PHOSPHORUS DYNAMICS AND WHEAT RESPONSE TO APPLIED P IN A SPATIALLY VARIABLE ENVIRONMENT[1]

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ABSTRACT

Considerable spatial and temporal variability exists in soil chemical and physical properties across farm landscapes in eastern Washington State. The purpose of this research is to investigate changes in P mineralogy across the Palouse landscape and ultimately to determine the influence of mineralogy on plant-available P and fertilizer P responses at different landscape positions. Soil samples were collected from landscape positions with varying soil pH and soil test P concentrations. Mineral fractionation analysis revealed that, even though soil pH averaged 5.3 among samples, less than 2% of total soil P was associated with Fe- and Al-P minerals while 65% was associated with Ca-P minerals. A working hypothesis is that P minerals are currently in various states of transition from Ca to Fe/Al forms. Sorption isotherms indicate differences in P retention among soils, with expectedly higher P retention in a sample with pH 5.2 compared to a soil with pH 7.0. Differential responses to P fertilizer occurred across landscape positions and were not accurately predicted by soil test P levels in either bicarbonate or acetate extracts.

INTRODUCTION

Spatial variability in soil chemical properties has been documented in the Palouse region of eastern Washington. In 2001, pH (1:1 soil:water) values ranging from < 5 to > 6.5 were documented in the surface 0 to 4-inches of soil from 185 samples collected in a non-aligned grid pattern from an 80-acre field near Pullman, Washington. Further analysis of the same samples revealed significant spatial variability in acetate-extractable P, even though the site had historically been managed with uniform P fertilizer applications (Figure 1).

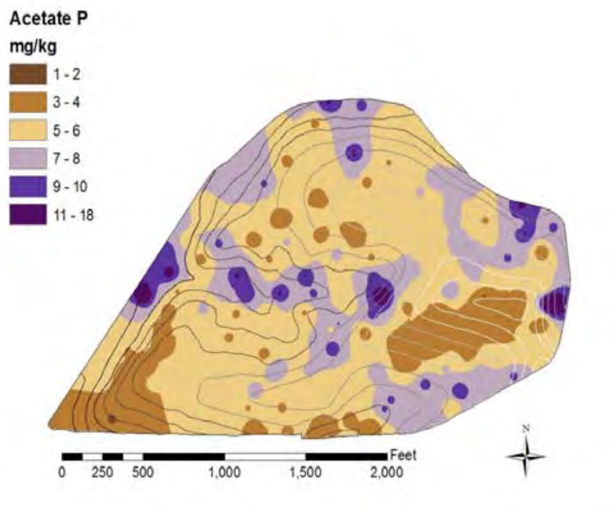

Figure 1. Spatial variability in acetate-extractable P at the 0 to 4-inch depth measured in 185 samples collected in 2001 from the Cunningham Agronomy farm near Pullman, WA.

In alkaline soil, inorganic P is associated mainly with Ca-based minerals. In acidic soil, inorganic P is associated mainly with Fe/Al-based minerals. In the past 25+ years soil pH has

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declined throughout eastern Washington and northern Idaho due to the use of ammonium-based fertilizers. It is likely that this recent pH decline has or will result in a shift in inorganic P forms from calcium to Fe/Al-based minerals. During the transition from neutral/alkaline to acidic soil pH, soluble and plant available forms of P may temporarily increase as calcium-based minerals dissolve and Fe/Al-based minerals form. Evolving soil pH conditions may also influence the appropriateness of soil test P extracts. Currently, both sodium bicarbonate and sodium acetate are used as extracts for soil test P in eastern Washington, at times with conflicting results in terms of resulting P recommendations.

Fractionating the forms of P in soils from the spatially variable Palouse region of eastern Washington and Northern Idaho could test the theory that mineral P forms are evolving due to recent soil acidification. Relating mineral forms to soluble and soil test P through equilibrium modeling could also test the hypothesis that during recent soil acidification transition-phase minerals are formed that support a higher level of plant-available P. This has practical significance in that these transition phases will eventually be replaced by more stable Fe/Al-P forms and higher amounts of fertilizer P will then be needed to sustain yields. This may already be the case in certain parts of the landscape where soils are moderately acidic. If so, this could have significant implications for P management.

