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Phosphorus Status of Horizons of Four Benchmark Loessial Soils of the Central Great Plains Region[1]

A. L. Black and R. S. Whitney[2]

ABSTRACT

Genetic horizons of the Colby, Weld, Rago, and Keith loessial soil series were investigated. Buried soils occurred in the Rago and Keith series. Each horizon was subjected to various chemical analyses and used in greenhouse fertilizer studies.

Marked differences in P content and availability to plants occurred among horizons and with profile depth. Yields and plant uptake of N and P from nonphosphated horizons were positively correlated with the initial $NaHCO_3$-soluble P in the soils when N was uniformly applied. By adding 8.8 or 35.2 ppm P per pot, yields were similar within a given horizon, but differed markedly among horizons of the same profile. With adequate N added, spring barley (*Hordeum vulgare* L. 'Moravian') yields from the Rago A-B subsoil horizon and the Rago Ap surface soil were similar, but the Weld B3ca subsoil horizon yielded 50% more than the Weld A1 surface soil. All other subsoil horizons were deficient in available P, and maximum yields occurred only when both N and P were added. Fertilized subsoils producing more dry matter yield than their respective surface soils were: Colby AC, Cca, and C; Weld B3ca, Cca, and C; and the Rago B21, A1b, B2bca, B3bca, and C. Fertilized subsoils producing yields similar to their surface soils were: Weld B22; Rago A-B; and the Keith A1b, B2b, B3bca, Cbca, and C. The remaining fertilized subsoils (Weld B21 and Keith B2 and B2ca) produced less yield than their respective surface soils.

Land modifying practices are becoming important for more efficient water control on irrigated and nonirrigated soils of the Great Plains. With the increase in the number of deep wells, there has been large-scale land leveling to improve water application. Terraces and level conservation benches are frequently used in nonirrigated areas to conserve precipitation. These land modifying practices, as well as erosion, expose subsoils that are generally much less fertile than the original surface soil.

Previous fertility investigations have been more concerned with the surface of eroded and noneroded areas and have paid little attention to the underlying soil horizons. Early investigations of subsoil fertility were mostly confined to the humid and subhumid regions where erosion has been more severe (7, 10).

That crop yields decrease proportionately with loss of surface soil is widely recognized. Many workers (1, 6, 8, 10, 13, 14) reported that deficiencies of N, P, and K were generally responsible for limiting crop growth on exposed subsoils. Smith and Polham (13) compared yields of five subsoils with three surface soils by adding different levels of P and K; N and lime were applied as needed. In this experiment surface soils were more productive than subsoils regardless of fertilizer treatment.

In recent studies, Carlson and Grunes (5) evaluated the chemical properties of subsoils and mixtures of subsoils and surface soils. They observed that barley grown on subsoil horizons in greenhouse tests yielded less than plants grown on surface horizons, regardless of fertilizer treatments. Using mixtures of A1p and C horizons, yields increased at each fertility level as the proportion of surface soil in each mixture increased. These results were attributed largely to the greater P availability of the surface horizon.

Murdock and Engelbert (11) concluded from tagged P placement studies that corn absorbed as much of its P from the subsoil as from the plow layer when moisture became limiting in the surface soil. Therefore, the importance of the amount of available nutrients in subsoil horizons should not be overlooked.

The major objective of this study was to determine what methods and measurements of plant growth, nutrient uptake, and soil test could be correlated with nutrient availability, principally P, of genetic horizons of four loessial soils.

MATERIALS AND METHODS

The Colby, Weld, Rago, and Keith soil series selected for study are benchmark loessial soils covering 12 to 20 million acres of the central Great Plains. Bulk samples of each horizon were collected from each series. Omitting two very thin transitional horizons (A–B) in the Weld and Keith series, 25 soil horizons were studied (Table 1). The Weld B21, Weld B22, Rago A1b, and Keith A1b were clay loams; all other horizons were loams.

Bulk soil samples were air dried and passed through a 2-mm mesh sieve. Half-gallon waxed cartons lined with polyethylene bags were filled with an equal volume of soil for each horizon. The weight of soil used in each pot was recorded.

