded that total organic P could not be measured

quantitatively with the current analytical methods.

Plant Availability of Organic Phosphorous

Pierre and Parker (1926) investigated the plant availability of

inorganic and organic P in soil extracts from 21 soils from the

Midwestern and Eastern United States. They found that even though

an average of 61% of the total P in the extracts was organic P, it was

totally unavailable to plants, while nearly all of the inorganic P was

absorbed by plants. Due to the lack of a reliable analytical method for

determining the organic P content in soils, little work concerning the

plant availability of organic P was done prior to the mid-1950's, and

organic P was considered by most soil scientists to be unavailable for

plant growth.

This assumption appears to be true for many of the agriculturally

significant temperate zone soils of the world which have a moderate

organic matter content (2-8%), a moderate pH (5.0-8.0), a moderate

annual rainfall (50-130 cm), and a history of agricultural management.

A study by Al-Abbas and Barber (1964a) of 24 agriculturally important

Indiana soils indicated that soil organic P content was uncorrelated with

plant yield and P uptake.

There are numerous references in the more recent literature that

clearly demonstrate that the organic P fraction does constitute a signi-

ficant reservoir of plant available P. Studies by Agboola et al. (1976)

and Adepetu and Corey (1976) of 115 Nigerian soils found that organic

P was the most important source of plant available P in fallow or newly

cleared land where rapid degradation of soil organic matter occurs.

Significant release of organic P in a plant available form does

not just occur in cases of shifting tropical agriculture however. Plant

availability of soil organic P has also been observed in the acid wheat growing soils of Kenya (Friend and Birch, 1960), some forest soils in Nigeria (Enwezor and Moore, 1966), some Texas vertisols (Hawkins and Kunze, 1965), some calcareous aridisols from Arizona (Fuller and McGeorge, 1951), and in some agriculturally important Iowa soils (Van Diest and Black, 1959). Van Diest and Black (1959) conducted incubation studies on 14 Iowa soils and concluded that P present in the organic form at the beginning of a season contributes substantially to plant nutrition in that season.

The examination of one alfisol and two mollisols from Ukrainian S.S.R. revealed that about 99% of the organic P fraction in virgin soils is present as side chains on the humus structural framework. However, with ploughing and prolonged utilization of these soils, there is a significant shift of organic P into non-hydrolysable residues. (Batsula and Krivonosova, 1973).

A historical review of the literature indicates that insights into the role of organic P in plant growth has, to a large extent, been dependent on the existing analytical techniques of the time. The most striking examples of organic P availability, such as shifting cultivation in the tropics, were noted first, with the more subtle relationships between soil organic P, soil characteristics, and soil management history being brought to light only recently.

Soil Testing and Organic Phosphorus

Most commonly used P soil tests are based on inorganic P as a measure of plant available P. Fuller and McGeorge (1951), Van Diest and Black (1959), and Adepetu and Corey (1976) showed that soil organic P mineralized during the growth of a crop significantly contributes to the P needs of the crop, while Agboola et al. (1976) demonstrated that in some cases the commonly used P soil tests which do not include the organic fraction, have poor correlation with P uptake by a test crop.

Abbott (1978) investigated the effects of returning to the soil varying amounts of a sorghum (Sorghum bicolor L., Moench) cover crop on the P nutrition of cotton and alfalfa. He found that measurement of inorganic P was adequate in predicting available P only in soils with very low reserves of organic P. For soils with larger reserves of organic P, soil test-plant P correlation was improved when the organic P in the extract was included. He concluded that soils sampled in the winter or spring for a summer crop should be tested for total extractable P while the inorganic extractable P would be better for prediction of available P for soils sampled in the summer for a fall or winter crop.

Parent Material Influence on Soil Fertility

General Factors

Of the five soil forming factors, including climate, time, organisms, parent material and topography, relatively little attention has been given to the effect of different types of parent material on soil fertility in general and P fertility specifically. In nearly all cases, climatic considerations far outweigh all other factors in determining soil fertility characteristics. Hart (1941) studied an area of complex geology in northeast Scotland in an effort to compare the mineralogy of soils with their parent material. His conclusion was that the mineralogical makeup of the soil was indeed related to that of the parent material, but tended to be much more complex.

Parsons and Herriman (1976) investigated some of the chemical and physical properties of soils derived from three types of parent material in a lithosequence in the mountains of southwestern Oregon. Granitic soils were coarse textured, had a low percent base saturation, a low cation exchange capacity (C.E.C.) and no argillic horizon. Soils derived from pyroclastic materials were fine textured, had a high percent base saturation, a high C.E.C. and an argillic horizon; while soils from a schist parent material had intermediate properties. The only reference to soil fertility was that the soils from pyroclastic parent material had a higher woodland productivity.

Phosphorus Availability

A study of 22 grassland soils in New Zealand showed that total

soil P was directly related to the P content of the soil's parent

material (Walker and Adams, 1958). It was pointed out that of the

six major elements in soil organic matter, that is C, H, O, N, S,

and P, only P must be supplied to the soil from breakdown of the

parent material. From this work it was concluded that the P content

of the parent material may be the limiting factor in the accumulation

of soil organic matter.

Hanley and Murphy (1970) examined 24 Irish soils and found

that not only did the P content increase with decreasing particle size,

but that the P content of limestone soils was significantly greater than

soils derived from shale parent material.

Other work relating parent material to P availability in soils

involved specific chemical or physical properties of these soils.

Nys' (1975) study of granitic alfisols showed that available P

migrated through soils at a rate similar to that of free aluminum.

Tatevosian and Valdes (1974) conducted an extensive investigation on

the availability of soil P in relation to the chemical and mineralogical

composition of the mechanical fractions of soils and their parent

materials. They found that soils derived from andesites, basalts,

and tuffs with plagioclase or secondary hydrous mica dominating the

mineral fraction contained significant amounts of available P in the
0.25-0.01 mm size fraction; while soils from limestone, porphyrites,
liparites and felsite displayed increasing available P content with
decreasing particle size. Uriyo and Kesseba (1973) found that P in
soils derived from parent materials high in phosphate minerals was
predominately in the form of calcium-P which has only limited
solubility and plant availability in many cases.

Other references in the literature concerning parent material
and P availability involve the selection of a suitable soil test method
for soils derived from a specific types of parent material (Agboola,
1973; Janik et al., 1973; Janik et al., 1974; Zunino et al., 1973).

Characterization of Phosphorus Status of Specific Soils

Numerous studies have been undertaken to evaluate the P
supplying power, or P status, of soils in specific geographical areas.
Virtually all of these studies have taken one of two forms. The first
method is to collect soil samples and conduct a greenhouse experi-
ment to define the P supplying power of the soils in question to a test
crop (Smith et al., 1957; Janik and Gusenleitner, 1974; Al-Abbas
and Barber, 1964a,b; and Nandra, 1974). The soils are analyzed by a
number of currently used P soil tests to see which one has the highest
correlation with P uptake by the test crop. Using this method, soil
tests are often chosen randomly, with success often the result of

investigating several extractants. This technique has had some success which is probably due to the fact that most of the common P soil tests extract some of the forms of plant available P in most soils. This method of determining P status has proven most successful in restricted geographical areas or in soils with a limited range in physicochemical properties (Gattani and Seth, 1973).

The second major method for determining P status in a given area is most typified by the work of Jackson et al. (1964) and Al-Abbas and Barber (1964a, b). In this method, the forms of soil P are determined by a suitable fractionation scheme and then correlated to P uptake and/or yield of a test crop in the greenhouse. Then, a limited number of soil test methods are selected, based on their proven ability to extract the most important forms of plant available P. An advantage of this method is that the fate of applied P can be determined and P soil testing procedures can be altered for soils receiving repeated applications of P fertilizer if such a change is deemed appropriate (Thomas, 1964).

It is interesting to note that Franklin and Reisenauer (1960) questioned whether the fractionation-greenhouse-soil testing method was adequate to determine the P status of soils. They investigated the correlation between P fixation and availability and a wide variety of soil chemical properties, including clay type and content, organic matter, C.E.C., anion exchange capacity, exchangeable Al, total P,

organic P, and inorganic P. Interestingly, they concluded that while

P fixation was most highly correlated with anion exchange capacity

and exchangeable Al, the best correlation to P availability was with

the inorganic P fraction.

MATERIALS AND METHODS

Soils

Introduction

The intent of this study was to examine differences in the P

status of soils derived from different parent materials in southwest

Oregon. Exact knowledge of the specific parent material of a soil is

often problematical, especially in the case of alluvial soils and to a

lesser extent, soils derived from colluvial parent material. In this

study it was felt that residual upland soils would be most specifically

related to parent material. In the case of alluvial or colluvial soils,

additional attention to geographical and geological setting is necessary

to insure correct identification of the soil parent material as well as

limitation to one specific type.

A second criterion for the selection of soils for this study relate

to the agricultural significance of the soil. Many residual upland

soils in southwest Oregon which are derived from a specific type of

parent material are devoted to nonagricultural uses such as recrea-

tion and timber production which normally require less intensive

utilization of P soil testing. Sheep and cattle raising is widely

practiced in southwest Oregon and cleared hill pastures are extensive

in most of this region. These hill pastures are used for grazing or

forage production primarily, although some small grain production is also practiced. Many of these upland soils were derived from specific types of parent material and appeared ideally suited to this study.

Parent Materials

The study region in southwest Oregon, shown in Figure 1, is made up of three major geological source areas: 1) The Klamath Mountains Source Area, containing extensive granitic soils. 2) The Coast Range Source Area, which consists almost entirely of sedimentary soils. 3) The Cascade Mountains Source Area, characterized by basaltic soils. Two soil series were selected from each source area with samples taken from three locations within each series. The sedimentary soils in the high rainfall areas of Coos County are different from the sedimentary soils developed under lower rainfall in Douglas County (Figure 2). To investigate this climatic effect, sedimentary soils from both Coos and Douglas Counties were included in the study. The Southern Oregon Experiment Station is located on the Central Point soil series, which is derived from granitic alluvium. Although this series is not extensive, it was included in this study because it is derived from a single type of parent material, and its P supplying power to a variety of crops is
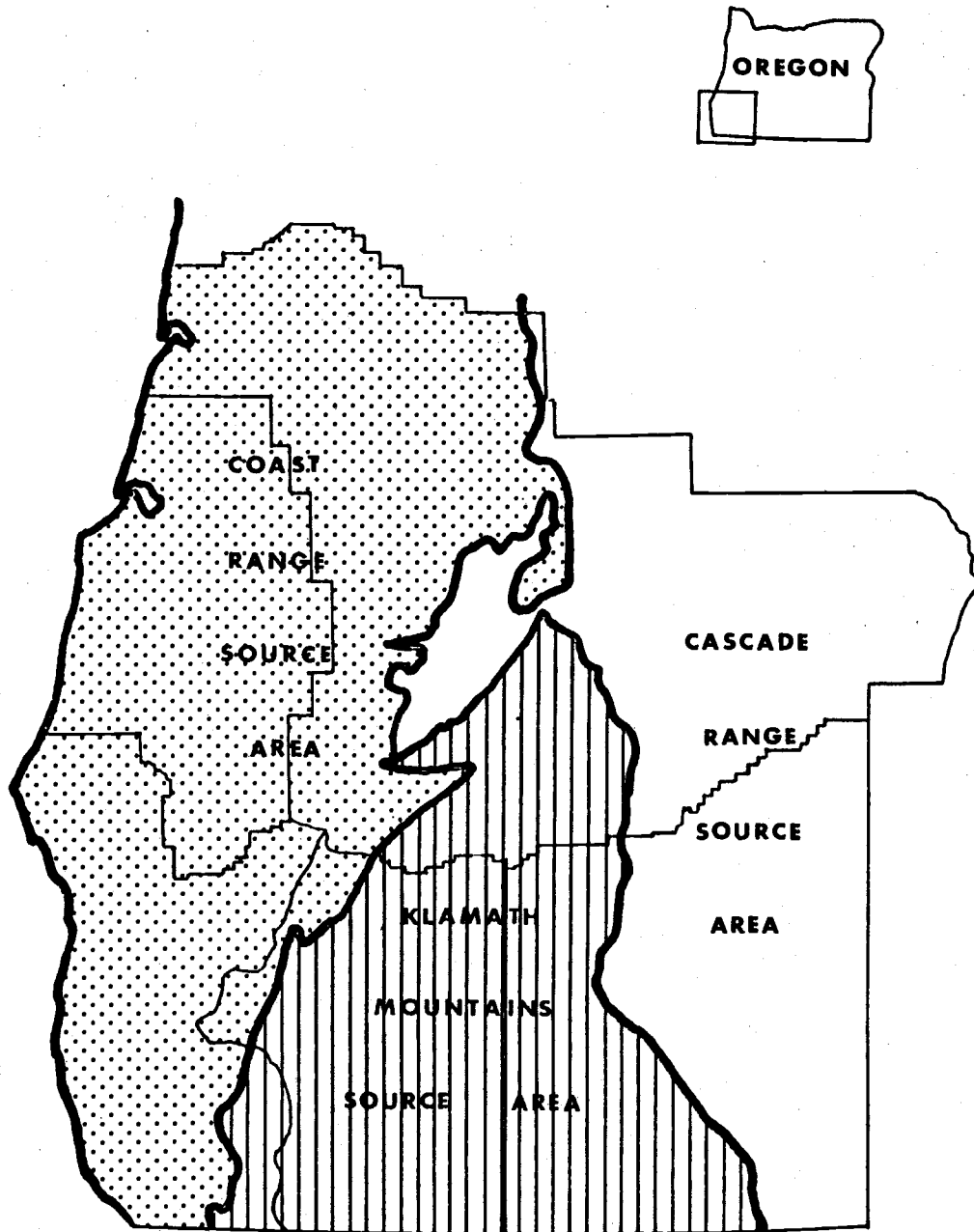
Figure 1. Generalized geology of southwest Oregon.
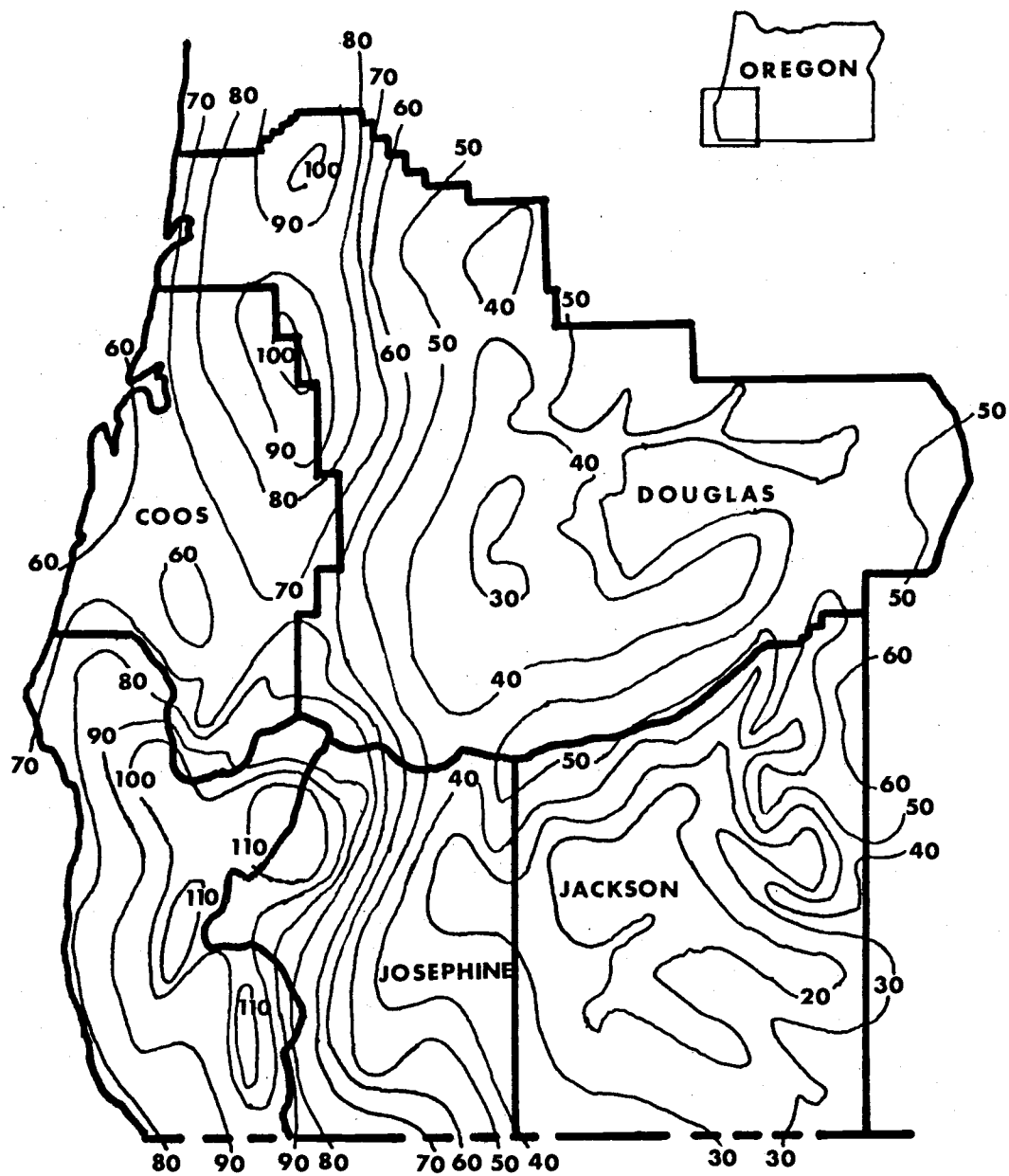
Figure 2. Annual precipitation in southwest Oregon (inches).

