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Inorganic and Organic Soil Phosphorus Fractions after Long-Term Animal Manure and Fertilizer Applications

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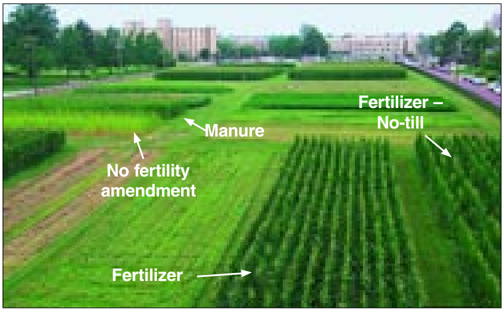
Maintenance of adequate amounts of soil P through application of inorganic and/or organic P sources is critical for long-term agricultural productivity. In the soil, applied P is partitioned into readily-available (labile) and less readily-available (stable) inorganic and organic forms with different desorption, dissolution, and mineralization rates that may contribute to plant P nutrition. In general, long-term studies have observed a decline in soil organic P fractions with continuous cultivation and no fertility inputs. In farming systems that rely on organic fertility amendments, such as animal manure, organic P fractions may be a more important source of plant-available P than for farming systems relying on P fertilizer.

Analysis of soil test phosphorus (P) fractions and Bray P-1 after 111 years of fertilizer or manure application on Sanborn Field indicates that cropping systems and fertility practices affect the proportion of soil inorganic and organic P.

Some have questioned whether traditional soil test procedures for plant-available P (e.g. Bray P-1) adequately assess the contribution of more stable inorganic and organic soil P fractions to nutrition of crops after long-term cultivation and repeated fertilizer P applications. We used a sequential P extraction method to determine potential differences in the form and quantity of different inorganic (P_i) and organic (P_o) soil P fractions (modified Hedley procedure) in long-term (111 years) cultivated plots and to assess the use of the Bray P-1 extractant for determining changes in soil P availability in fertility programs utilizing fertilizer or animal manure.

Plots on Sanborn Field at the University of Missouri campus have been unamended or annually amended with commercial fertilizers based on soil test recommendations for Missouri or with 6 tons/A (wet weight basis) horse or dairy manure since 1888. Based on analyses initiated in 1990, dairy manure applied to Sanborn Field has had an average moisture content of 79 ± 7 percent and a nutrient content of 1.9 ± 0.4 percent total nitrogen (N), 0.4 ± 0.5 percent total P, and 0.9 ± 0.7 percent total potassium (K). Horse manure applied prior to the 1950s contained a relatively larger proportion of bedding material compared to dairy manure. All manure was broadcast-applied in the fall and commercial fertilizers were broadcast-applied in the spring. Fertilizer P was applied as crude grade acid phosphate or normal superphosphate (16 to 20 percent P_2O_5) up to the 1940s and triple superphosphate (46 percent P_2O_5) was applied



Sanborn Field is shown during the 2000 growing season. Note the difference in corn growth response among the historical continuous corn plots with no added fertility amendment and added manure or fertilizer.

afterward. Rock phosphate (30 to 37 percent P_2O_5) was also applied sporadically to fertilized plots. All plots considered in this study were tilled using a moldboard plow and then were disked twice before planting. We collected soil samples from Sanborn Field to a depth of 8 in. during the fall of 1999 from long-term cropping systems plots including continuous corn, continuous wheat, a corn-wheat-red clover rotation, and continuous timothy. Additional soil from the same plots was analyzed by subsampling stored samples taken to a depth of 8 in. in 1915, 1938, and 1962.

Yield goals for grain and forage crops on Sanborn Field increased from the cropping period of 1888-1949 to the cropping period of 1990-1999, corresponding to changes in crop genetics, fertilizer sources, and other developments in agricultural technology (**Table 1**). Higher rates of N, P, and K fertilizer were applied on fertilizer-treated plots based on University of Missouri soil test recommendations to meet the higher yield goals. However, average crop yields observed on fertilizer- and manure-treated plots during the three selected periods were below yield goals, especially on the grain crops (**Table 1**), suggesting a possible consistent over-application of nutrients due to an over-estimation of the yield potential. Over-application of animal manure, and sometimes commercial P fertilizer, can lead to soil P accumulation in agricultural soils.

Corn grain yields were consistently higher in fertilizer-amended plots compared to the manure-amended and control treatments over the three periods of Sanborn's history (**Table 1**). The relatively lower corn yields with manure can be explained by the low manure application rate (6 wet tons/A), the effects of varying amounts of bedding in the manure on N released to the crop, especially in the early periods of Sanborn's history when horse manure was used, and the fact that most of the manure additions were calculated on a wet weight basis (thereby reducing the actual amount of nutrient-containing manure applied). Wheat yields increased with either added manure or fertilizer compared to the control

TABLE 1. Yield goals, fertilizer nutrient applications, and average grain and forage yields in selected periods for Sanborn Field.

