AVAILABILITY OF P AND K IN RESTORED PRIME FARMLAND[1]

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Additional Key Words: P fixation; soil mixing; Reclamation.

Abstract. Modifications in soil nutrient availability of mine soils were studied in greenhouse and field experiments to investigate the effect of topsoil and subsoil mixing on available P and to study the response of corn to P and K fertilization. Topsoil and subsoil from an unmined Sadler silt loam (fine-silty, mixed, mesic, Glossic Fragiudalfs) were mixed in different proportions, treated with P and subjected to wetting and drying cycles in a greenhouse. Available P decreased due to wetting and drying, and more so, soil mixing, particularly with a more acidic subsoil. Two-year field studies with corn were conducted at two sites, at site 1 the soil was constructed predominantly from a Belknap silt loam (coarse-silty, mixed, acid, thermic Typic Fluvaquents) using end-dump trucks and at site 2, from a predominantly Sadler silt loam using scraper pans. Phosphorus and K were applied in a randomized complete block factorial design with four replications. In the first year, corn response to K was observed in earleaf tissue but not grain yield, at site 1. No response was observed in the second year. This was attributed to unfavorable moisture distribution. Site 2 data showed no response to P or K in both years. Compaction and moisture stress were thought as possible causes. A progressive build-up in soil test P and K was observed at both sites. About 18 kg P ha^{-1} were required for a 1 mg kg^{-1} increment in Bray I extractable P on a disturbed compared to 12 kg P ha^{-1} on an undisturbed Belknap soil. For K, 15 kg K ha^{-1} were required for a disturbed soil compared to 8.7 for an undisturbed Belknap soil. These results suggest that higher P and K fixation due to soil mixing may contribute to higher fertilizer requirements on disturbed soils compared to undisturbed ones.

Introduction

Current regulations require that prime farmland disturbed by surface mining be restored to a productivity level equal to or greater than its premined state. Frequently, efforts in meeting this condition are limited by poor soil physical conditions, low fertility, and moisture limitations, which characterize surface mined soils.

Previous studies have indicated that soil compaction (Indorante et al., 1981; Grandt, 1988), and its associated effect on root development, contribute to the observed weather sensitivity of row crops. Acidity (Dancer and Jansen,

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1987), low organic matter (OM) levels (Powell et al., 1986), microbial population, diversity, and activity (Stroo and Jencks, 1982; Visser et al., 1983) have been associated with deficiencies of essential nutrients, such as N and P, and consequently low productivity of surface mined soils.

The natural decrease in OM content with increasing soil depth and the relative difficulty of completely segregating the A horizon from underlying subsoil strata during soil removal, stock-piling, replacement, and leveling operations, results in a significant reduction in OM of the replaced topsoil (Powell et al., 1986). Beckwith (1965) and Sanchez and Uehara (1980) observed that some subsoil materials possess a higher P fixation capacity than topsoil. Field observations (Snarski et al., 1981; Barnhisel, 1988) indicate that topsoil and subsoil blending degrades topsoil physical and chemical properties. Better crop response was observed with topsoil and subsoil materials placed separately as opposed to mixing them (Jansen et al., 1985).

Although progress has been made towards establishing lime and fertilizer recommendations for forage on post mine soils (Barnhisel, 1976), similar work remains for row crops. According to Dancer and Jansen (1987), higher Bray I extractable P levels were required to attain the same level of corn production on disturbed soil sites than on undisturbed ones. In some instances, poor crop response to added P has been reported, yet low extractable P levels were observed at the end of the growing season (Dancer, 1984). Surface mining activities seem to modify soil characteristics significantly, leading to a higher P fixation and correspondingly, a higher fertilizer requirement.

The objectives of the present study were: (1) to investigate the effect of topsoil and subsoil mixing on phosphorus availability, (2) to determine the nutritional status and yield of corn following P and K treatment on restored prime farmland, and (3) to monitor changes and transformations of soil P and K following the treatments.