well known. Thus, a total of 25 locations from nine soil series were sampled.

The granitic soils selected were the Siskiyou, Holland and Central Point series. The Siskiyou series consists of moderately deep, somewhat excessively drained soils formed in residuum and colluvium from granitic bedrock. It is a member of the coarse-loamy, mixed, mesic family of Typic Xerochrepts. Siskiyou soils occur on uplands with slopes of 20 to 70 percent, and are used primarily for improved pastures and timber production. The Holland series is a member of the fine-loamy, mixed mesic family of Ultic Haploxeralfs. It occurs on moderate to very steep slopes and is derived from bedrock consisting mainly of quartz diorite and granodiorite. Its main uses include pasture, small grain, and timber production. The Central Point series is a very deep well drained soil formed in granitic alluvium. It is a member of the coarse-loamy, mixed, mesic family of Pachic Haploxerolls. These soils occur on nearly level terraces and are suited for all locally adapted crops.

The sedimentary soils selected in Coos County were the Coosbay and Dement series. Both are derived from residuum and colluvium from sedimentary bedrock and occur on level to very steeply sloping terraces and uplands. Both series are used for forage, pasture, and timber production. The Coosbay series belongs to the medial, mesic family of Andic Dystrochrepts while the Dement series belongs to the

fine, mixed, mesic family of Typic Dystrochrepts.

The Nonpareil and Willakenzie series were chosen to represent the sedimentary soils from the drier interior portions of Douglas County. The Nonpareil soils are on gently sloping to very steep uplands with slopes of 3 to 50 percent. Parent material consists of tuffaceous sandstone, siltstone or shale. Where slopes are moderate small grains can be grown on these soils, while areas with steep slope are used for improved pasture. The Nonpareil series belongs to the loamy, mixed, mesic, shallow family of Dystric Xerochrepts. The Willakenzie series is found extensively along the western part of the Willamette Valley in Oregon. These soils have gently sloping to steep convex slopes on the foothills surrounding upland regions. They are formed in residuum and colluvium from weathered siltstone and tuffaceous sandstone. The Willakenzie series belongs to the fine-silty, mixed, mesic family of Ultic Haploxeralfs and is used principally for small grains, hay and pasture.

The basaltic soils included in this study were the Dixonville and Newberg series. The Dixonville series is a moderately deep, well-drained soil formed in residuum and colluvium from basalt and other igneous rocks of basaltic composition. These soils occur on gentle to steeply sloping foothills of the Coast Range and Cascade Mountains of western Oregon. Where slopes are moderate, most locally adapted crops can be raised, while areas of higher slope are used for hay and

improved pasture. The Dixonville series is a member of the fine,
mixed, mesic family of Pachic Ultic Argixerolls. The Newberg series
consists of deep, well drained soils formed in alluvium from basaltic
and sedimentary rocks. The alluvium from which the Newberg soils
in Douglas County have been derived, consists of approximately 70%
from basaltic rocks and 30% from sedimentary rocks, and thus
Newberg is considered to be a basaltic soil for the purpose of this
study. These soils occur on broad undulating flood plains and are
suited to row crops, orchards or small grains. The Newberg series
belongs to the coarse-loamy, mixed, mesic family of Fluventic
Haploxerolls.

The location and extent of each of the nine soil series selected
for this investigation are listed in Table 4. The locations of the in-
dividual sampling sites are shown in Figure 3. Detailed descriptions
of the parent material for each soil series are summarized in Table 5.

Sampling and Handling of Soils

One of the objectives of this study was to evaluate the effective-
ness of various P soil testing procedures, therefore it was necessary
to obtain soil samples from sites within individual soil series having
a range in P soil test values. To accomplish this, four to eight sites
from each soil series were sampled, with the exception of the Central
Point series which was sampled at only one site. Based on a

TABLE 4. Parent material, location and extent of the soil series
studied.

Soil Series	Parent Material	County(s)	Hectares
Siskiyou	Granitic	Josephine	8,583
Holland	Granitic	Josephine	6,842
Central Point	Granitic	Jackson	850
Coosbay	Sedimentary	Coos	10,121*
Dement	Sedimentary	Coos	4,049*
Nonpareil	Sedimentary	Douglas	15,385
Willakenzie	Sedimentary	Douglas	2,308
Dixonville	Basalt	Douglas	8,907
Newberg	Basalt	Douglas, Jackson Josephine	13,279

* Approximate areas.
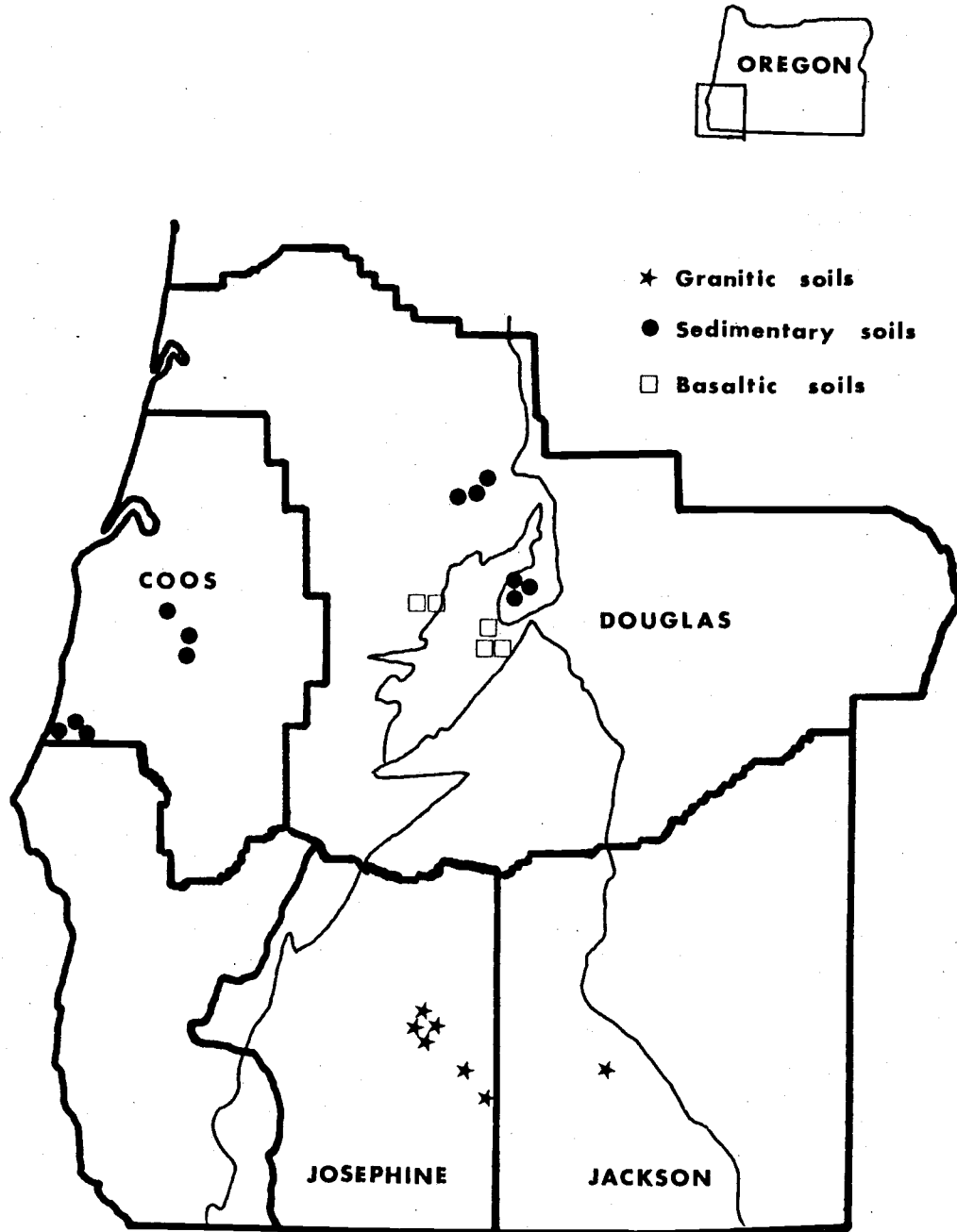
Figure 3. Soil sampling site locations.

TABLE 5. Description of geologic parent material for each soil series.

| Soil Series | Parent Material | |
	Description	Formation Name
Siskiyou	Granitoid rocks; diorite to quartz diorite range in composition	none
Holland	same as Siskiyou	none
Central Point	Alluvium from granitoid rocks	none
Coosbay	Dark gray siltstone and arkosic sandstone	Riddle Fm.
Dement	Light yellow micaeceous, tuffaceous sandstone	Coaledo Fm.
Nonpareil	Dark gray mudstone, and tuffaceous sandstone	Umpqua Fm.
Willakenzie	Tuffaceous sandstone and silt-stone	Yamhill Fm.
Dixonville	Basalt flows, breccia, and tuffs	none
Newberg	70% of Newberg from alluvium from basalt, andesite, and andesitic pyroclastics	none
	30% of Newberg from alluvium from slatey mudstone and graywacke	Galice Fm.

preliminary P soil test of all samples, three locations from each soil series were selected for further study.

All soils were sampled during June 14-17, 1977. Approximately 40 kilograms of soil was taken at each sampling site. All samples were taken to a depth of 18 cm after first removing the top 2 cm of soil in order to avoid sampling of the plants or crop residue on the soil surface. To insure homogeneity of the bulk soil samples, they were passed through a sieve with square holes 1.27 cm on a side, air dried in the greenhouse, and then mixed in a rotary cement mixer for 30 minutes. The mixer was cleaned prior to mixing of each sample to avoid contamination. The samples were then stored in burlap sacks lined with heavy duty plastic bags. Soil samples to be used for laboratory analyses were ground, passed through a 14 mesh sieve, and stored in plastic lined soil sample bags.

Later observations during the greenhouse study revealed a uniform inhibition of growth, and the eventual death, of the test crop grown in one of the Newberg soils. This soil was taken from an apple orchard which had received applications of very persistent herbicides, commonly used in orchards to control weed growth. For this reason, no data from this soil was recorded and only the two remaining Newberg samples were investigated.

<center>Soil Chemical Analyses</center>

Introduction

The characterization of the P supplying power, or P status, of soils can be examined directly by measuring the P uptake by plants grown under controlled conditions either in the greenhouse or in the field. The P status of soils can also be examined indirectly by using various chemical soil tests. Common analyses in this type of research include P soil tests for available-P, determination of the forms of soil P, and a series of general soil analyses to examine the general differences between the various soils which may indirectly affect their P supplying power.

Phosphorus Soil Tests

Three P soil tests were used to estimate the P availability from the soils studied (Table 6). The Bray P_1 soil test is currently

TABLE 6. Phosphorus soil test methods.

