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ABSTRACT

Naturally occurring zeolites could be used as soil amendments to increase the solubility of phosphate rock. This exchange-fertilizer system may prove to be economical. Zeolite (clinoptilolite) from the Pine Ridge Indian Reservation, South Dakota and phosphate rock (mill shale formation) from the Fort Hall Indian Reservation, Idaho were applied to a Keith soil (Typic Argiustoll) from the Pine Ridge Reservation. The influence of the exchange fertilizer on the growth of sorghum-sudangrass (Sorghum bicolor (L.) Moench, 'NB280S') was determined by changes in dry matter production, nutrient concentration, and nutrient uptake. Mill shale rock (9.9% P) at rates of 100, 200, 300, and 400 mg P kg^{-1} soil was combined with zeolite to create zeolite/mill shale ratios of 0, 2, 4, and 6 to 1. The effects of a soluble source of P, alone, and in combination with the zeolite, also were ascertained. Dry matter yields, and N, P, K, Ca, Mg, Cd, Cu, Fe, Mn, and Zn concentrations were determined in five cuttings of sorghum-sudangrass. Based on regression analysis, increasing zeolite/mill shale ratio caused linear increases in total dry matter production. For every cutting, increasing the mill shale P rate increased plant Cd concentrations and total Cd uptake. Field tests, however, must be completed to determine if potential health hazards from Cd in plants grown in mill shale-amended soils actually exist. Soluble P alone caused increases in total P uptake while increasing zeolite/soluble P produced significant decreases in average plant Fe concentrations. Regardless of P source,

zeolite increased concentrations of NH_4HCO_3-diethylenetriaminepentaacetic acid (AB-DTPA) Cu in soil extracts measured at the end of the study. Larger plant Cu concentrations also were found, indicating that the zeolite enhanced the solubility of Cu-bearing minerals. Whereas the mixing of the Pine Ridge zeolite and the Fort Hall mill shale increased yield, the ability of the mixture to supply P for plant growth is still unknown because of a lack of a consistent positive response in the soil tested.

INTRODUCTION

Natural materials with high cation exchange capacities may serve as soil amendments that could increase the rate of P release from untreated phosphate rock ores. This exchange-fertilizer system could be an economical alternative to soluble P fertilizers if the resources are available locally.

Untreated phosphate-rock ores vary greatly in their relative agronomic effectiveness. Generally, sedimentary phosphate rocks are more soluble in acidic soils than metamorphic or igneous rocks (Anderson et al., 1985; Leon et al., 1986). Exchangers added with the phosphate rock sequester Ca^{2+} and shift the equilibrium shown in Eq. 1 to release more P for plant absorption (Lai and Eberl, 1986).

$$\text{phosphate rock} + \text{M-exchanger} = \text{Ca-exchanger} + H_2PO_4^- + M^+ \qquad (1)$$

where M^+ is a monovalent exchange cation.

Previous experiments showed that an increase in the ratio of H-, Na- or NH_4^+-saturated clinoptilolite (zeolite) to a phosphate rock from Florida significantly increased the amount of P that was extracted from four acidic soils. The release of P could be renewed by the addition of more zeolite, or by recharging the zeolite with NH_4Cl. This laboratory research utilized zeolite/phosphate-rock ratios of 0, 12.5, 25, and 50 to 1 resulting in zeolite applications equivalent to 0 to 450 Mg ha^{-1} (Lai and Eberl, 1986).

In subsequent greenhouse experiments, an NH_4-saturated clinoptilolite significantly increased dry matter production of sorghum-sudangrass (Sorghum bicolor, (L.) Moench, 'NB 280S'). As the zeolite/phosphate-rock ratio increased, plant yields increased. Yield increases were related to increased solubility of phosphate rock caused by both the sequestering action of the zeolite and soil acidification resulting from nitrification of the NH_4^+ released from the zeolite (Barbarick et al., 1988, 1990)

Combinations of three exchangers (bentonite, peat, and zeolite) with a reactive (Florida) and less soluble (Phalborwa) phosphate rock provided few significant responses in sorghum-sudangrass yield or nutrient content. The zeolite-phalborwa combination, however, produced significant accumulative yield increases through six plant cuttings (Barbarick et al., 1991).

The hypothesis for the present research was that an increasing zeolite/phosphate rock ratio would increase dry matter yields and plant elemental concentrations and uptake because of increased nutrient availability. The objective of this study was to evaluate the combination of a natural zeolite (clinoptilolite from the Pine Ridge Indian Reservation) and a phosphate rock (mill shale from the Fort Hall Indian Reservation) as a fertilizer material. The effects of four zeolite/phosphate rock ratios on plant dry matter production and plant concentrations and uptake of N, P, K, Ca, Mg, Cd, Cu, Fe, Mn, and Zn by sorghum-sudangrass grown in a Keith (Typic Argiustoll) soil from Pine Ridge Indian Reservation was studied.

MATERIALS AND METHODS

Samples of the Keith soil (Table 1) were air-dried and crushed to pass a 4-mm screen. Combinations of NH_4-saturated zeolite/mill shale (Table 1) at ratios of 0, 2, 4, and 6 to 1 and with rates of 100, 200, 300, and 400 mg P kg^{-1} soil were produced. All combinations of zeolite/mill shale added to the Keith soil were replicated three times. Nitrogen in the form of solid urea (46-0-0) was added to supplement the N from the zeolite to provide at least 100 mg N kg^{-1} soil. Each zeolite/mill shale treatment (and urea, if needed) was added to 2.5 kg of soil and mixed for about 1 minute in an inverting mixer. The mixture was placed in pots made of 10-cm diameter by 38-cm long PVC pipe and having a plastic plate glued to the bottom to prevent drainage of soil solution. Urea was added to all pots after the first and second plant harvests to provide an overall total of 300 mg N kg^{-1} soil to all treatments.

For the soluble P treatments, $Ca(H_2PO_4)_2 \cdot H_2O$ was used to provide P rates of 0, 25, 50, 75, 100, 125, and 150 mg P kg^{-1} soil. Urea was added before planting to supply 100 mg N kg^{-1} soil plus 100 mg N kg^{-1} soil following both the first and second harvests. The zeolite/soluble P ratios (0, 2, 4, and 6 to 1) were created by using the zeolite rates associated with the intermediate mill shale P rate of 200 mg kg^{-1} soil in combination with 50 or 100 mg P kg^{-1} soil supplied as $Ca(H_2PO_4)_2 \cdot H_2O$. All soluble P and zeolite/soluble P treatments were mixed and placed in pots as described above. Each treatment was prepared in triplicate.

Six sorghum-sudangrass seeds were planted in each pot. The pots were positioned under Na-vapor lamps to provide light 14 hr d^{-1} at about 750 E m^{-2} sec^{-1}. Plants were thinned in each pot after 21 d of growth to leave the two largest. During the growing period, the pots were watered to field capacity by weight (0.31 g H_2O g^{-1} soil) at least once per week.

The top growth (10 cm above the soil surface) was harvested at 3 to 6 week intervals for a total of five cuttings. The plants were rinsed in distilled water, dried at 70°C for 24 hr and weighed to determine dry matter yield. Plant material was ground in a Wiley[4] mill to pass a 20-mesh stainless-steel screen. Portions of each sample were digested with H_2SO_4 (Thomas et al., 1976) and the digest was analyzed for total N on a Lachat autoanalyzer (Bremner and Mulvaney, 1982). A second portion of each sample was digested with HNO_3 (Havlin and Soltanpour, 1980) and the digest was analyzed on a Jarrel-Ash Model 975 Plasma Atomcorp Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) for P, K, Ca, Mg, Zn, Fe, Cd, Cu, and Mn. The soil pH and AB-DTPA extractable P (Workman et al., 1988) were determined in all treatments after the five plant cuttings.

Analyses of variance (F tests) were completed on all measured plant and soil parameters. Regression analyses for selected results were conducted (Steel and Torrie, 1980; Ryan et al., 1982).

RESULTS AND DISCUSSION

Increasing the zeolite/mill shale P ratio significantly increased both the dry matter yields of the sorghum-sudangrass (Fig. 1) and the soil AB-DTPA extractable P, K, Mn, and Cu levels found at the end of the study (Table 2). The rate of mill shale P significantly affected the AB-DTPA levels of Fe, Cu, and Cd and the ionic salt content (EC) but did not affect plant growth or soil concentrations of AB-DTPA P. Regardless of mill shale P rate, the NH_4-saturated zeolite effectively improved plant growth. The K, Mn, and Cu concentrations were adequate in all soils whereas P was at a medium soil-test level (Soltanpour et al., 1985). Specific results for the zeolite/mill shale effects on plant characteristics are presented in Appendix Tables 1 through 11.

The addition of Cd associated with the mill shale may pose potential environmental and health problems. Appendix Table 7 shows that plant Cd concentrations significantly increased as mill-shale-P rate increased. In fact most plant Cd levels exceed the 0.5 mg Cd kg^{-1} plant maximum tolerable forage concentration recommended for livestock (NRC, 1980). Fig. 2 illustrates the linear effects of mill-shale-P rate on the fourth and fifth cutting Cd concentrations while Fig. 3 provides the total Cd uptake for the five plant cuttings. Table 2 also shows that the soil AB-DTPA extractable Cd concentrations increased as the mill-shale-P rate increased, since this P source originally contained 88 mg Cd kg^{-1}. These greenhouse data should not be equated with field results, since plants grown in containers will more thoroughly absorb elements from the limited volume of soil in a greenhouse pot. Field experiments are required to determine if plants will take up significant quantities of Cd from the mill shale.

As shown in Fig. 4, increasing soluble P rate by itself significantly increased the total P uptake by the sorghum-sudangrass. In the soil at the end of the study, the increasing soluble P rate only affected the AB-DTPA extractable P (Table 3).

In the zeolite-soluble P study, increasing P rate increased the AB-DTPA-extractable soil levels of P, Mn, and Cu while increasing the zeolite/soluble P ratio increased the pH and AB-DTPA concentrations of K, Mn, and Cu (Table 3). Fig. 5 shows that the zeolite increased AB-DTPA Cu not only in the mill shale P treatments but also in the soluble P pots as well. This figure provides the regression analysis of the 200 mg P kg^{-1} soil mill shale rate for AB-DTPA Cu (Table 3), since the soluble P treatments used zeolite rates exactly equal to this set of zeolite/mill-shale-P ratios. Consequently, this procedure allowed comparison of the effects of exactly the same rate of zeolite for the two P sources. The increased release of Cu resulted directly from the solubilizing effects of the zeolite.

