**Soil Phosphorus Fractions After Long-Term Fertilizer Placement In Different Kansas Soils**

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## ABSTRACT

Phosphorus fertilizer placement can affect the long-term dynamics and forms of P, and the overall soil P pools. These changes can vary by soil type, and affect P uptake and use efficiency by crops. The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soil under P fertilizer placements (broadcast versus deep band) after 10 years of crop rotation. Three field studies were conducted for 10 years from 2006 to 2015 in three different soils at Scandia, Ottawa and Manhattan. Three treatments were evaluated, including a control with no P fertilizer application and two fertilizer treatments (80 lbs. $P_2O_5$ acre$^{-1}$): (1) surface broadcast and (2) deep band at approximately 15 cm depth. All treatments received strip-tillage. After 10 years, soil samples were collected from the row and between the row at two sampling depths (0-3 and 3-6 inches) and soil P pools (inorganic and organic P labile) via sequential P fractionation were measured. Significant changes in soil labile P pools for treatments compared to control were observed due to the long-term effect of P fertilizer placement. The broadcast P fertilizer placement increased the total labile ($Pt_{LP}$) and inorganic labile P ($Pi_{LP}$) in the soil surface (0-3 in) and deep band in the subsoil (3-6 in) at all sites studied. However, highest amount of organic labile P ($Po_{LP}$) was observed for the control broadcast treatments in the subsoil (3-6 in) just at Scandia site. Also, the $Pt_{LP}$ in the soil profile (0-6 in) was affected by maximum P adsorption capacity (MPAC) and P fertilizer placement and was observed the broadcast treatment showed higher amount of $Pt_{LP}$ than deep band and control treatments at Scandia site with low MPAC. However, at Ottawa location with medium MPAD the higher amount of $Pt_{LP}$ was observed for deep band than broadcast and control treatments. In addition, at Manhattan site with the higher MPAC of this study the broadcast and deep band treatments showed the same amount of $Pt_{LP}$ in the soil profile and higher than the control treatment.

## INTRODUCTION

Fixation of plant nutrients by soils is a major concern for economical use efficiency of fertilizer. Phosphorus (P) from applied fertilizer can become fixed in some soils, due to conversions into compounds of more limited bioavailability for plant uptake (Stutter et al., 2015), P it is the second macronutrient that most often limits agricultural production (Coelho et al., 2019), and a higher dose is required for optimum crop yield. Phosphorus in the soil exists in inorganic (Pi) as well as organic (Po) forms of comparable solubility, labile, moderately labile and non-labile (Weihrauch and Opp, 2018) and the soil fixation of all these forms depends upon many factors, *viz*., the organic matter content, pH of the soil, soil parent material (type of clay and sesquioxides), soil maximum P adsorption capacity, fertilizer placement etc. Thus, efficient P management in crop production is mandatory to minimize depletion of soil P reserves, environmental issues due to the waste from the higher rates, and production costs. Indeed, fertilizer P placement can affect crop P utilization in the short-term during the growing season. However, the long-term interactions of placement and plant root uptake in different soils can also affect the forms of P and the overall soil P pools, especially the residual labile P concentration at various soil depths and soil-plant interactions. The Hedley's fractionation (1982) is one of the most common methods to identify the redistribution of P applied to the soil its different forms. The objective of this study was to evaluate the changes in the labile P fractions in three Kansas soil under different P fertilizer placements (broadcast versus deep band) after 10 years of crop rotation.

## MATERIALS AND METHODS

Field experiments were conducted at the Kansas Research and Extension Centers located in Scandia, Ottawa and, Manhattan. Initial soil samples were collected in April 2006 before initiating the study by collecting a representative sample from the 0-3 and 3-6 inch layers for the characterization of general soil properties of the experimental areas (Table 1). The experiments were arranged in a randomized block design of a corn-soybean rotation with four replications in Scandia and Ottawa, and corn-soybean-wheat rotation with three replications in Manhattan for 10 consecutive years. A strip-tillage operation was performed before planting corn; while soybean and wheat were planted into the corn residue with no prior tillage. Strip-tillage was used for all plots including the control, which received no P fertilizer application. Deep-band P fertilizer application was completed with the strip-tillage operation applied in a concentrated zone spaced at 30 inches and made in the same row location during 10 years. Corn and soybean were planted in the center of the strip in the same row each year. The phosphorus fertilizer source for the broadcast treatment was triple superphosphate (0-45-0) applied broadcast by hand to the soil surface before planting corn. The P fertilizer source for deep banding was ammonium polyphosphate (10-34-0). Treatments included a control with no P application and two treatments involving placements of 80 lbs. of $P_2O_5$ $acre^{-1}$ as broadcast or deep band. After the last crop harvest for each experiment in 2015, soil samples were collected from 0-3 and 3-6 inches depths from the in-row position. Soil P fractions were determined by the sequential P fractionation method proposed by Hedley et al. (1982) with modifications by Condron et al. (1985). To evaluate maximum P adsorption capacity (MPAC), 2.5g subsamples of air-dried soil were mixed with 11 rates of added P (0, 4, 8, 12, 20, 28, 36, 44, 56, 68, and 80 mg $L^{-1}$) as potassium dihydrogen phosphate ($KH_2PO_4$ (p.a.)), in a 25 mL equilibrium solution of calcium chloride (0.01 M $CaCl_2.2H_2O$) and using Langmuir equation. All statistical analyses were completed in SAS Studio (version 9.3; SAS, Institute, Inc, Cary, NC). The GLIMMIX procedure was used for analysis of variance (ANOVA).