Method [1]	Extracting Solution	Soil: Solution Ratio
Bray P_1	0.025 $\underline{N}$ HCl + 0.03 $\underline{N}$ NH_4F	1:7
Olsen P	0.5 $\underline{N}$ $NaHCO_3$, pH 8.5	1:20
NaOAc P	0.74 $\underline{N}$ NaOAc + 0.52 $\underline{N}$ HOAc	1:5

[1] Bray and Kurtz (1945), Olsen et al. (1954), and Morgan (1939), respectively.

recommended for western Oregon soils while the Olsen soil test is

used for Oregon soils from east of the Cascade Mountains (Kauffman

and Gardner, 1976). The Morgan NaOAc soil test is currently used

in parts of Washington. All samples were initially analyzed in

duplicate by each of the three P soil tests. Two additional samples

were run if the original two values were not within ± 10%. All soil

extracts were stored in air tight plastic bottles and all spectrophoto-

metric determinations were performed using a Beckman DB-GT

grating spectrophotometer.

Organic Phosphorus Determination

The organic P content of the 24 soils in this study were deter-

mined following the extraction method of Mehta et al. (1954). One

sample from each of the 24 soils was analyzed, followed by the

analysis of six randomly selected soils in order to check precision.

An initial attempt to determine organic-P by the H_2O_2 oxidation

method of Dickman and De Turk (1938) gave erratic results.

Phosphorus Fractionation Study

The procedure of Chang and Jackson (1957) for fractionating

inorganic soil P was followed with some modifications as outlined by

Jackson et al. (1964). The changes consisted of extracting Al-P by

0.5 $\underline{N}$ NH_4F adjusted to pH 8.5 instead of pH 7.0, and extraction of

Ca-P was made after the reduction of Fe and removal of occluded Fe-P and Al-P. The extraction with 1 $\underline{N}$ NH_4Cl prior to Al-P extraction was omitted because phosphate soluble in NH_4Cl could be refixed by Fe and Al. The outline of the procedure followed is shown in Figure 4. One sample from each of the 24 soils was analyzed, followed by duplicate analysis of three randomly selected soils as a check of precision.

Other Chemical Soil Tests

A series of general soil chemical analyses were performed on each of the 24 soil samples to characterize their fertility levels and aid in establishing appropriate levels for the fertilizer treatments used in the greenhouse experiment. The methods of soil chemical analyses are listed in Table 7.

Greenhouse Experiment

Introduction

A method of measuring the P supplying power of a soil is to determine the P uptake by plants grown in a controlled environment. A test crop of Yamhill wheat (Triticum aestivum) was grown in each of the 24 soils, with and without the addition of P fertilizer. In this way, P uptake by wheat and yield response of wheat to P fertilizer
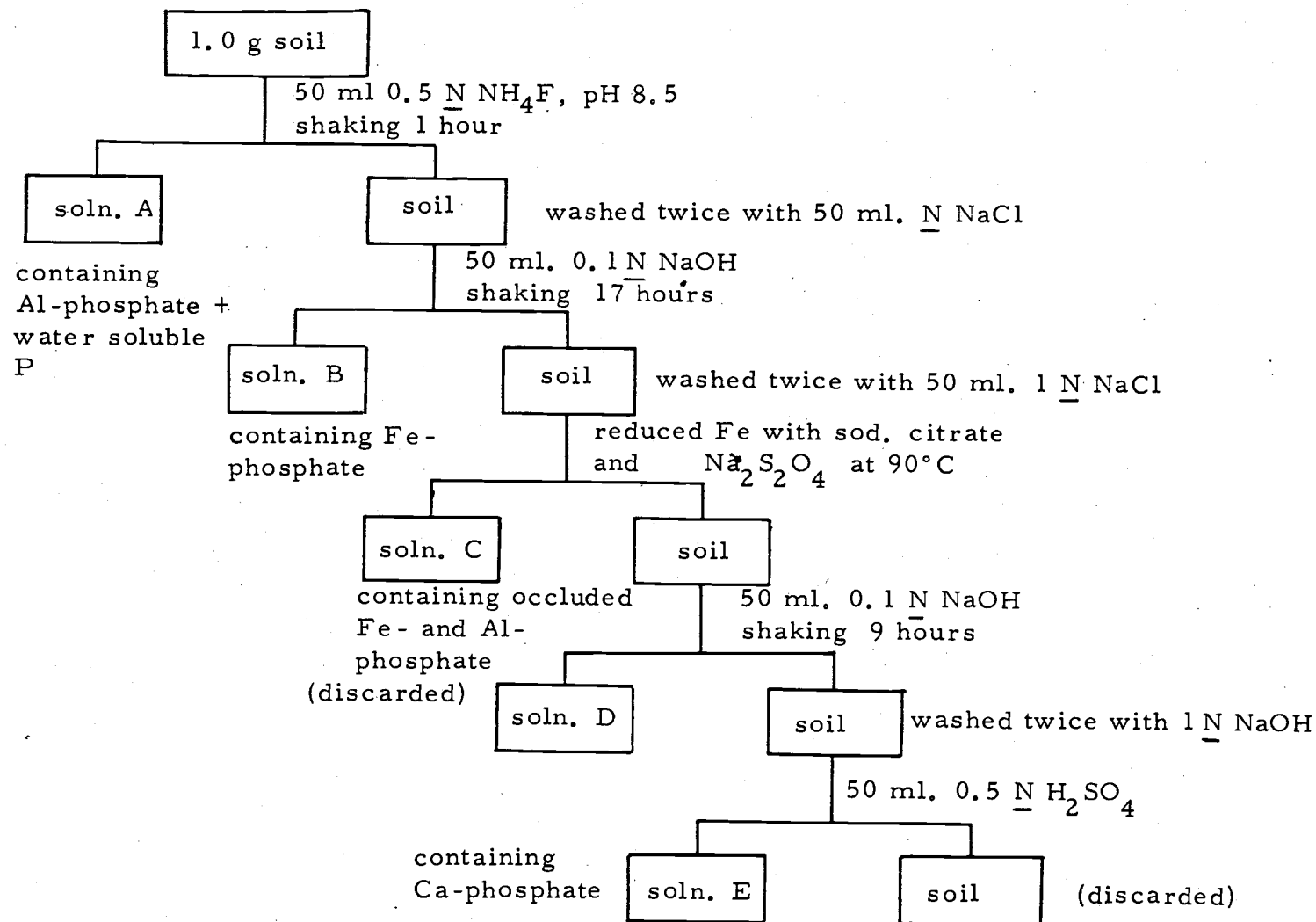
Figure 4. Flow sheet for the fractionation inorganic soil P.

TABLE 7. Methods of soil analysis.

Soil Test	Method [1]	Reference
pH	1:2 soil to water ratio	Jackson (1958)
KCl pH	1:2 soil to 1 N KCl ratio	Jackson (1958)
Lime requirement	SMP buffer pH	Shoemaker et al. (1961)
K, Ca, Mg	atomic absorption, ammonium acetate extractable	Pratt (1965)
Organic matter	Walkley-Black titration	Walkley & Black (1934)
C. E. C.	ammonium acetate distillation	Schollenberger (1945)

[1] from Kauffman and Gardner (1976)

could be measured.

Treatments

Each replication in this experiment consisted of two plastic pots each containing 2.0 kg of each of the 24 soil samples. P fertilizer at a rate of 112 kg/ha was added to one of the pots. All pots received blanket applications of nitrogen and sulfur at rates of 168 and 16.8 kg/ha in accordance with fertilizer recommendations for winter wheat in western Oregon (Gardner et al., 1977). Potassium (K) fertilizer was added, where needed, to bring the extractable K plus fertilizer K up to 200 ppm. Calcium hydroxide was added, where needed, to bring the percent base saturation of the soil up to 50%. Fertilizer applications were on a weight basis, assuming one hectare of soil to plow depth weighs 2,242,000 kg.

Treatments (Tables 8 and 9) were replicated four times and the pots were arranged on the greenhouse benches in a randomized block design.

Procedure

Air dry soil (2.0 kg) from each of the 24 soil samples was mixed with inorganic nutrients and lime and placed in plastic pots with a bottom drainage hole. The mixing was performed using a twin-shell blender. The soil was brought to field capacity with

TABLE 8. Fertilizer nitrogen, sulfur, and phosphorus application rates.

Treatments	Application Rates					
	$N^{1/}$		$S^{2/}$		$P^{3/}$	
	gms/pot	kg/ha	gms/pot	kg/ha	gms/pot	kg/ha
P treated pots	0.150	168	0.015	16.8	0.0437	48.9
untreated pots	0.150	168	0.015	16.8	0	0

[1/] Supplied from ammonium nitrate fertilizer (NH_4NO_3).

[2/] Supplied from gypsum fertilizer ($CaSO_4 \cdot 2H_2O$).

[3/] Supplied from triple superphosphate fertilizer [$Ca(H_2PO_4)_2$].

TABLE 9. Fertilizer potassium and lime application rates.

Soil Series	Location	K [1]		Lime [2]	
		gms/pot	kg/ha	gms/pot	tons/ha [3]
Siskiyou	1	0.120	135	0.548	0.830
	2	0	0	0	0
	3	0.232	261	0	0
Holland	1	0	0	0	0
	2	0.0969	108	0	0
	3	0	0	0	0
Central Point	1	0.232	261	0	0
Coosbay	1	0	0	6.45	9.77
	2	0.0278	31.2	3.17	4.80
	3	0	0	2.31	3.50
Dement	1	0	0	0.981	1.50
	2	0	0	3.89	5.89
	3	0	0	6.99	10.6
Nonpareil	1	0.120	135	0	0
	2	0	0	0.544	0.824
	3	0	0	0	0
Willakenzie	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
Dixonville	1	0.224	251	0	0
	2	0.208	234	0	0
	3	0	0	0	0
Newberg	1	0	0	0	0
	2	0.208	234	0	0

[1] Supplied from potassium chloride fertilizer (KCl)

[2] Calcium Hydroxide [reagent $Ca(OH)_2$]

[3] Based on 100 score $CaCO_3$ equivalent.

distilled water and kept moist for 36 days prior to seeding of the test

crop. This allowed for equilibration of the calcium hydroxide with

the soil and the germination of weed seeds thus facilitating weed

removal. Five wheat seeds were planted in each pot at a depth of

3 cm. Breeder seed sized for large seed (> 2.8 mm) was used.

Fifteen days following emergence, the plants were thinned to 3 per

pot, with an effort being made to maintain equal spacing between the

plants in each pot. Twelve weeks after emergence the plants were

clipped to a height of 1.5 cm. At the time of harvest, plants had 0 to

5 tillers with the average being 2 tillers per plant. The harvested

plant material was oven dried at 65°C for two to three days and

weighed. Each plant sample was ground in a wiley mill to pass a

40 mesh sieve and later assayed for P concentration by the nitric acid-

perchloric acid digest method of Jackson (1958), using a vanadate-

molybdate color forming reagent.

Planting date and greenhouse conditions were chosen to simu-

late field conditions. Temperature conditions were diurnal with

alternating 20°C and 10°C day/night sequences. The fall and winter

of 1977 were quite mild and the desired temperature ranges were

easily maintained. Distilled water was added on one to three day

intervals as needed to provide adequate soil moisture. All drainage

water was collected in aluminum pans and recycled. Supplemental

flourescent lighting was supplied during a 12 hour photo period for the

duration of the experiment. The lights were kept at a height of 10 to 20 cm above the tops of the plants and the flourescent tubes were spaced every 15 cm.

Statistical Analysis

Regression and correlation techniques were used to define the numerical relationships between P soil tests, forms of soil P, P uptake by wheat plants, and yield response of wheat to P fertilizer. These relationships were determined for all soils collectively and for the soils derived from the four types of parent materials. In all tables presenting statistical data, ** means significance at the 1% level of probability, * means significance at the 5% level of probability, and no symbol indicating no significance at the 5% level of probability.

All correlation coefficients involving P soil test values or values for the fractions of soil P were calculated using the $\log_{10}$ of the soil test value expressed in ppm.

RESULTS AND DISCUSSION

Soil Chemical Analyses

Phosphorus Soil Tests

The amounts of P extracted by the Bray P_1, Olsen, and

Morgan's NaOAc P soil tests are listed in Table 10. In all cases but

one, the Bray P_1 soil test extracted as much or more P than the

other soil tests. For higher testing soils the Olsen procedure ex-

tracted more P than NaOAc and with lower testing soils NaOAc

extracted more P than did Olsen. All three soil test values were

significantly correlated to each other at the 1% level of probability.

The Bray P_1 and Olsen soil test values were the most highly

correlated (r = 0.93), while the Bray P_1 and NaOAc soil tests were

the least correlated (r = 0.70). The Olsen vs. NaOAc correlation had

an r value of 0.84.

Forms of Soil Phosphorus

The distribution of the four major forms of soil P are presented

in Table 11, and Figures 5 and 6. The organic-P and Fe-P fractions

tend to be dominant in each of the four parent material soil categories

with the Al-P and Ca-P much less abundant. The relatively less

weathered granitic soils tended to be comparatively low in organic P

TABLE 10. Phosphorus soil test values.

| Soil Series | Location | P Soil Tests | | |
		Bray-P_1	Olsen	NaOAc
		---------- ppm P ----------		
Siskiyou	1	46	25	7.4
	2	74	28	9.9
	3	17	10	6.2
Holland	1	63	40	17.3
	2	14	14	7.1
	3	64	28	6.6
Central Point	1	5	1	6.6
Coosbay	1	1	1	1.5
	2	4	2	1.3
	3	3	1	2.2
Dement	1	5	3	3.9
	2	2	0	2.5
	3	9	2	3.7
Nonpareil	1	3	1	6.9
	2	7	6	5.2
	3	3	0	5.2
Willakenzie	1	31	19	5.2
	2	7	5	3.1
	3	2	0	2.2
Dixonville	1	7	2	2.9
	2	5	2	3.2
	3	36	26	17.4
Newberg	1	41	34	14.3
	2	8	5	7.4

TABLE 11. Forms of soil phosphorus.