Materials and Methods

Greenhouse study

To study the effect of topsoil and subsoil mixing on P availability, topsoil (TS, pH_W 6.9) and subsoil (SS1, pH_W 7.1) samples of a Sadler silt loam (fine-silty, mixed, mesic, Glossic Fragiudalfs) were collected from a non mined site in Ohio County, Kentucky. Mixtures of topsoil and subsoil were prepared to make up 0, 25, 50, 75, and 100% subsoil (%SS). Three 1-kg portions of each mixture were weighed out, and mixed thoroughly with 50, 100, and 150 mg P as finely ground triple super phosphate $[Ca(H_2PO_4)_2.H_2O]$. In plastic pots, the samples were watered to field capacity (0.3 kg kg^{-1}) with deionized water and allowed to dry to wilting point (0.1 kg kg^{-1}) under greenhouse conditions. At the end of each two wetting and drying cycles, 100 g soil sub samples were collected from each mixture. The experiment was repeated using the same topsoil but with a subsoil (SS2, pH_W 4.5), predominantly a Sadler, collected from a stock-pile of a surface mine. Soil analyses for exchangeable bases based on the neutral 1M NH_4OAc (Thomas, 1982), available P by the Bray I (Bray and Kurtz, 1945) and Mehlich III (Mehlich, 1984) and P fractionation (Chang and Jackson, 1957) were performed on the sub samples collected.

Field Experiments

Field studies were conducted at two post mined sites in Hopkins and Muhlenberg Counties, western Kentucky. Soil at site 1 was reconstructed predominantly from a Belknap silt-loam (coarse-silty, mixed, mesic, Glossic Fragiudalfs) using end-dump trucks during the fall of 1987. This field was in fertilized alfalfa (Medicago sativa L.) in 1988 and 1989. Soil test data for spring 1990 indicated low P and K levels (Table 1). Phosphorus (0, 32, and 64 kg P ha^{-1}) and K (0, 75, and 150 kg K ha^{-1}) were broadcast (as in 1988), applied as factorial in a randomized complete block design with four replications. The field was planted to corn (Zea Mays L.) in June 1990 and 1991. Nitrogen (160 kg N ha^{-1}) was applied at planting and top-dressed at 80 kg N ha^{-1}.

Soil at site 2 was replaced from a Sadler silt loam using scraper pans during the spring 1988. This field was in unfertilized soybeans (Glycine max L.) in 1989. Soil test data for spring 1990 indicated very low P and low K levels (Table 1). Phosphorus (0, 37, 74, and 111 kg P ha^{-1}) and K (0, 139, and 278 kg K ha^{-1}) were applied as factorial in a randomized complete block design with four replications. The field was planted to corn in June 1990 and 1991. Nitrogen was applied at the same rates as at site 1.

Table 1. Some characteristics of the soils used in this study[#].

Greenhouse experiment								
Soil	pH_w	OM	CEC	Ca	Mg	K	Na	BP
		%	cmol(+) kg^{-1}					mg kg^{-1}
TS	6.9	3.07	15.2	7.96	0.92	0.37	0.06	9.3
SS1	7.1	1.37	10.9	7.50	1.28	0.44	0.05	5.2
SS2	4.5	0.89	10.0	2.00	1.90	0.47	0.08	3.2

Field experiments											
Site	Text	pH_w	CEC	Ca	Mg	K	Na	BS	OM	BP	NK
			cmol(+) kg^{-1}					%		mg kg^{-1}	
1	sil	7.0	12.9	6.5	1.2	0.2	0.1	61.8	1.6	4.9	79.9
2	sil	6.9	11.2	5.6	1.8	0.2	0.1	69.3	1.6	0.8	97.3

[#] pH_w, OM, CEC, Ca, Mg, K, Na, and BS refer to 1:1 soil to water pH, organic matter content, cation exchange capacity, NH_4OAc extractable Ca, Mg, K, and Na, and base saturation, respectively. BP and NK are Bray I and NH_4OAc extr. P and K, respectively. Text is soil texture based on the pipette method.