The purpose of this research is to investigate changes in P mineralogy across the Palouse landscape and ultimately to determine influences of mineralogy on soil test P and responses to P fertilizer at different landscape positions. These questions likely have broader applications to east-central and eastern Washington since soil pHs have been declining throughout the region.

METHODS

Twenty-five soil samples were collected at the 0 to 4-inch depth in September 2005 from the Cunningham Agronomy Farm near Pullman, WA. Samples were selected to represent a range of soil test P, soil pH and landscape position scenarios based on the original 185 georeferenced samples used to generate Figure 1. The 2005 sample pHs (1:1 soil:water) ranged from 4.91 to 7.02, acetate-extractable P ranged from 2.5 to 8.1 mg/kg soil, and bicarbonate-extractable P ranged from 13 to 38 mg/kg soil (Table 1).

Total, organic, and mineral P were determined using a dry combustion-extract procedure (Kuo, 1996). Inorganic P was partitioned into soluble, Al, Fe and Ca forms using a sequential extracts (Kuo, 1996). Initially, P partitioning was performed on a subset of 10 of the original 25 samples. All analyses were performed in duplicate with averages reported in Table 1. Future analyses will involve determining equilibrium activities of dilute salt-soluble $H_2PO_4^-$, SO_4^{2-}, Ca, Mg, Fe and Al, as well as pH and EC (Fixen et al., 1983; Lindsay et al., 1989) to indicate which P minerals are controlling solubility in the samples. Phosphorus sorption isotherms were also developed for the soils collected in 2005 using procedures adapted from Fox and Kamprath (1970). At this time isotherms have been completed for two of the samples (4 and 18) representing different soil conditions in the original sample set described in Table 1.

Three sites were selected to represent a range of soil conditions across a single Palouse toposequence: north aspect (pH = 5.0; acetate P = 4.4 mg/kg; bicarbonate P = 23 mg/kg); hill top (pH = 4.9; acetate P = 3.4 mg/kg; bicarbonate P = 17 mg/kg); south aspect (pH = 5.1; acetate P = 2.7 mg/kg; bicarbonate P = 15 mg/kg). A P rate (0, 10, 20 and 40 lb P_2O_5/acre) study with four replications was established at each landscape position with a spring wheat crop in 2006. Fluid P fertilizer was banded together with N 2 inches beneath the seed row at all locations with a no-till drill. Grain yield was measured at maturity.

RESULTS AND DISCUSSION

Soil pH and P fractions varied widely in the 25 samples collected in 2005 (Table 1). On average, inorganic P was 72% of total P. Acetate P was related to total P ($r = 0.44$; $p < 0.05$) and inorganic P ($r = 0.49$; $p < 0.05$), but not organic P ($r = 0.22$; ns). Bicarbonate P in the 2005 samples generally showed better relationships with total P ($r = 0.76$; $p < 0.01$), inorganic P ($r = 0.77$; $p < 0.01$), and organic P ($r = 0.60$; $p < 0.01$). Acetate P was related to bicarbonate P (Figure 2) with two outliers: sample #6 had the lowest acetate P and one of the lowest bicarbonate P concentrations while sample #1 had the highest acetate P and one of the lowest bicarbonate P concentrations.