Soil Series	Location	Inorganic-P			Organic-P
		Al-P	Fe-P	Ca-P	
		-------- ppm P -----------------			
Siskiyou	1	63	219	19	32
	2	181	166	45	104
	3	26	102	23	35
Holland	1	151	274	39	280
	2	18	157	113	135
	3	120	225	45	239
Central Point	1	3	17	203	251
Coosbay	1	2	61	18	75
	2	12	98	14	377
	3	8	51	14	213
Dement	1	34	148	24	396
	2	38	119	14	302
	3	110	164	7	336
Nonpareil	1	0	44	24	280
	2	10	108	11	163
	3	2	73	14	229
Willakenzie	1	41	164	20	267
	2	21	78	7	141
	3	3	129	12	204
Dixonville	1	7	47	24	277
	2	19	63	25	314
	3	102	94	37	336
Newberg	1	62	197	174	191
	2	4	48	223	38
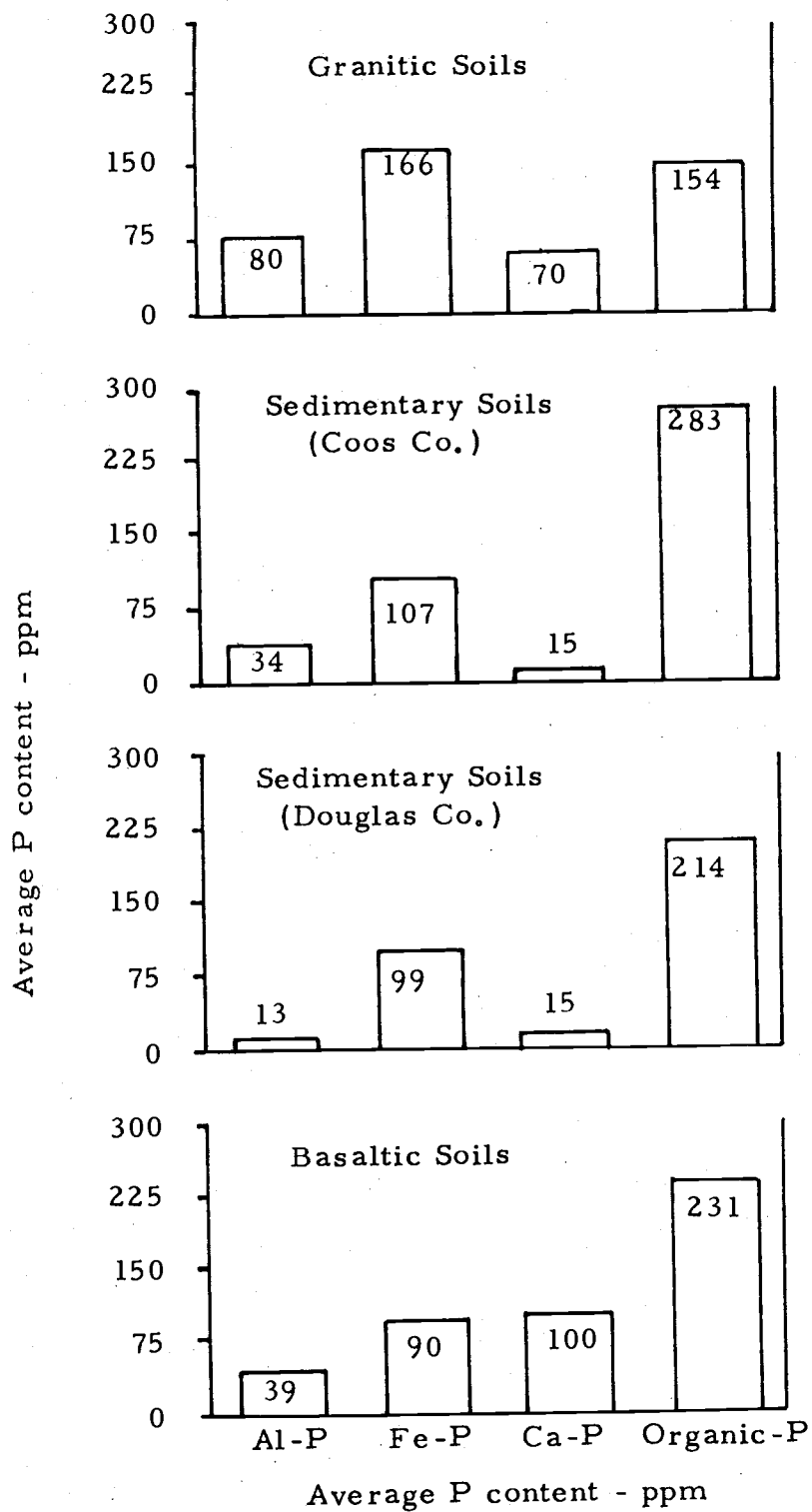
Figure 5. Distribution of the forms of soil phosphorus in
soils derived from different parent materials.
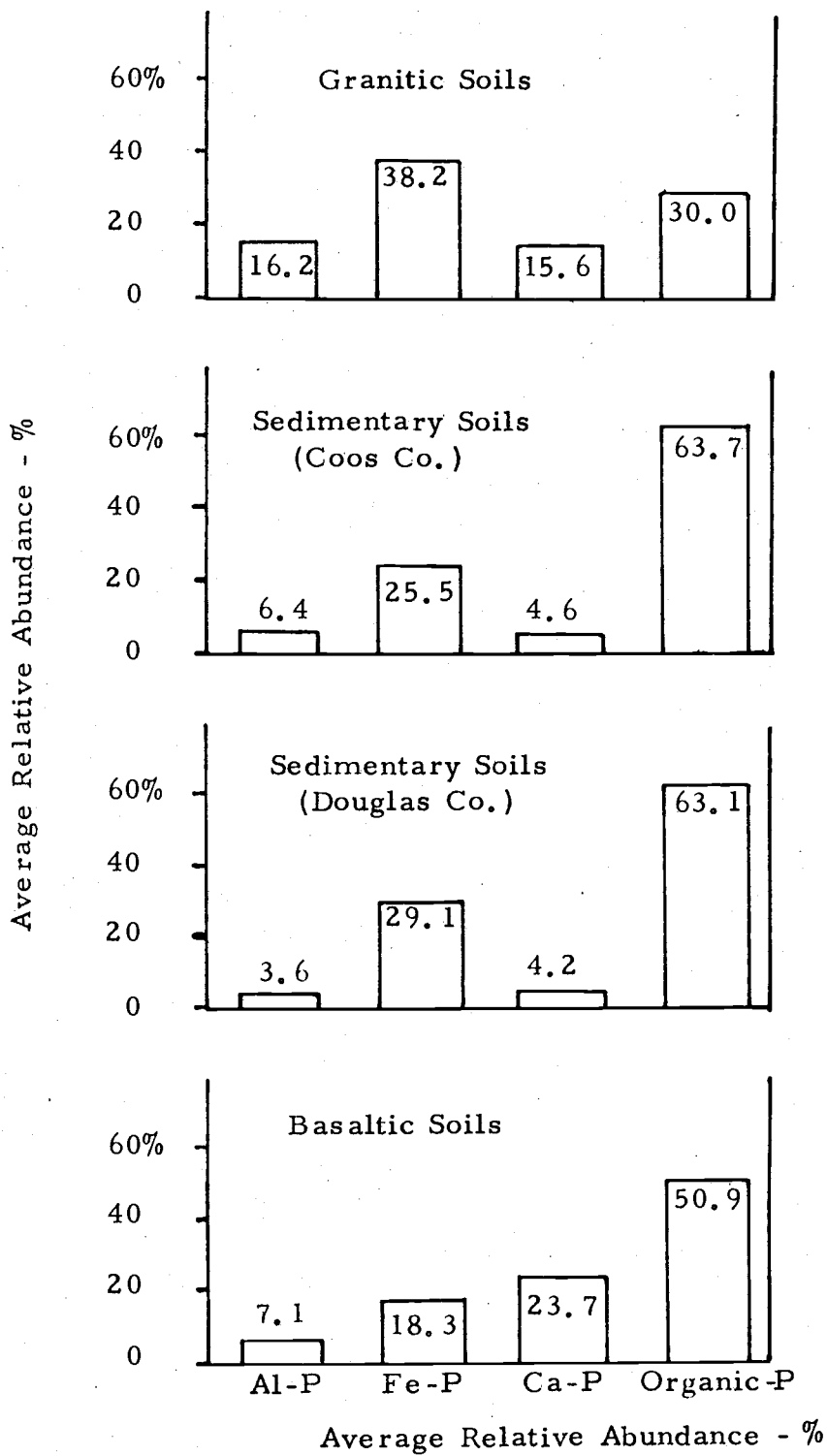
Figure 6. Average relative abundances of the forms of soil
P in soils derived from different parent materials.

and high in Al-P and Fe-P content while the sedimentary soils from

Coos County, which are the most highly weathered, were compara-

tively high in organic-P and low in Ca-P. Calcium-P is relatively

low in nearly all of the soils except the three alluvial soils; Central

Point and Newberg 1 and 2. The relative distribution of the four

major forms of soil P in the sedimentary and basaltic soils of

Douglas County are very similar (Figure 5).

The average sum of inorganic-(Al-P + Fe-P + Ca-P) and

organic-P is nearly constant for each of the four parent material

groups (Table 12). The average total P in the basaltic soils is the

highest while total P content in the sedimentary Douglas County soils

is the lowest (Table 12).

TABLE 12. Inorganic + organic-P and total P in soils derived from
different parent materials.

Parent Material	Inorganic + Organic P	Total P [1]
	---------------ppm P ------------	
Granitic	469	683
Sedimentary (Coos Co.)	439	678
Sedimentary (Douglas Co.)	414	566
Basaltic	456	748

[1] Total P from Mehta et al. (1954).

The organic-P content of the Coos County sedimentary soils is significantly higher than that of any of the other soil parent material groups (Figure 5).

Correlations Between Phosphorus Soil Tests and Forms of Inorganic Soil Phosphorus

The correlations between P soil test values and amounts of inorganic forms of soil P for all soils are listed in Table 13.

TABLE 13. Simple linear correlation coefficients between P-soil test values and inorganic P fractions for all soils.

Soil Test Method	Inorganic P Fraction		
	Al-P	Fe-P	Ca-P
	---------- r value[1] -------------		
Bray P_1	0.79**	0.60**	0.36
Olsen P	0.76**	0.68**	0.35
NaOAc P	0.47*	0.31	0.55**
degrees of freedom	22	22	22

[1] Correlations are based on values expressed as $ppm_{log_{10}}$.

The Bray P_1 and Olsen soil test values were significantly correlated with the amounts of Al-P and Fe-P with the Fe-P r values being somewhat lower. The NaOAc P soil test value was significantly correlated to both Ca-P and Al-P levels although the correlation coefficients were rather small.

When the correlations between P soil test values and amounts
of inorganic forms of soil P were examined for each of the soil parent
material groups, a different picture developed (Table 14). The
Bray P_1 and Olsen soil test values were highly correlated with the
Al-P and Fe-P content of the granitic soils as well as with the Al-P
fraction of the sedimentary soils of Douglas County. These two soil
test values were moderately correlated with the amounts of Al-P and
Fe-P in the basaltic soils. The poorest correlations between P soil
test values and the amounts of inorganic P were for the sedimentary
soils of Coos County where the only significant correlation was between
the Bray P_1 soil test values and the Al-P fraction. Neither the
NaOAc soil test nor the Ca-P fraction were significantly correlated to
any of the P fractions or P soil test values, respectively.

Correlations Between Phosphorus Soil Tests and Organic Phosphorus

When all soils were examined together, the correlations be-
tween soil organic P levels and the three P soil test values were very
low. This was also true, with one exception, for all of the correlations
based on type of parent material. There was a significant correlation
between the organic P content and Bray-P_1 soil test value on the
sedimentary Coos County soils (Table 15).

TABLE 14. Simple linear correlation coefficients between P-soil test values and inorganic P fractions for soils derived from different parent materials.

Variables	Soil Test Value vs Inorganic P Fractions			
	Parent Material Types			
	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value[1]			
Al-P vs Bray P_1	0.99**	0.81*	0.87**	0.82*
Al-P vs Olsen P	0.94**	0.52	0.94**	0.77
Al-P vs NaOAc P	0.56	0.77	0.07	0.69
Fe-P vs Bray P_1	0.87**	0.66	0.53	0.85*
Fe-P vs Olsen P	0.99**	0.71	0.61	0.85*
Fe-P vs NaOAc P	0.44	0.66	0.27	0.72
Ca-P vs Bray P_1	0.67	0.50	0.09	0.34
Ca-P vs Olsen P	0.70	0.07	0.11	0.48
Ca-P vs NaOAc P	0.16	0.17	0.64	0.53
degrees of freedom	5	4	4	3

[1] Correlations are based on values expressed as $ppm_{log_{10}}$.

Table 15. Simple linear correlation coefficients between soil organic P and P-soil test values for soils derived from different parent materials.

Soil Test Method	Soil Test Value vs Organic-P				
	Parent Material Type				
	All Soils	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value[1]				
Bray P_1	0.17	0.04	0.81*	0.05	0.19
Olsen P	0.26	0.15	0.67	0.18	0.04
NaOAc P	0.13	0.38	0.47	0.52	0.09
degrees of freedom	22	5	4	4	3

[1] Correlations are based on values expressed as ppm$_{log_{10}}$.

Discussion

Considering all soils, the Bray P_1 and Olsen soil test values were similarly related to the different forms of soil P (Table 13). These two soil tests were significantly correlated with both the Al-P and Fe-P fractions, but were not significantly correlated with the amounts of either Ca-P or organic-P. The NaOAc soil test value was much less correlated with the forms of soil P than the Bray P_1 and Olsen soil test values. The NaOAc values were uncorrelated with Fe-P and organic-P and correlations with Al-P and Ca-P were significant but had comparatively low r values.

These same trends were observed in the correlation between P soil test method and forms of soil P when the soils were grouped according to parent material. The highest correlations were between amounts of Al-P and Fe-P and the Bray P_1 and Olsen soil test values particularly on the granitic soils, followed by the sedimentary and basaltic soils of Douglas County. The poorest correlations between P soil tests and forms of soil P were on the sedimentary soils of Coos County. In this case the only significant correlation was between Al-P and the Bray P_1 soil test.

Organic-P levels were poorly correlated with the three P soil test values in most cases (Table 15). The only significant correlation between P soil test values and organic P content was with the Bray-P_1

test on the Coos County soils.

