FORMS OF PHOSPHORUS AND THEIR AVAILABILITY IN SOILS AND STRATA OVERLYING LIGNITE

by

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ABSTRACT

A study was initiated to study phosphorus forms and availability in three soils and two geological strata overlying lignite. 12 samples were taken from the soils and strata in a pre-mining area near Calvert, Texas. Soil phosphorus was fractionated for all samples. Total phosphorus, organic phosphorus, and available phosphorus were also determined. A greenhouse study was established to evaluate plant growth response to native phosphorus and fertilizer phosphorus additions. The 12 samples were treated with four phosphorus rates, and Weeping lovegrass (*Eragrostis curvula*.) was the indicator crop. Three cuttings were taken at approximately 30 days of growth. The plant material was dried, weighed, and statistically analyzed.

All soils were very low in phosphorus content. The Wilcox material had a much higher calcium phosphate content than any other soil, present as the insoluble primary mineral apatite and, therefore, unavailable to the plant. All soils responded to added phosphorus with no significantly higher yields obtained past 30 ppm phosphorus. Under fertilization, plants grew equally well on all soils studied, except the Carrizo sand and the Bub C.

AKNOWLEDGEMENTS

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INTRODUCTION

Increasing energy demand in the United States, combined with rising imported fuel costs, has resulted in accelerated use of domestic energy sources. One of the most abundant, but under utilized forms of energy in the United States is coal. It offers a potential means to meet future energy needs. Coal is classified as anthracite, bituminous, subbituminous, or lignite. Figure 1 shows the strippable coal reserves in the United States. Only lignite, a soft, brown, low energy coal, is indigenous to Texas.

Texas has an estimated total lignite reserve of 91 billion metric tons, with 9.4 billion metric tons considered potentially mineable. Approximately 10 million metric tons of lignite are currently mined in Texas each year, with predictions of 79 million metric tons to be mined annually by 1985 (Hons, 1978). As a result, more than 400,000 hectares of land may be disturbed in Texas alone. Figure 2 shows the mineable lignite reserves in Texas. Environmental concerns for air quality, water quality, and revegetation of mined lands requires sound management and application of agronomic principles in the reclamation process.

Lignite is exposed by removing up to 50 meters of overburden material with large electrically powered draglines. The lignite is then removed, loaded on to haul trucks, transported to the power plant, and burned producing steam generated electricity. In Texas, mining is currently underway

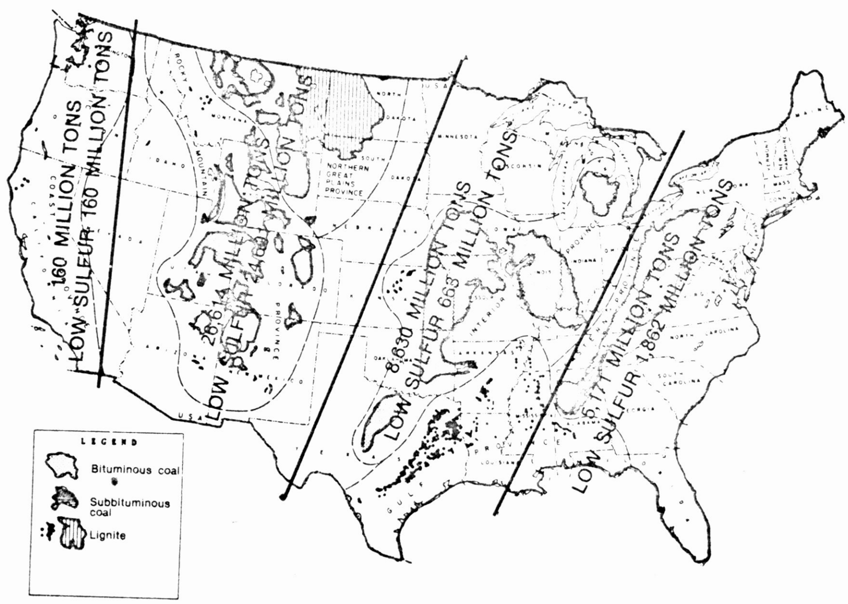

Figure 1. Strippable coal reserves in the United States.

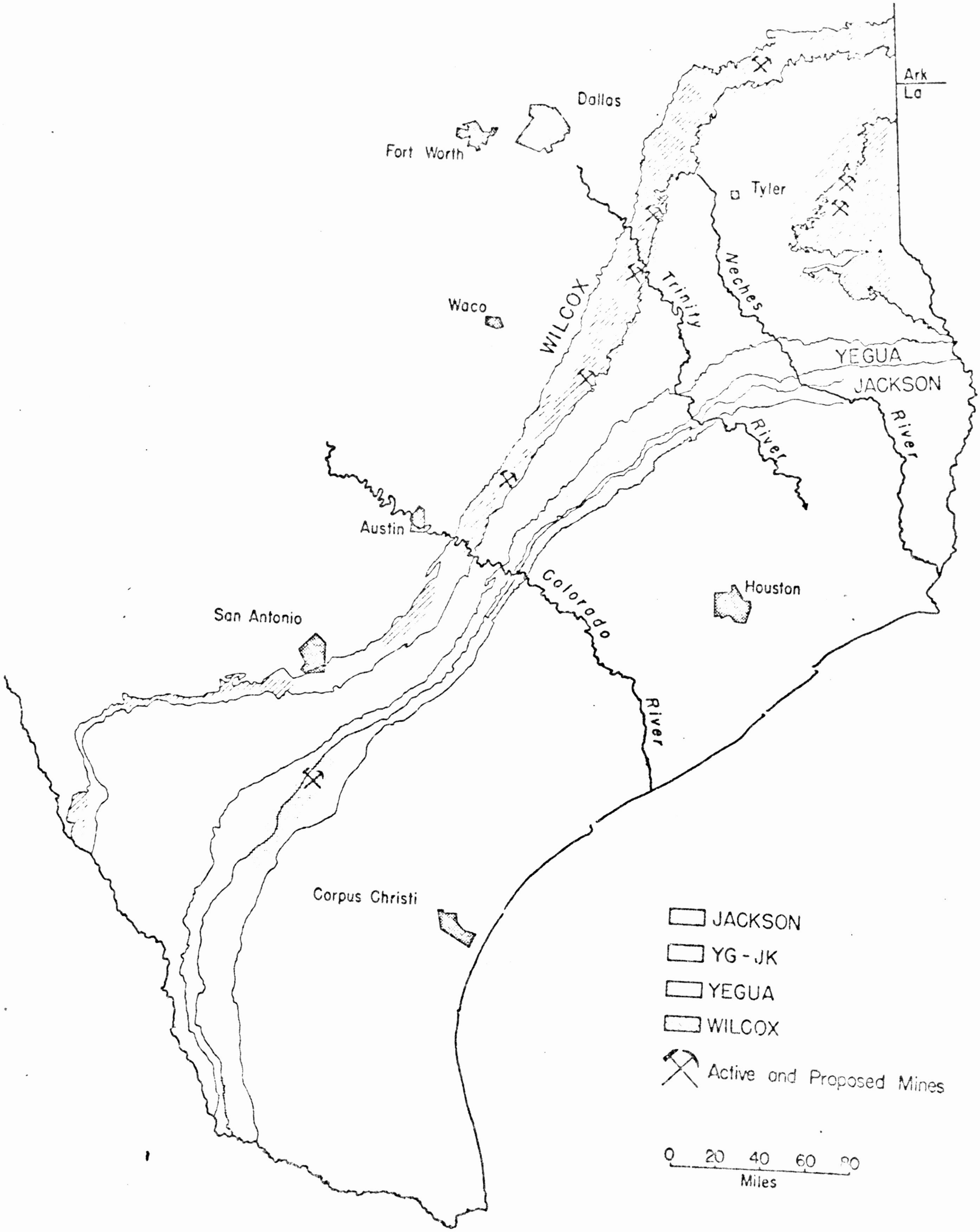

Figure 2. Near surface lignite reserves in Texas.

in several counties and operating mines are planned for numerous other sites (Figure 2).