## RESULTS AND DISCUSSION

After the 10 year period, significant changes in soil P labile pools for treatments compared to the control with interaction between the two factors (treatments and soil depths) were observed due to the long-term effect of P fertilizer placement across locations.

### Inorganic Labile P Pool ($Pi_{LP}$)

Overall, the amount $Pi_{LP}$ showed higher amount in the soil surface (0-3 in) for the broadcast treatment compared to the deep band and control treatments across locations, Scandia, Ottawa, and Manhattan (**Fig. 1 D, E and F**). However, the higher amount of $Pi_{LP}$ in the 3-6 in soil layer was observed for deep band treatment compered to broadcast and control treatments. These results suggested that P fertilizer placement for broadcast in the soil surface and deep band for subsoil may contribute to the saturation of adsorption P sites in the soil under reduced tillage with minimal soil disturbance over 10 years. Since the adsorption sites are gradually saturated, the binding energy of P solubilized later is weakly adsorbed and consequently increase P availability (Rheinheimer *et al.*, 2003).

**Organic Labile P Pool ($Po_{LP}$)**

The P fertilizer placement affected the amount of $Po_{LP}$ just for Scandia with no significant effects for Ottawa and Manhattan sites (**Fig. 1, A, B and C**). The highest proportion of $Po_{LP}$ was observed for control and broadcast treatments at the subsoil (3-6 in). Also, our results showed that treatments with the largest amount of $Pi_{LP}$ showed the smallest amount of $Po_{LP}$, broadcast in the soil surface and deep band in the subsoil, respectively. The Pi and Po pools act in a similar way in buffering the absorbed P by plants in soils with low or no addition of P fertilizers (Coelho et al., 2019). The Po pool is considered as the main supply of P for plant uptake when no fertilizer is added to the soil (Gatiboni et al., 2007) what may explain these results found in this study.

**Total Labile P Pool ($Pt_{LP}$)**

In general, the $Pt_{LP}$ showed the same tendency found for Pi with higher amount in the soil surface (0-3 in) for the broadcast and in the 3-6 in soil layer was for deep band treatment (**Fig. 1, G, H and I**) for all locations and could be affected by fertilizer placement as described for $Pi_{LP}$. In addition, preliminary results of this study suggested that the $Pt_{LP}$ in the soil profile (0-6 in) showed different tendencies across locations (**Fig. 2**) and affected by maximum P adsorption capacity (MPAC). The broadcast treatment showed higher amount of $Pt_{LP}$ (118 ppm) than deep band (112 ppm) and control (84 ppm) treatments at Scandia site with low MPAC (288 ppm). However, at Ottawa location with medium MPAD (348 ppm) the higher amount of $Pt_{LP}$ was observed for deep band (126 ppm) than broadcast (119 ppm) and control (86 ppm) treatments. In addition, at Manhattan site with the higher MPAC (424 ppm) of this study the broadcast and deep band treatments showed the same amount of $Pt_{LP}$ (174 ppm) and higher than the control treatment (84 ppm). The maximum P adsorption capacity of this soils plus the P placement may have affected these results. With lower MPAC the continuum accumulation application of P as broadcasted in a reduced tillage may have contributed to reducing large P sorption reactions and that may have contributed to increasing labile P concentrations near the soil surface (Coelho et al., 2019) plus the presence of low molecular weight compounds present in organic matter near the surface from the crop residues might block P adsorption sites increasing the P availability (Guppy et al., 2005). In addition, the soil with medium amount of P fixing components when P fertilizer is deep banding in the plant row with lower soil volume and minimum disturbance of the soil promoted by reduced tillage, can contribute to reduce the high P sorption reactions, and that may have contributed to increasing the labile P levels. However, in the soil with higher P sorption reactions the effect of P fertilizer placement as broadcast and deep band on TotP are the same in soil profile after 10 years of crop rotations or maybe the 10 years of P application were not enough to saturate the adsorptions P sites of the soil.