Greenhouse Experiment

Yield Response of Wheat Plants to Phosphorus Fertilizer

The increases in yield due to the addition of P fertilizer were calculated using yield data from each of the 24 soils (Table 16). The granitic and basaltic soils were generally less responsive to fertilizer P than were the Coos County soils and some of the sedimentary soils from Douglas County.

Phosphorus Uptake by Wheat Plants

The uptake of P in the absence of P fertilizer was widely variable, ranging from 0.9 mg P/pot in one of the Coosbay soils to 15.9 mg/pot in the Dixonville #3 soil. The addition of P fertilizer increased the average P uptake from 7.2 to 10.9 mg P/pot. Complete yield and P uptake data are in Appendix Table 2.

Correlations Between Phosphorus Soil Tests and Yield Response to Phosphorus by Wheat Plants

The correlations between the three P soil test values and yield response of wheat to P fertilizer are listed in Table 17. While the three correlations were all statistically significant, the Bray P_1 and Olsen soil test values were more highly correlated to yield response

TABLE 16. Yield response of wheat to P fertilizer, P uptake, and
% P in wheat plants.

Soil Series and Parent Material	Location	Yield Response to P[1]	P Uptake[2]	P in plants[3]
		gms/pot	mg/pot	%
Granitic				
Siskiyou	1	0.5	10.6	0.29
	2	0.4	13.5	0.28
	3	0.9	8.1	0.26
Holland	1	0.7	15.4	0.28
	2	1.1	10.2	0.27
	3	0.2	10.8	0.23
Central Point	1	1.6	3.3	0.13
Sedimentary				
Coosbay	1	2.2	0.9	0.10
	2	2.0	4.2	0.19
	3	2.0	3.4	0.17
Dement	1	1.6	5.9	0.20
	2	3.0	1.2	0.13
	3	1.4	5.6	1.20
Nonpareil	1	2.6	2.5	0.14
	2	0.8	7.0	0.21
	3	2.2	2.3	0.15
Willakenzie	1	0.5	13.9	0.31
	2	1.4	6.8	0.19
	3	3.3	1.1	0.11
Basaltic				
Dixonville	1	1.7	5.4	0.16
	2	1.0	5.5	0.16
	3	-0.3	15.9	0.29
Newberg	1	0.7	13.3	0.25
	2	0.9	6.4	0.20

[1] Yield of P fertilized pot - Yield of unfertilized pot.
[2] Amount of P in unfertilized plants.
[3] % P in unfertilized plants.

than was the NaOAc test. Considering all soils, the r values relating

the Bray P_1 and Olsen soil tests to yield response to P fertilizer

were very nearly identical.

The Bray P_1 test however appears to be more sensitive than

the Olsen test at low soil test values, due to its ability to extract

relatively higher quantities of P from a given soil (Figure 7).

TABLE 17. Simple linear correlation coefficients between P-soil
test values and yield response of wheat to P fertiliza-
tion for all soils.

Soil Test Method	Soil Test Value vs. Yield Response to P Fertilizer
	r value [1]
Bray P_1	-0.87**
Olsen P	-0.86**
NaOAc P	-0.71**
degrees of freedom	22

[1] Correlations based on P values expressed as $ppm_{\log_{10}}$.

When the soils were grouped according to parent materials, a

familiar pattern emerged (Table 18). On the granitic soils and sedi-

mentary soils of Douglas County, the Bray P_1 and Olsen soil test

values were, 1) highly correlated to yield response of wheat,

2) nearly equal in predicting yield response, and 3) more highly

correlated to yield response than the NaOAc soil test values. Only

in the case of the basaltic soils were the NaOAc soil test values more
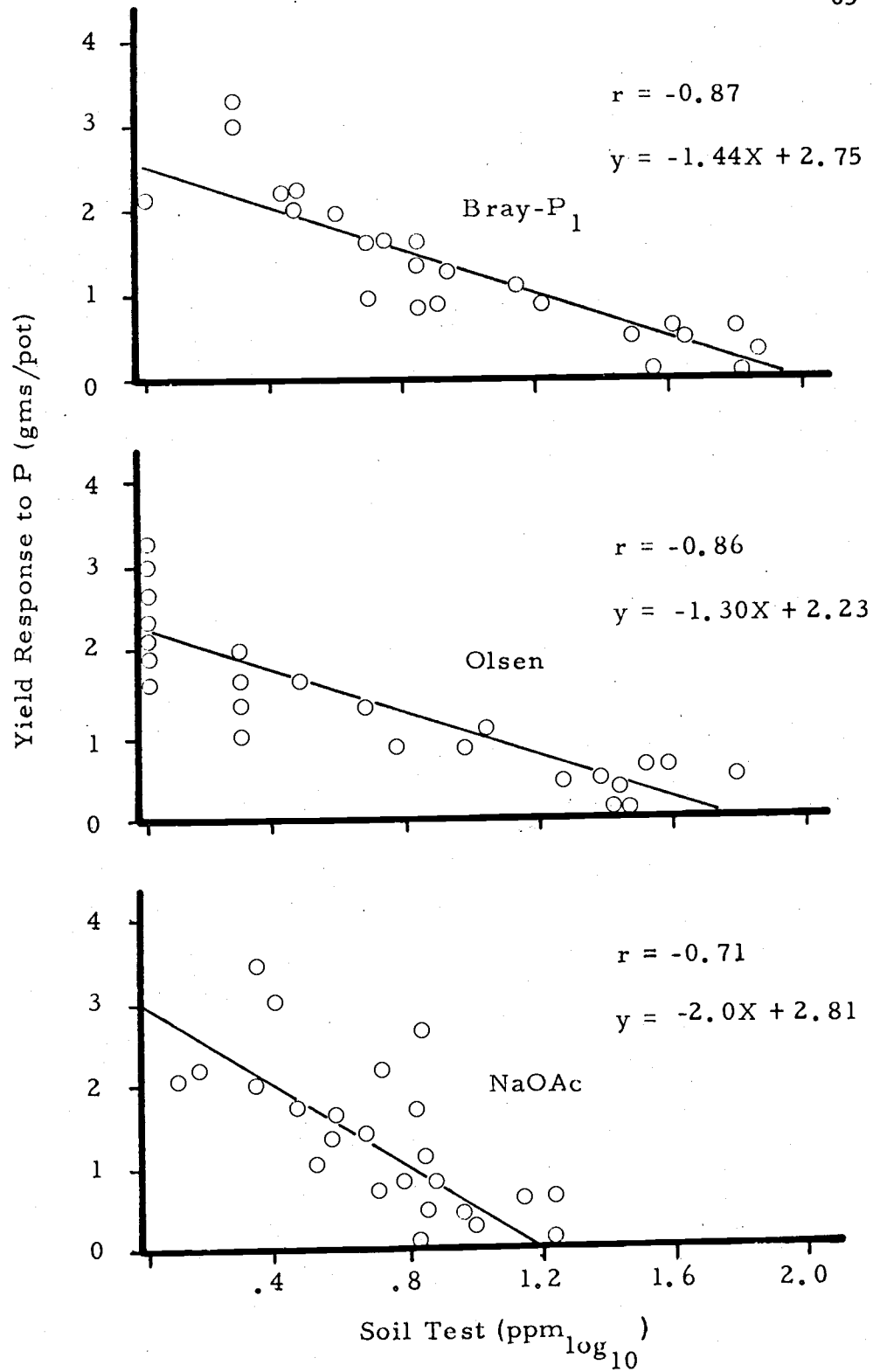
Figure 7. Scatter diagrams of yield response to P versus P soil test values.

TABLE 18. Simple linear correlation coefficients between P-soil test values and yield
response of wheat to P fertilization for soils derived from different parent
material.

Soil Test Method	Soil Test Value vs Yield Response to P Fertilizer			
	Parent Material Type			
	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value [1]			
Bray P_1	-0.95**	-0.65	-0.90**	-0.72
Olsen P	-0.87**	-0.70	-0.93**	-0.76
NaOAc P	-0.23	-0.39	-0.55	-0.85
degrees of freedom	5	4	4	3

[1] Correlations based on P values expressed as $ppm_{\log_{10}}$.

highly correlated to yield response than the other tests.

Again the lowest correlations were for the sedimentary soils of

Coos County, where there were no significant correlations between

any of the P soil test values and yield response to P.

Correlations Between Phosphorus Soil Tests and Phosphorus Uptake by Wheat Plants

The correlations between the three P soil test values and P

uptake by the test crop follow a pattern very similar to the corres-

ponding correlations between the P soil test values and yield response

to P. All three soil tests were significantly correlated with P uptake

although the Bray P_1 and Olsen tests more accurately predicted P

uptake than did the NaOAc test. The correlations for the Bray P_1 and

Olsen soil tests were quite high indicating that they were good indi-

cators of plant available P over a wide range of soil types.

TABLE 19.   Simple linear correlation coefficients between P-soil
test values and P uptake by wheat for all soils

Soil Test Method	Soil Test Values vs. P Uptake By Wheat
	r value [1]
Bray P_1	0.94**
Olsen P	0.96**
NaOAc P	0.80**
degrees of freedom	22

[1] Correlations based on P values expressed as $ppm_{\log_{10}}$.

In each case, the correlation between soil test values and P

uptake was higher than between soil test values and yield response to

P fertilizer.

Just as with yield response, the Bray P_1 soil test was more

sensitive at relatively low soil test values than the Olsen test was in

predicting P uptake (Figure 8).

The correlations between P soil test values and P uptake for

soils from the different parent materials were quite high (Table 20).

The Bray P_1 and Olsen soil test values were highly correlated with

P uptake from soils derived from each of the four types of parent

material. The NaOAc test was significantly correlated to P uptake

for the granitic and basaltic soils, but for each of the four parent

materials, the Bray P_1 and Olsen soil tests were superior to the

NaOAc test in predicting P uptake by the test crop.

Again the lowest correlations between the three P soil tests and

P uptake were for the Coos County soils.

Correlations Between Forms of Soil Phosphorus and Yield Response by Wheat Plants to Phosphorus Fertilizer

When all soils were included in the regression analysis of the

forms of soil P, only the Al-P fraction was significantly correlated

with yield response to fertilizer P (Table 21). Iron-P, Ca-P and

organic-P values had low correlations with yield response, with the
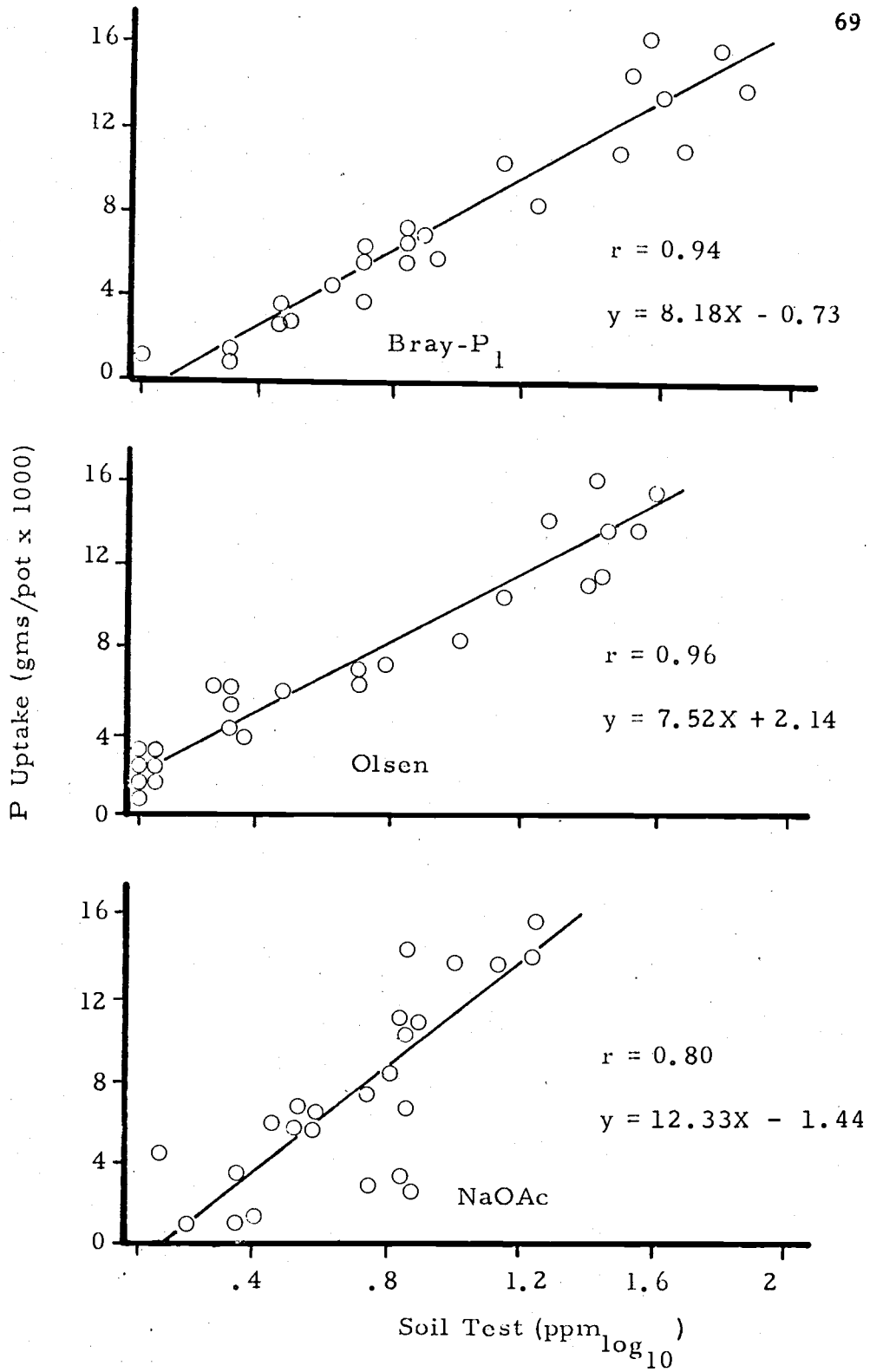
Figure 8. Scatter diagrams of P uptake by wheat versus P soil test values.

TABLE 20. Simple linear correlation coefficient between P-soil test values and P uptake by wheat for soils derived from different parent materials.