Reclamation normally occurs as part of the mining process. The overburden spoil is first leveled to a similar contour to the surrounding undisturbed area, fertilized, disked, and planted to a cover crop, such as Coastal bermudagrass.

For successful revegetation, the spoil material must be able to supply the nutrients needed for plant growth. Nitrogen and phosphorus are typically deficient in mine spoil, as they are in many undisturbed soils throughout the southeastern United States. While potassium is often deficient in soils of the area, it is generally abundant in fresh spoil material (Hons, 1978).

Since nitrogen and phosphorus are often limiting to plant growth, they recieve the greatest consideration in reclamation efforts. The chemistry of nitrogen in spoil material is similar to that in soils, and substantial plant growth response is obtained from nitrogen fertilization. Similarly, phosphorus additions are generally beneficial to plant growth. The chemistry of phosphorus in both soil and mine spoil is complex because plant availability of phosphorus is regulated by the relative abundance, distribution, and solubility of the various phosphorus compounds found in soils. Phosphorus is present in soils as aluminum phosphate, iron phosphate, calcium phosphate, occluded phosphate, and organic phosphorus. The presence, and subsequent availability, of these forms are controlled by such factors as: (1) soil pH, (2) soluble Fe, Al, Mn, (3) presence of Fe, Al, Mn containing minerals, (4) available Ca and Ca containing minerals, (5) amount and decomposition of organic matter, and(6) microorganism activity. Understanding the interaction of these factors with phosphorus in spoil should enable better management decisions in reclamation.

Determining the distribution of phosphorus present in various forms and evaluating plant availability of phosphorus, both with and without fertilizer additions, should indicate the ability of spoil material to supply phosphorus for plant growth. Therefore, the present study was established with the following objectives:

(1) To determine the ability of soil horizons and stratigraphic layers to support plant growth.

(2) To determine the amount and chemical forms of phosphorus present in soils and strata overlying lignite.

(3) To evaluate plant available phosphorus as a function of form present and rate of fertilizer phosphorus added.

LITERATURE REVIEW

Lignite Mining and Reclamation

Lignite, a soft, brown, coal-like material, is widely distributed in several Eocene rock units of the Texas Gulf Coast Plain. The primary commercial lignite deposits are found in East and Central Texas within the Wilcox geological formation (Kaiser, 1974). Secondary deposits are located in the Yequa and Jackson formations. Currently, mining and reclamation occurs only in these various geologic formations. In general, lignite occurs nearer to the surface in the northern part of the state and at greater depths in the southern part.

Initial research efforts in Texas related to reclamation and the nature of the spoil material have just recently been completed. Askenasy (1977) studied the establishment of row crops on mine spoil in East Texas and obtained favorable yields of sorghum, corn, and soybeans, with adequate nitrogen and phosphorus fertilization. Hons (1978) found both legumes and grasses responded to phosphorus additions when high nitrogen rates were used. Reclamation studies currently underway include the use of grass and legume cover crops for erosion control and nitrogen nutrition in the revegetation of mined land to commercial pine forest in East Texas, (Jenkins 1980). McCallister (1980) is studying chemical changes that occur in spoil as a function of time after mining.

Weeping lovegrass (*Eragrostis curvula*.) has been suggested as a good grass crop for revegetation of mined lands since it grows well under a wide range of soil and environmental conditions. Vogel and Berg (1965) found that fertilized lovegrass grew well on mine spoils at pH 4.0-4.5 and was also tolerant of low moisture conditions. In a greenhouse study, Fleming et. al. (1974) found lovegrass would tolerate high Al concentrations on nutrient solutions, low soil pH, and would respond to added phosphorus. They concluded lovegrass would be a suitable species for use in revegetation of mine spoil.

Considerable research has been conducted in revegetation of mined areas throughout the United States (Vogel and Berg, 1968, Aldon, 1978, Plass, 1978, Power, 1978). However, few are applicable to Texas because of major differences in both spoil and climate. While reclamation in many parts of the country is very difficult, Texas has two distinct advantages. First, the topography in the mining areas is only gently sloping and the material overlying lignite is unconsolidated marine sediments. Therefore, steep slopes and very rocky spoil are not problems in Texas as they are in much of the Eastern United States. Secondly, the strippable reserves of lignite lie mostly east of the 30 inch rainfall line which prevents the severe moisture limitations present for reclamation in the Western United States.

The major problems associated with reclamation of mined lands in Texas are chemical rather than physical or climatic in nature. Developing our understanding of both nitrogen and phosphorus chemistry in spoil should enable better decision making and more successful reclamation efforts. Only the literature pertaining to phosphorus is included in this writing.

Soil Phosphorus

Soil phosphorus did not receive much consideration in the United States unitl about 1900. Since that time several procedures have been developed for analysis of the different forms of phosphorus found in soils. One of the earliest procedures developed was Fraps' fractionation scheme which differentiated between the phosphorus forms present in calcareous soils and siliceous soils, based on the different solubilities of phosphorus minerals in 0.2 N nitric or hydrochloric acid (Fraps, 1906). Other fractionation methods have evolved using acetic acid, sodium hydroxide, sulfuric acid, and ammonium fluoride as extracting agents.

More recently Chang and Jackson (1957) developed a procedure for fractionation of soil phosphorus into five separate and distinct inorganic forms: (1) Al-phosphate, (2) Fe-phosphate, (3) Ca-phosphate, (4) reductant-soluble (iron oxide coated) phosphates, and (5) occluded Fe-Al phosphates. This procedure was based on the selective solubility of soil phosphates in various extractants, as were most previous procedures, but differed in three respects: (1) extraction of reductant-soluble iron phosphate was based on the method reported by Aguilera and Jackson (1953), (2) occluded iron-aluminum phosphates were differentiated from other forms, and (3) the sequence of extractions provided five discrete chemical phosphorus forms. Petersen and Corey (1966) modified the Chang and Jackson procedure to provide an easier, more efficient means of fractionation in routine analysis of a large number of samples. Their procedure is also based on the difference in solubility of the different phosphorus forms and separates phosphorus into four discrete inorganic forms. The Petersen and Corey method does not allow for the extraction of occluded iron-aluminum phosphates.

Organic phosphorus also contributes to the total phosphorus reserves in soil. It is normally determined by the difference in total phosphorus as measured by digestion in perchloric acid, and the inorganic phosphorus as measured by the Chang and Jackson procedure.

Phosphorus in Texas Soils

Relatively little work has been published on phosphorus fractions in Texas soils. Supak (1969) studied the effect of long term fertility treatments on the phosphorus status of three Texas Vertisols, and fractionated soil phosphorus using Chang and Jackson's procedure as modified by Fife (1959) and Glenn (1959).

Mannan (1969) studied conversion products at various time intervals for water soluble phosphorus compounds when applied to several Texas soils, again, utilizing Glenn's modification of the Chang and Jackson procedure. Mannan found low phosphorus levels present in the Nacagdoches soil and much higher levels in the Houston Black, and Beaumont soils (Table 1). Hawkins (1960) found phosphorus values of 292 ppm and 490 ppm for the surface horizons of the Beaumont and Houston Black Clays, and were comparable to the values obtained for the same soils by Mannan.