Fertilizer materials were thoroughly mixed with each soil using a twin-shell blender. Three rates of P—0, 8.8, and 35.2 ppm P/pot (0, 17.6, and 70.4 lb of P/acre)—were applied using concentrated superphosphate as a source of P. NH_4NO_3 was applied at a uniform rate of 112.5 ppm N/pot (225 lb of N/acre). Treatments were randomized in two replications, and the position of the pots was rotated within replications at weekly intervals.

Spring barley (*Hordeum vulgare* L. 'Moravian') was used as an indicator crop, and plants were thinned after emergence to six plants per pot. Soils were watered to maintain moisture between 1/3 and 15 bars of suction. When the barley plants were in the early boot stage, 35.2 ppm Fe chelate (6% metallic Fe) was uniformly applied to each pot. Tops of plants were harvested at the full bloom stage, dried at 60C, weighed, and ground for chemical analyses.

Soils were analyzed for $CaCO_3$ equivalent by the H_2SO_4 titration method; for pH, by the glass electrode method using a 1:1 soil-to-water ratio; and for organic matter, by a modified Walkley-Black procedure (9). Soluble P was extracted with $NaHCO_3$ and determined (12). Total soil P and inorganic P, extracted with 2N H_2SO_4 before and after soil ignition of organic matter (9), were determined colorimetrically (3); organic P was obtained by difference. Total soil N was estimated by a modified

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[2] Soil Scientist, USDA, Sidney, Mont., formerly Akron, Colo.; Professor and Head, Department of Agronomy, Colorado State University, Fort Collins, Colo., respectively.

Table 1—Chemical analyses of related soils derived from loess

Soil series	Horizon	Depth	pH	$CaCO_3$ eq. (lime)	Organic matter	Total soil N	$NaHCO_3$-soluble P	Total soil P	Inorganic soil P	Organic soil P
		inches		%	%	%	ppm	ppm	ppm	ppm
Colby	A1	0–4	7.7	0.4	1.91	0.109	8.4	380	244	136
	AC	4–7	8.0	3.3	1.84	0.108	1.6	441	287	154
	Cca	7–14	8.2	6.4	1.21	0.067	2.0	500	377	123
	C	14–24	8.5	3.6	0.38	0.029	0.8	465	414	51
Weld	A1	0–4	7.4	0.4	1.90	0.100	6.8	588	435	153
	B21	5–10	7.3	0.6	1.75	0.096	2.8	361	178	183
	B22	10–15	7.6	0.6	1.61	0.095	4.0	490	322	168
	B3ca	15–19	8.2	5.6	1.22	0.073	13.6	709	578	131
	Cca	19–26	8.6	5.9	0.51	0.036	7.2	579	485	94
	C	26–34	8.5	2.8	0.14	0.013	1.2	441	406	35
Rago	Ap	0–4	7.1	0.3	2.05	0.110	24.4	485	327	158
	A–B	4–14	7.4	0.2	1.13	0.073	8.4	494	338	156
	B21	14–20	7.6	0.3	1.02	0.073	6.8	441	306	135
	A1b	20–24	7.9	2.1	1.22	0.080	7.2	474	333	141
	B2bca	24–32	8.1	2.7	1.19	0.076	6.4	550	421	129
	B3bca	32–41	8.2	4.3	0.60	0.042	4.8	730	598	132
	C	41–60	8.2	4.3	0.26	0.023	4.0	505	468	37
Keith	A1p	0–4	7.1	0.1	2.22	0.121	28.8	513	350	163
	B2	6–12	7.4	0.5	1.25	0.084	6.4	522	360	162
	B2ca	12–18	8.0	3.3	1.23	0.089	5.6	523	339	184
	A1b	18–23	8.1	2.4	1.54	0.098	6.4	577	401	176
	B2b	23–29	8.2	4.7	1.49	0.096	8.4	623	495	128
	B3bca	29–40	8.4	5.1	0.80	0.057	5.2	583	475	108
	Cbca	40–46	8.5	5.9	0.29	0.025	2.8	550	502	48
	C	46–60	8.4	5.1	0.25	0.023	2.8	553	506	47

Table 2—Plant uptake of N and P, and plant P content, as affected by soils (horizons) and P fertilization