The increases in soil extractable AB-DTPA Cu were greater than would be expected from the simple mixing of the different quantities of zeolite with the Weld soil. Table 4 indicates that the mill shale and soluble P treatments increased the AB-DTPA extractable Cu by factors of 10.0 and 3.3, respectively, above what was measured for the control treatments. Bunzl (1981) and Eberl and Landa (1985) have described the solubilizing effects of exchangers on trace minerals in soils.

The increased plant availability of Cu created by the solubilizing action of the zeolite resulted in significant increases in plant Cu concentrations in two cuttings of the zeolite/mill shale treatments (Appendix Table 8) and three cuttings of the zeolite/soluble P treatments (Appendix Table 19). Fig. 6 provides the only significant regression equations for plant Cu for the two different P-source treatments. Barbarick et al. (1988, 1990) attributed similar effects found in their studies to differences in soil pH created by nitrification of NH_4^+ released from a zeolite (clinoptilolite). The zeolite/mill shale treatments in the current study showed no significant differences in final pH (Table 2). Even though increasing the zeolite/soluble P caused a significant increase in pH, the maximum change was from pH 6.6 (zeolite/mill shale P of 0) to 6.8 (zeolite/mill shale P of 6; Table 3). Barbarick et al. (1989, 1990) observed a change in pH from 7.1 to 5.1 in zeolite-amended Weld soil as a function of changing zeolite/phosphate rock ratio from 0 to 7.5. The zeolite/mill shale P treatments in the current study increased Cu availability independent of changes in soil pH.

Increasing zeolite/soluble P significantly decreased the weighted-average plant Fe concentrations (total Fe uptake divided by total yield; Fig. 8). The cause of this phenomenon is unknown; it may be related to the sequestering of Fe by the zeolite.

CONCLUSIONS

Increasing the zeolite/mill-shale-P ratio, regardless of P rate, significantly increased the total dry matter yields of sorghum-sudangrass grown in the Keith soil. One potential problem with use of the mill shale P is the addition of plant-available Cd to the soil; however, only field testing can verify if a true hazard does exist.

Soluble P alone only affected the total P uptake by the plants. The addition of zeolite with either the mill shale or soluble P source increased AB-DTPA Cu levels in the soil and the plant Cu concentrations for a number of cuttings. The zeolite apparently has the ability to solubilize minerals that contain certain plant micronutrients.

While the results are far from definitive, the zeolite by itself improved plant yields. The efficacy of the zeolite/mill-shale-P combination, however, is still unknown.

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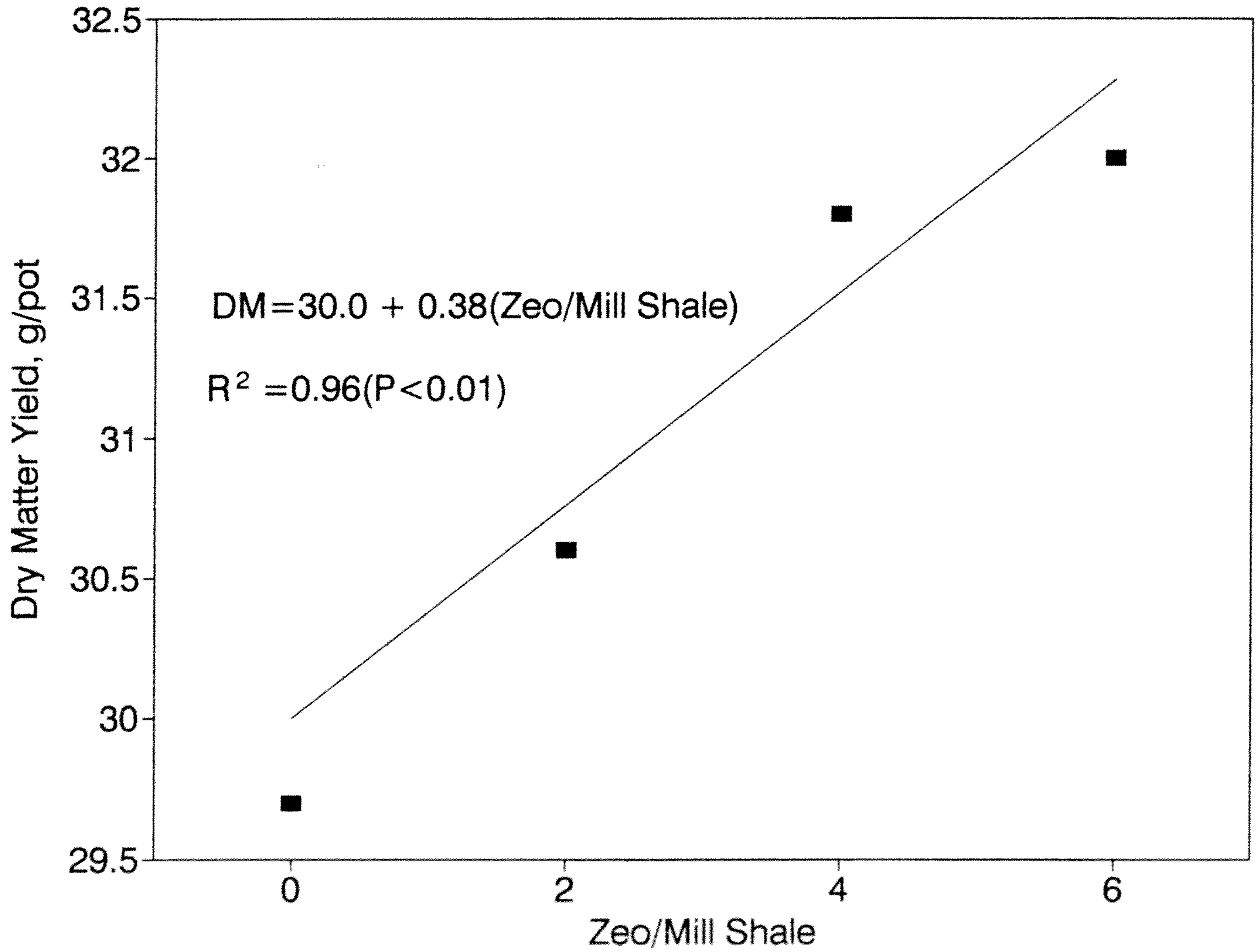

Figure 1 - Accumulative dry matter yields averaged over all mill-shale-P rates.

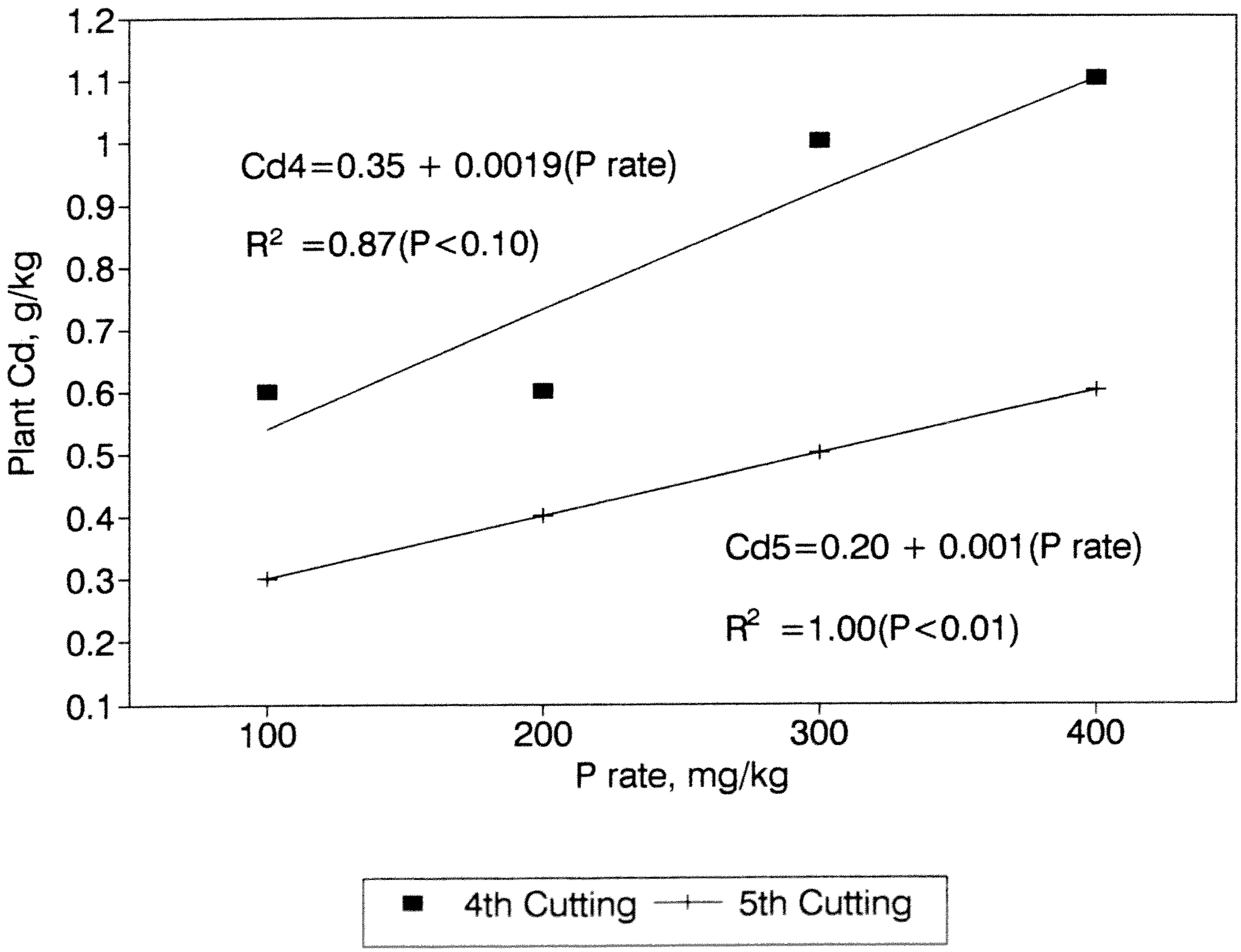

Figure 2 - Plant Cd concentrations for mill-shale-P rates.