The only information available for phosphorus fractions present in mine spoil material was determined by Askenasy. He found total phosphorus levels of 304 ppm and 337 ppm in two locations near Fairfield, Texas. In contrast, the surface horizon of the Axtell soil, native to the mining area, contained only 109 ppm total phosphorus.

Table 1. Phosphorus fractions for several Texas soils.

AUTHOR	SOIL	Al-P	Fe-P	Red-Sol-P	Ca-P	Org-P	Total P
		ppm p					
Askenasy	Mine Spoil	1.24	79.30	-	126.68	97.49	304.71
	Axtell	1.24	39.77	-	205.11	91.36	337.48
Hawkins	Beaumont	10.0	23.3	42.0	9.1	171.1	292.0
	Houston Black	25.3	2.9	42.0	41.8	353.6	490.0
Mannan	Beaumont	11.1	25.1	97.5	15.0	130.0	330.0
	Houston Black	14.4	9.8	91.3	231.3	188.5	560.0
	Nacogdoches	8.4	17.5	75.0	15.3	36.0	180.0
Supak	Houston Black	11.1	2.4	22.0	256.3	254.3	554.2
	Lake Charles	22.5	25.8	23.9	3.0	152.3	229.6
	San Saba	34.4	3.6	42.8	120.3	219.9	440.9

MATERIALS AND METHODS

Sampling Method

Samples were collected from three soils overlying the Wilcox geological formation near Calvert, Texas, in an area scheduled for lignite mining in the near future. Axtell fine sandy loam (fine, montmorillonitic, thermic family of Udertic Paleustalfs), Bub gravelly sandy loam (clayey, mixed thermic, shallow family of Typic Hapludalfs), and Padina fine sandy loam (loamy, siliceous, thermic family of Grossarenic Paleustalfs), are the principle soils found in the study area. Soil samples were collected by excavation of a pit and taken to represent each major horizon of these soils. Thin or very similar horizons were composited as one sample. In addition to soil samples, the two major geological strata of the area were sampled by compositing material obtained from deep corings. Samples representing the A1, B2, B3, and C horizons of the Axtell; the A1 and C horizons of the Bub; and the A1, A2, B1, and B2 horizons of the Padina were collected. A modal description of each soil is given in the appendix. The underlying material can best be described as being either Wilcox material or Carrizo sands. The 12 samples serve as a basis for the study of phosphorus and response to added phosphorus in the greenhouse.

Sample Preparation and Laboratory Analysis

Samples were air dried, ground, and passed through a 5 mm seive for the greenhouse study, and through a 2.5 mm seive for the laboratory analysis. Particle size distribution was determined by the hydrometer method. Soil pH was determined electrometrically in a 1:2 soil water suspension.

Phosphorus Fractionation and Total Phosphorus

Fractionation of inorganic soil phosphorus was carried out on duplicate samples using Petersen and Cory's modification of the Chang and Jackson procedure (Chang and Jackson,1957), (Petersen and Corey, 1966), with larger soil samples and greater extractant volumes used to compensate for extremely low phosphorus levels. Phosphorus levels were determined colorimetrically by the formation of the molybdenum blue complex.

Total phosphorus was determined on duplicate samples following digestion with $HClO_4$ at 180° C for six hours (Murphy and Riley 1962).

Organic phosphorus was calculated from the difference between total phosphorus and inorganic phosphorus.

Greenhouse Study

In addition to laboratory analysis, a greenhouse study was initiated to determine the ability of the samples to supply phosphorus for plant growth and to determine plant growth response to fertilizer phosphorus application.

One Kg of soil was weighed into pots and fertilized at 0, 30, 60, and 90 ppm phosphorus as $Ca(HPO_4)_2 \cdot 2H_2O$. Each treatment was replicated four times, giving a total of 192 pots. 100 ppm nitrogen and potassium were applied to all samples. Weeping lovegrass was seeded at a rate of about 200 mgm seed/Kg soil. Pots were watered approximately every two days depending upon greenhouse temperature and growth rate of the crop, and were weighed and watered to field capacity weekly.

Grass was harvested at 35, 65, and 80 days, dried at 65°C for four days, and weighed. 50 ppm nitrogen was applied following each cutting.

Yield values were statistically analyzed using the standard SAS computer program and significance established using Sheffe's multiple range test to account for unequal cell frequencies.

RESULTS AND DISCUSSION

Soil Characteristics

The characteristics of soils used in the study, and the symbols used to identify them are given in Table 2. Particle size distribution includes a broad range of sand, silt, and clay contents among the study soils. Clay content ranged from 6.4% in the Bub and Padina A1 horizons to 46.9% in the Axtell B2. Sand content ranged from 16.4% in the Wilcox material to 84.6% in the Bub A1. Textural classes varied from clay to loamy sand. Water and nutrient holding capacity would range from high in the clays to low in the sands, and may influence plant growth.

Soil pH values were between 4.9 and 6.7 except for the Carrizo sand at pH 3.0. In general, potential toxicities would be expected in those soils of pH 5.0 or below due to the greater solubility of Fe, Al, and Mn under acid conditions. In addition, the formation of insoluble Fe and Al phosphate compounds in the more acidic samples would be expected to reduce plant available phosphorus and result in phosphorus deficiencies even when fertilizer phosphorus is applied.

Phosphorus Fractionation

The distribution of soil phosphours into its various components is given in Table 3 and Figures 3 and 4. Values for the four inorganic fractions were extremely low compared to values reported for 100 Wisconsin soils (Petersen and

Table 2. Characteristics and identifying symbols of the study soils.

SYMBOL USED	SOIL	TEXTURAL CLASS	PH
AX A1	AXTELL A1	SANDY LOAM	6.4
AX B2	AXTELL B2	CLAY	5.7
AX B3	AXTELL B3	SANDY CLAY LOAM	5.5
AX C	AXTELL C	SANDY CLAY LOAM	5.6
BU A1	BUB A1	LOAMY SAND	6.6
BU C	BUB C	SANDY LOAM	5.0
PA A1	PADINA A1	SANDY LOAM	6.1
PA A2	PADINA A2	SANDY LOAM	6.5
PA B1	PADINA B1	SANDY LOAM	6.6
PA B2	PADINA B2	SANDY CLAY	4.9
WI	WILCOX	SILTY CLAY LOAM	6.3
CA	CARRIZO	SANDY LOAM	3.0

Table 3. Phosphorus fractions for all soil samples.

SOIL	Al-P	Fe-P	Ca-P	Red Sol-P	Org-P	Total P
	ppm p					
AX A1	4.14	4.66	1.51	6.00	48.0	64.4
AX B2	1.68	4.67	5.57	5.39	74.2	91.5
AX B3	.94	5.66	3.35	8.99	33.9	52.8
AX C	2.83	8.26	2.87	15.81	30.7	60.5
BU A1	8.28	12.78	2.49	7.91	88.7	120.2
BU C	4.19	6.72	10.72	7.21	52.5	81.4
PA A1	5.66	6.76	2.82	6.82	55.2	77.2
PA A2	.99	3.82	1.33	7.66	39.2	52.9
PA B1	2.06	9.37	1.80	12.34	46.5	72.2
PA B2	.93	2.98	3.86	3.12	47.9	58.8
WI	2.91	7.05	367.15	4.95	27.9	410.0
CA	2.83	8.48	2.82	5.79	41.5	61.4

