Comparison of Organic and Inorganic Phosphorus Fractions in an Established Buffer and Adjacent Production Field

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Comparison of Organic and Inorganic Phosphorus Fractions in an Established Buffer and Adjacent Production Field

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Abstract: Since the U.S. Department of Agriculture’s Conservation Reserve Program was established in 1985, thousands of acres of cropland have been converted to conservation buffers. The distributions of soil phosphorus (P) in various organic and inorganic fractions in a buffer and an adjacent crop production field were compared. Most of the extractable inorganic P (32 to 39%) in both the crop field and the buffer was present in the calcium (Ca)-P fraction. Levels of the most labile P fractions were higher in the cropped area; however, more P was in the iron (Fe)-P fraction in the buffer (23 vs. 18%). There were few differences among organic P fractions between the buffer and crop field. Soil sampling depth had a significant effect on the distribution of P. Differences between the cropped area and the buffer were less significant as depth increased. These results suggest that care should be taken in choosing sampling depths when relating P fraction distribution to potential P loss.

Keywords: Conservation buffer, labile phosphorus, organic phosphorus, phosphorus fractionation

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INTRODUCTION

The U.S. Department of Agriculture’s Conservation Reserve Program (CRP) was established by the Food Security Act of 1985. Since its inception, thousands of acres of cropland in stream riparian zones have been converted to conservation buffers through the planting of native grasses and trees. Riparian buffers can reduce sediment and, to a lesser extent, nutrient losses and achieve other conservation goals, such as enhancing wildlife habitat (Gilliam 1994; Correll 2000).

Several researchers have compared the phosphorus (P) status of soils in buffer areas with those of adjacent cropped fields. Magid (1993) found higher levels of labile and moderately labile organic P in soils from a 25-year-old buffer than from an adjacent continuously fertilized field. However, sequentially extracted inorganic P levels were higher in the continuously fertilized field than in the buffer. Cooper and Gilliam (1987) reported significant increases in total P concentrations in riparian areas adjacent to cropped land over a 20-year period. Chalmers, Bacon, and Clarke (2001) studied the effect of 3- to 5-year set-aside periods on soil nutrient levels and reported a slight increase in extractable P but concluded that 3- to 5-year set-aside periods generally had no effect on soil P levels. In a study of the effect of cultivation practices on P fractions, Hedley, Stewart, and Chauhan (1982) reported that there were differences in various P fractions between a continuously cropped field and an adjacent permanent pasture.

The chemistry of P in soils is complex, and several fractionation procedures have been developed to quantify the various inorganic and organic forms of P in soils. The Chang and Jackson (1957) method and modifications by Williams, Syers, and Walker (1967), Smillie and Syers (1972), Peterson and Corey (1966), and Fife (1962) have been widely used to investigate soil inorganic P forms, which include iron (Fe)-P, aluminum (Al)-P, calcium (Ca)-P, and occluded P. Kuo (1996) presented a fractionation scheme that incorporated the original Chang and Jackson (1957) fractionation procedure and most of the subsequent modifications. The inorganic P (P\textsubscript{i}) fractionation used in the present study is primarily based on the Kuo (1996) fractionation scheme as described by Zhang and Kovar (2000).

Quantification of the various known organic P (P\textsubscript{o}) compounds in soil has been described in several studies (Anderson 1967; Halstead and Anderson 1970; Stott and Tabatabai 1985) and is advocated by Kuo (1996) as a means of fractionating soil P\textsubscript{o}. Soil organic P consists of inositol phosphates, phospholipids, nucleic acids, phosphoproteins, and various sugar phosphates, as well as a significant number of compounds that have not been identified. Organic P in microbial biomass consists of nucleic acids, inositol phosphates, and polyphosphates. Microbial biomass P usually represents a small fraction of the total P in soil and rapidly turns over to supply inorganic P to plant roots (Tate 1984).
Phosphorus Fractions in a Buffer and Production Field