Soil Test Method	Soil Test Value vs P Uptake			
	Parent Material Type			
	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value[1]			
Bray-P_1	0.89**	0.79*	1.00**	0.96**
Olsen-P	0.93**	0.88**	0.97**	0.95**
NaOAc-P	0.76*	0.57	0.48	0.93**
degrees of freedom	5	4	4	3

[1] Correlations based on P values expressed as $ppm_{log_{10}}$.

TABLE 21. Simple linear correlation coefficients between forms of soil P and yield response of wheat to P fertilization for all soils.

Form of Soil P	Form of Soil P vs. Yield Response to P by Wheat
	r value [1]
Al-P	-0.67**
Fe-P	-0.37
Ca-P	-0.37
Organic-P	-0.22
degrees of freedom	22

[1] Correlations based on P values expressed as $ppm_{\log_{10}}$.

latter being the lowest.

Some significant correlations between forms of soil P and yield response to P fertilizer were observed when the soils were grouped according to their parent material (Table 22). With the granitic soils the Al-P, Fe-P, and Ca-P fractions were all significantly correlated to yield response to P fertilizer. The only other significant correlation with yield response to P was with Al-P values for the sedimentary soils from Douglas County. All four forms of soil P had very low correlations with yield response to P on the Coos County soils.

TABLE 22. Simple linear correlation coefficients between forms of soil P and yield response of wheat to P fertilization for soils derived from different parent materials.

Form of Soil P	Form of Soil P vs Yield Response to P Fertilizer			
	Parent Material Type			
	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value[1]			
Al-P	-0.92**	-0.26	-0.82*	-0.76
Fe-P	-0.83*	-0.27	-0.40	-0.49
Ca-P	-0.71*	-0.22	-0.11	-0.14
Organic-P	-0.17	-0.24	-0.22	-0.14
degrees of freedom	5	4	4	3

[1] Correlations based on P values expressed as $ppm_{log_{10}}$.

Correlations Between Forms of Soil Phosphorus and Phosphorus
Uptake by Wheat Plants

Considering all soils P uptake by wheat was significantly

correlated with Al-P, and to a lesser degree Fe-P values (Table 23).

Calcium-P and organic P values were not significantly correlated to

P uptake with the organic P correlation being extremely low.

TABLE 23. Simple linear correlation coefficients between forms of
soil P and P uptake by wheat for all soils.

Form of Soil P	Form of Soil P vs. P Uptake by Wheat
	r values[1]
Al-P	0.77**
Fe-P	0.59**
Ca-P	0.34
Organic-P	0.08
degrees of freedom	22

[1] Correlations are based on P values expressed as $ppm_{\log_{10}}$.

When broken down by parent material type, the correlations

between P uptake and forms of soil P for the four groups of soils

were very similar to the same correlations involving yield response

to P (Table 24). Aluminum-P and Fe-P values were highly corre-

lated with P uptake from the granitic soils, while just the Al-P

fraction was significantly correlated to P uptake with the two groups

TABLE 24. Simple linear correlation coefficients between forms of soil P and P uptake by wheat for soils derived from different parent materials.

Form of Soil P	Form of Soil P vs P Uptake by Wheat			
	Parent Material Type			
	Granitic Soils	Sedimentary Soils Coos County	Sedimentary Soils Douglas County	Basaltic Soils
	r value[1]			
Al-P	0.92**	0.61	0.89**	0.89*
Fe-P	0.89**	0.57	0.57	0.77
Ca-P	0.52	0.19	0.07	0.19
Organic-P	0.07	0.71	0.02	0.28
degrees of freedom	5	4	4	3

[1] Correlations based on P values expressed as $ppm_{log_{10}}$.

of Douglas County soils. Following a well established pattern, the poorest correlations between forms of soil P and P uptake were found on the Coos County soils.

Organic-P values were poorly correlated with P uptake for all of the parent materials. While the correlation coefficient between organic P content and P uptake from the Coos County soils was not statistically significant at the 5% level of probability, it was much greater than the corresponding coefficients for the other soil parent materials. In fact, for the Coos County soils, the correlation between P uptake and organic P was higher than that between P uptake and any other form of soil P.

Discussion

The results of the greenhouse experiment, indicate several relationships between P soil test values, forms of soil P, and uptake of P by wheat. Aluminum-P, and to a lesser extent, Fe-P were the forms of soil P that were most highly correlated to P uptake in the 24 soils from southwest Oregon that were included in this study. Correlations between these two forms of P and P uptake and yield response to P were not improved when Al-P was added to Fe-P. Because the Bray P_1 and Olsen soil tests selectively remove Al-P plus some Fe-P, it seems reasonable that these two soil tests would correlate well with plant availability of P. The converse also appears

reasonable for the NaOAc soil test.

The Bray P_1 soil test was superior to the NaOAc soil test in its correlations with both P uptake by wheat and yield response of wheat to P over a broad range of soils. Even on specific soil types, the Bray P_1 test values were consistently more highly correlated to these two measures of P availability to plants than the NaOAc values. The only case in which the NaOAc test values were more highly correlated to P uptake and yield response than the Bray P_1 test values was in the case of yield response on the basaltic soils. This may have been due to the relatively large amounts of Ca-P in the two Newberg soils which is not effectively extracted by the dilute acid-fluoride solution of the Bray P_1 soil test.

In all cases the Bray P_1 and Olsen soil tests were very nearly equal in their correlation to P uptake and yield response to P. However, the Bray P_1 test extracted relatively more P from a given soil than did the Olsen test, and differentiated P soil test levels more precisely at the lower P soil test values.

The organic-P fraction was largely uncorrelated to plant uptake of P on soils with low to moderate amounts of soil organic matter. However, on the Coos County soils, which had an average organic matter content of 11.4%, the correlation between the amount of organic-P and P uptake by the test crop was much higher than for any of the other soil groups.

Uptake of P by wheat was consistently more highly correlated with the amounts of major plant available forms of soil P namely Al-P and Fe-P than was yield response to P fertilizer. Because of this, it appears that P uptake is a better indicator of P availability than yield response to P. This is most likely due to the fact that P uptake is largely dependent on P availability from the soil, while yield considerations may depend on a much larger number of soil fertility parameters.

SUMMARY AND CONCLUSIONS

In this research, 24 soils from Jackson, Josephine, Coos, and Douglas Counties of southwest Oregon were selected on the basis of the parent material from which they were derived, either granitic, sedimentary, or basaltic. The purposes of this study were to characterize the P status of the widely diverse soils in southwest Oregon and evaluate the effectiveness of currently used soil testing procedures in predicting plant availability of P. A greenhouse experiment to measure the uptake of P and yield response to P by wheat plants in conjunction with fractionation of soil P was used to determine which forms of soil P were available for plant growth, and to predict which P soil test would be most suited for these soils.

It was observed that the Al-P fraction and to a lesser degree, the Fe-P fraction were the forms of soil P most highly correlated to P uptake by plants in most cases. Depending on parent material, other forms of soil P were also observed to be correlated to uptake of P. The Ca-P fraction appeared to be somewhat correlated to plant growth on the alluvial soils which were relatively enriched in Ca-P. While uncorrelated to P uptake on most soils, there was some indication that the organic-P fraction of the sedimentary soils of Coos County was an important source of plant available P.

In nearly all cases the Bray P_1 and Olsen soil test values were

highly correlated to levels of Al-P and to a lesser extent Fe-P. In contrast, the NaOAc soil test values were poorly correlated to the Al-P and Fe-P fractions of soil P. Based on these observations, it would be predicted that the Bray P_1 and Olsen soil tests would be more highly correlated to the various parameters used to measure P availability to plants than the NaOAc soil test. The organic-P levels in the soils correlated poorly with the soil test values except in the case of the Coos County soils, where the Bray P_1 test values were significantly correlated with the organic-P fraction.

The correlation of P uptake values and yield response to P fertilizer with the three soil testing procedures confirmed that in virtually all soils, regardless of parent material, the Bray P_1 and Olsen tests were highly correlated to plant available P and were superior to the NaOAc test in this respect. However, the Bray P_1 test was more sensitive than the Olsen test at relatively low soil test values.

This research supports the following conclusions:

1. The Bray P_1 and Olsen soil tests appear to be superior to the sodium acetate P soil test in predicting the uptake of P by wheat plants and the response of wheat to P fertilizer.

2. The Bray P_1 soil test is preferred over the Olsen soil test due to its greater sensitivity at relatively low soil test values, where the critical values for some crops undoubtedly lie.

3. While the organic-P in most of the soils studied was poorly correlated with plant growth, there appears to be an important reservoir of plant available P in the organic-P fraction of the sedimentary soils of Coos County. These soils have a relatively high organic matter content.

4. The Bray P_1 was the only soil test which was significantly correlated to the organic-P content of the Coos County soils, and therefore is probably better suited to these soils than the other two tests.

5. The P uptake and yield data in this study were obtained from a greenhouse pot study and caution should therefore be used in relating the results to critical P soil test levels under field conditions.

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APPENDICES

Appendix Table 1a. Preliminary soil sampling results.

Soil Series	Location	Bray-P_1 Value	Final Designation
		ppm-P	
Siskiyou	McCarthy a	16	Siskiyou 1
	McCarthy b	44	Siskiyou 2
	Gray's Creek	82	Siskiyou 3
	Mt. Ashland	91	
Holland	Miller a	14	Holland 2
	Riverbanks Road	16	
	Marthaller a	18	Holland 1
	Upper River Road a	24	
	Miller b	35	
	Johnson a	49	
	Williams Highway	57	
	Upper River Road b	76	Holland 3
	Johnson b	115	
	Marthaller b	177	
Central Point	S. Oregon Expt. Stn.	7	Central Point 1
Coosbay	Waterman a	9	
	Cannon	9	Coosbay 2
	W. Foster	9	Coosbay 3
	Waterman b	10	Coosbay 1
Dement	Holland a	7	Dement 1
	Mast a	8	
	Mast b	9	Dement 2
	Holland b	10	
	Geaney a	12	Dement 3
	Geaney b	12	
Nonpareil	Baxter a	2	Nonpareil 3
	Baxter b	3	
	Ritchey a	8	
	Ritchey b	11	Nonpareil 2
	Highway 138 a	15	
	Mosher a	27	Nonpareil 1

Appendix Table 1a.   continued.

Soil Series	Location	Bray-P$_1$ Value	Final Designation
		ppm-P	
Willakenzie	Knott	2	Willakenzie 3
	Goodrich Road	6	
	Foster	9	Willakenzie 2
	Highway 138 b	20	
	Mosher b	30	Willakenzie 1
Dixonville	Hatfield a	8	Dixonville 1
	Hatfield b	10	
	Hatfield c	11	Dixonville 2
	Hatfield d	26	Dixonville 3
Newberg	Guido a	8	
	Guido b	10	
	Laurence a	10	Newberg 1
	Kruse a	20	Newberg 2
	Kruse b	23	
	Laurence b	23	

Appendix Table 1b. Exact soil sampling site locations.

Soil Series	Location	Site Location
Siskiyou	1	On the north side of a gravel road 30 m past the summit of a hill by the McCarthy house in the SE1/4, SE1/4, SW1/4 of Section 28, T36S, R6W, Josephine Co.
	2	In a pasture 40 m SW of the McCarthy house in the NW1/4, NE1/4, NW1/4 of Section 33, T36S, R6W, Josephine Co.
	3	On the north side of a gravel road in the SW1/4, SE1/4, NE1/4 of Section 29, T37S, R5W, Josephine Co.
Holland	1	Twenty meters west of a grove of large trees in the SW1/4, SE1/4, SE1/4 of Section 19, T36S, R6W, Josephine Co.
	2	Fifty meters NE of a large white house in the SE1/4, SE1/4, SW1/4 of Section 11, T38S, R5W, Josephine Co.
	3	On the north edge of Upper River Road in the NE1/4, NW1/4, SW1/4 of Section 17, T36S, R6W, Josephine Co.
Central Point	1	One hundred meters north of a large barn in the NE1/4, NE1/4, NW1/4, NE1/4 of Section 28, T37S, R1E, Jackson Co.

Appendix Table 1b. continued.

Soil Series	Location	Site Location
Coosbay	1	On the north side of a dirt road in the SE1/4, NE1/4, NW1/4 of Section 18, T30S, R14W, Coos Co.
	2	On the north side of a gravel road in the NE1/4, NE1/4, NE1/4 of Section 24, T30S, R15W, Coos Co.
	3	On the north side of a gravel road in the NE1/4, NW1/4, NE1/4 of Section 19, T30S, R14W, Coos Co.
Dement	1	Five meters south of a dirt road in the SE1/4, NW1/4, SW1/4, NW1/4 of Section 14, T28S, R12W, Coos Co.
	2	Ten meters north of a dirt road in the NW1/4, NW1/4, SE1/4, SE1/4 of Section 2, T28S, R12W, Coos Co.
	3	On the south side of a dirt road in the NW1/4, NE1/4, NE1/4, SW1/4 of Section 20, T27S, R12W, Coos Co.
Nonpareil	1	In a hill pasture in the S1/2, NW1/4 NW1/4, SW1/4 of Section 21, T26S, R4W, Douglas Co.
	2	Ten meters east of a dirt road in the NW1/4, SW1/4, SW1/4, NE1/4 of Section 21, T24S, R5W, Douglas Co.
	3	On the north side of a gravel road in the NW1/4, NW1/4, NE1/4, NE1/4 of Section 30, T24S, R5W, Douglas Co.

Appendix Table 1b. continued.

Soil Series	Location	Site Location
Willakenzie	1	In a pasture in the NE1/4, SE1/4, SW1/4, SW1/4 of Section 21, T26S, R4W, Douglas Co.
	2	In a pasture in the SW1/4, NE1/4, NW1/4, SW1/4 of Section 28, T26S, R4W, Douglas Co.
	3	Just north of a gravel road in the W1/2, NE1/4, NW1/4, NW1/4 of Section 15, T24S, R5W, Douglas Co.
Dixonville	1	Five meters west of a gravel road in the NE1/4, SW1/4, SW.1/4, NE1/4 of Section 2, T28S, R5W, Douglas Co.
	2	In a hay field in the NE1/4, SE1/4, SE1/4, NW1/4 of Section 2, T28S, R5W, Douglas Co.
	3	Five meters north of a dirt road in the SW1/4, NE1/4, NE1/4, SW1/4 of Section 35, T28S, R5W, Douglas Co.
Newberg	1	Fifteen meters west of the South Umpqua River in the E1/2, SE1/4, NW1/4, NE1/4 of Section 9, T27S, R6W, Douglas Co.
	2	Just south of a paved highway in the SW1/4, SE1/4, NE1/4, NE1/4 of Section 9, T27S, R6W, Douglas Co.