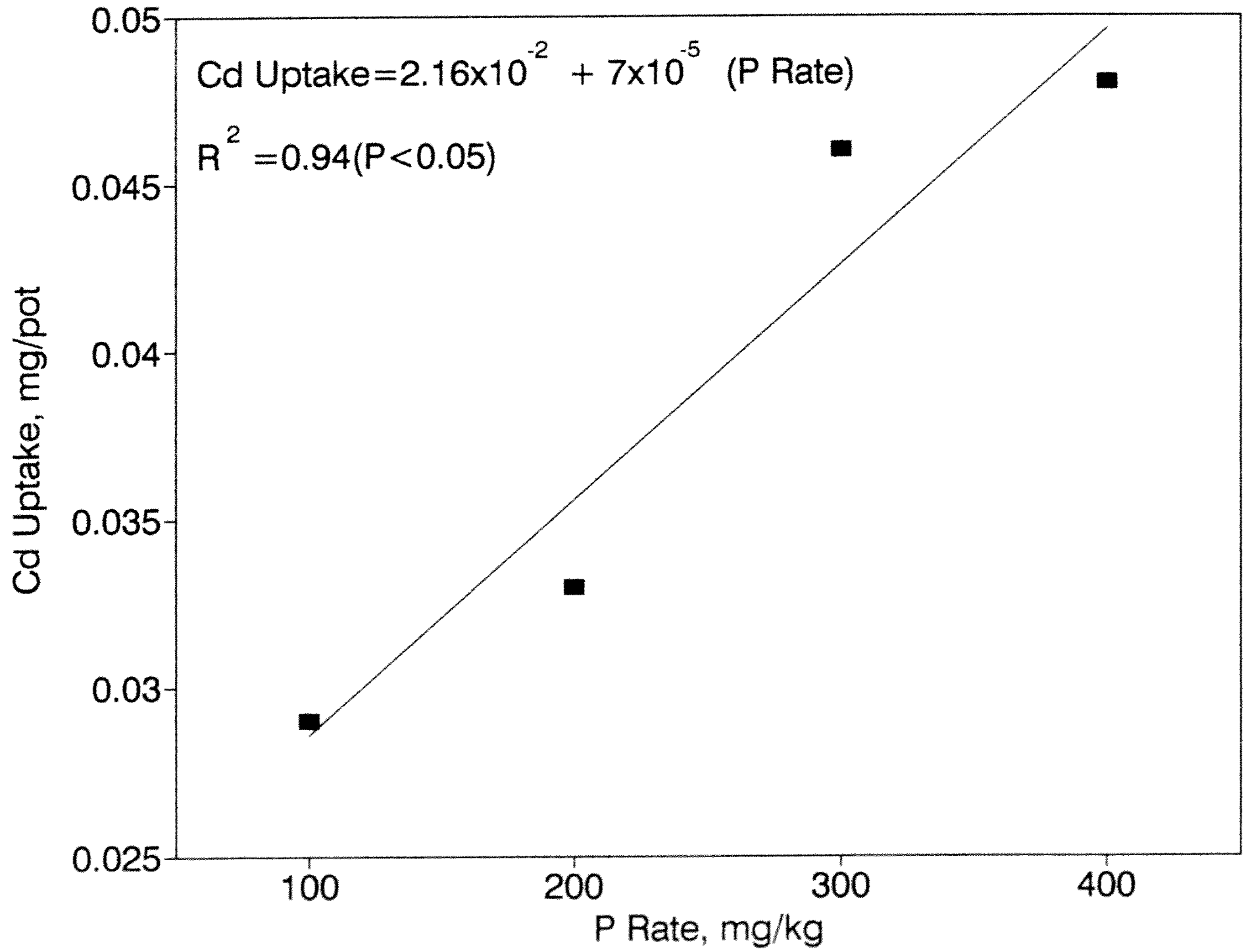

Figure 3 - Total plant Cd uptake for all mill-shale-P rates.

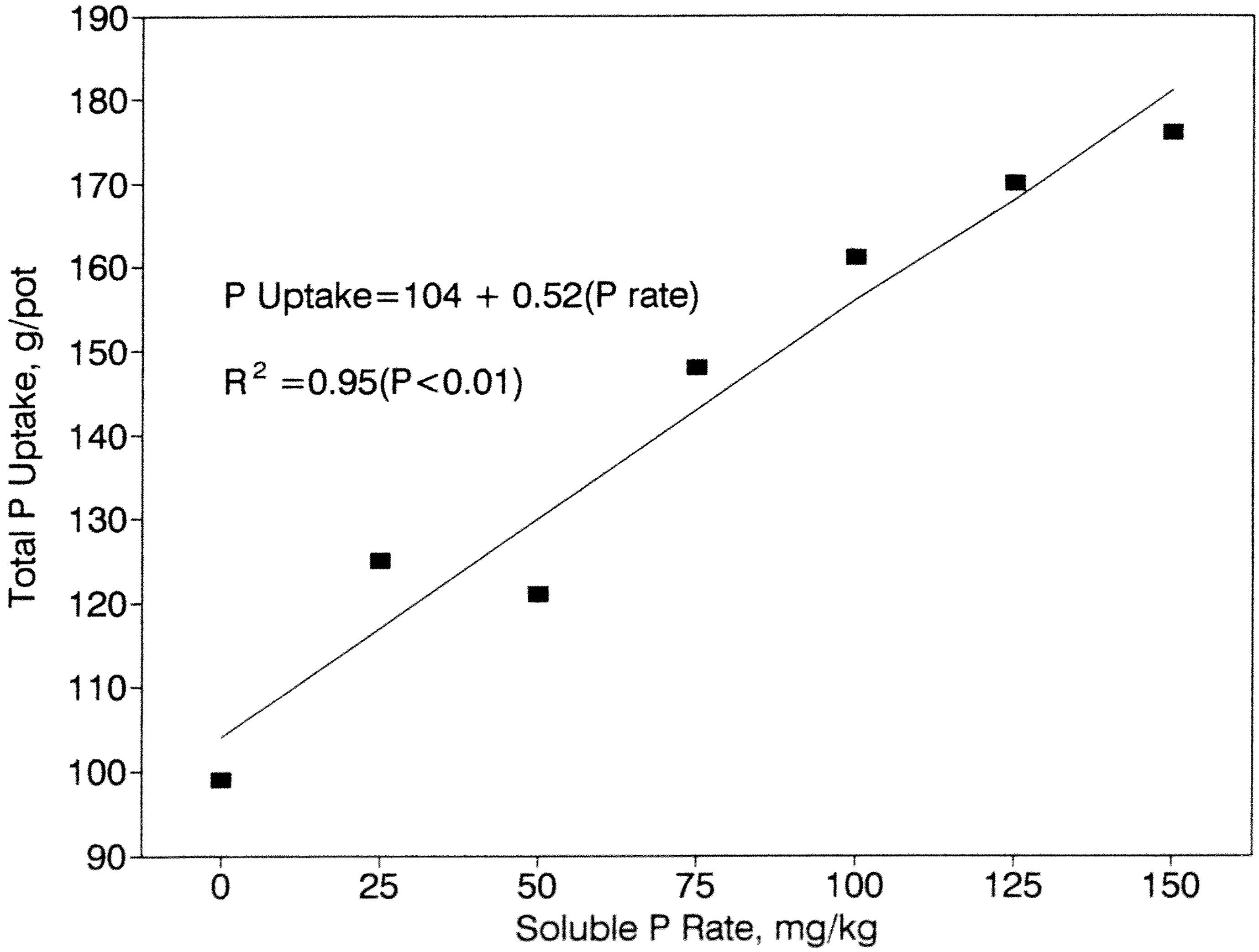

Figure 4 - Total plant P uptake for soluble-P rates.

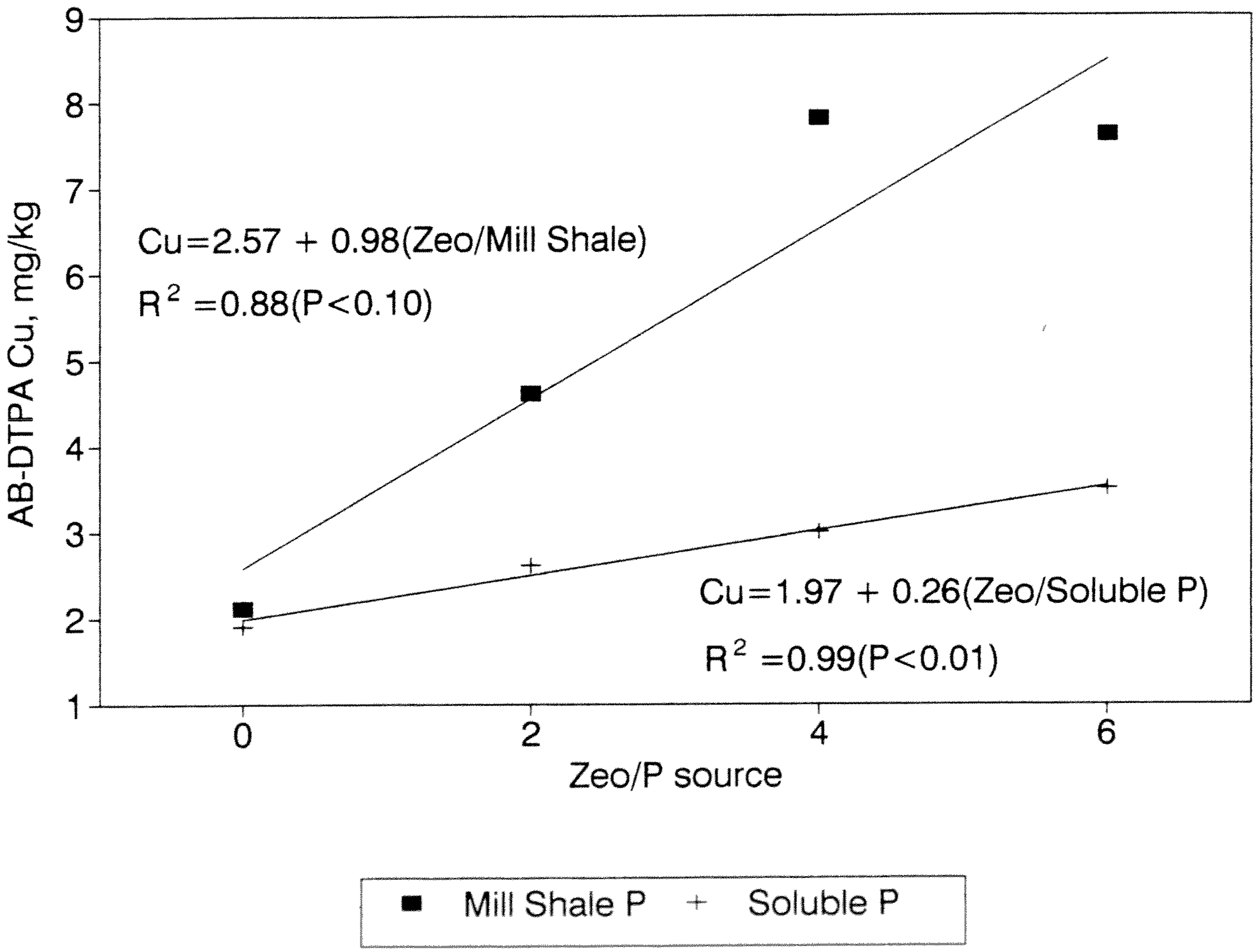

Figure 5 - AB-DTPA soil extractable Cu found after five cuttings.