Soils were analyzed for available P according to the Bray I and Mehlich III both at planting before fertilizer application and at harvest. Phosphorus fractionation was performed according to the Chang and Jackson Procedure (1957). Ear-leaf tissue sampled at silking were analyzed for five nutrients. Nitrogen and P were determined by the micro-Kjeldahl procedure as presented by Jones and Case (1990). Potassium, Ca, and Mg were determined by the nitric-perchloric wet-ashing procedure (Jones and Case, 1990).

Results and Discussion

Greenhouse study

Topsoil and SS1 had similar 1:1 soil to water pH (pH_W) values (Table 1), with TS having higher exchangeable Ca and Bray I extractable P, but lower K and Mg than SS1. Topsoil had higher OM and CEC than SS1 while subsoil 2 (SS2) had a lower pH_W, OM, exchangeable Ca, CEC, and Bray I extractable P, but higher Mg, K, and Na than TS and SS1.

The effect of subsoil mixing on topsoil available P is presented in Fig. 1. There was a significant decrease in Bray I extractable P with increasing proportion of subsoil added to topsoil. The effect was greater in soil mixtures where a more acidic subsoil medium, SS2, was introduced. Figure 1 shows that adding 25% of SS2 to TS caused almost a 50% decrease in Bray I extractable P. Similar results were obtained with Mehlich III extractable P.

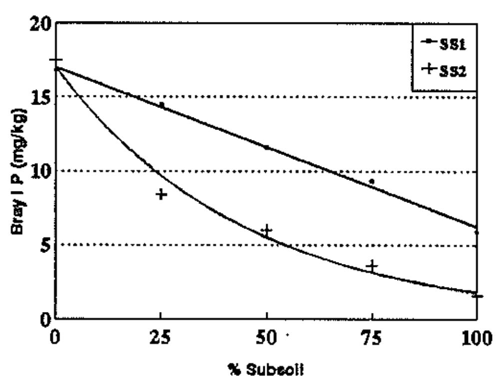

Fig. 1 Bray I P as affected by subsoil addition.

The decrease in available P (calculated as applied P minus extractable P) at a given time during the experiment was used as an estimate of the amount of P sorbed (Velayuthan, 1980). Table 2 shows that P sorption increased significantly as the proportion of subsoil in the mixture increased, particularly with SS2. These results relate closely with those of Beckwith (1965) that some subsoil materials exhibit a higher P fixation capacity.

Table 2. Sorbed P as affected by topsoil and subsoil mixing##.

%SS	Sorbed P SS1)		Sorbed P (SS2)	
	Bray	Mehl.	Bray I	Mehl.
	------------mg kg^{-1} ---------			
0	83.2	78.2	81.9	77.0
25	85.5	81.0	91.0	87.8
50	88.5	85.1	93.8	87.5
75	90.7	86.1	96.1	112.0
100	94.1	89.1	98.1	97.8
$LSD_{.05}$	2.0	3.0	2.0	2.3

##Averaged across three P rates and eight cycles.

Field experiments

Soil characteristics at the beginning of field experiments are presented in Table 1. It is worth noting that soil at site 2 had much lower available P, compared to that at site 1, since unlike site 1, no previous P fertilization had taken place.

Corn response to P and K

Results for 1990 are summarized in Table 3. Phosphorus fertilization increased ear-leaf P and Ca significantly, but decreased K (possibly dilution). On the other hand, K application increased ear-leaf K, but decreased Ca and Mg contents. Many studies have reported

Table 3. Ear-leaf composition, yield, and soil test P and K as affected by P and K application, Site 1, 1990.