Appendix Table 2a. Wheat dry matter yields.

Soil Series	Location	Replication							
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		---------------------- grams/pot ----------------------							
Siskiyou	1	4.59	3.69	4.05	3.77	4.31	3.77	3.36	3.24
	2	4.39	4.72	4.61	5.31	6.20	4.22	5.90	5.34
	3	3.59	2.95	2.29	3.40	3.90	3.04	4.43	3.07
Holland	1	5.99	6.57	6.12	5.05	5.96	4.96	7.24	5.88
	2	4.22	3.93	4.73	3.78	5.47	3.47	3.84	3.80
	3	4.67	4.71	4.29	4.26	4.97	4.31	5.39	5.15
Central Point	1	4.21	2.42	3.93	2.72	4.59	2.41	4.14	2.92
Coosbay	1	2.65	0.83	3.16	0.97	2.89	0.84	3.46	0.75
	2	4.11	1.84	4.41	1.58	4.02	3.14	4.96	2.89
	3	3.84	2.14	4.17	1.64	3.88	2.24	4.19	1.97
Dement	1	4.65	2.55	4.14	2.39	4.70	3.06	4.64	3.72
	2	4.34	0.85	3.74	0.84	3.55	1.10	4.11	0.85
	3	4.06	3.28	4.48	2.30	3.84	2.50	4.70	3.35
Nonpareil	1	4.46	2.12	4.52	1.67	4.16	1.29	4.00	1.65
	2	3.95	3.53	3.55	3.20	4.99	3.84	3.76	2.75
	3	3.96	1.63	4.21	1.38	2.94	1.53	3.88	1.34
Willakenzie	1	4.31	4.36	4.07	4.95	5.23	4.10	6.24	4.75
	2	4.77	2.88	4.84	3.42	5.15	4.27	4.98	3.49
	3	4.19	1.23	4.56	0.87	4.49	1.37	3.94	0.64

Appendix Table 2a. continued.

Soil Series	Location	Replication							
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		---------------------- gms/pot ----------------------------							
Dixonville	1	5.25	3.38	5.27	3.09	5.29	3.29	4.72	3.71
	2	4.52	4.06	4.85	3.39	4.15	2.84	4.29	3.67
	3	5.57	5.25	5.50	5.34	4.70	6.03	4.98	5.54
Newberg	1	5.59	4.59	5.71	4.75	5.18	5.55	6.22	5.14
	2	4.74	2.98	3.56	3.12	4.29	3.13	3.98	3.54

Appendix Table 2b. Phosphorus content of wheat dry matter.

Soil Series	Location	Replication							
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		‰ P							
Siskiyou	1	0.36	0.32	0.36	0.28	0.30	0.29	0.31	0.28
	2	0.27	0.26	0.27	0.31	0.31	0.32	0.32	0.22
	3	0.25	0.27	0.38	0.27	0.25	0.24	0.27	0.25
Holland	1	0.32	0.26	0.27	0.28	0.31	0.28	0.26	0.29
	2	0.23	0.29	0.25	0.27	0.26	0.26	0.24	0.28
	3	0.27	0.22	0.24	0.22	0.28	0.25	0.26	0.24
Central Point	1	0.22	0.10	0.24	0.13	0.19	0.14	0.22	0.13
Coosbay	1	0.16	0.09	0.17	0.1	0.14	0.09	0.16	0.10
	2	0.19	0.21	0.19	0.23	0.18	0.14	0.20	0.17
	3	0.19	0.17	0.17	0.17	0.20	0.17	0.19	0.17
Dement	1	0.20	0.22	0.19	0.21	0.16	0.19	0.21	0.19
	2	0.17	0.12	0.17	0.14	0.17	0.14	0.17	0.12
	3	0.21	0.20	0.17	0.22	0.19	0.21	0.18	0.17
Nonpareil	1	0.21	0.12	0.21	0.18	0.20	0.10	0.22	0.18
	2	0.24	0.24	0.23	0.21	0.21	0.19	0.20	0.20
	3	0.22	0.17	0.21	0.15	0.25	0.15	0.22	0.14

Appendix Table 2b. continued

Soil Series	Location	Replication							
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		% P							
Willakenzie	1	0.30	0.33	0.26	0.29	0.29	0.30	0.26	0.31
	2	0.27	0.19	0.26	0.21	0.24	0.19	0.26	0.20
	3	0.20	0.11	0.16	0.11	0.21	0.10	0.22	0.12
Dixonville	1	0.25	0.17	0.24	0.16	0.24	0.16	0.26	0.15
	2	0.22	0.15	0.21	0.18	0.25	0.16	0.23	0.13
	3	0.37	0.24	0.30	0.32	0.42	0.32	0.44	0.26
Newberg	1	0.25	0.25	0.27	0.26	0.20	0.28	0.28	0.21
	2	0.15	0.20	0.26	0.20	0.20	0.20	0.22	0.20

Appendix Table 2c. Plant uptake of phosphorus.

Soil Series	Location	Replication							
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		--- mg P/pot ---							
Siskiyou	1	16.5	11.8	14.7	10.7	12.9	10.8	10.6	9.0
	2	11.9	12.3	12.6	16.3	19.3	13.5	18.6	11.9
	3	9.0	8.0	8.6	9.1	9.8	7.4	12.1	7.7
Holland	1	19.0	17.1	16.7	14.0	18.5	13.7	19.1	16.8
	2	9.9	11.4	11.8	10.1	14.1	8.9	9.3	10.5
	3	12.7	10.5	10.5	9.5	13.8	10.7	14.1	12.4
Central Point	1	9.3	2.7	9.3	3.6	8.8	3.3	9.0	3.7
Coosbay	1	4.3	0.8	5.4	1.0	4.2	0.8	5.5	0.8
	2	7.8	3.8	8.4	3.6	7.2	4.4	10.0	4.8
	3	7.2	3.7	7.0	2.8	7.6	3.8	8.1	3.3
Dement	1	9.4	5.6	7.8	5.0	7.6	5.9	9.9	7.0
	2	7.3	1.0	6.2	1.2	6.1	1.6	7.0	1.0
	3	8.7	6.5	8.8	5.0	7.4	5.3	8.4	5.6
Nonpareil	1	9.4	2.6	9.7	3.0	8.5	1.3	9.0	2.9
	2	9.5	8.5	8.2	6.7	10.6	7.3	8.3	5.4
	3	8.8	2.7	8.8	2.0	7.3	2.4	8.5	1.9

Appendix Table 2c. continued.

Soil Series	Location	Replication								
		1		2		3		4	
		+P	-P	+P	-P	+P	-P	+P	-P
		mg P/pot								
Willakenzie	1	12.7	14.4	10.8	14.3	15.0	12.1	16.3	14.6
	2	12.9	5.5	12.8	6.8	12.4	8.2	13.1	6.8
	3	8.5	1.4	7.5	1.0	9.4	1.4	8.6	0.7
Dixonville	1	13.1	5.7	12.5	5.0	12.6	5.1	12.2	5.7
	2	10.0	6.3	10.0	6.0	10.2	4.7	9.7	4.9
	3	20.6	12.7	16.7	17.2	19.9	19.0	21.8	14.6
Newberg	1	14.0	14.0	15.2	12.4	10.3	15.6	17.5	10.9
	2	7.3	6.1	9.4	6.1	8.5	6.3	8.6	7.2

Appendix Table 3. Soil chemical analyses.

Soil Series	Location	pH	pH in 1N KCl	S.M.P.[1]	K ppm	Ca	Mg	C.E.C.	Organic Matter %	Base Saturation %
						---	meq/100 gms	---		
Siskiyou	1	6.1	4.4	6.7	140	2.7	0.63	8.9	4.3	21
	2	6.2	5.0	6.8	240	4.7	0.76	9.7	5.0	63
	3	6.7	5.0	6.7	84	5.1	1.7	10.6	4.1	66
Holland	1	6.4	5.3	6.8	600	7.7	1.6	14.7	7.4	74
	2	6.1	5.1	7.0	152	3.5	2.8	9.7	4.1	69
	3	6.2	5.0	6.6	268	4.5	0.99	12.0	8.4	51
Central Point	1	6.3	4.9	6.6	84	12.2	3.2	20.2	8.1	77
Coos Bay	1	5.3	3.8	4.9	256	0.33	0.82	21.0	5.7	9
	2	5.5	4.3	5.4	186	5.1	1.9	23.5	11.0	32
	3	5.8	4.4	6.0	320	2.3	1.8	16.1	8.9	31
Dement	1	6.0	4.6	6.1	330	7.5	2.2	23.7	9.2	44
	2	5.8	4.2	5.2	600	7.9	3.8	37.0	15.4	36
	3	5.8	4.3	5.6	330	3.4	1.5	30.4	18.0	19
Nonpareil	1	6.0	5.1	6.7	140	7.4	7.3	21.7	8.5	70
	2	5.4	4.2	6.1	388	5.3	2.5	19.1	7.0	46
	3	6.2	4.4	6.3	280	8.8	9.2	19.1	6.0	98
Willakenzie	1	5.7	4.5	5.9	164	7.2	1.6	15.2	6.6	61
	2	6.0	4.5	6.3	256	6.6	2.7	16.6	8.0	60
	3	6.2	4.5	6.3	268	5.0	3.9	17.2	5.8	56
Dixonville	1	6.4	4.9	6.5	88	11.6	3.5	20.6	9.8	74
	2	6.1	4.6	6.2	96	10.4	3.5	19.8	10.7	70
	3	7.1	5.6	6.6	544	14.1	4.3	21.3	15.1	93
Newberg	1	6.3	5.1	6.7	444	7.7	3.6	14.8	5.1	84
	2	6.8	5.1	7.2	96	4.8	2.6	8.7	1.4	88

[1] SMP lime requirement (Shoemaker et al., 1961).

Appendix Table 4. Soil series profile descriptions.[1]

Siskiyou Series

(Colors are for moist soil unless otherwise noted.)

A1--0 to 4 inches; very dark grayish brown (10YR 3/2) gravelly sandy loam, grayish brown (10YR 5/2) dry; weak very fine granular structure; slightly hard, very friable, nonsticky and nonplastic; many very fine roots; many irregular pores; 20 percent small pebbles; medium acid (pH 6.0); clear wavy boundary. (2 to 6 inches thick)

B1--4 to 11 inches; dark brown (10YR 4/3) sandy loam, very pale brown (10YR 7/3) dry; weak fine and medium subangular blocky structure; slightly hard, very friable, nonsticky and nonplastic; common irregular pores; common very fine and fine roots; 15 percent small pebbles; medium acid (pH 5.6); clear wavy boundary. (0 to 9 inches thick)

B2--11 to 19 inches; dark yellowish brown (10YR 4/4) sandy loam, very pale brown (10YR 7/3) dry; weak medium subangular blocky structure; hard, friable, nonsticky and nonplastic; few very fine and fine roots; common irregular pores; 15 percent small pebbles; medium acid (pH 5.6); clear wavy boundary. (0 to 9 inches thick)

C1--19 to 31 inches; yellowish brown (10YR 5/4) sandy loam, light gray (10YR 7/2) dry; massive; hard, friable, nonsticky and nonplastic; few roots; common irregular pores; 15 percent pebbles; medium acid (pH 5.6); clear wavy boundary. (8 to 15 inches thick)

C2--31 to 36 inches; pale brown (10YR 6/3) sandy loam, light gray and white (10YR 7/2, 8/2) dry; massive; slightly hard, friable, nonsticky and nonplastic; few roots; common irregular pores; strongly acid (pH 5.2); gradual wavy boundary. (4 to 10 inches thick)

C3r--36 to 46 inches; weathered granodiorite; dark brown (7.5YR 4/4) stains in fractures.

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[1] All profile descriptions are those of the National Cooperative Soil Survey, U.S.A.

Appendix Table 4. continued.

Holland Series

(Colors are for dry soil unless otherwise noted.)

O11--3 to 1 inches; dried leaf, twig and limb litter.

O12--1 to 0 inches; partially decomposed litter.

A11--0 to 2 inches; dark grayish brown (10YR 4/2) loam; very dark brown (10YR 2/2) moist; moderate fine granular structure; slightly hard, very friable; many fine and medium roots; many very fine interstitial pores; common fine iron concretions; medium acid (pH 6.0); abrupt wavy boundary. (2 to 6 inches thick)

A12--2 to 9 inches; dark brown (10YR 4/3) light loam, dark brown (10YR 3/3) moist; moderate fine and very fine granular structure; slightly hard, very friable; many fine and medium roots; few fine tubular pores, many very fine interstitial pores; common fine iron concretions; slightly acid (pH 6.4); abrupt wavy boundary. (0 to 8 inches thick)

A3--9 to 17 inches; brown (7.5YR 5/4) light loam, dark brown (7.5YR 3/4) moist; weak subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; common medium roots, few fine tubular pores; many very fine interstitial pores; common fine iron concretions; slightly acid (pH 6.5); clear wavy boundary. (7 to 17 inches thick)

B1t--17 to 42 inches; brown (7.5YR 5/4) sandy clay loam, reddish brown (5YR 4/3) moist; moderate medium and fine subangular blocky structure; hard, friable, sticky, slightly plastic, common medium roots, few large roots; common fine and medium pores; few thin clay films on faces of peds, many moderately thick clay coatings line pores; slightly acid (pH 6.5); gradual smooth boundary. (5 to 30 inches thick)

B21t--42 to 70 inches; reddish brown (5YR 5/4) clay loam, dark reddish brown (5YR 3/4) moist; moderate medium and coarse subangular blocky structure; very hard, friable, sticky, slightly plastic; few medium and large roots; common fine and medium tubular pores; common moderately thick clay films on faces of peds with pores continuously lined; medium acid (pH 5.8); gradual smooth

Appendix Table 4. continued.