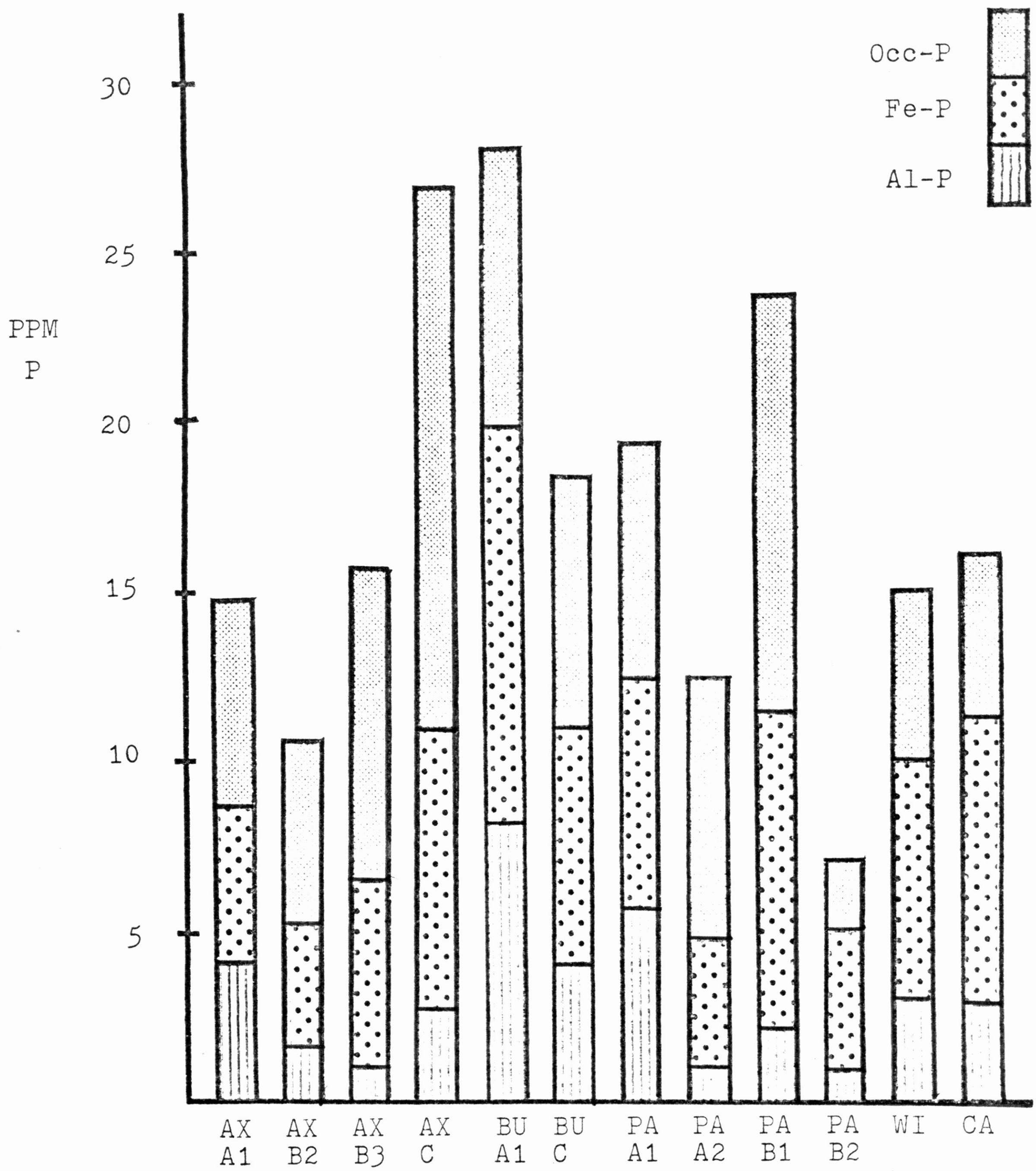

Figure 3. Al-P, Fe-P, and Occ-P fractions for all soils.

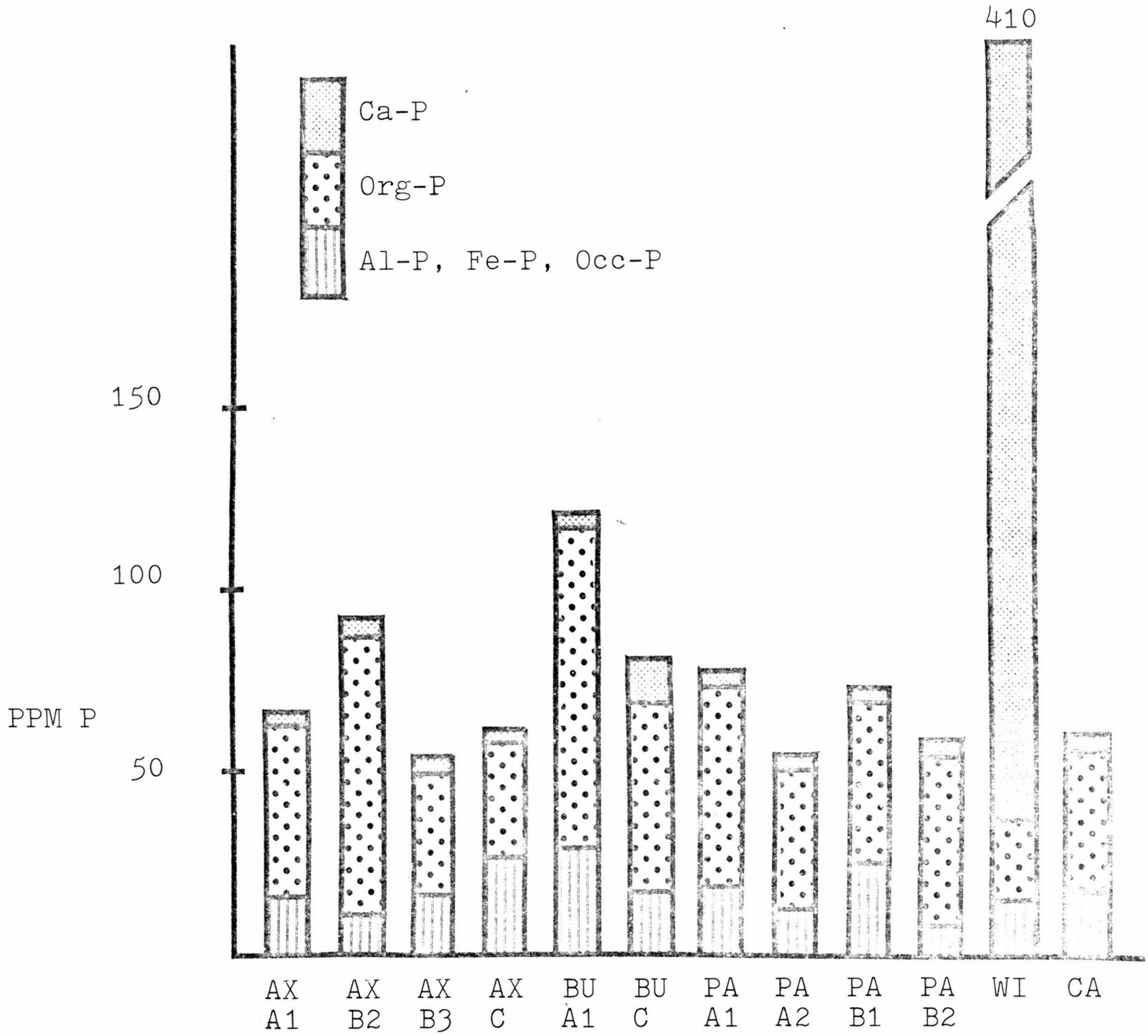

Figure 4. Phosphate fractions for all soils.

Corey, 1966), but were somewhat comparable to the phosphorus contents of six Nigerian profiles (Udo and Ogenwale, 1977), and three Texas soils (Hawkins, 1960; Askenasy, 1977).