Soil series	Horizon	Depth	$NaHCO_3$-soluble P	P added, ppm per pot								
				0	8.8	35.2	0	8.8	35.2	0	8.8	35.2
				P content			P uptake per pot			N uptake per pot		
		inches	mg/pot	%			mg			mg		
Colby	A1	0–4	19.8	0.14	0.21	0.35	21.3	34.2	61.1	380	367	406
	AC	4–7	3.2	0.07	0.10	0.31	1.4	17.9	65.2	73	294	434
	Cca	7–14	4.2	0.06	0.12	0.28	0.7	19.6	56.6	43	309	400
	C	14–24	2.0	0.07	0.10	0.23	0.9	21.1	61.9	60	312	322
Weld	A1	0–4	14.7	0.21	0.30	0.40	34.2	51.8	73.2	313	424	454
	B21	5–10	5.5	0.07	0.12	0.30	1.4	15.7	46.9	61	257	284
	B22	10–15	7.9	0.06	0.11	0.28	4.3	21.3	54.2	205	314	351
	B3ca	15–19	28.0	0.10	0.14	0.31	21.4	35.6	83.6	332	381	389
	Cca	19–26	16.2	0.04	0.10	0.27	5.3	25.5	76.9	249	389	424
	C	26–34	2.3	0.08	0.10	0.26	1.6	22.3	66.8	91	295	379
Rago	Ap	0–4	49.6	0.23	0.26	0.34	61.0	77.2	81.2	352	382	350
	A–B	4–14	17.1	0.11	0.15	0.28	26.8	41.1	68.1	342	353	325
	B21	14–20	13.9	0.07	0.10	0.22	5.4	25.9	62.2	186	338	373
	A1b	20–24	14.0	0.05	0.11	0.23	8.0	27.5	75.2	265	303	413
	B2bca	24–32	12.0	0.09	0.11	0.20	9.5	28.4	59.8	262	385	397
	B3bca	32–41	11.0	0.07	0.12	0.22	11.8	27.8	64.3	292	358	420
	C	41–60	10.0	0.07	0.10	0.19	6.0	25.3	56.6	266	382	441
Keith	A1p	0–4	60.5	0.17	0.22	0.38	43.1	54.6	101.2	406	409	402
	B2	6–12	12.7	0.06	0.11	0.38	6.3	22.9	83.9	259	344	376
	B2ca	12–18	11.7	0.06	0.13	0.30	1.6	20.6	62.7	132	327	376
	A1b	18–23	12.8	0.07	0.11	0.25	3.1	21.0	58.2	165	339	381
	B2b	23–29	17.4	0.09	0.12	0.19	7.6	24.4	45.3	222	362	385
	B3bca	29–40	11.1	0.07	0.10	0.21	1.9	20.0	53.7	144	339	389
	Cbca	40–46	6.3	0.08	0.10	0.20	4.5	22.1	53.8	225	413	427
	C	46–60	6.6	0.04	0.09	0.19	1.9	22.4	48.0	183	414	418

Gunning method (2). For plant samples, the N method was modified to include NO_3-N. Phosphorus in the plant tops was measured colorimetrically (3) following wet digestion, using the Bolin-Stamberg acid mix (4).

RESULTS AND DISCUSSION

Soil Properties

The results of soil analyses are shown in Table 1. In general, $CaCO_3$ equivalent and pH increased with horizon depth in the profile. Zones of high lime accumulation were accompanied by high pH values. Organic matter and total soil N decreased with profile depth except for buried soil horizons in the Rago and Keith series.

The $NaHCO_3$-soluble P varied among horizons (Table 1). Previously cultivated Rago and Keith surface soils contained 24.4 and 28.8 ppm P, respectively, whereas the Colby and Weld surface soils sampled from native sod contained 8.4 and 6.8 ppm P, respectively. All subsoils except the Weld B3ca contained < 8.4 ppm P. Therefore, nearly all subsoils could be classed in the range of available P where plant responses to added P were anticipated (14).

Total soil P varied only slightly with profile depth in the Colby, Rago, and Keith series and no significant relationship existed between total P and inorganic P, or total P and $NaHCO_3$-soluble P. In all four soil series, inorganic P was positively correlated with the $NaHCO_3$- soluble P ($r = 0.671$) and with the $CaCO_3$ equivalent ($r = 0.691$) at the 1% level of significance. Organic P was positively correlated with the organic matter content at the 5% level of significance ($r = 0.434$).