Holland Series, continued:

boundary. (12 to 40 inches thick)

B22t--70 to 88 inches; light brown (7.5YR 6/4) sandy clay loam, dark brown (7.5YR 4/4) moist; moderate coarse subangular blocky structure; very hard, friable, sticky, slightly plastic; few large roots; common fine tubular pores; common thin clay films on faces of peds with pres continuously lined; medium acid (pH 5.9); gradual smooth boundary. (0 to 34 inches thick)

B3t--88 to 99 inches; pink (7.5YR 7/4) heavy sandy loam, strong brown (7.5YR 5/6) moist; massive; hard, friable, slightly sticky; many fine and very fine interstitial pores; clay films bridging and coating sand grains; medium acid (pH 5.7); clear wavy boundary. (10 to 15 inches thick)

C--99 to 110 inches; very pale brown strongly weathered quartz diorite, yellowish brown moist; rock fabric clearly visible; fragments crush readily to coarse sandy loam; many fine and very fine interstitial pores.

Appendix Table 4. continued.

Central Point Series

(Color for moist conditions unless otherwise noted.)

Ap--0 to 6 inches; black (10YR 2/1) sandy loam, dark gray (10YR 4/1) dry weak medium granular structure; hard, friable, slightly stocky, nonplastic; many roots; slightly acid (pH 6.5); clear smooth boundary. (5 to 8 inches thick)

A12--6 to 17 inches; black (10YR 2/1) sandy loam, dark gray (10YR 4/1) dry; massive (compaction pan); hard, friable, slightly sticky, slightly plastic; many roots; common fine and very fine pores; few worm casts; slightly acid (pH 6.4); clear smooth boundary. (8 to 12 inches thick)

B1--17 to 30 inches; very dark brown (10YR 2/2) sandy loam, dark gray (10YR 4/1) dry; weak medium and fine subangular blocky structure; hard, friable, sticky, slightly plastic; many roots; many very fine and fine tubular pores; common worm holes and worm casts; slightly acid (pH 6.4); clear wavy boundary. (10 to 15 inches thick)

B21--30 to 42 inches; very dark grayish brown (10YR 3/2) sandy loam, dark grayish brown (10YR 3/2) dry; weak medium prismatic and weak medium subangular blocky structure; very hard, friable, sticky, plastic; common roots, many very fine to fine tubular pores; common worm holes and worm casts; krotovina of A1 material at 34 inches; neutral (pH 6.6); gradual wavy boundary. (10 to 15 inches thick)

B22--42 to 49 inches; dark brown (10YR 3/3) sandy loam, brown (10YR 5/3) dry; common fine distinct yellowish red mottles; weak medium prismatic and weak coarse subangular blocky structure; very hard, friable, sticky, plastic; few roots; very many fine to coarse tubular pores; neutral (pH 6.6); clear wavy boundary. (5 to 9 inches thick)

C1--49 to 59 inches; dark brown (10YR 3/3) sandy loam, brown (10YR 5/3) dry; common fine distinct yellowish red mottles; massive; very hard, friable, sticky, plastic; few roots; very many fine to coarse tubular pores; 25 percent angular fragments of quartz

Appendix Table 4. continued.

Central Point Series, continued:

2 to 4 mm. in size; neutral (pH 6. 6); abrupt wavy boundary. (8 to 14 inches thick)

    IIC2--59 to 67 inches; dark brown (10YR 3/3) loamy sand, brown (10YR 4/3) dry; massive; loose, nonsticky, nonplastic; few roots; very many fine to coarse tubular pores; 40 percent angular and rounded pebbles; neutral (pH 6. 6).

Appendix Table 4. continued.

Coosbay Series

(Colors are for moist soil unless otherwise stated.)

01--2 inches to 0; litter of dead and decayed leaves, twigs, branches, roots and moss.

A1--0 to 5 inches; dark reddish brown (5YR 2/2) silt loam with a smeary feel, dark reddish gray (5YR 4/2) dry; strong very fine granular structure; soft, very friable, nonsticky and nonplastic; slightly smeary; many very fine roots; many very fine irregular pores; about 10 percent 1 to 3 mm firm silt nodules; slightly acid; abrupt wavy boundary. (4 to 6 inches thick)

B1--5 to 13 inches; dark reddish brown (5YR 3/4) silty clay loam, reddish brown (5YR 4/4) dry; strong fine subangular blocky and strong coarse granular structure; hard, very friable, sticky and slightly plastic; many very fine roots; many very fine irregular pores; about 5 percent silty shot; about 1 percent fine black (5YR 2/1) charcoal flecks; strongly acid (pH 5.4); clear smooth boundary. (4 to 8 inches thick)

B21--13 to 25 inches; yellowish red (5YR 4/6) silty clay loam, brown (7.5YR 5/4) dry; moderate medium subangular blocky structure; hard, friable, sticky and slightly plastic; common very fine roots; few very fine irregular and common very fine tubular pores; few weathered sandstone fragments; strongly acid (pH 5.1); clear smooth boundary.

B22--35 to 33 inches; brown (7.5YR 4/4) silty clay loam, brown (7.5YR 5/4) dry; moderate coarse subangular structure parting to weak fine subangular blocky; hard, friable, sticky and slightly plastic; few very fine to coarse roots; few very fine irregular and common very fine and few medium tubular pores; few weathered sandstone fragments; very strongly acid (pH 4.9); gradual smooth boundary. (combined B2 horizon 18 to 30 inches thick)

B3--33 to 46 inches; strong brown (7.5YR 4/6) silty clay loam, strong brown (7.5YR 5/6) crushed, light brown (7.5YR 6/4) dry; weak medium subangular blocky structure; hard, friable, sticky and plastic; very few very fine roots; common very fine tubular pores;

Appendix Table 4. continued.

Coosbay Series, continued:

10 percent weathered sandstone fragments; very strongly acid (pH 4.7); clear wavy boundary. (0 to 15 inches thick)

C1--46 to 58 inches; strong brown (7.5YR 4/6) silty clay loam, light brown (7.5YR 6/4) dry; massive; hard, friable, sticky and plastic; few thin yellowish red (5YR 4/6) coatings on fracture faces; 30 percent weathered sandstone pebbles; very strongly acid (pH 4.5); clear irregular boundary. (9 to 13 inches thick)

Cr--58 to 65 inches; variegated light yellowish brown, brown, and strong brown (10YR 6/4, 4/3, 7.5YR 5/6) fractured, weathered sandstone with many coarse distinct black (5YR 2/1) manganese oxide stains on fracture planes.

Appendix Table 4. continued.

Dement Series

(Colors are for moist soil unless otherwise noted.)

A1--0 to 7 inches; very dark grayish brown (10YR 3/2) silt loam, brown (10YR 5/2) dry; moderate fine and medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; common very fine to medium roots; many very fine pores; slightly acid (pH 6.2); abrupt smooth boundary. (6 to 10 inches thick)

B21--7 to 23 inches; reddish brown (5YR 4/3) heavy silty clay loam, brown (7.5YR 5/4) dry; moderate fine and medium subangular blocky structure; very hard, firm, sticky, plastic; common very fine to medium roots; many very fine to medium poores; common thin reddish brown (5YR 4/4) exped coatings; very strongly acid (pH 5.0); clear smooth boundary. (14 to 20 inches thick)

B22--23 to 36 inches; reddish brown (5YR 5/4) heavy silty clay loam, brown (7.5YR 5/4) dry; weak medium subangular blocky structure; very hard, firm, sticky, plastic; common fine to medium roots; common very fine and fine pores; few thin reddish brown (5YR 4/4) exped coatings; strongly acid (pH 5.4); clear smooth boundary. (10 to 15 inches thick)

B3--36 to 45 inches; reddish brown (5YR 4/4) heavy silt loam, brown (7.5YR 4/4) dry; weak coarse subangular blocky structure; hard, friable, slightly sticky, slightly plastic; common fine and medium roots; few very fine pores; very few thin reddish brown exped coatings; strongly acid (pH 5.4); clear smooth boundary. (6 to 10 inches thick)

C--45 to 72 inches; variegated weathered sedimentary bedrock with common fine and medium red (2.5YR 5/6) iron stains along fracture planes of upper part.

Appendix Table 4. continued.

Nonpareil Series

(Colors are for moist soil unless otherwise noted.)

A1--0 to 4 inches; brown (10YR 4/3) loam, plae brown (10YR 6/3) dry; moderate fine subangular blocky structure; hard, friable, slightly sticky, slightly plastic; many very fine roots; many very fine tubular pores; very strongly acid (pH 4.8); clear smooth boundary. (2 to 10 inches thick)

B21--4 to 14 inches; brown (10YR 4/3) loam, pale brown (10YR 6/3) dry; weak medium prismatic parting to moderate fine subangular blocky structure; hard, friable, sticky, plastic; common very fine roots; many very fine tubular pores; 10 percent weathered pebbles; very strongly acid (pH 4.8); clear wavy boundary. (4 to 14 inches thick)

B22--14 to 17 inches; dark yellowish brown (10YR 4/4) loam, light yellowish brown (10YR 6/4) dry; moderate fine subangular blocky structure; hard, friable, sticky, plastic; common very fine roots; many very fine tubular pores; 15 percent weathered pebbles; very strongly acid (pH 4.8); gradual wavy boundary. (4 to 6 inches thick)

C--17 to 24 inches; weathered sandstone; common black stains and reddish brown (5YR 4/5) clay films in fractures.

Appendix Table 4. continued.

Willakenzie Series

(Colors are for moist soil unless otherwise noted.)

A1--0 to 4 inches; dark brown (7.5YR 3/2) silty clay loam, brown (7.5YR 5/3) dry; weak medium and fine subangular blocky structure; hard, friable, slightly sticky, slightly plastic; many fine roots; many very fine pores; very few fine concretions; medium acid (pH 6.0); clear smooth boundary. (3 to 9 inches thick)

B1--4 to 12 inches; dark brown (7.5YR 3/4) silty clay loam, strong brown (7.5YR 5/6) dry; moderate medium and fine subangular blocky structure; hard, friable, sticky, plastic; many fine roots; many very fine pores; medium acid (pH 6.0); clear wavy boundary. (7 to 10 inches thick)

B21t--12 to 18 inches; dark brown (7.5YR 4/4) silty clay loam, strong brown (7.5YR 5/6) dry; weak medium parting to moderate fine and very fine subangular blocky structure; hard, friable, sticky, very plastic; many fine roots; common very fine and fine pores; few thin clay films in pores and on some surfaces of peds; medium acid (pH 6.0); clear smooth boundary. (5 to 8 inches thick)

B22t--18 to 26 inches; dark brown (7.5YR 4/4) silty clay loam, strong brown (7.5YR 5/6) dry; weak medium subangular blocky parting to moderate fine subangular blocky structure; firm, very sticky, very plastic; common fine roots; many very fine pores; few thin clay films on faces of peds; medium acid (pH 5.0); gradual wavy boundary. (6 to 12 inches thick)

B23t--26 to 32 inches; dark brown (7.5YR 4/4) silty clay loam, strong brown (7.5YR 5/6) dry; weak medium and fine parting to moderate very fine subangular blocky structure; firm, very sticky, very plastic; common fine roots; many very fine pores, many thin clay films; strongly acid (pH 5.4); abrupt wavy boundary. (5 to 7 inches thick)

IIC1--32 to 36 inches; yellowish red (5YR 5/6) silty clay loam, weak fine angular blocky structure; friable, very sticky, very plastic; few fine pores; common thick films on the rock fragments; 80 percent siltstone fragments; very strongly acid (pH 4.7); abrupt smooth lower boundary. (0 to 4 inches thick)

Appendix Table 4. continued.

Willakenzie Series, continued:

IIC2--36 to 54 inches; hard fractured partially consolidated siltstone bedrock.

Appendix Table 4. continued.

Dixonville Series

(Colors are for moist soil unless otherwise noted.)

A11--0 to 4 inches; very dark brown (10YR 2/2) silty clay loam, dark brown (10YR 4/3) dry; moderate fine subangular blocky structure; friable, sticky, plastic; many very fine roots, many very fine and many irregular pores; medium acid (pH 5.8); clear smooth boundary. (4 to 6 inches thick)

A12--4 to 12 inches; very dark brown (10YR 2/2) silty clay, dark brown (10YR 4/3) dry; moderate medium and fine subangular blocky structure; friable, very sticky, very plastic; many very fine roots; few very fine pores; medium acid (pH 6.0); clear smooth boundary. (6 to 10 inches thick)

B21t--12 to 21 inches; dark reddish brown (5YR 3/2) clay, reddish brown (5YR 4/3) dry; moderate medium and fine subangular blocky structure; firm, very sticky, very plastic; many very fine roots; common very fine pores; many thin clay films; slightly acid (pH 6.1); gradual smooth boundary. (4 to 13 inches thick)

B22t--21 to 34 inches; dark reddish brown (5YR 3/3) clay, yellowish red (5YR 4/4) dry; moderate medium subangular blocky structure; very hard, very firm, very sticky, plastic; common very fine roots; common very fine pores; many moderately thick clay films; slightly acid (pH 6.2); clear wavy boundary. (6 to 17 inches thick)

C--34 to 40 inches; variegated saprolite; massive; very firm, very hard, sticky, plastic.

Appendix Table 4. continued.

Newberg Series

(Colors are for moist soil unless otherwise noted.)

AP--0 to 7 inches; dark brown (10YR 3/3) fine sandy loam, brown (10YR 4/3) dry; moderate fine granular structure; soft, very friable; few fine roots; many irregular pores; medium acid (pH 6.0); clear smooth boundary. (7 to 12 inches thick)

AC--7 to 19 inches; dark brown (10YR 3/3) fine sandy loam, dark yellowish brown (10YR 4/4) dry; weak fine subangular blocky structure; soft, very friable; few fine roots; many irregular pores; medium acid (pH 5.8); clear smooth boundary. (6 to 12 inches thick)

C1--19 to 28 inches; brown (10YR 4/3) coarse sandy loam, pale brown (10YR 6/3) dry; massive; soft, friable; few roots; many irregular pores; medium acid (pH 5.8); clear smooth bounday. (8 to 14 inches thick)

C2--28 to 48 inches; dark grayish brown (10YR 4/2) loamy fine sand, pale brown (10YR 6/3) and light brownish gray (10YR 6/2) dry; single grained; loose, many irregular pores; medium acid (pH 5.8); gradual smooth boundary. (18 to 24 inches thick)

C3--48 to 64 inches; dark grayish brown (10YR 4/2) loamy sand, light brownish gray (10YR 6/2) dry; single grained; loose, many irregular pores, medium acid (pH 6.0).