An alternative method for characterizing soil \( P_o \) fractions involves the use of acid and alkaline extractants that separate the various fractions based on the type and strength of \( P_o \) physicochemical interactions with other soil components (Bowman and Cole 1978; Hedley, Stewart, and Chauhan 1982; Cross and Schlesinger 1995). The most common extractants are 0.5 \( M \) sodium bicarbonate (\( \text{NaHCO}_3 \)) and various concentrations of hydrochloric acid (\( \text{HCl} \)) and sodium hydroxide (\( \text{NaOH} \)). The fractionation scheme involves a sequence of extractions that separates soil \( P_o \) into labile, moderately labile, and nonlabile fractions. In recent years, this scheme has been widely used to evaluate \( P_o \) turnover in diverse soils under varying management (Hedley, Stewart, and Chauhan 1982; Sharpley and Smith 1985; Ivanoff, Reddy, and Robinson 1998). The \( P_o \) fractionation scheme of Zhang and Kovar (2000) was used in the current study.

The objective of this study was to assess the current P status in a 13-year-old CRP buffer and a continuously cropped production area from which the buffer was created by comparing the form and quantity of different organic and inorganic P fractions. We hypothesized that there would be significantly greater quantities of \( P_i \) in the production area as a result of annual fertilizer and frequent animal manure applications.

MATERIALS AND METHODS

Soils

The study area is located on the flood plain of Tipton Creek in central Iowa. The soil in the area is classified as Lawler series (fine loamy over sandy mixed mesic Aquic Hapludolls). The cropped area has been in continuous cultivation for more than 50 years, with a typical 2-year rotation of corn (\textit{Zea mays} L.) and soybean (\textit{Glycine max} L. Merr.). After harvest each year, the field is chisel plowed to incorporate crop residues. Liquid swine manure was applied at a rate of approximately 40,000 L ha\(^{-1}\) in 1995, 1996, 2000, 2002, and 2003, resulting in P application of approximately 57 kg ha\(^{-1}\) in each year that manure was applied. The only other amendments included fall applications of anhydrous ammonia following a soybean crop and occasional application of agricultural lime (6 to 11 Mg ha\(^{-1}\)). The buffer area, which is approximately 30 m wide, was set aside from the crop field in 1991 and planted to switchgrass (\textit{Panicum virgatum}). Management of the buffer includes periodic mowing and burning for weed control.

Representative soil samples were collected from the surface 0–5, 0–10, and 0–15 cm of the buffer and the adjacent cropped area. Cores were collected from 10 randomly selected locations across a 25- by 50-m area of the buffer and from a similar sized portion of the cropped area adjacent to the buffer with a 2.5-cm soil probe and mixed to form composite samples for each depth and area. All soils were air dried, sieved (2 mm), and stored at 23°C.
prior to extraction. Subsamples were analyzed for pH (1:2 soil to water); Mehlich 3-extractable P; exchangeable potassium (K), calcium (Ca), and magnesium (Mg); total carbon (TC); and organic matter content (OM) by the Iowa State University Soil Testing Laboratory, according to methods outlined by Brown (1998). Particle size distribution was determined by the hydrometer method (Day 1965). Inorganic and organic P fractions were extracted from quadruplicate 0.5-g samples and reported as means for each location and sampling depth according to the following fractionation schemes (Zhang and Kovar 2000).

**Fractionation of Inorganic Phosphorus**

A 0.5-g sample of soil was placed in a 40-mL centrifuge tube and sequentially extracted with 25 ml each of 1 M NH₄Cl (Labile-Pᵢ), 0.5 M NH₄F (Al-Pᵢ), and 0.1 M NaOH (Fe-Pᵢ) by shaking horizontally for 0.5, 1, and 17 h, respectively, followed by centrifugation at 26,860 g for 15 min. Reductant-soluble Pi (Red-Pᵢ) was subsequently extracted by adding 20 mL of 0.3 M Na₃C₆H₅O₇, 2.5 mL of 1 M NaHCO₃, and 0.5 g Na₂S₂O₄ to the residue in each tube and heating for 15 min at 85°C, followed by centrifugation at 26,860 g for 15 min. Calcium-bound Pᵢ (Ca-Pᵢ) was subsequently extracted by adding 25 mL of 0.25 M H₂SO₄ followed by centrifugation at 26,860 g for 15 min.