Results from the mineral fractionation analysis indicate that Al- and Fe-P comprise less than 2% of the inorganic P fraction in these soils (Table 1). Calcium-P ranged from 50 to 92% of total P and occluded Fe-P ranged from 19 to 42%. Results suggest that Ca-P minerals still dominate these samples. This appears to be the case both for soils in this subset with relatively high pH (e.g., #18, pH = 7.02; Al+Fe-P < 1% of total P and Ca-P = 83% of total P) as well as soils with relatively low pH (e.g., #5, pH = 5.03; Al+Fe-P = 2.2% of total P and Ca-P = 59% of total P). Calcium-P minerals are not predicted to be as stable as Al and Fe minerals in low pH soils. Thermodynamics predict that these minerals will eventually dissolve and reform Al- and Fe-P minerals. Apparently the kinetics of these reactions are sufficiently slow that this has not occurred yet. The implications of significant Ca-P minerals present in a recently acidified environment are unknown at this time.

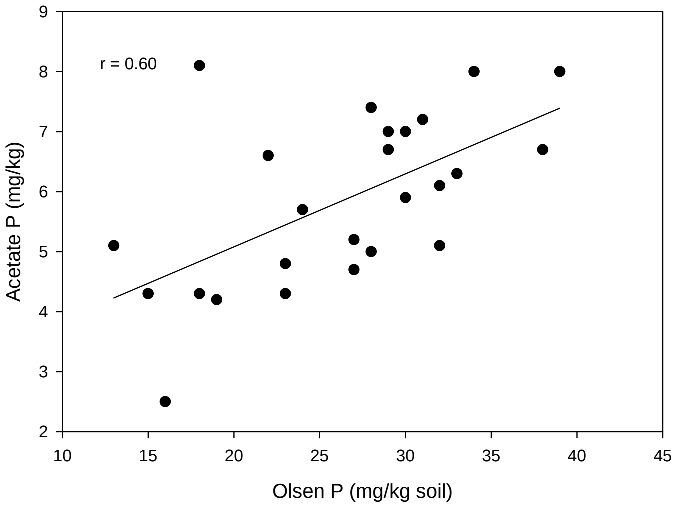

Figure 2. The relationship between Olsen (bicarbonate-extractable) and Morgan (acetate-extractable) P for the subset of 25 samples described in Table 1.

Isotherm data suggest soil 4 sorbs more P than soil 18 (Figure 3). In general, soil 4 was more acidic (pH = 5.17) than soil 18 (pH = 7.02). Both soils had similar acetate-extractable P concentrations, but soil 4 had approximately twice as much bicarbonate-extractable P than soil 18. Results are preliminary and firm conclusions cannot be drawn at this time. However, the results suggest that recently acidified samples (e.g., #4) have a high capacity for P sorption and may not support higher levels of soluble P (Table 1) in the transition between Ca-P and Fe/Al-P minerals. Results also suggest the bicarbonate soil test may not adequately reflect P bioavailability from soil 4, which had a 2-fold greater concentration than soil 18 (Table 1).

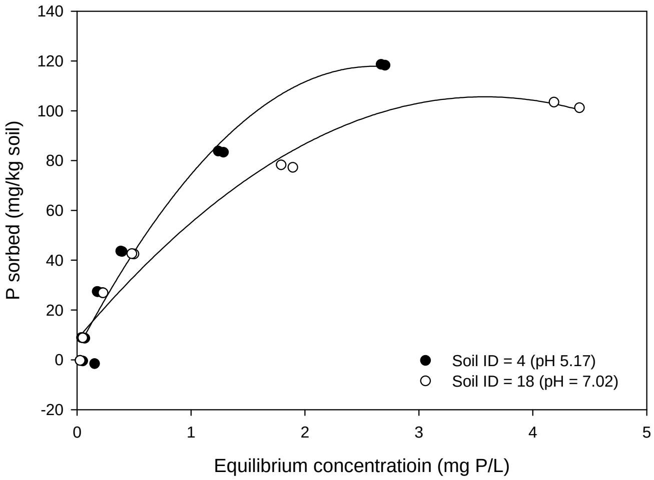

Figure 3. Phosphorus sorption isotherms for soil #4 and #18 (from Table 1).