Aluminum phosphate varied from a low of .93 ppm in the Padina B2 to a high of 8.3 ppm in the Bub A1, a range of 1.5% to 6.8% of the total phosphorus content

Iron phosphate was low but slightly higher than Al-P, ranging from 2.9 ppm (5.0%) in the Padina B2 to 12.8 ppm (10.6%) in the Bub A1.

Calcium phosphate levels were also low, and agreed fairly well with data for other Texas soils (Hawkins, 1960; Askenasy, 1977; Supak, 1969; Mannan, 1969). While the range for Ca-P was extreme, 1.3 ppm (2.5%) in the Padina A2, to 367 ppm in the Wilcox material, no soil horizon sample contained over 11 ppm as Ca-P. The Wilcox material contained over 30 times the Ca-P content of any of the soils, and it accounted for 89.5% of the total phosphorus in the sample.

Occluded phosphate (includes both occluded and reductant soluble P) levels were low ranging from 3.1 ppm in the Padina B2 to 15.8 ppm in the Axtell C, and agreed well with the amounts found in the Beaumont, Lake Charles, and Victoria clays (Hawkins, 1960).

Organic phosphorus was the largest single constituent of total phosphorus in the samples, contributing at least 50% to total phosphorus in all soils except the Wilcox. Higher organic phosphorus levels would be expected in the surface horizons of soils where the greatest accumulation of organic matter is found. While true for the Bub and Padina soils, the Axtell B2 contained more organic phosphorus than the A1 horizon.

Organic phosphorus values ranged from 27.9 ppm in the Wilcox material to 88.7 ppm in the Bub A1, and may be considered low when compared to levels determined for Houston Black clay and Victoria clay (Hawkins, 1960), but compare favorably with other East Texas Soils (Mannan, 1969; Askenasy, 1977). The low organic matter content of East Texas soils results from a combination of high moisture and warm temperatures which encourages rapid decomposition of organic matter,and relatively low biomass production resulting in low levels of organic materials being returned to replenish the soil. Phosphorus present in organic matter is largely unavailable to the plant because of the time required for biological mineralization which converts it to a plant available form.

The total phosphorus levels given in Table 2 may be considered low. For 11 of the soils, it ranged from 52.8 ppm to 120 ppm. The notable exception is 410 ppm total phosphorus found in the Wilcox material (almost 4 times greater than that of the Bub A1). The Ca-P content accounted for nearly 90% of the total phosphorus in the Wilcox.

Total phosphorus in the samples is very low compared to levels reported for other soils. Values as high as 4,750 ppm and 3,720 ppm have been found in limestone soils of Barbados (Ahmad and Jones, 1967). Black and Whitney, (1966), found 500-600 ppm total phosphorus were common amounts in four loessial soils of the Central Great Plains region. In Texas, total phosphorus amounts of 416 ppm, 476 ppm, and 780 ppm were found in the surface horizons of the Victoria, Beaumont, and Houston clays respectively (Hawkins, 1960).

Results of the phosphorus fractionation study suggest that significant response to fertilizer phosphorus application would be expected on soils except possibly the Wilcox material. Since there is little difference in the distribution of phosphorus into its various compounds in the soils, a prediction regarding response to added phosphorus as a function of dominant form of phosphorus cannot be made. One would expect the greatest fixation of added phosphorus to occur in those soils of lowest pH, giving the Carrizo, Padina B2, and Bub C the greatest fixation potential. Since organic phosphorus becomes available to plants very slowly, and there is little difference in the content among the study soils, its contribution to plant growth may be considered negligible. The high Ca-P level of the Wilcox material would be expected to provide the greatest level of plant available phosphorus and therefore would provide the least probable response to fertilizer phosphorus.

Greenhouse Study

Results of the greenhouse study are given in Table 4 and Figures 5 and 6. Table 4 gives means per pot for each cutting and means for each pot for all three cuttings aver-

Table 4. Response to added phosphorus for all soils.

SOIL	P RATE	1st CUTTING	2nd CUTTING	3rd CUTTING	AVE.
		gms			
AX A1	0	0.68	0.64	0.26	0.53 ab
	30	2.67	2.40	0.73	2.01 e
	60	2.32	1.95	1.00	1.81 de
	90	2.75	2.20	0.85	2.01 e
AX B2	0	0.28	0.20	0.15	0.22 a
	30	2.08	2.19	0.64	1.64 cde
	60	2.78	2.39	0.96	2.04 e
	90	2.37	2.26	0.71	1.78 de
AX B3	0	0.26	0.29	0.11	0.22 a
	30	2.44	2.45	0.79	1.89 e
	60	2.70	2.44	0.73	1.95 e
	90	2.48	2.00	0.84	1.77 de
AX C	0	0.19	0.27	0.15	0.20 a
	30	1.96	1.81	0.55	1.44 cde
	60	2.20	2.12	0.66	1.66 cde
	90	2.20	1.89	0.54	1.54 cde
BU A1	0	0.64	0.52	0.36	0.50 ab
	30	2.11	2.04	0.75	1.63 cde
	60	2.65	1.71	0.82	1.72 de
	90	2.32	2.03	0.82	1.73 de
BU C	0	0.13	0.15	0.30	0.16 a
	30	1.34	1.01	0.34	0.90 bc
	60	1.38	1.35	0.32	1.02 bcd
	90	1.20	1.47	0.50	1.07 bcd
PA A1	0	1.01	1.13	0.60	0.91 bc
	30	2.36	2.03	0.52	1.64 cde
	60	2.70	1.71	0.84	1.75 de
	90	2.77	2.16	0.46	1.80 de
PA A2	0	0.16	0.23	0.31	0.23 a
	30	1.92	1.55	1.09	1.52 cde
	60	2.43	2.19	0.88	1.80 de
	90	1.91	1.72	0.94	1.57 cde
PA B1	0	0.57	0.46	0.31	0.46 ab
	30	2.17	1.58	0.87	1.54 cde
	60	1.82	1.76	1.16	1.58 cde
	90	1.98	1.86	0.69	1.51 cde
PA B2	0	0.14	0.16	0.76	0.30 a
	30	2.29	2.07	1.57	1.97 e
	60	2.34	2.23	1.75	2.14 e
	90	2.60	2.39	1.22	2.07 e
WI	0	0.14	0.31	0.12	0.18 a
	30	2.31	1.84	0.70	1.61 cde
	60	2.34	2.24	1.11	1.89 e
	90	2.55	2.55	1.05	2.05 e

Means followed by a letter in common are not significantly different at the 1% level.