**Fractionation of Organic Phosphorus**

In general, the fractionation scheme follows the procedures developed by Bowman and Cole (1978) and modified by Sharpley and Smith (1985) and Ivanoff, Reddy, and Robinson (1998). Organic P was fractionated into a labile pool, a moderately labile pool, and a nonlabile pool. Labile Po was extracted by adding 0.5 g of soil and 25 mL of 0.5 M NaHCO₃ (pH 8.5) to 40-mL centrifuge tubes and shaking for 16 h, followed by centrifugation at 26,860 g for 15 min. Microbial biomass Po in the soil was determined by adding 2 mL of CHCl₃ to separate 0.5-g samples that were allowed to stand for 24 h. Samples were then extracted with 25 mL of 0.5 M NaHCO₃ (pH 8.5) for 16 h and centrifuged at 26,860 g for 15 min. Moderately labile Po was extracted by adding 25 mL of 1.0 M HCl to the residue and shaking for 3 h, followed by centrifugation at 26,860 g for 15 min. Humic acid (HA)– and fulvic acid (FA)–associated Po were subsequently extracted by adding 25 mL of 0.5 M NaOH to the residue, followed by shaking for 16 h and centrifugation at 26,860 g for 15 min. The NaOH extract was acidified with concentrated HCl to separate the nonlabile fraction (HA fraction) from the moderately labile fraction (FA fraction). Finally, the highly resistant, nonlabile Po fraction was determined by ashing the residue from the NaOH extraction at 550°C for 1 h, followed by dissolution in 1.0 M sulfuric acid (H₂SO₄).
In both the $P_i$ and $P_o$ fractionations, $P$ concentration in the extracts was determined colorimetrically by the phosphomolybdate method of Murphy and Riley (1962). Acid or alkaline extracts were neutralized prior to $P$ determinations. Organic $P$ in the extracts was calculated from the difference between total $P$ and $P_i$. Total $P$ in the extracts was measured after an aliquot was digested with $2.5 M \text{H}_2\text{SO}_4$ and potassium persulfate ($\text{K}_2\text{S}_2\text{O}_8$), according to the method of Bowman (1989), as modified by Thien and Myers (1992).

**Data Analysis**

Differences in $P$ fractions and sampling depths were evaluated with analysis of variance (ANOVA). When treatment effects were significant ($p < 0.05$), Fisher’s LSD and Duncan’s Multiple Range Tests were used to detect differences among treatment means. Statistical analyses were performed with the Statistical Analysis System software (SAS Institute 2000).

**RESULTS AND DISCUSSION**

As expected, soil physical and chemical properties differed between the two sampling locations (Table 1). The cropped area had higher pH, slightly higher silt and clay contents, higher levels of extractable Ca and magnesium (Mg), and less organic matter than the buffer. The higher pH and greater amounts of extractable Ca and Mg in the cropped area reflect the regular application of swine manure and agricultural lime. Organic matter levels in the 0–5-cm layer of the cropped area were only 0.5% lower than in the buffer. This suggests that regular manure applications to the cropped area and periodic burning of the buffer have increased OM in the former and decreased it in the latter. The higher percentage of sand in the buffer indicates that the buffer has functioned as a sink for course sediments but not for finer particles. Mehlich 3-extractable $P$ levels were higher in the cropped area than in the buffer but exceeded the level considered optimal for crop production by the Iowa State University Extension Service (Mehlich 3 $P$ 16 to 20 mg kg$^{-1}$) in both areas. Also, Mehlich 3 $P$ levels were higher in the 0–5-cm samples compared to other sampling depths in the cropped area but not in the buffer, suggesting that despite annual tillage, $P$ was stratified in the cropped area.