Grain yield and the response to P fertilizer rate varied with landscape position (Figure 4). Yield averaged 63 bu/ac at the south slope position and 70 bu/acre at the north slope position. At the ridge top position P applied at the rate of 20 lb P_2O_5/acre increased spring wheat grain yield by 19 bu/acre. Soil test P (bicarbonate and acetate) at the ridge top position was intermediate between the north and south slope positions (see methods), and would not be considered low based on the bicarbonate method, but would be low with the acetate method, at each location.

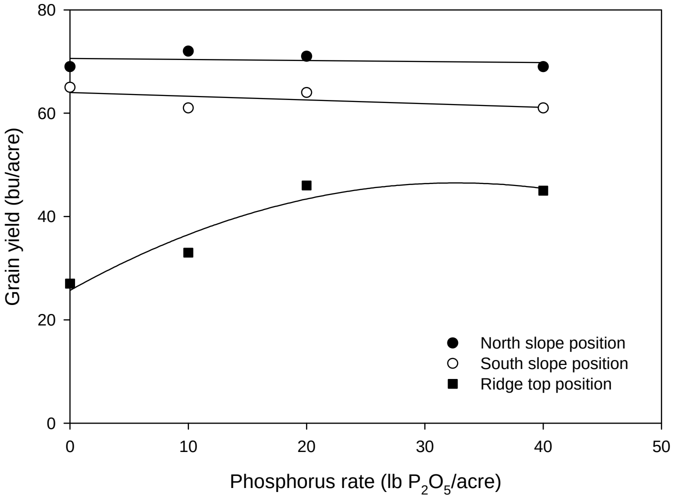

Figure 4. The effect of P rate and landscape position on spring wheat grain yield in 2006.

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Table 1. Soil pH and P fractionation in a subset of samples collected at the 0 to 4-inch depth in 2005 from a spatially variable field in eastern Washington. The samples were selected from georeferenced points originally sampled in 2001 (Figure 1).

Sample ID	pH	Acetate P	Bicarb. P	Total P	Inorganic P	Organic P	Soluble P	Al-P	Fe-P	Ca-P	Occluded Fe-P
		---------------------- mg/kg soil ----------------------									
1	5.30	8.1	18	466	339	127	0.5	0.0	5.5	379	194
2	5.77	8.0	34	617	486	131	--[1]	--	--	--	--
3	5.80	7.4	28	689	476	213	--	--	--	--	--
4	5.17	4.7	27	777	541	235	1.0	0.0	12.0	423	183
5	5.03	6.7	38	785	586	199	3.3	3.0	15.0	461	183
6	5.36	2.5	16	397	265	132	0.8	0.0	7.5	239	137
7	5.23	6.7	29	687	512	175	--	--	--	--	--
8	5.34	4.3	15	524	366	158	--	--	--	--	--
9	5.18	4.3	18	407	270	137	--	--	--	--	--
10	5.27	7.2	31	741	516	225	--	--	--	--	--
11	5.14	4.8	23	473	330	143	--	--	--	--	--
12	4.91	4.3	23	431	263	168	--	--	--	--	--
13	5.16	6.3	33	794	579	215	1.0	2.5	18.0	450	154
14	5.54	7.0	29	631	469	162	0.5	0.0	10.0	411	120
15	5.09	6.1	32	679	509	170	--	--	--	--	--
16	5.70	8.0	39	816	596	220	0.8	0.0	20.0	411	200
17	5.74	6.6	22	596	421	175	--	--	--	--	--
18	7.02	5.1	13	567	436	131	0.5	0.0	4.5	469	137
19	5.08	5.7	24	734	524	210	0.5	1.0	14.5	395	183
20	5.08	4.2	19	583	423	160	0.5	0.0	10.0	536	137
21	5.02	5.9	30	790	567	223	--	--	--	--	--
22	5.05	5.2	27	576	436	139	--	--	--	--	--
23	5.38	7.0	30	792	558	234	--	--	--	--	--
24	5.31	5.1	32	825	576	249	--	--	--	--	--
25	5.17	5.0	28	818	593	225	--	--	--	--	--

[1] Results pending.

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