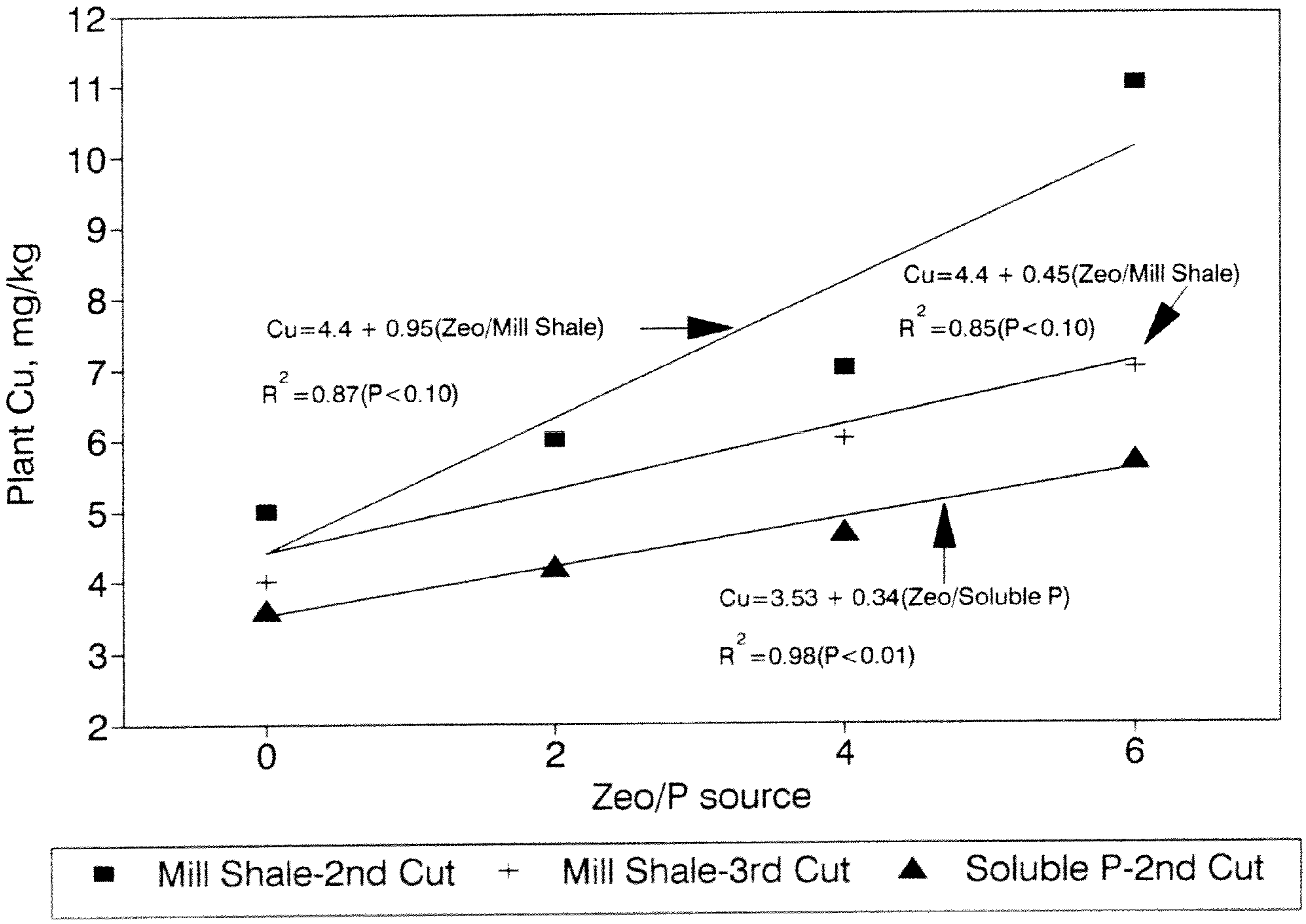

Figure 6 - Plant Cu concentrations for both P sources.

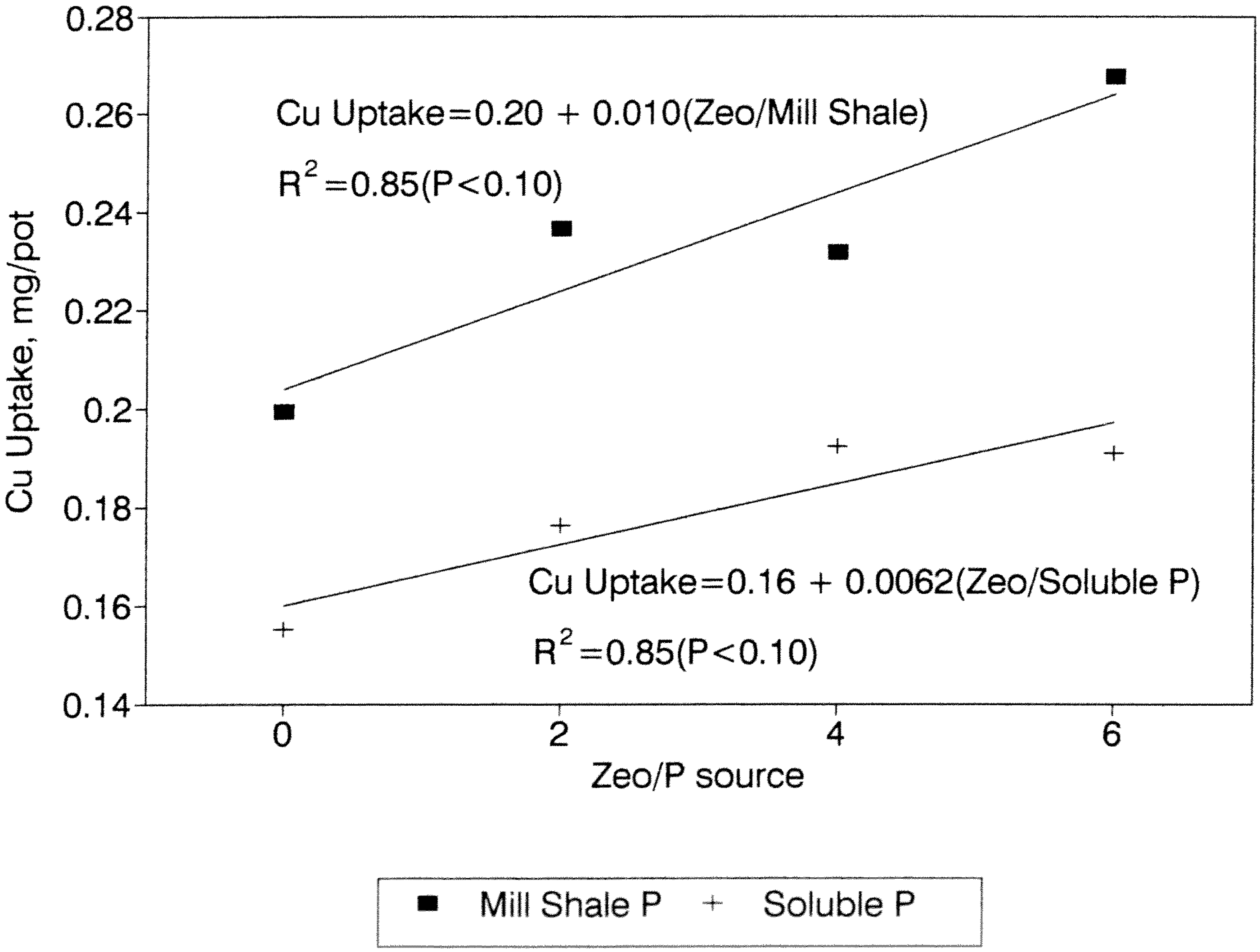

Figure 7 - Total Cu uptake for both P sources.