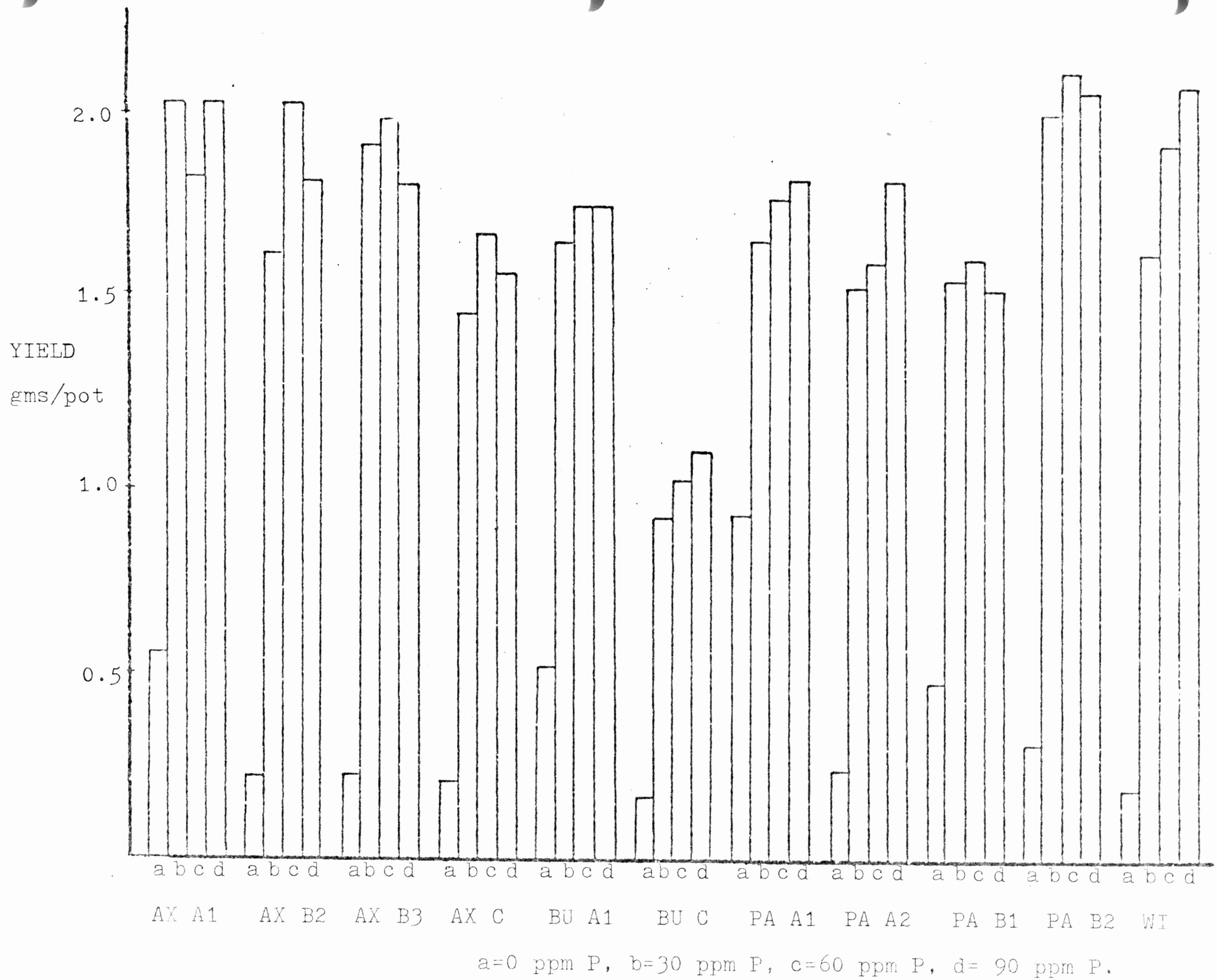

Figure 5. Response of Weeping lovegrass to added phosphorus.

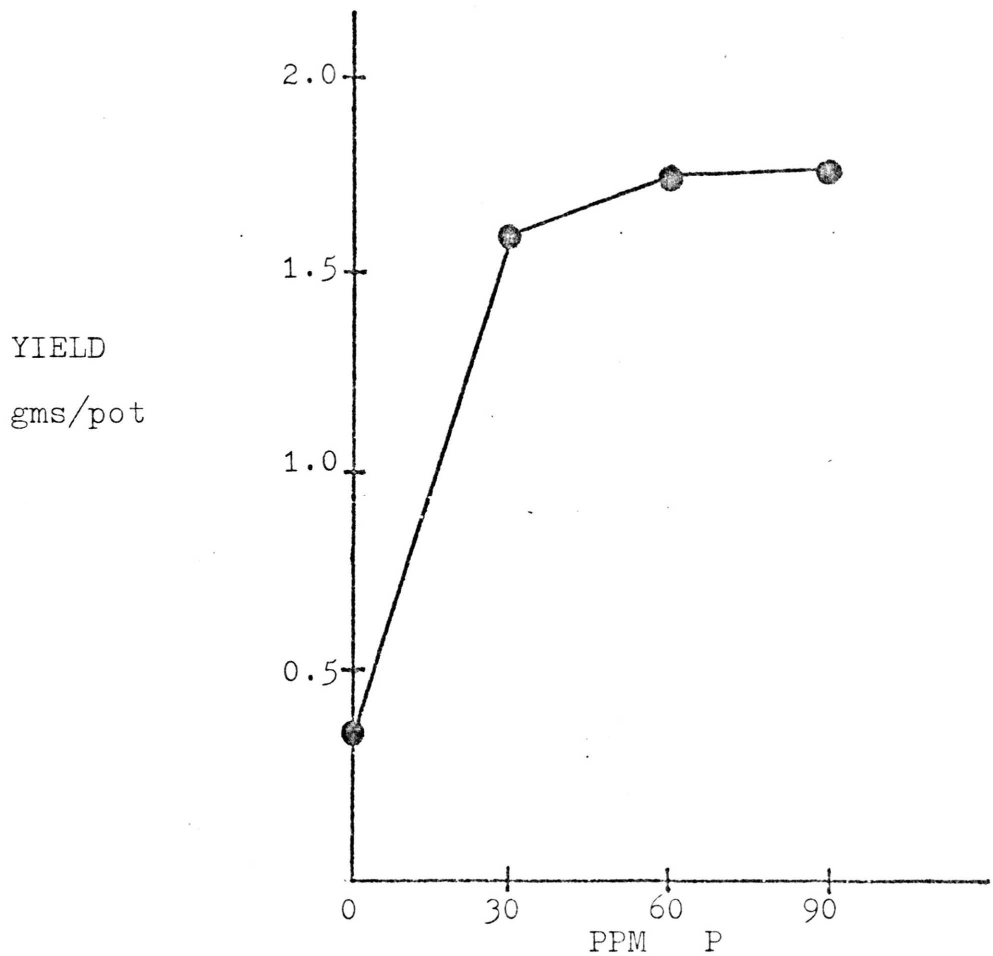

Figure 6. Response to added phosphorus for all soils.

aged over four replications. Since no differences in response occurred as a function of cutting, the statistical analysis and figures are based on the mean per pot for the three cuttings combined, and will serve as a basis for the discussion and conclusions. The yields for cutting three are lower due to a malfunction of the watering system and represent only a 15 day growth period.

The discussion centers around four major aspects of the data: (1) The lack of growth in the Carrizo sand, (2) response to zero added phosphorus, (3) response to added phosphorus for all soils (4) response to phosphorus in the Wilcox material.

No growth was obtained at any phosphorus level from the Carrizo sand. At pH 3.0, Al, Fe, and Mn toxicities may be expected in addition to phosphorus deficiencies. Since all plants died within three days of germination, toxicity is the most logical explanation. Weeping lovegrass has been shown to tolerate soil pH values as low as 4.0 with some growth possible even at pH 3.5 (Vogel and Berg, 1968). Yields on the Padina B2 at pH 4.9 were not significantly different than for any other soil (pH 5.0-6.0).

When no fertilizer phosphorus was added, yields were low (Table 4, Figure 5). The Padina A1 horizon provided significantly better growth than any other soil without phosphorus addition. The increased yield most probably results from a higher native available phosphorus level than present in the other soils. However, when all soils were extracted with NH_4OAc-HCl, pH 4.0, no differences in available phosphorus could be identified. All samples were too low in available phosphorus to develop any blue color. A possible explanation may be the presence of an organic component in the Padina which could contribute a higher available phosphorus level than possible in the other soils.

Significant increases in yield were obtained for addition of phosphorus fertilizer in all soils but not for increasing levels of phosphorus beyond 30 ppm. Yields obtained from the Bub C were significantly lower than the other soils at added phosphorus levels. This is due, in part, to the high percentage of gravel and stones present in this soil contributing to a poor environment for plant growth.