Period	Crop	Yield goal, bu or tons/A	Fertilizer nutrients applied N	P_2O_5	K_2O	Grain or forage yields[1] None	Fertilizer	Manure
			.... lb/A			.... bu or tons/A		
1888 - 1949[2]	Corn (grain)	79 bu/A	126	44	82	21 bu/A	42.9 bu/A	35.7 bu/A
	Wheat (grain)	40 bu/A	82	27	66	20 bu/A	20 bu/A	20 bu/A
	Clover (forage)	3.0 tons/A	128	34	130	0.7 tons/A	3.1 tons/A	1.4 tons/A
	Timothy (forage)	3.0 tons/A	—	—	—	1.1 tons/A	—	2.4 tons/A
1950 - 1989[3]	Corn (grain)	179 bu/A	167	67	144	21 bu/A	100 bu/A	64.3 bu/A
	Wheat (grain)	40 bu/A	76	23	67	13 bu/A	40 bu/A	36.6 bu/A
	Clover (forage)	NA	NA	NA	NA	1.8 tons/A	3.6 tons/A	3.2 tons/A
	Timothy (forage)	NA	—	—	—	1.0 tons/A	—	2.9 tons/A
1990 - 1999[4]	Corn (grain)	179 bu/A	208	0	0	25 bu/A	118 bu/A	64.3 bu/A
	Wheat (grain)	70 bu/A	82	32	25	17 bu/A	33 bu/A	33.3 bu/A
	Clover (forage)	4.2 tons/A	0	46	168	2.0 tons/A	1.4 tons/A	4.3 tons/A
	Timothy (forage)	4.0 tons/A	—	—	—	1.0 tons/A	—	2.7 tons/A

[1]Average annual grain or forage yields over selected period.
[2]Crop residues removed after harvest. Horse manure with bedding applied for manure treatment. Fertilizer was not applied to the timothy cropping system.
[3]Crop residues returned after harvest. Dairy manure applied for manure treatment. Information not available (NA) regarding yield goals for clover and timothy during this period. Fertilizer was not applied to the timothy cropping system. For clover, P and K fertilizer were added based on soil test recommendations and information on specific rates was not recorded.
[4]Crop residues returned after harvest. Dairy manure applied for manure treatment. N, P, and K fertilizers added based on soil test recommendations. Numbers presented are averages over years of actual fertilizer applied. Fertilizer was not applied to the timothy cropping system.

during the two periods from 1950 to 1999, but not during the period from 1888 to 1949. Clover yields were higher with added fertilizer or manure during 1888 to 1989, but were not responsive to fertilizer from 1990 to 1999. Timothy yields were consistently higher with added manure compared to the control.

The accumulation of Bray P-1 in cropping systems under different soil fertility treatments over time on Sanborn Field is shown in **Figure 1**. Under Missouri soil test recommendations, soil Bray P-1 values greater than 20 to 22.5 parts per million (ppm) are above the level required for optimal plant growth and yield response. By 1999, soil Bray P-1 levels were significantly higher in the fertilized and manure treatments under all cropping systems compared to the unfertilized check treatment (**Figure 1**). The unfertilized check treatment also showed a general decrease in Bray P-1 from 1915 to 1999, probably due to crop removal (data not shown).

Other research at Sanborn Field observed an initial marked decline in Bray P-1 in the manured plots, followed by a continuous increase. This trend in soil test P was attributed to the early use of horse manure with a high proportion of bedding. An additional effect on extractable and organic soil P occurred after 1950 when residue management was changed and straw and stalks were incorporated into the soil after cropping.

Addition of P as fertilizers or manure significantly increased readily-available P_i among all cropping systems at Sanborn Field compared to the unfertilized checks and the native prairie site (**Table 2**). With the exception of the corn-wheat-clover rotation, long-term application of P fertilizer and manure also significantly increased moderately-available P_i. Researchers in Canada have observed significant increases in P_i fractions, with 10 years of P fertilizer applications for continuous corn production in southern Ontario. In contrast, we did not observe significant increases in available-P_i, with long-term application of fertilizer, but did find significant increases in available-P_i with applications of manure in the continuous corn and wheat cropping systems (**Table 2**). Long-term application of commercial P fertilizers did not significantly increase P_o fractions or residual P (Total P - P_i - P_o), compared to the plots receiving no amendments, or to the native prairie site. The lack of increased P_o fractions in commercial P fertilized plots on Sanborn Field may have been associated with the continuous use of conventional tillage in plot preparation and the practice of removing all crop residues before 1950. Tillage may stimulate the conversion of P_o to P_i.