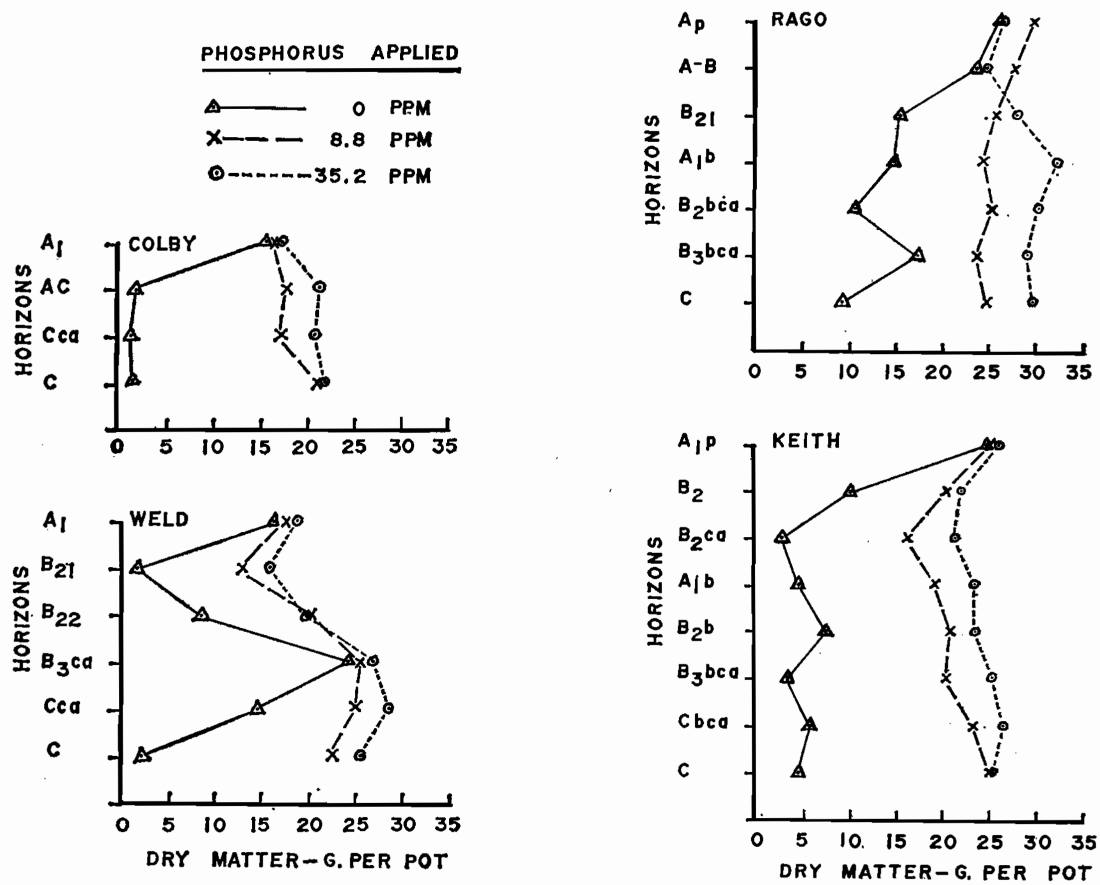

Fig. 1—Total dry matter production of barley (g per pot) grown on different horizons as affected by applied P, (N uniformly applied)

Growth Responses

Statistical analyses using the "F" test revealed a highly significant effect of P treatment on yield from various horizons when adequate N was applied. Yield increases resulting from P fertilization were well in excess of 100% on most subsoils. The average yield increase on all soils due to the first 8.8 ppm P added was 105%. The addition of the last 26.4 ppm P (35.2 ppm P rate) increased the average yield of all soils an additional 23%. Thus, 82% of the average yield increase obtained from added P came from the first 8.8 ppm P added.

Yield responses to fertilizer P, with added N, were obtained on all subsoil horizons (Fig. 1). However, the yield increases produced on the Weld B3ca and Rago A–B subsoils were not as great as those obtained on other subsoils. With P fertilization, the yield obtained from a subsoil was never much less than the yield produced on the respective surface soil of each series. Sixteen of 21 subsoil horizons produced yields equal to, or greater than, their respective surface soil when both N and P were added. In a similar greenhouse study made by Carlson and Grunes (5), surface soils yielded more than subsoils regardless of treatment.