Although four different phosphorus rates were applied, there was no further response in any of the soils past 30 ppm phosphorus. Yields obtained from samples fertilized with 60 or 90 ppm did not differ significantly from those resulting from application of 30 ppm phosphorus for any soil. A possible explanation for this response is the low phosphorus requirement being met at the 30 ppm phosphorus level.

Lovegrass yields obtained in this study were found to be comparable to those obtained in the field. A yield of 2.0 gms/pot per cutting is equivilent to 4,550 Kg dry matter per hectare. Thus, an average of 2 gm/pot for three cuttings would be equivilent to an annual yield of 13,650 Kg/ha in the field. McMurphy et. al. (1975) reported lovegrass yields of approximately 10,000 Kg/ha under high levels of fertilization and management.

Little response to added phosphrous was expected for the Wilcox material, based on the high amount of total phosphorus, and specifically Ca-P. However, plants responded equally well to added phosphorus in the Wilcox as they did in other soils, and little growth was obtained at the zero phosphorus level. This response indicates that a majority of the Ca-P in the Wilcox is in an insoluble form, and therefore unavailable to the plant.

A common but unavailable Ca-P form is the primary mineral apatite which occurs as fluor-apatite ($Ca_5(PO_4)_3 \cdot F$) or hydroxy-apatite ($Ca_5(PO_4)_3 \cdot OH$). To investigate the possibility that the high, but unavailable, Ca-P level in the Wilcox material originated from apatite, the sand fraction was separated by sedimentation in water and further separated into the light and heavy mineral fraction using tetrabromoethane (sp. gr. 2.87 gm/cc) (Drees, 1980). The heavy mineral fraction was collected, ground, mounted on tape, and subjected to x-ray diffraction analysis using a Phillips Model XRG 3000 x-ray diffractometer generating copper-k-alpha radiation. The resulting diffractogram is shown in Figure 7. The minerals present in the heavy mineral fraction are identified by their characteristic lattice d spacings. The presence of pyrite is confirmed by the peaks at 3.13, 2.70, 2.21, 1.91, 1.63, 1.56, 1.50, and 1.44 angstroms, hematite by the peaks at 2.70 and 1.68 angstroms, and boehemite by the peaks at 2.36 and 1.82 angstroms.

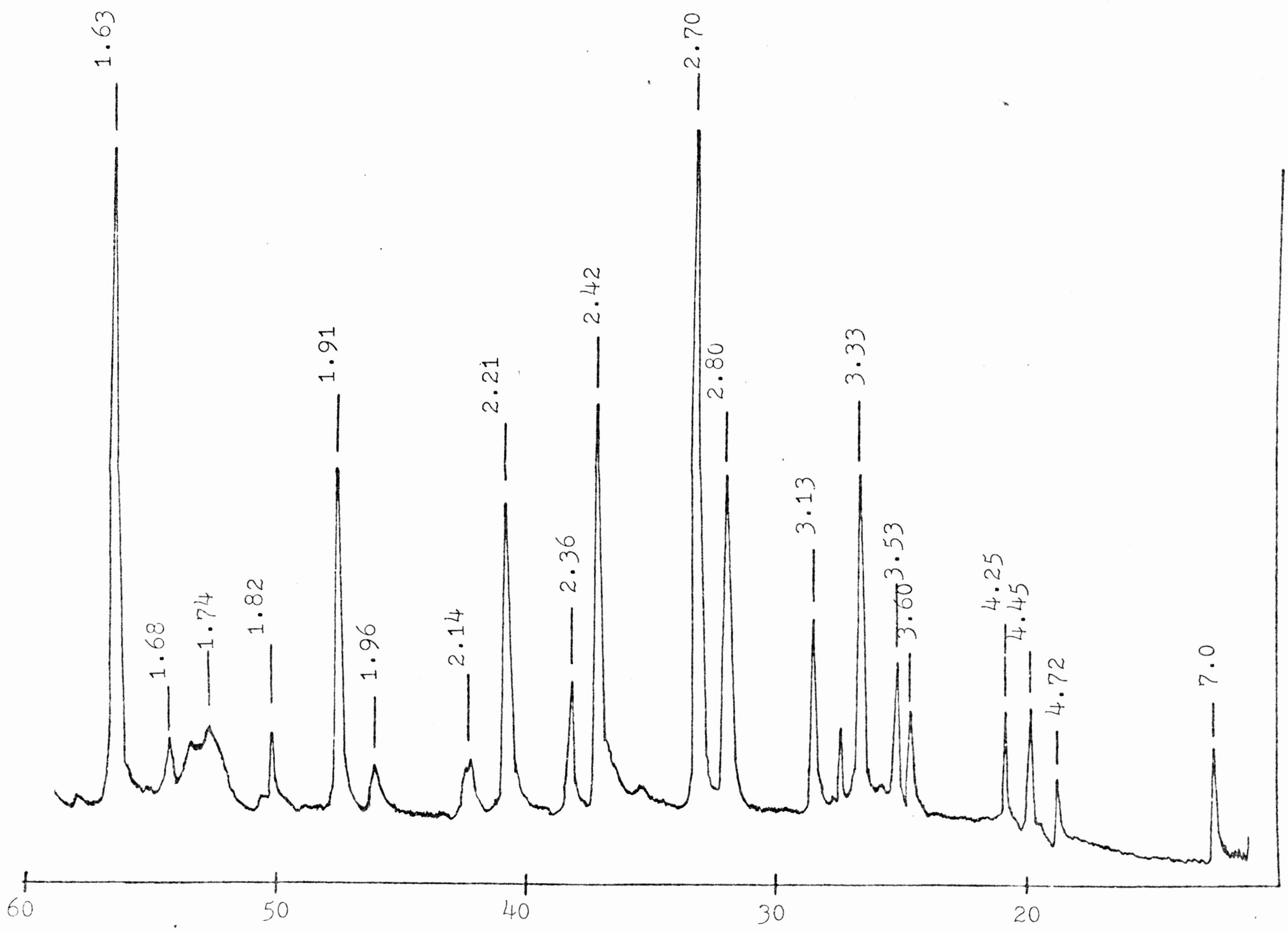

Figure 7. X-ray diffractogram for heavy mineral fraction of the Wilcox sample.

Those peaks occuring at 4.25, 3.33, 1.82, 1.54, and 1.38 angstroms are characteristic of quartz. Apatite characteristically produces strong reflections at 2.80 and 2.70 angstroms. While the 2.80 angstrom peak is most likely contributed by apatite, the strong 2.70 peak is also characteristic of pyrite.

To further confirm the presence of apatite, the heavy mineral fraction was mounted in Canada balsam (refractive index = 1.54) for observation under the petrographic microscope (Miles 1980). Observation of discrete crystalline apatite grains confirms the presence of this mineral in the Wilcox material. Since apatite is very slowly soluble, and an unavailable form of phosphorus, its contribution to plant growth would be negligable and response to phosphorus addition in the Wilcox material might well be expected.

The data obtained in this study illustrates that plants will grow well in soil materials originating on the land surface, or several feet down when properly fertilized and physical and chemical properties are not limiting to plant growth. The results of the phosphorus fractionation study and the greenhouse study allow definite conclusions and recommendations to be made.

SUMMARY AND CONCLUSIONS

Phosphorus fractionation and a greenhouse study were conducted using 12 samples taken from three soils and two geologic strata to determine the amounts and forms of phosphorus present, to evaluate plant available phosphorus as a function of form present and rate of fertilizer phosphorus added, and to determine the ability of soil horizons and stratigraphic layers to supply phosphorus for plant growth. The data obtained supports several conclusions.

The total phosphorus content of the Axtell, Bub, and Padina soils, and the Carrizo sand strata is extremely low, with over 50% of the total present as organic phosphorus.