**Inorganic Phosphorus Fractions**

The greatest portion of extractable $P_i$ was present in the Ca fractions of both the crop field and the buffer (Tables 2 and 3). Ca-associated $P_i$ was positively correlated to Mehlich 3-extractable $P$, ammonium acetate extractable Ca, pH,
Table 1. Soil pH, particle size distribution, total carbon (TC), organic matter (OM), Mehlich III extractable phosphorus (P), and ammonium acetate exchangeable cations (K, Ca, and Mg) for samples collected from three depths of a crop production field and an adjacent conservation buffer.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>TC (%)</th>
<th>OM (%)</th>
<th>P (mg kg(^{-1}))</th>
<th>K (mg kg(^{-1}))</th>
<th>Ca (mg kg(^{-1}))</th>
<th>Mg (mg kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>0–5</td>
<td>7.7</td>
<td>36</td>
<td>32</td>
<td>32</td>
<td>3.2</td>
<td>5.9</td>
<td>102</td>
<td>192</td>
<td>4471</td>
<td>717</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>7.7</td>
<td>37</td>
<td>31</td>
<td>32</td>
<td>3.0</td>
<td>5.6</td>
<td>59</td>
<td>138</td>
<td>4272</td>
<td>763</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>7.7</td>
<td>37</td>
<td>30</td>
<td>33</td>
<td>2.8</td>
<td>5.3</td>
<td>46</td>
<td>127</td>
<td>4565</td>
<td>643</td>
</tr>
<tr>
<td>Buffer</td>
<td>0–5</td>
<td>7.0</td>
<td>46</td>
<td>26</td>
<td>28</td>
<td>3.5</td>
<td>6.5</td>
<td>39</td>
<td>137</td>
<td>3073</td>
<td>528</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>7.1</td>
<td>46</td>
<td>29</td>
<td>25</td>
<td>3.3</td>
<td>6.2</td>
<td>36</td>
<td>127</td>
<td>3144</td>
<td>562</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>7.1</td>
<td>46</td>
<td>28</td>
<td>26</td>
<td>2.9</td>
<td>5.4</td>
<td>33</td>
<td>108</td>
<td>3420</td>
<td>559</td>
</tr>
</tbody>
</table>
Table 2. Inorganic phosphorus (Pi) sequentially extracted from labile, aluminum (Al)-bound, iron (Fe)-bound, reductant soluble (RS), calcium (Ca)-bound, and residual (Res) soil P fractions (total inorganic P (TPi) is the sum of the six Pi fractions)

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Labile-Pi (mg P kg$^{-1}$)</th>
<th>Al-Pi (mg P kg$^{-1}$)</th>
<th>Fe-Pi (mg P kg$^{-1}$)</th>
<th>RS-Pi (mg P kg$^{-1}$)</th>
<th>Ca-Pi (mg P kg$^{-1}$)</th>
<th>Res-Pi (mg P kg$^{-1}$)</th>
<th>TPi (sum) (mg P kg$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>0–5</td>
<td>35.9Aa</td>
<td>56.0Aa</td>
<td>62.2Aa</td>
<td>2.4Aa</td>
<td>107.6Aa</td>
<td>80.6Aa</td>
<td>344.7Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>16.8Ba</td>
<td>33.4Ba</td>
<td>49.3Bb</td>
<td>2.3Aa</td>
<td>103.2Aa</td>
<td>79.3Aa</td>
<td>284.3Ba</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>9.2Ca</td>
<td>25.2Ca</td>
<td>44.8Cb</td>
<td>2.5Aa</td>
<td>103.3Aa</td>
<td>79.1Aa</td>
<td>264.1Ca</td>
</tr>
<tr>
<td>Buffer</td>
<td>0–5</td>
<td>11.3Ab</td>
<td>27.6Ab</td>
<td>61.2Ab</td>
<td>1.3Bb</td>
<td>92.0Ab</td>
<td>72.3Ab</td>
<td>265.7Ab</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>7.0Bb</td>
<td>23.4Bb</td>
<td>55.0Ba</td>
<td>1.6ABa</td>
<td>86.6Ab</td>
<td>65.8Ab</td>
<td>239.4Bb</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>6.4Ba</td>
<td>21.6Ba</td>
<td>51.2Ca</td>
<td>2.5Aa</td>
<td>88.3Ab</td>
<td>67.8Ab</td>
<td>237.8Bb</td>
</tr>
</tbody>
</table>