Plants grown on surface horizons, as well as on the Weld B3ca and Rago A–B subsoils, failed to respond markedly to P fertilizer in the presence of a high rate of applied N (Fig. 1). These horizons contained sufficient available P for high yields. In a preliminary pot test, barley grown on these same horizons responded significantly to applications of N in the absence of added P, whereas no plant responses to N were obtained on the remaining subsoil horizons because of inadequate available soil P. The yields obtained from nonphosphated subsoils in this study, in the presence of added N, were positively correlated ($r = 0.774$) with the initial level of $NaHCO_3$-soluble P in the soil at the 1% level. This method of extracting soluble P estimated the availability of soil P over a wide range of subsoils and surface soils.

Yields from the Weld Cca and C horizons were similar to the Weld B3ca horizon at both applied levels of P, but all three horizons produced yields 50% greater than the Weld surface soil (Fig. 1, Weld). The Colby subsoil horizons also produced considerably higher yields than the Colby surface horizon when both N and P were added (Fig. 1, Colby). Subsoils of the Keith and Rago profile produced yields similar to their respective surface soil when fertilized similarly (Fig. 1, Keith and Rago). The reason for such large yield differences among horizons of the Colby and Weld series when fertilized similarly is not apparent. It is unlikely that N or P was responsible for such large yield differences among horizons, because plant uptake of N or P was similar when both N and P were applied at high rates (Table 2).

Plant N Uptake

Nitrogen uptake (mg per pot) by barley plants grown on nonphosphated horizons was positively correlated (r = 0.827) at the 1% significance level with the $NaHCO_3$-soluble P in soil. The correlation was significant at the 5% level (r = 0.470) when 8.8 ppm P was added, and nonsignificant at the high rate of applied P. Plant uptake of N tended to be similar for all horizons when the supply of N and P was adequate (Table 2).

Total plant uptake of soil and fertilizer N approached the amount of N applied (a 1:1 ratio) only when adequate available P was present or applied. With no available P added, the average ratio for plants growing on all surface horizons and the Weld B3ca and Rago A–B subsoil horizons was 0.92:1. The remaining subsoils were deficient in native available P, and the average ratio was only 0.35:1. With 8.8 or 35.2 ppm of available P added, the average ratio of all horizons was 0.92:1 and 1.01:1, respectively. Therefore, plant uptake of available N was limited principally by inadequate levels of available P.

Plant P Uptake

Total uptake of P by barley (mg per pot) at all rates of P fertilizer application was positively correlated with the inherent $NaHCO_3$-soluble P in the soil (mg per pot) at the 1% level of significance. As the rate of P fertilizer applied increased (0, 8.8, and 35.2 ppm P/pot), the corresponding correlation coefficients were 0.854, 0.826, and 0.704, respectively.

Plant uptake of P increased as the rate of added P fertilizer increased (Table 2). However, total P uptake was related to $NaHCO_3$-soluble P at all three P treatment levels. With no P added, the relation of total P uptake to $NaHCO_3$-soluble P was 0.785:1. This relation suggests that the pool of soil P used by the plant approximated that measured by the $NaHCO_3$ soil test for P. Various other soil tests for P (total P, inorganic or organic P) was unrelated to available soil P.

Plant P Content

The concentration of P in barley tops was positively correlated with $NaHCO_3$-soluble P at all three rates of added P. With no added P, the correlation was significant at the 1% level (r = 0.694). Adding P fertilizer, 8.8 and 35.2 ppm P/pot, reduced the correlation to the 5% level of significance with correlation coefficients of 0.655 and 0.520, respectively.

The linear relationship of yield to plant P content was poor mainly because of the variable P concentrations of plant tops grown on soils which approached, or exceeded, an adequate level of available P (Table 2). The minimum P concentration in plant tops required for high yields appeared to be about 0.09%. Plant P concentrations of $< 0.09\%$ were definite indications of an inadequate supply of available soil P.

With adequate N plus P fertilization, the yield obtained from a subsoil was never much less than the yield produced on the respective surface soil of each series. Sixteen of 21 subsoil horizons produced yields equal to, or greater than, their respective surface soil. These results differ from those obtained by previous workers on other soils (5, 13). The relatively high productivity of the subsoil horizons investigated in this study may be a unique characteristic of loessial soils which would imply that the consequences of natural or mechanical removal of the surface horizon may not be as severe as for other soil groups. Therefore, soil management guidelines might be altered accordingly for loessial soils of the central Great Plains.

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