Still, broadcast and deep band placements had similar effects over many years and can promote increase and depletion of inorganic and total labile P pools from some soil layers at different locations. Long-term crop production might benefit from combined P placements strategy.

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**Table 1.** Initial soil parameters for three experimental sites at three Kansas Mollisol soils.

| Site | pH | TON[a] | TOC[b] | K | Ca | Mg | Na | CEC[c] | Clay | Silt | Sand | MPAC[d] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | - - - g $kg^{-1}$ - - - | | - - - - - - - ppm - - - - - - - | | | | $cmol_c$ $kg^{-1}$ | - - - - g $kg^{-1}$ - - - - | | | ppm |
| | | | | | 0-3 in | | | | | | | 0-6 in |
| Scandia | 6.5 | 1.8 | 20 | 586 | 2159 | 371 | 31 | 17 | 210 | 590 | 200 | 288 |
| Ottawa | 5.5 | 1.8 | 20 | 311 | 2003 | 347 | 12 | 24 | 320 | 500 | 180 | 348 |
| Manhattan | 5.7 | 2.1 | 23 | 131 | 2124 | 377 | 15 | 22 | 260 | 600 | 140 | 424 |
| | | | | | 3-6 in | | | | | | | |
| Scandia | 6.5 | 1.6 | 14 | 452 | 2443 | 426 | 45 | 21 | 290 | 550 | 160 | |
| Ottawa | 5.5 | 1.2 | 13 | 192 | 2309 | 407 | 14 | 26 | 360 | 480 | 160 | |
| Manhattan | 5.2 | 1.9 | 18 | 109 | 2275 | 344 | 27 | 27 | 320 | 580 | 100 | |

[a] TON, total organic nitrogen; [b] TOC, total organic carbon; [c] CEC, cation exchange capacity; [d] MPAC, maximum phosphorus adsorption capacity