Long-term application of animal manure generally resulted in significant increases in most P_i and P_o fractions and total P compared to the unfertilized treatment (**Table 2**). Generally, the moderately-available P_i extract appeared to be more responsive than the readily-available P_i extract to manure applications, compared to added P fertilizer. The native prairie site had a larger proportion of total P in organic forms compared to the cultivated plots, especially in the moderately-available P_o extract (**Table 2**). Long-term cultivation of the native prairie originally present at Sanborn Field did not result in a significant decrease in either residual or total P. Total P levels on Sanborn Field appeared to be more affected by fertility treatment and not by cropping system.

Correlations of estimated plant P uptake with extracted P fractions, by fertility treatment for the four sampling years considered in this study, did not show strong relationships with sequential P fractions, Bray P-1, or total P. These results indicate that plant response on Sanborn Field is influenced by several interacting soil, plant, and climatic factors in addition to soil P availability.

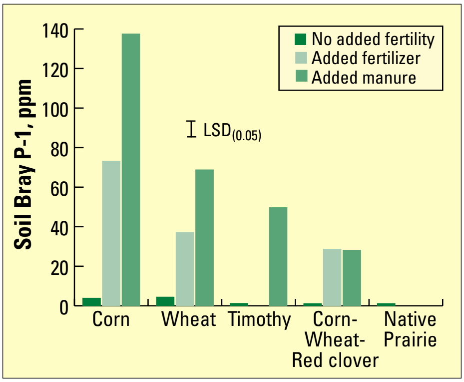


Figure 1. Soil test P (Bray P-1) of soil fertility plots on Sanborn Field and in native prairie soil in the fall of 1999.

The results of this study confirm that long-term cropping systems and fertility practices significantly alter the amounts and proportion of labile and stable soil P pools compared to the initial native prairie soil. A major factor affecting the accumulation of soil P in Sanborn Field has been the unrealistically high yield goals, leading to over-fertilization. Changes in management which have occurred over the 111 year cropping history of Sanborn Field have also had a significant impact on soil P, including changes in crop residue management and applied animal manure composition. This study also shows that long-term manure applications have significantly different effects on soil inorganic and organic P pools than applications of commercial P fertilizers. Both labile and more stable P pools are increased by long-term manure applications. These results support previous studies which have suggested that soil P availability dynamics, in cropping systems that receive predominantly organic P amendments, may differ from conventional cropping systems relying on commercial P fertilizers. **No direct evidence could be found to support the hypothesis that any individual soil P fraction, such as moderately-available P_i or P_o, has a better relationship than conventional soil test P extractants, such as the Bray P-1 extractant, with plant P uptake under contrasting fertility practices over 111 years of cultivation.** BC

TABLE 2. Selected inorganic and organic sequential P fractions[1] from Sanborn Field during the 1999 cropping season.

Crop	Fertility treatment	Inorganic P: Readily-available P_i	Inorganic P: Available P_i	Inorganic P: Moderately-available P_i	Organic P: Available P_o	Organic P: Moderately-available P_o	Total P
		ppm P					
Corn	None	3.0	18.4	19.4	22.5	30.8	225
	Fertilizer	54.1	54.8	75.8	36.6	103.9	487
	Manure	55.5	181.2	148.6	23.0	148.6	621
Wheat	None	3.8	3.3	29.4	53.5	50.6	274
	Fertilizer	35.3	34.4	80.2	52.3	73.3	465
	Manure	47.7	82.6	198.3	76.0	135.0	709
Corn-wheat-red clover	None	5.0	6.4	15.4	30.3	69.0	203
	Fertilizer	27.1	39.3	44.6	36.3	67.7	389
	Manure	21.3	40.7	44.5	59.7	82.2	516
Timothy	None	4.3	14.8	21.0	41.8	62.5	249
	Manure	41.7	51.4	114.9	69.3	99.1	617
Native prairie	None	4.0	6.5	21.8	59.6	176.5	323
	$LSD_{(0.05)}$	8.2	50.3	40.7	42.1	82.9	226

Note: Readily-available P_i = resin; available P_i = $NaHCO_3$; moderately-available P_i = NaOH; available P_o = $NaHCO_3$; moderately-available P_o = NaOH.

[1]Hedley, M.J., J.W.B. Stewart, and B.S. Chauhan. 1982. Changes in the inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubation. Soil Sci. Soc. Am. J. 46:970-976.

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For more about Sanborn Field plots, go to the web-site at http://aes.missouri.edu/sanborn/index.stm

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