P rate	Ear-leaf N	Ear-leaf P	Ear-leaf K	Ear-leaf Ca	Ear-leaf Mg	Grain Yield	Bray I P
kg ha^{-1}	g kg^{-1}					Mg ha^{-1}	mg kg^{-1}
0	31.2	2.63	17.5	4.46	2.16	8.15	5.3
32	30.7	2.82	15.8	5.12	2.46	7.89	7.9
64	30.1	2.92	15.0	5.02	2.50	7.68	12.5
$LSD_{.05}$	1.2	0.14	1.2	0.51	0.41	1.37	2.9
K rate	N	P	K	Ca	Mg	Yield	NH_4OAc K
0	31.0	2.84	12.9	5.58	3.27	6.91	71.1
75	30.4	2.82	17.4	4.76	2.06	8.17	79.0
150	30.5	2.72	18.1	4.27	1.77	8.65	87.1
$LSD_{.05}$	1.2	0.14	1.2	0.51	0.41	1.37	9.7

that increased K uptake following K fertilization often decreases Ca and Mg uptake (Stout and Baker, 1981; Dibb and Thompson, 1985) and have attributed this to competition between K, and Ca and Mg during root uptake.

Results for grain yield indicated a significant response to K, but none for P. In general, yields were higher than the Phase III target value of 6.7 Mg ha^{-1} on this soil (Fehr et al., 1977). Optimum earleaf K content of about 18 g kg^{-1} corresponding to near maximum relative yield (ratio of any yield value to the maximum yield observed) was obtained at a soil test (NH_4OAc-K) value of about 86 mg kg^{-1} (Fig. 2). This is higher than the value of 71 mg kg^{-1} observed by Thom (1985) for a similar soil prior to disturbance.

Results for site 2 showed a significant response to K in ear-leaf tissue, but none for P (refer to Semalulu, 1992 for more detailed data). The lack of response to P, in spite of the very low initial soil test P level, was attributed to moisture stress. In addition, severe

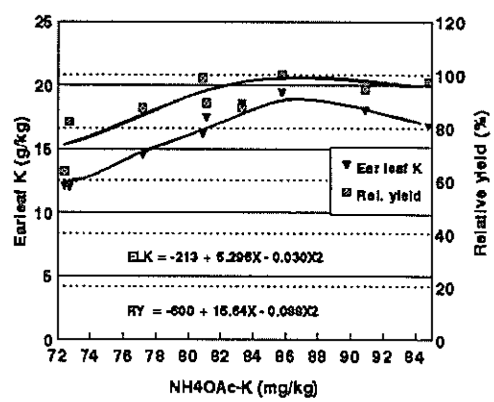

Fig. 2. Corn response to K, site 1.

compaction of soil at this site was observed during soil sampling (about 10 cm depth) the signs of which were evident during the growing season (prominent rip marks where the ripper had passed prior to seeding and water stagnation in some areas of the field during early spring). However, bulk density values were not determined.

Table 4. Changes in P fractions during the study

P rate	3/90			10/90			10/91		
	Al-P	Fe-P	Ca-P	Al-P	Fe-P	Ca-P	Al-P	Fe-P	Ca-P
$kg\ ha^{-1}$	--------------------------mg kg^{-1} --------------------------								
				Site 1					
0	21	79	19	14	181	33	21	157	31
32	24	57	18	21	184	37	31	178	40
64	29	59	24	32	193	41	43	203	45
$LSD_{.05}$	7	26	8	8	12	6	7	43	11
				Site 2					
0	9	82	20	5	90	27	8	81	25
37	8	90	17	7	101	25	18	111	31
74	10	83	16	12	105	25	42	129	39
111	9	90	21	15	114	33	43	152	52
$LSD_{.05}$	0.5	6	7	3	6	10	12	18	13

In 1991, climatic limitations severely affected crop performance at both sites (rainfall data presented in Semalulu, 1992). Heavy spring rains affected seed germination, in addition to possibly contributing to N loss. Also, the crop experienced water shortage at the later periods of growth, particularly during grain filling. Our results indicate a response to K at site 1 in the ear-leaf tissue, but not to P. Grain yields were lower than those in 1990, and not related to treatments. Similar trends were observed at site 2. Yields were lower than those for site 1. Compacted soil at site 2, coupled with unfavorable rainfall distribution as outlined above, might have further affected crop performance at site 2.