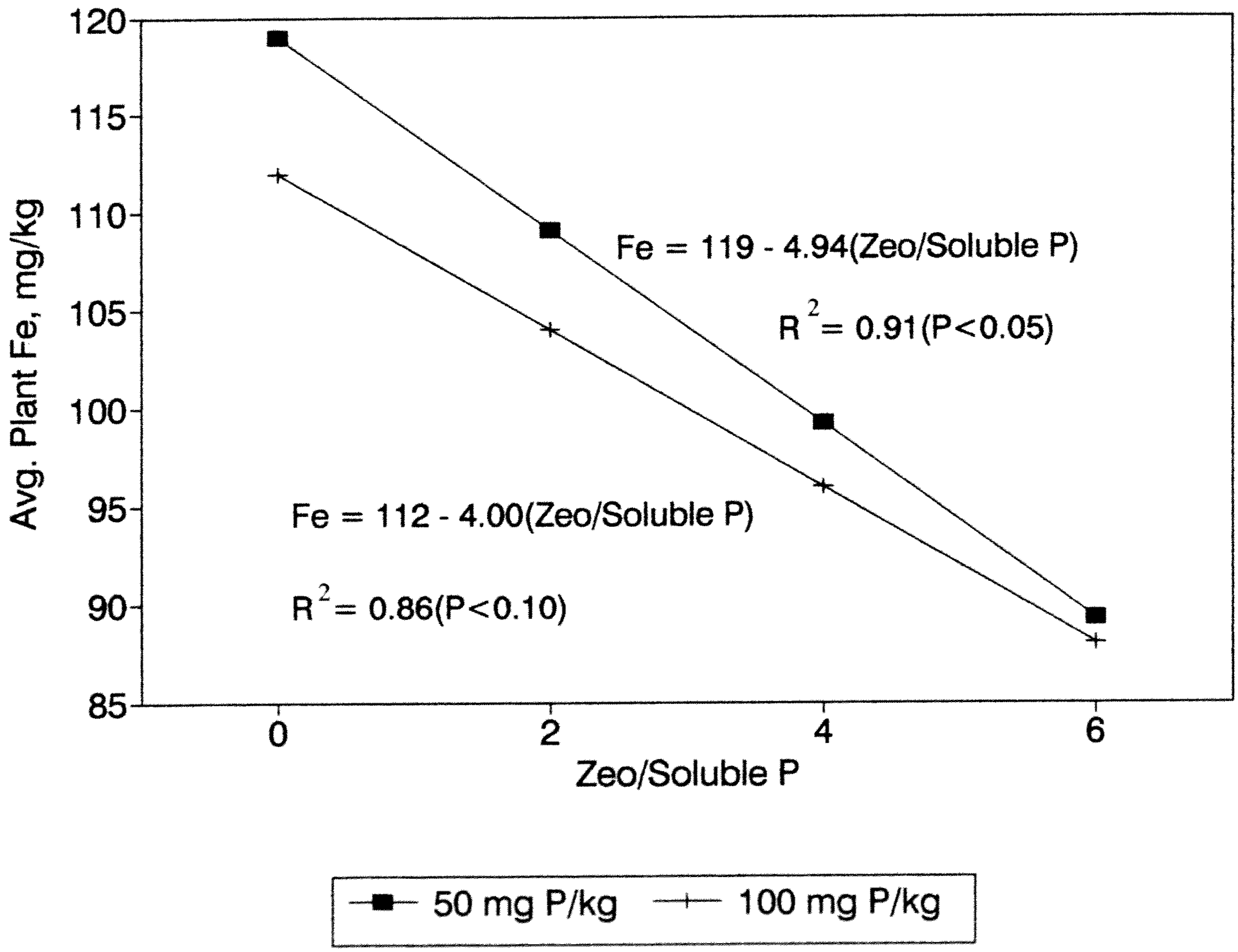

Figure 8 - Weighted-average plant Fe concentrations for the soluble-P rates.

Table 1-Fort Hall mill shale and Pine Ridge zeolite and soil properties.

	pH	EC ds/m	CaCO3 Eq. %	Total N %	NH4-N mg/kg	NO3-N mg/kg	SAR
Mill Shale	6.9	0.9	1.6	0.2	14	4	1.7
Zeolite	7.7	12.5	---	0.6	5520	11	10.4
Soil	6.5	0.4	---	---	---	14	<1

	P	K	Zn	Fe	Mn	Cu	Pb	Cd
	AB-DTPA extractable, mg/kg							
Mill Shale	49	80	55	89	6	5.5	1.0	13.9
Zeolite	63	2712	3	15	12	5.0	6.4	nd
Soil	9	887	1	11	3	1.5	---	

	Ni	Mo	B	Cr	Sr	Ba	Al	Ti
	AB-DTPA extractable, mg/kg							
Mill Shale	5.7	0.3	0.2	1.2	1	1	0.6	0.5
Zeolite	0.1	nd	0.1	0.2	27	23	1.8	0.9

	Ca	Mg	Na	K	P	Al	Fe	Mn	Ti
	Total, %								
Mill Shale	21.2	0.2	0.2	0.4	9.93	1.2	1.1	nd	0.03
Zeolite	0.9	0.6	0.5	1.2	0.02	3.6	1.4	0.03	0.09

	Cu	Zn	Ni	Mo	Cd	Cr	Sr	B
	Total, mg/kg							
Mill Shale	263	660	96	9.5	88	1340	742	47
Zeolite	214	65	7	5.6	2	7	430	nd

	Ba	Pb	V	As	Se
	Total, mg/kg				
Mill Shale	171	40	705	25	5.6
Zeolite	1320	48	18	2	nd

	Ca	Mg	Na	K	CEC
	NH4OAc extractable, meq/100g				
Zeolite	29.7	0.4	20.9	19.4	110
Soil	9.5	2.3	0.1	2.2	19

nd=non-detectable

Table 2-Soil parameters following the fifth cutting.

P rate	Zeo/Mill P	pH	EC	P	K	Zn	Fe	Mn	Cu	Cd
				AB-DTPA Extractable						
				------------			mg/kg			------------
100	0	6.7	0.3	5.0	485	0.9	27	7	1.8	0.15
	2	6.7	0.4	5.2	494	0.9	27	8	3.1	0.14
	4	6.6	0.3	6.6	547	1.2	38	10	4.9	0.16
	6	6.6	0.4	7.8	704	1.4	34	11	8.4	0.18
200	0	6.7	0.4	7.0	539	1.1	33	10	2.1	0.21
	2	6.7	0.4	6.4	564	1.1	31	9	4.6	0.19
	4	6.6	0.5	8.2	649	1.4	44	13	7.8	0.21
	6	6.6	0.3	8.4	603	1.4	44	17	7.6	0.19
300	0	6.7	0.4	8.1	529	1.8	41	13	2.3	0.16
	2	6.7	0.4	7.4	564	1.4	35	13	4.0	0.18
	4	6.6	0.5	6.2	523	1.0	18	10	4.3	0.17
	6	6.5	0.5	7.5	607	1.1	27	15	6.4	0.20
400	0	6.7	0.4	5.7	397	0.9	16	10	2.6	0.18
	2	6.7	0.4	6.6	531	1.1	23	11	5.0	0.19
	4	7.0	0.5	9.6	662	1.2	24	15	6.5	0.24
	6	6.5	0.5	7.8	613	1.2	20	15	6.2	0.21
LSD						0.2				
100	Avg. over ratios	6.7	0.4	6.1	558	1.1	32	9	4.6	0.16
200		6.6	0.4	7.5	589	1.3	38	12	5.5	0.20
300		6.6	0.4	7.3	556	1.3	30	13	4.2	0.18
400		6.7	0.5	7.4	551	1.1	21	13	5.1	0.20
LSD			0.1				10		0.9	0.03
Avg. over rates	0	6.7	0.4	6.4	488	1.2	29	10	2.2	0.18
	2	6.7	0.4	6.4	538	1.1	29	10	4.2	0.18
	4	6.7	0.4	7.7	595	1.2	31	12	5.9	0.20
	6	6.6	0.4	7.9	632	1.3	31	14	7.2	0.19
LSD				1.2	81			3	1.1	
F test and significance										
P rate		NS	*	NS	NS	NS	*	NS	+	*
Zeo/Mill P ratio		NS	NS	+	**	NS	NS	*	**	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	+	NS	NS	NS	NS

NS=non significant, +=significance at the 0.10, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Table 3-Soil parameters for the soluble P treatments following the fifth cutting.

Soluble P rate mg/kg	Zeo/P ratio	pH	EC	P	K	Zn	Fe	Mn	Cu	Cd
				AB-DTPA Extractable						
				--------------------		mg/kg	--------------------			
0		6.9	0.5	7	586	1.0	28	18	1.9	0.12
25		6.8	0.6	9	579	0.9	19	16	1.7	0.12
50		6.8	0.4	17	601	1.0	43	19	2.0	0.13
75		6.8	0.4	20	612	1.0	40	18	1.9	0.12
100		6.8	0.5	25	608	1.1	44	19	1.9	0.13
125		6.7	1.2	27	572	1.0	42	21	2.0	0.13
150		6.6	0.6	38	586	1.0	53	18	2.0	0.13
LSD				4						
F test significance P rate		NS	NS	**	NS	NS	NS	NS	NS	NS
50	0	6.6	0.5	14	566	1.0	39	19	1.9	0.13
	2	6.8	0.6	16	612	0.9	31	21	2.5	0.13
	4	6.8	0.7	15	638	0.9	31	22	3.0	0.12
	6	6.8	0.7	19	709	1.1	53	30	4.1	0.14
100	0	6.5	0.5	30	519	1.1	52	17	1.8	0.13
	2	6.7	0.5	31	609	1.0	55	22	2.6	0.13
	4	6.7	0.6	30	632	1.0	42	21	3.1	0.13
	6	6.8	0.6	26	683	0.8	25	20	2.9	0.12
LSD				3			16	3	0.4	
50	Avg.	6.7	0.6	16	631	1.0	38	23	2.9	0.13
100	ratio	6.7	0.5	29	611	1.0	44	20	2.6	0.13
LSD				4				2	0.2	
Avg. over P rate	0	6.6	0.5	22	542	1.1	45	18	1.9	0.13
	2	6.7	0.6	23	611	1.0	43	22	2.6	0.13
	4	6.8	0.6	22	635	0.9	36	22	3.0	0.12
	6	6.8	0.6	22	696	1.0	39	25	3.5	0.13
LSD		0.2			50			3	0.4	
F test and significance										
P rate		NS	NS	**	NS	NS	NS	*	+	NS
Zeo/P ratio		*	NS	NS	**	NS	NS	**	**	NS
P rate X Zeo/P		NS	NS	+	NS	NS	+	**	*	NS

NS=non significant, +=signiqicance at the 0.10, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Table 4-Measured and predicted changes in soil AB-DTPA Cu.

Zeolite	Mill Shale	Zeo/P	rate	Initial	Final	Final-Init.	Above Control
g added/pot			mg/kg	mg AB-DTPA Cu/kg			
0	5.2	0	200	1.5	2.1	0.6	---
31.2	5.2	6	200	1.6⁺	7.6	6.0	5.4
31.2	0	6	avg.⁺⁺	1.5⁺	3.5	2.0	1.4

⁺ Predicted from the mixing of the indicated quantities of zeolite and Mill Shale with the soil (see Table 1 for initial levels of AB-DTPA Cu for the zeolite and the Mill Shale).

⁺⁺ Represents the average of the 50 and 100 mg soluble P kg^{-1} soil treatments.