Total phosphorus in the Wilcox material is high compared to the other samples, with nearly 90% of the phosphorus present as Ca-P. X-ray diffraction and petrographic analysis confirms that the source of much of the Ca-P is the primary mineral apatite, which is very insoluble and, therefore, unavailable to the plant.

There is little difference in the distribution of phosphorus forms, and no definite correlation exists between phosphorus form and pH in any of the samples.

Carrizo sand is too acid (pH 3.0) to support plant growth due primarily to toxicities of Fe, Al, and Mn. Therefore, the Carrizo sand should not remain at the spoil surface. The physical characteristics of the Bub C provide a poor environment for plant growth and yields will likewise be reduced if this material is allowed to remain at the spoil surface.

A significant increase in yield was obtained is response to 30 ppm added phosphorus compared to no phosphorus. No significant increase in yield was obtained at the phosphorus rates above 30 ppm. Therefore, 30 ppm phosphorus is adequate to provide excellent growth of Weeping lovegrass in the study samples. When fertilized, plants grew equally well on any of the samples, except for the Bub C and Carrizo sand. Therefore, it makes little difference which of the other materials occur at the spoil surface following mining, regardless of their origin.

Without phosphorus, lovegrass yields were significantly higher for the Padina A1 than for any of the other samples, indicating a greater amount of plant available phosphorus. However, extraction for available phosphorus with the standard state soil testing lab extractant (NH_4OAC-HCl, pH 4.2) showed no measurable available phosphorus in any of the samples. The phosphorus present in the Padina A1 is adequate to provide a moderate yield of Weeping lovegrass without any additional fertilizer application.

RECOMMENDATIONS

The data obtained in the study, and resulting conclusions provide practical information to insure successful revegetation of the study area following lignite mining.

For optimum plant growth and revegetation, the Carrizo sand strata and Bub C horizon should not remain at the surface of the spoil. Neither of these materials will support plant growth as well as the other samples. Burying the Carrizo or Bub C as they are exposed in the mining process, and covering them with any of the other materials is both a necessary and practical solution. Both represent extensive enough deposits that can be easily recognized and separated during the stripping process.

The spoil should be fertilized with at least 30 ppm phosphorus (60 kg/ha). Excellent yields of Weeping lovegrass can be obtained on the soils studied at this phosphorus rate. Growing subsequent crops of lovegrass would provide information on the long term requirements.

Because plants grow equally well on any of the samples, except for the Bub C and Carrizo sand, topsoiling would be of no advantage in this area, and therefore, economically unjustified. The spoil material, whether originating on the surface or subsurface, will support plant growth in response to phosphorus fertilization and management, and successful reclamation of the area to its original level of productivity can be achieved.

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APPENDIX

Profile Description of the Axtell Fine Sandy Loam.

Classification: Fine, montmorillonitic, thermic family of Udertic Paleustalfs.

Typical Profile Description:

A1 - 0-6 inches, grayish brown (10YR 5/2) fine sandy loam, dark grayish brown (10YR 4/2) moist; massive; very hard, friable; many fine roots; common fine pores; medium acid; clear smooth boundary. (3 to 6 inches thick)

A2 - 6-8 inches, light brownish gray (10YR 6/2) fine sandy loam, grayish brown (10YR 5/2) moist; massive; hard, friable; common fine roots; common fine pores; medium acid; abrubt wavy boundary. (1 to 9 inches thick)

B21t - 8-19 inches, yellowish red (5YR 5/6) clay, yellowish red (5YR 4/6) moist; common medium and coarse distinct light brownish gray (10YR 6/2) and yellowish brown (10YR 5/4) mottles; moderate medium and fine blocky structure; extremely hard, very firm; common fine roots, mainly between peds; few fine pores; thick continuous clay films on peds; verical cracks partially filled with browner soil; few fine black concretions; strongly acid; gradual wavy boundary, (6 to 15 inches thick)

B22t - 19-39 inches, distinctly and coarsely mottled brown (10YR 5/3), and yellowish red (5YR 5/6) clay loam; many medium and coarse distinct grayish brown (10YR 5/2), yellowish brown (10YR 5/6), and strong brown (7.5YR 5/6) mottles; moderate medium and coarse blocky structure; extremely hard, very firm; few fine roots and pores; thin patch clay films on peds; few medium shiny pressure faces; cracks extend from horizon above; few fine and medium black concretions; strongly acid; gradual wavy boundary. (15 to 30 inches thick)

B3 - 39-60 inches, light brownish gray (10YR 6/2) sandy clay loam, grayish brown (10YR 5/2) moist; common medium distince strong borwn (7.5YR 5/6) and faint olive gray (5Y 5/2) mottles; weak coarse blocky structure; extremely hard, very firm; few fine roots and pores; thin patchy clay films on peds; few fine and medium black concretions; slightly acid; gradual smooth boundary. (10 to 30 inches thick)

C - 60-75 inches, pale brown (10YR 6/3) sandy clay loam, brown (10YR 5/3) moist; common medium distinct yellowish brown (10YR 5/6) and light gray (2.5Y 7/2) mottles; massive; very hard, firm; few horizontal cleavage planes; few fine and medium black and brown concretions and soft bodies; slightly acid.

Profile Description of the Bub Gravelly Sandy Loam.

Classification: Clayey, mixed, thermic, shallow Typic Hapludalfs.

Typical Profile Description:

A1 - 0-4 inches; dark reddish brown (5YR 3/4) gravelly clay loam; moderate fine and very fine granular structure; hard, friable; common fine and very fine roots; about 35 to 50 percent flattened fragments of ironstone 2 to 10 inches in size; slightly acid; clear smooth boundary, (2 to 6 inches thick)

Bt - 4 to 15 inches; yellowish red (5YR 4/6) clay; moderate medium subangular blocky structure; very hard, firm; common fine roots; clay films on surfaces of peds; about 10 to 15 percent flattened fragments of ironstone 1/4 to 1 inch in size; very strongly acid; abrupt wavy boundary, (6 to 13 inches thick)

Cr - 15 to 100 inches; alternate layers of fractured ironstone ledges about 6 to 10 inches thick and yellowish red (5YR 4/6) clay and partially weathered glauconite and glauconite marl about clay loam texture; few fine faint yellowish red (5YR 5/8) and dark reddish brown (5YR 2/2) mottles; massive; cleavages and faces of some ironstone plates are coated with clay; medium acid.

Profile Description of the Padina Fine Sandy Loam.

Classification: Loamy, siliceous, thermic Grossarenic Paleustalfs.

Typical Profile Description:

A1 - 0-8 inches; pale brown (10YR 7/4) fine sand, light yellowish brown (10YR 5/3) moist; single grained; loose; common fine, medium and coarse roots; medium acid; clear smooth boundary, (4 to 14 inches thick)

A2 - 8-49 inches; very pale brown (10YR 7/4) fine sand, light yellowish brown (10YR 6/4) moist; single grained; loose; few fine and medium roots; medium acid; clear wavy boundary, (35 to 72 inches thick)

B21t - 49-65 inches; very pale brown (10YR 7/3) sandy clay loam, pale brown (10YR 6/3)moist; common coarse distinct reddish yellow (5YR 6/6) mottles and few fine distinct strong brown and light gray mottles; weak coarse blocky structure; very hard, very firm; few fine roots; few fine pores; thin patchy clay films; strongly acid; gradual smooth boundary. (8 to 28 inches thick)

B22t - 65-82 inches; white (10YR 8/2) sandy clay loam, light gray (10YR 7/2) moist; many coarse prominent red (2.5YR 4/6), and common medium prominent reddish yellow (7.5YR 6/6) mottles; weak coarse blocky structure; hard, firm; few fine roots; few fine pores; few thin patchy clay films; stongly acid.