Phosphorus changes and transformations

There was a progressive increase in Bray I and Mehlich III extractable P due to P application, both at the end of a growing season and between years, proportional to the P rates applied. Table 4 shows that this was largely reflected in the aluminum phosphate fraction.

Figure 3 presents the relationship between the change in Bray I extractable P as a function of the total amount of P applied. Significant ($P<.01$) linear relationships were observed. For site 1,

$$Y = 0.498 + 0.057P;\ R^2 = 0.963 \qquad (1)$$

and for site 2,

$$Y = -0.468 + 0.061P;\ R^2 = 0.824 \qquad (2)$$

where Y is the change in Bray I extractable P (mg kg^{-1}), and P is the total amount of P (kg ha^{-1}) applied. From equation 1 and 2, the amount of P required to raise Bray I extractable P by 1 mg kg^{-1} was 17 kg ha^{-1} for site 1, and 16 kg ha^{-1} for site 2.

Previous work by Thom (1985) on an undisturbed Belknap silt loam soil in Webster County, western Kentucky, gave a value of 12 kg ha^{-1}. In studies on the P behavior of an undisturbed Sadler silt loam soil in Caldwell County, western Kentucky, Gallo (1989) reported high P immobilization by this soil. Results from this study suggest an even higher P-fixation capacity after disturbance.

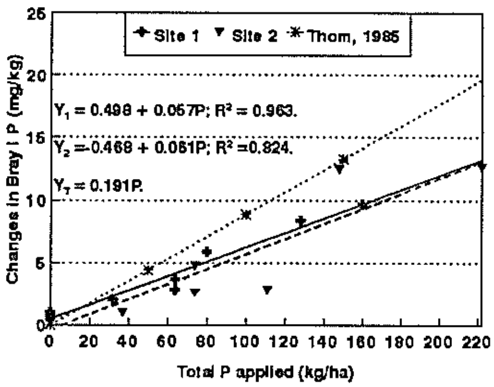

Fig. 3. Changes in Bray I P vs total P applied

Potassium changes and transformations

A progressive increase in NH_4OAc and Mehlich III extractable K was observed due to K fertilization. The change in NH_4OAc-K for site 1 was significantly related to total K applied ($P<.01$)

$$Y = 26.6 + 0.066K;\ R^2 = 0.738 \qquad (3)$$

where Y is the change in NH_4OAc extractable K, (mg kg^{-1}), and K is the total amount of K (kg ha^{-1}) applied.

From equation 3, 15 kg K ha^{-1} were required for to achieve a 1 mg kg^{-1} increment in NH_4OAc extractable K, which is higher than the value of 8.7 obtained by Thom (1985) for a similar soil prior to disturbance. However, a similar relationship for site 2 soil was not significant.

Conclusions

Soil compaction and moisture availability and distribution are major factors affecting corn growth on reclaimed soils. The optimum ear-leaf K concentration (18 g kg^{-1}) was obtained at higher NH_4OAc-K levels for a disturbed Belknap soil than for an undisturbed one (86 versus 71 mg kg^{-1}). Fertilization increased soil test P and K, and for P, this was most reflected in the aluminum phosphate fraction. Higher P and K rates were required to raise the soil test P and K levels of a disturbed Belknap soil by 1 mg kg^{-1} than for an undisturbed one (17 versus 12 kg P ha^{-1} and 15 versus 8.7 kg K ha^{-1}). Mixing of topsoil with subsoil during coal surface mining activities significantly reduces available P. The associated increase in P fixation of the resulting reconstructed soils probably accounts for the higher P fertilizer requirements as observed in the results of this study.

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