Appendix Table 1-Dry matter yields for the zeolite/mill shale P treatments.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total
				g/pot			
100	0	6.9	6.3	5.4	7.0	5.2	30.8
	2	5.8	5.7	4.9	7.0	6.3	29.7
	4	5.5	5.5	6.4	8.5	6.5	32.4
	6	7.1	4.4	4.6	7.8	6.0	29.9
200	0	8.0	4.6	5.9	8.2	5.7	32.4
	2	7.2	5.7	5.1	6.8	6.4	31.2
	4	5.7	7.0	6.7	9.7	5.9	35.0
	6	7.9	5.1	5.8	7.8	6.2	32.8
300	0	2.7	4.6	6.3	7.8	5.8	27.2
	2	2.0	7.9	6.1	9.0	6.9	31.9
	4	6.1	6.0	5.0	6.0	5.5	28.6
	6	6.0	7.2	4.9	7.4	6.5	32.0
400	0	8.1	5.1	4.2	6.4	5.5	29.3
	2	7.2	5.7	4.0	6.0	6.3	29.2
	4	6.6	5.0	4.3	9.0	5.9	30.8
	6	7.1	7.4	5.9	7.5	5.9	33.8
LSD							
100 Avg. over		6.3	5.5	5.3	7.6	6.0	30.7
200 ratios		7.2	5.6	5.9	8.1	6.0	32.8
300		4.2	6.4	5.6	7.5	6.2	29.9
400		7.3	5.8	4.6	7.2	5.9	30.8
LSD		0.8					
Avg. over rates	0	6.4	5.1	5.4	7.3	5.5	29.7
	2	5.6	6.3	5.0	7.2	6.5	30.6
	4	6.0	5.9	5.6	8.3	6.0	31.8
	6	7.0	6.0	5.3	7.6	6.1	32.0
LSD							
F test and significance							
P rate		*	NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS	NS

NS=non significant, +=significance at the 0.10, *= significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 2-Plant P concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total Uptake
				g/kg			mg/pot
100	0	2.6	3.8	4.3	3.4	3.1	101
	2	2.6	4.2	4.3	3.0	3.2	100
	4	2.9	3.8	3.3	2.5	2.5	93
	6	2.5	4.7	4.0	2.9	3.0	96
200	0	2.5	4.2	3.5	2.2	3.0	92
	2	2.5	4.2	3.9	3.4	3.0	100
	4	2.3	3.5	3.3	2.2	3.0	98
	6	2.4	3.9	3.3	2.5	2.9	93
300	0	4.2	3.8	3.5	2.4	3.0	85
	2	5.4	3.7	3.6	2.5	2.9	102
	4	2.8	4.0	4.2	3.1	3.1	95
	6	3.6	3.5	3.6	2.8	3.0	103
400	0	2.6	4.1	4.9	3.6	3.1	100
	2	2.8	4.5	4.2	3.2	3.3	98
	4	3.3	3.9	3.4	2.5	3.4	89
	6	2.5	3.4	3.4	2.5	3.2	98
	LSD						
100	Avg. over ratios	2.6	4.1	4.0	2.9	3.0	99
200		2.4	4.0	3.5	2.6	3.0	98
300		4.0	3.7	3.7	2.7	3.0	101
400		2.8	4.0	4.0	3.0	3.2	95
	LSD	0.6					
Avg. over rates	0	3.0	4.0	4.1	2.9	3.1	95
	2	3.3	4.1	4.0	3.0	3.1	100
	4	2.8	3.8	3.5	2.6	3.0	95
	6	3.0	3.9	3.6	2.7	3.0	106
	LSD						
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 3-Plant Ca concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total Uptake
				g/kg			mg/pot
100	0	4.5	4.6	4.4	6.0	5.4	154
	2	5.0	5.5	4.8	5.8	4.6	151
	4	4.9	5.6	4.3	5.4	4.8	161
	6	4.4	5.7	4.8	6.1	5.8	157
200	0	4.7	6.0	4.6	4.0	4.7	150
	2	4.8	5.6	4.6	6.8	4.8	162
	4	4.0	5.2	4.4	5.2	6.1	175
	6	3.9	5.4	4.3	6.6	4.9	162
300	0	4.8	5.2	4.9	5.6	5.5	142
	2	5.3	5.5	4.5	5.2	5.3	164
	4	4.4	5.0	4.4	6.5	3.9	135
	6	5.1	4.9	4.0	6.2	5.1	161
400	0	4.3	4.9	4.6	6.4	4.5	143
	2	4.4	5.4	5.1	5.4	4.2	140
	4	4.8	5.5	4.7	5.6	5.4	151
	6	4.2	5.6	4.3	5.2	5.1	163
LSD							
100	Avg. over	4.7	5.3	4.6	5.8	5.1	156
200	ratios	4.4	5.5	4.5	5.7	5.1	163
300		4.9	5.2	4.5	5.9	4.9	149
400		4.4	5.4	4.7	5.7	4.8	149
LSD							
Avg. over	0	4.6	5.2	4.6	5.5	5.0	147
rates	2	4.9	5.5	4.7	5.8	4.7	154
	4	4.5	5.4	4.5	5.7	5.0	156
	6	4.4	5.4	4.3	6.0	5.2	161
LSD							
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 4-Plant N concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total Uptake
		g/kg					mg/pot
100	0	28	24	23	11	14	621
	2	27	24	26	12	13	596
	4	31	24	20	11	12	583
	6	32	25	24	11	13	554
200	0	31	24	21	11	13	570
	2	29	22	23	12	13	609
	4	33	20	18	10	13	553
	6	26	20	20	11	13	558
300	0	30	28	25	11	13	528
	2	23	26	24	10	11	581
	4	30	22	23	14	14	565
	6	29	17	20	11	12	582
400	0	26	23	30	13	13	627
	2	23	27	25	14	14	594
	4	36	24	24	12	13	558
	6	33	15	20	10	12	583
LSD							
100 Avg. over		29	24	23	11	13	588
200 ratios		26	21	20	11	13	573
300		33	23	23	12	12	563
400		30	22	25	12	13	590
LSD							
Avg. over rates	0	29	25	25	12	13	587
	2	30	25	25	12	13	595
	4	28	23	21	12	13	564
	6	29	19	21	11	13	569
LSD			4				
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	+	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 5-Plant K concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total Uptake
				g/kg			mg/pot
100	0	27	24	20	20	18	698
	2	28	24	21	20	18	662
	4	29	28	21	20	16	732
	6	27	25	20	20	18	667
200	0	27	32	19	13	19	673
	2	27	23	18	18	18	653
	4	25	28	22	18	17	778
	6	24	23	23	20	16	710
300	0	34	33	24	19	19	653
	2	34	30	22	21	20	754
	4	28	26	21	18	18	669
	6	29	25	18	19	19	705
400	0	26	22	21	21	19	631
	2	28	27	19	15	19	650
	4	29	24	20	18	20	679
	6	24	24	22	20	21	779
LSD			6				
100	Avg. over ratios	28	25	21	20	18	689
200		26	26	21	17	17	703
300		31	29	21	19	19	691
400		27	24	20	18	19	681
LSD		4	3			1	
Avg. over rates	0	28	28	21	18	19	663
	2	29	26	20	18	19	679
	4	28	27	21	19	18	709
	6	26	24	21	20	19	711
LSD							
F test and significance							
P rate		**	*	NS	NS	**	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	*	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 6-Plant concentrations of Mg for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5	Total Uptake
				g/kg			mg/pot
100	0	2.6	3.0	3.0	3.7	3.0	95
	2	2.6	3.5	3.4	3.3	2.6	91
	4	2.4	3.3	2.8	2.9	2.5	91
	6	2.4	3.5	3.2	3.2	2.9	88
200	0	2.4	3.4	2.9	2.4	2.6	86
	2	2.6	3.3	2.9	3.4	2.6	91
	4	2.0	2.9	2.7	2.7	3.0	94
	6	2.3	2.9	2.8	3.5	2.9	93
300	0	2.8	3.1	2.9	3.1	2.8	79
	2	2.7	3.3	3.1	2.9	2.6	94
	4	2.8	3.4	3.4	3.9	2.4	90
	6	2.9	3.0	2.7	3.3	2.8	91
400	0	2.6	3.1	3.3	3.7	2.5	87
	2	2.4	3.6	3.3	3.1	2.6	84
	4	2.6	3.2	3.0	3.1	2.7	85
	6	2.5	3.1	2.8	2.8	2.6	91
LSD							
100	Avg. over	2.5	3.3	3.1	3.3	2.8	91
200	ratios	2.3	3.1	2.8	3.0	2.8	92
300		2.8	3.2	3.0	3.3	2.6	90
400		2.5	3.2	3.1	3.2	2.6	86
LSD							
Avg. over rates	0	2.6	3.2	3.0	3.2	2.7	86
	2	2.6	3.4	3.2	3.2	2.6	90
	4	2.5	3.2	3.0	3.2	2.7	90
	6	2.5	3.1	2.9	3.2	2.8	91
LSD							
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 7-Plant Cd concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5
				mg/kg		
100	0	1.7	1.0	0.7	0.5	0.3
	2	1.8	1.4	1.0	0.7	0.3
	4	1.8	1.5	0.7	0.5	0.3
	6	1.6	1.3	0.9	0.7	0.4
200	0	1.8	1.9	1.1	0.5	0.4
	2	1.9	1.1	0.8	0.6	0.4
	4	1.5	1.3	0.8	0.4	0.4
	6	1.8	1.2	1.0	0.7	0.3
300	0	2.7	2.9	2.1	1.0	0.5
	2	3.6	2.8	1.6	1.0	0.5
	4	2.4	1.3	1.0	1.0	0.3
	6	2.9	2.0	1.1	0.9	0.5
400	0	2.3	1.2	1.1	0.9	0.5
	2	2.1	1.9	1.3	1.0	0.5
	4	3.3	2.5	1.6	1.5	0.7
	6	3.5	1.6	1.2	0.9	0.8
LSD			0.8			
100 Avg. over		1.8	1.3	0.8	0.6	0.3
200 ratios		1.8	1.4	0.9	0.6	0.4
300		3.2	2.3	1.5	1.0	0.5
400		2.8	1.8	1.3	1.1	0.6
LSD		0.6	0.4	0.4	0.4	0.2
Avg. over rates	0	2.8	1.7	1.1	0.7	0.4
	2	2.4	1.8	1.3	0.8	0.4
	4	2.3	1.6	1.6	0.8	0.4
	6	2.7	1.5	1.2	0.8	0.5
LSD						
F test and significance						
P rate		**	**	**	*	*
Zeo/Mill P ratio		NS	NS	NS	NS	NS
P rate X zeo/Mill P ratio		NS	**	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 8-Plant Cu concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5
				mg/kg		
100	0	11	5	6	6	7
	2	12	6	6	6	7
	4	14	13	6	5	6
	6	12	9	8	6	7
200	0	10	5	4	4	7
	2	12	6	6	6	7
	4	12	7	6	4	6
	6	12	11	7	5	6
300	0	12	6	4	4	6
	2	18	8	5	4	6
	4	11	7	6	6	6
	6	15	6	6	6	6
400	0	9	5	7	7	7
	2	12	7	8	5	7
	4	14	8	6	5	6
	6	13	7	6	5	6
LSD						
100	Avg. over	12	8	6	6	7
200	ratios	11	7	6	5	6
300		14	7	5	5	6
400		12	7	7	6	7
LSD				1		
Avg. over rates	0	11	5	5	5	7
	2	13	7	6	5	7
	4	13	9	6	5	6
	6	13	8	7	6	6
LSD			2	1		
F test and significance						
P rate		NS	NS	*	NS	NS
Zeo/Mill P ratio		NS	*	*	NS	NS
P rate X zeo/Mill P ratio		NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 9-Plant Fe concentrations in the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5
				mg/kg		
100	0	127	104	188	78	233
	2	116	108	164	75	225
	4	126	155	147	66	145
	6	95	248	118	76	214
200	0	129	170	114	45	157
	2	121	147	146	71	142
	4	104	125	172	80	276
	6	103	278	116	83	164
300	0	158	304	142	72	194
	2	185	649	117	81	207
	4	109	139	126	74	129
	6	125	96	102	74	165
400	0	112	220	114	74	153
	2	174	124	108	63	116
	4	152	155	142	63	166
	6	125	275	150	61	147
LSD						
100	Avg. over	116	161	154	74	204
200	ratios	114	180	137	70	185
300		144	297	122	75	174
400		141	194	128	65	146
LSD						
Avg. over	0	132	199	139	67	184
rates	2	149	264	134	73	173
	4	123	144	147	71	179
	6	112	224	121	74	172
LSD						
F test and significance						
P rate		NS	NS	NS	NS	NS
Zeo/Mill P ratio		NS	NS	NS	NS	NS
P rate X zeo/mill P ratio		NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 10-Plant Mn concentration for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5
				mg/kg		
100	0	60	83	100	121	73
	2	60	108	101	121	58
	4	68	110	88	121	66
	6	58	117	91	113	72
200	0	56	114	90	77	53
	2	55	111	90	109	53
	4	58	91	88	107	84
	6	57	136	86	120	60
300	0	73	95	101	141	81
	2	93	97	95	127	80
	4	62	102	88	96	47
	6	94	104	81	109	62
400	0	53	105	90	103	49
	2	55	100	101	100	49
	4	74	131	102	126	76
	6	92	163	100	135	65
LSD		17				26
100	Avg. over	62	105	95	119	67
200	ratios	57	113	88	104	63
300		81	100	91	118	67
400		68	125	98	116	60
LSD		8				
Avg. over rates	0	60	99	95	110	64
	2	66	104	97	114	60
	4	66	109	92	113	68
	6	75	130	90	119	65
LSD		8				
F test and significance						
P rate		**	NS	NS	NS	NS
Zeo/Mill P ratio		**	NS	NS	NS	NS
P rate X zeo/Mill P ratio		**	NS	NS	NS	*