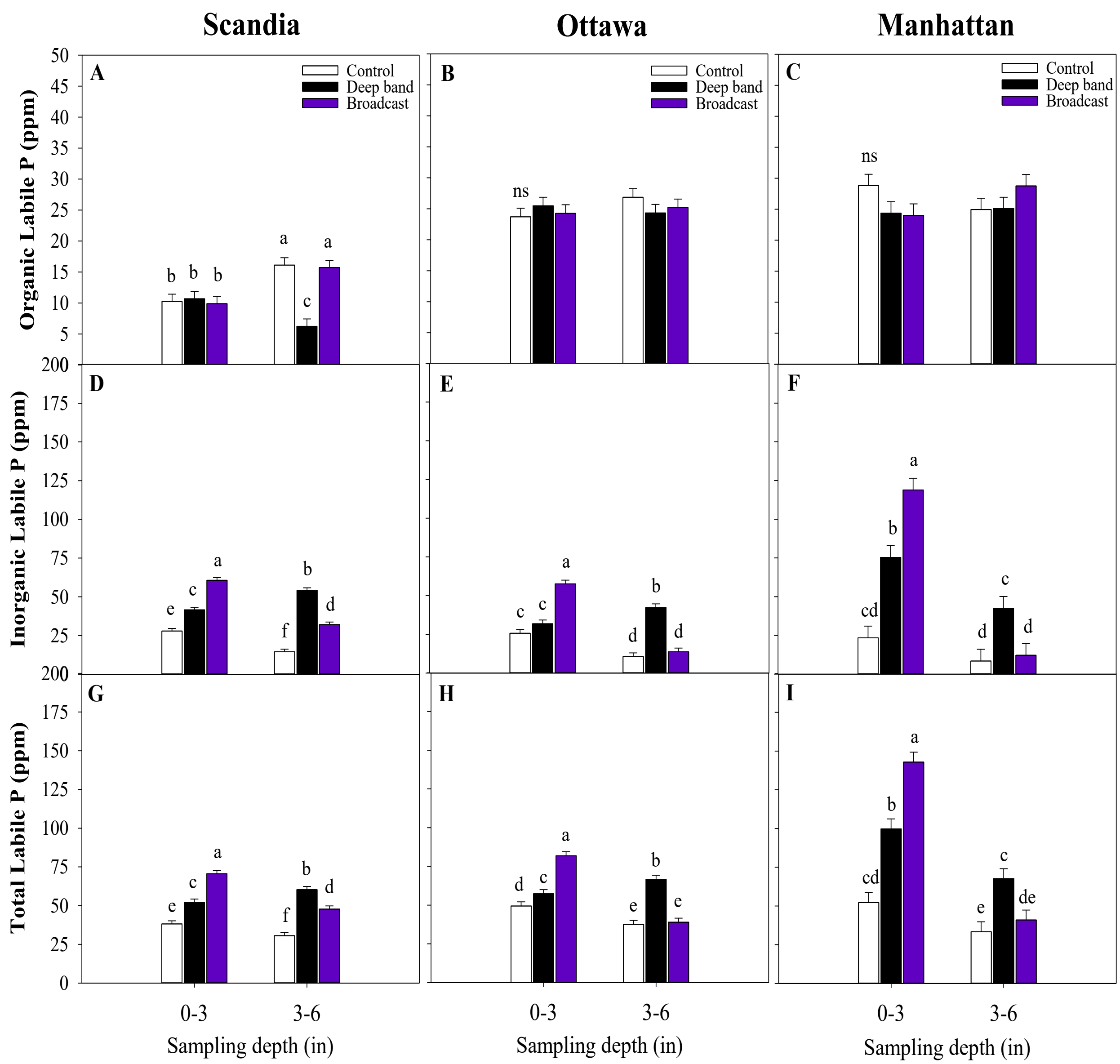


**Figure 1.** Labile P pool: organic - $Po_{LP}$ (A, B, C), inorganic - $Pi_{LP}$ (D, E, F) and total - $Pt_{LP}$ (G, H, I) for two soil sampling depths for three locations Scandia, Ottawa and Manhattan, respectively, as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of a corn-soybean rotation for Scandia and Ottawa and, corn-soybean-wheat rotation for Manhattan . Error bars indicate the standard error of the mean and mean values followed by the same letter are not statistically different ($p > 0.05$). ns = not significant

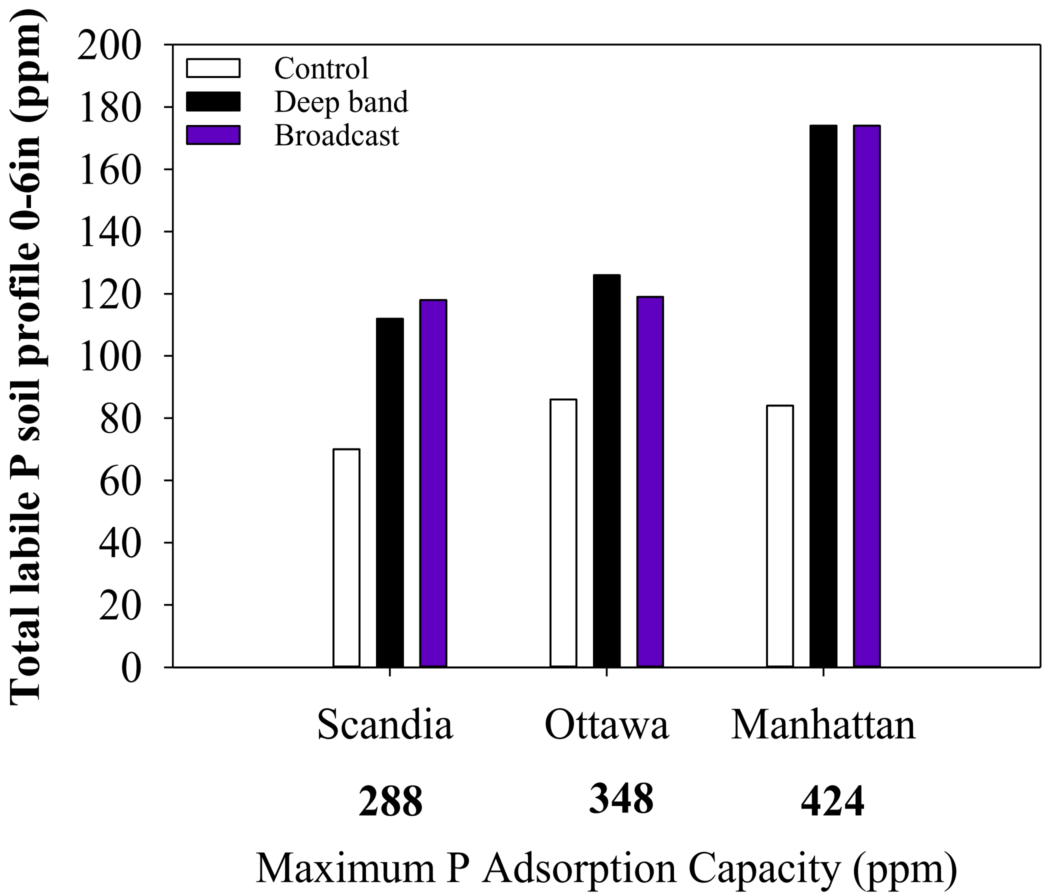


**Figure 2.** Total labile P in the soil profile (0-6 inches) as affected by P fertilizer treatments (deep-band, broadcast, and control) after 10 years of crop rotation and Maximum P adsorption capacity for three locations Scandia, Ottawa, and Manhattan.