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 11-Plant Zn concentrations for the zeolite/mill shale study.

P rate	Zeo/Mill P	Cutting 1	2	3	4	5
		mg/kg				
100	0	23	18	29	28	25
	2	21	20	28	26	26
	4	22	18	22	18	21
	6	23	20	29	24	24
200	0	21	26	29	20	25
	2	23	21	27	25	26
	4	19	20	20	18	25
	6	21	20	25	23	23
300	0	28	26	28	19	23
	2	34	30	26	21	23
	4	23	18	35	26	26
	6	32	21	27	24	23
400	0	26	21	37	34	30
	2	23	22	24	28	26
	4	28	20	21	23	24
	6	31	22	23	18	22
LSD				4		
100	Avg. over	22	19	27	24	24
200	ratios	21	22	25	22	25
300		29	24	29	22	24
400		27	21	26	26	25
LSD		4	3			
Avg. over	0	25	23	31	25	26
rates	2	25	23	26	25	25
	4	23	19	24	21	24
	6	27	21	26	22	23
LSD			3	4		
F test and significance						
P rate		**	*	NS	NS	NS
Zeo/Mill P ratio		NS	+	*	NS	NS
P rate X zeo/Mill P ratio		NS	NS	*	NS	NS

NS=non significant, *=significance at the 0.05 and **= significance at the 0.01 probability level.

Appendix Table 12-Dry matter yields for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 g/pot	4	5	Total
0		4.8	5.6	4.3	8.6	5.6	28.9
25		5.3	5.1	4.6	5.9	5.7	26.6
50		4.9	4.6	4.3	4.5	6.6	24.9
75		5.3	5.6	5.3	8.5	6.3	31.0
100		6.2	5.7	7.4	8.3	5.7	33.3
125		9.2	4.7	5.2	10.5	7.3	36.9
150		6.8	4.9	5.2	5.7	6.9	29.5
LSD							
F test significance							
P rate		NS	NS	NS	NS	NS	NS
50	0	3.7	6.9	8.4	10.0	6.3	35.3
	2	8.8	5.3	5.5	4.8	7.4	31.8
	4	8.2	5.2	5.5	6.2	6.8	31.9
	6	10.1	4.7	5.6	7.1	7.2	34.7
100	0	5.1	7.0	8.5	10.1	5.4	36.1
	2	9.8	4.4	5.1	9.0	6.7	35.0
	4	8.0	6.2	5.1	5.4	6.7	31.4
	6	7.6	5.5	5.4	5.5	6.2	30.2
LSD					2.0		
50 Avg. over		7.7	5.5	6.2	7.0	7.0	33.4
100 ratio		7.6	5.7	6.1	7.5	6.3	33.2
LSD							
Avg. over	0	4.4	6.9	8.5	10.0	5.8	35.6
P rate	2	9.3	4.8	5.3	6.9	7.1	33.4
	4	8.1	5.7	5.3	5.8	6.8	31.7
	6	8.9	5.1	5.5	6.3	6.7	32.5
LSD		2.7		1.3	2.0		3.6
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/P ratio		**	NS	**	**	NS	NS
P rate X Zeo/P		NS	NS	NS	*	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 13-Plant P concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 g/kg	4	5	Total Uptake mg/pot
0		4.0	4.3	4.0	2.9	3.0	99
25		5.7	5.7	4.4	4.6	3.6	125
50		6.2	7.1	5.1	3.8	3.4	121
75		7.2	6.5	4.6	3.8	3.8	148
100		6.8	6.0	4.3	4.2	4.0	161
125		5.7	6.0	4.8	4.4	4.0	170
150		6.7	7.4	5.3	4.2	4.6	176
LSD		2.1				0.6	24
F test significance							
P rate		+	NS	NS	NS	**	**
50	0	5.1	5.6	3.8	2.9	3.2	136
	2	4.3	5.8	4.4	4.0	3.4	132
	4	3.9	4.5	3.7	3.4	3.4	117
	6	3.6	4.8	3.2	2.1	3.3	113
100	0	5.2	5.3	4.2	3.2	4.0	149
	2	4.6	5.3	4.2	3.1	3.3	140
	4	5.6	5.3	5.1	4.6	4.0	152
	6	5.7	5.8	4.9	5.9	4.0	147
LSD					1.5		
50	Avg.	4.2	5.2	3.8	3.1	3.3	124
100	ratio	5.3	5.4	4.6	4.2	3.8	148
LSD		1.1		0.7	1.0	0.4	14
Avg. over	0	5.1	5.4	4.0	3.1	3.6	144
P rate	2	4.4	5.6	4.3	3.6	3.3	136
	4	4.8	4.9	4.4	4.0	3.7	134
	6	4.6	5.3	4.1	4.0	3.6	131
LSD							
F test and significance							
P rate		**	NS	**	*	*	**
Zeo/P ratio		NS	NS	NS	NS	NS	NS
P rate X Zeo/P		NS	NS	NS	*	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 14-Plant Ca concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	1	2	Cuttings 3 g/kg	4	5	Total Uptake mg/pot
0		5.3	6.1	4.8	5.5	5.4	156
25		4.8	5.0	4.7	6.3	4.8	135
50		5.2	5.8	5.1	6.9	5.1	137
75		6.0	5.8	5.3	6.3	5.2	176
100		5.1	5.6	4.6	6.5	6.0	188
125		3.9	5.6	4.9	6.3	5.7	189
150		4.5	6.0	4.6	5.9	5.2	167
LSD		0.9					
F test significance							
P rate		**	NS	NS	NS	NS	NS
50	0	4.2	4.8	4.4	4.3	4.1	154
	2	4.5	5.6	4.6	6.5	4.4	158
	4	4.4	5.2	3.6	5.8	4.6	147
	6	4.9	5.5	4.1	6.1	5.5	183
100	0	4.1	4.9	4.0	4.1	5.6	159
	2	4.6	4.9	4.3	5.7	5.0	168
	4	4.9	4.5	4.8	6.1	4.6	149
	6	4.4	5.1	4.4	6.7	4.7	145
LSD						0.8	16
50	Avg.	4.5	5.3	4.2	5.7	4.7	160
100	ratio	4.4	4.9	4.4	5.7	5.0	155
LSD							
Avg. over	0	4.1	4.8	4.2	4.2	4.9	157
P rate	2	4.4	5.2	4.4	6.1	4.7	165
	4	4.7	4.9	4.2	5.9	4.6	149
	6	4.7	5.3	4.2	6.4	5.1	161
LSD					0.8		
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/P ratio		NS	NS	NS	**	NS	NS
P rate X Zeo/P		NS	NS	NS	NS	**	*

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 15-Plant N concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	1	2	Cuttings 3 g/kg	4	5	Total uptake mg/pot
0		39	27	29	12	12	621
25		40	27	29	15	14	647
50		31	30	29	16	12	574
75		40	25	23	12	13	623
100		33	23	22	12	13	652
125		26	21	23	12	12	633
150		29	24	22	13	12	601
LSD		8					
F test significance							
P rate		*	NS	NS	NS	NS	NS
50	0	24	24	16	8	11	515
	2	26	22	25	16	13	634
	4	26	19	25	11	13	584
	6	23	20	18	9	13	565
100	0	21	22	19	8	12	532
	2	23	23	22	12	13	628
	4	29	20	24	13	13	591
	6	30	24	23	13	14	596
LSD							
50	Avg.	25	21	21	11	12	574
100	ratio	26	22	22	12	13	587
LSD							
Avg. over	0	22	23	18	8	11	523
P rate	2	25	23	24	14	13	630
	4	27	20	25	12	13	587
	6	26	22	21	11	14	581
LSD				3	4	2	40
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/P ratio		NS	NS	**	**	+	**
P rate X Zeo/P		NS	NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 16-Plant K concentrations for the soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 (g/kg)	4	5	Total Uptake mg/pot
0		35	29	20	20	21	700
25		31	26	20	20	17	610
50		31	29	25	23	21	627
75		32	25	22	18	19	688
100		28	22	22	21	21	768
125		26	20	22	19	19	774
150		30	24	22	21	20	734
LSD					2	2	
F test significance							
P rate		NS	NS	NS	*	*	NS
50	0	26	31	21	20	20	813
	2	26	25	19	21	20	711
	4	23	22	19	20	20	678
	6	24	24	18	15	21	708
100	0	26	31	25	20	23	875
	2	25	23	19	21	19	757
	4	29	25	18	18	22	712
	6	28	25	19	19	21	685
LSD						1	
50	Avg.	25	26	19	19	20	727
100	ratio	27	26	20	19	21	756
LSD							
Avg. over	0	26	31	23	20	21	844
P rate	2	25	24	19	21	20	734
	4	26	23	19	19	21	695
	6	26	24	18	17	21	696
LSD			3			1	72
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/P ratio		NS	**	NS	NS	**	**
P rate X Zeo/P		NS	NS	NS	NS	**	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 17-Plant Mg concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 g/kg	4	5	Total Uptake mg/pot
0		2.9	3.4	3.0	3.3	2.8	89
25		3.2	3.5	3.0	3.6	2.7	85
50		3.6	3.9	3.3	3.6	2.6	82
75		3.6	3.8	3.0	3.3	2.9	97
100		3.1	3.1	2.7	3.2	3.2	101
125		2.6	3.2	2.9	3.3	3.0	107
150		2.8	3.7	3.0	3.2	2.9	99
LSD							
F test significance							
P rate		NS	NS	NS	NS	NS	NS
50	0	2.5	2.9	2.1	2.4	2.4	85
	2	2.8	3.2	3.0	3.6	2.6	93
	4	2.4	2.9	2.3	3.4	2.6	86
	6	2.6	2.8	2.3	2.5	2.8	90
100	0	2.3	2.6	2.4	2.5	3.0	92
	2	2.5	2.8	2.6	3.0	2.5	92
	4	3.0	2.9	3.0	3.3	2.7	91
	6	2.9	3.3	3.2	4.1	2.8	92
LSD					0.7		
50	Avg.	2.6	2.9	2.4	3.0	2.6	89
100	ratio	2.7	2.9	2.8	3.2	2.8	93
LSD							5
Avg. over	0	2.4	2.7	2.2	2.5	2.7	89
P rate	2	2.6	3.0	2.8	3.3	2.6	92
	4	2.7	2.9	2.6	3.3	2.6	89
	6	2.8	3.1	2.7	3.3	2.8	92
LSD							
F test and significance							
P rate		NS	NS	NS	NS	NS	NS
Zeo/P ratio		NS	NS	NS	NS	NS	NS
P rate X Zeo/P		NS	NS	NS	*	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 18-Plant Cd concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3	4	5
				mg/kg		
0		2.0	1.8	0.9	0.6	0.2
25		2.0	1.3	0.8	0.6	0.1
50		1.8	2.1	1.2	0.9	0.2
75		1.8	1.7	0.9	0.7	0.2
100		1.8	1.0	0.6	0.4	0.2
125		1.3	1.3	0.8	0.5	0.2
150		1.6	1.5	1.0	0.6	0.2
LSD						
F test significance						
P rate		NS	NS	NS	NS	NS
50	0	1.0	1.0	0.4	0.2	0.2
	2	1.5	0.9	0.7	0.7	0.3
	4	1.6	1.1	0.5	0.5	0.2
	6	1.3	0.7	0.5	0.5	0.3
100	0	0.9	0.7	0.9	0.2	0.2
	2	1.2	0.8	1.0	0.6	0.3
	4	1.6	0.9	1.6	0.7	0.4
	6	1.6	1.0	0.7	0.5	0.3
LSD						
50	Avg.	1.4	1.0	0.5	0.5	0.2
100	ratio	1.3	0.9	1.1	0.5	0.3
LSD				0.6		
Avg. over	0	0.9	0.9	0.6	0.2	0.2
P rate	2	1.4	0.9	0.9	0.6	0.3
	4	1.6	1.0	1.0	0.6	0.3
	6	1.5	0.8	0.6	0.5	0.3
LSD		0.4			0.3	
F test and significance						
P rate		NS	NS	*	NS	NS
Zeo/P ratio		*	NS	NS	*	NS
P rate X Zeo/P		NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 19-Plant Cu concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 mg/kg	4	5
0		6.3	4.2	4.2	5.3	6.0
25		6.4	3.6	3.8	6.6	6.1
50		6.0	4.4	4.4	4.4	6.2
75		7.5	3.8	3.2	4.4	6.2
100		5.9	2.8	2.9	5.4	6.8
125		4.4	3.3	3.3	5.0	6.4
150		5.3	5.5	4.1	5.0	6.6
LSD		1.5				
F test significance						
P rate		*	NS	NS	NS	NS
50	0	5.7	4.2	2.3	4.4	6.0
	2	6.1	3.8	4.1	6.7	6.6
	4	7.5	4.8	6.5	4.7	6.3
	6	6.6	6.0	4.0	3.5	6.3
100	0	4.7	3.1	3.5	4.1	7.0
	2	5.9	4.6	3.8	3.4	6.1
	4	7.3	4.7	5.4	5.2	6.9
	6	7.4	5.4	4.5	5.5	7.9
LSD				0.7	1.4	
50	Avg.	6.5	4.7	4.2	4.8	6.3
100	ratio	6.3	4.4	4.3	4.5	7.0
LSD						
Avg. over	0	5.2	3.6	2.9	4.2	6.5
P rate	2	6.0	4.2	4.0	5.0	6.3
	4	7.4	4.7	6.0	5.0	6.6
	6	7.0	5.7	4.3	4.5	7.1
LSD		1.5	1.3	0.7		
F test and significance						
P rate		NS	NS	NS	NS	NS
Zeo/P ratio		+	*	**	NS	NS
P rate X Zeo/P		NS	NS	*	**	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 20-Plant Fe concentrations for the soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 (mg/kg)	4	5
0		172	197	120	73	180
25		139	130	121	58	121
50		202	146	128	62	201
75		170	147	137	59	159
100		136	151	116	58	201
125		96	413	128	62	182
150		107	138	110	67	187
LSD		54				
F test significance						
P rate		*	NS	NS	NS	NS
50	0	134	263	136	57	50
	2	99	214	90	92	49
	4	90	189	88	59	82
	6	104	152	83	65	70
100	0	123	167	130	52	140
	2	98	123	107	70	116
	4	101	84	115	81	88
	6	104	139	105	62	48
LSD						
50	Avg.	107	204	100	68	63
100	ratio	107	124	114	66	98
LSD			59			
Avg. over	0	128	215	133	55	95
P rate	2	98	160	99	81	82
	4	96	137	102	70	85
	6	104	145	94	64	59
LSD		25				
F test and significance						
P rate		NS	*	NS	NS	NS
Zeo/P ratio		*	NS	NS	NS	NS
P rate X Zeo/P		NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 21-Plant Mn concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 (mg/kg)	4	5
0		67	109	109	123	68
25		67	99	110	127	63
50		73	118	106	169	73
75		86	134	116	125	82
100		80	127	102	123	88
125		62	150	104	114	72
150		70	140	97	110	76
LSD		14	26			
F test significance						
P rate		*	+	NS	NS	NS
50	0	55	89	81	80	59
	2	64	135	92	166	53
	4	69	121	73	88	54
	6	72	128	77	197	82
100	0	61	89	71	78	84
	2	61	123	100	129	64
	4	81	99	100	138	53
	6	69	113	92	121	59
LSD						
50	Avg.	65	118	80	133	62
100	ratio	68	106	91	116	65
LSD						
Avg. over	0	58	89	76	79	72
P rate	2	63	129	96	148	58
	4	75	110	86	113	54
	6	70	120	84	159	71
LSD			22			
F test and significance						
P rate		NS	NS	NS	NS	NS
Zeo/P ratio		+	*	NS	NS	NS
P rate X Zeo/P		NS	NS	NS	NS	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.

Appendix Table 22-Plant Zn concentrations for soluble P treatments.

Soluble P rate mg/kg	Zeo/P ratio	Cuttings 1	2	3 mg/kg	4	5
0		23	24	24	28	22
25		23	18	25	33	27
50		18	20	23	21	21
75		17	21	21	21	25
100		16	16	23	19	26
125		15	18	26	25	26
150		14	18	25	22	26
LSD		4	5			
F test significance						
P rate		**	**	NS	NS	NS
50	0	11	16	21	18	23
	2	14	17	26	29	24
	4	15	15	23	20	23
	6	13	16	17	14	21
100	0	11	16	18	17	27
	2	14	16	21	18	20
	4	16	15	24	30	26
	6	16	15	27	32	30
LSD					8	
50	Avg.	13	16	22	20	23
100	ratio	14	16	22	24	26
LSD						
Avg. over	0	11	16	19	18	25
P rate	2	14	16	23	24	22
	4	16	15	24	25	25
	6	14	16	22	23	26
LSD						
F test and significance						
P rate		NS	NS	NS	NS	NS
Zeo/P ratio		NS	NS	NS	NS	NS
P rate X Zeo/P		NS	NS	NS	**	NS

NS=non significant, *=significance at the 0.05 and **=significance at the 0.01 probability level.