*Means followed by the same letter (uppercase denotes within location differences, lowercase denotes between location differences) are not different by Fisher’s LSD ($p = 0.05$).
and, clay content ($r = 0.8^*, 0.93^{**}, 0.94^{**}$, and $0.96^{**}$, respectively) and negatively correlated with sand content ($r = 0.97^{**}$). High levels of Ca-Pi in these soils was not surprising given that at least some of the soil’s alluvial parent material probably originated from the limestone bedrock in the area above the flood plain. There were also significant amounts of residual Pi, Fe-Pi, Al-Pi, and labile Pi in both locations. Residual Pi was positively correlated with clay content and pH ($r = 0.98^{**}$ and $0.912^{**}$, respectively) and negatively correlated with percent sand ($r = 0.94^{**}$), indicating that this fraction was probably associated with more stable Ca phosphates. Fe-Pi was positively correlated with percent OM ($r = 0.81^*$), suggesting that OM may be the principal source of Fe in this system. This may also suggest that some of the Fe-Pi was actually P bound to humic surfaces via Fe bridges (Weir and Soper 1963; Gerke and Hermann 1992). The most labile Pi fractions (labile Pi and Al-Pi) were strongly correlated with Mehlich 3 extractable P ($r = 0.99^{**}$ and $0.99^{**}$, respectively). This correlation is not unexpected given that the Mehlich 3 reagent was developed to extract these fractions (Mehlich 1984) and contains NH$_4$F, the Al-Pi extractant used in the sequential fractionation. There was relatively little reductant soluble Pi (RS-Pi) in either the crop field or the buffer, but there was a strong negative correlation between RS-Pi and OM content ($r = 0.92^{**}$), probably due to the physical occlusion of P sorption sites (McDowell and Condron 2001). The fact that there was little RS-Pi but significant Al-Pi and Fe-Pi is expected because these soils are not highly weathered and likely contain only small amounts of free Fe-Al oxide. Additionally, sum total Pi (TP$_i$) was higher in the crop field than in the buffer, again presumably as a result of manure applications.

For all fractions, except Fe-P$_i$, extractable P$_i$ concentrations in 0–5- and 0–10-cm samples were higher in the crop field than in the buffer (Tables 2 and 3). However, there were fewer differences between the crop field and the

### Table 3.
Inorganic phosphorus (Pi) sequentially extracted from labile, aluminum (Al)-bound, iron (Fe)-bound, reductant soluble (RS), calcium (Ca)-bound, and residual (Res) soil P fractions as a percentage of the total Pi from Table 2

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (cm)</th>
<th>Labile-Pi (%)</th>
<th>Al-Pi (%)</th>
<th>Fe-Pi (%)</th>
<th>RS-Pi (%)</th>
<th>Ca-Pi (%)</th>
<th>Res-Pi (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>0–5</td>
<td>10.3Aa</td>
<td>16.2Aa</td>
<td>18.0Ab</td>
<td>0.6Aa</td>
<td>31.5Cb</td>
<td>23.4Bb</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>6.0Ba</td>
<td>11.7Ba</td>
<td>17.3Ab</td>
<td>0.8Aa</td>
<td>36.3Ba</td>
<td>27.9Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>3.5Ca</td>
<td>9.5Ca</td>
<td>17.0Ab</td>
<td>0.9Aa</td>
<td>39.1Aa</td>
<td>30.0Aa</td>
</tr>
<tr>
<td>Buffer</td>
<td>0–5</td>
<td>4.3Ab</td>
<td>10.4Ab</td>
<td>23.4a</td>
<td>0.5Ba</td>
<td>34.6Aa</td>
<td>27.2Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>2.8Ab</td>
<td>9.8Ab</td>
<td>23.0Ab</td>
<td>0.7Ba</td>
<td>36.2Aa</td>
<td>27.5Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>2.7Aa</td>
<td>9.1Aa</td>
<td>21.5Aa</td>
<td>1.1Aa</td>
<td>37.1Aa</td>
<td>28.5Aa</td>
</tr>
</tbody>
</table>

*Means followed by the same letter (uppercase denotes within location differences, lowercase denotes between location differences) are not different by Fisher’s LSD ($p = 0.05$).
buffer in the 0–15-cm samples, with only the Fe-P$_i$, Ca-P$_i$, and Res-P$_i$ showing differences. Interestingly, in the 0–10- and 0–15-cm samples, the concentration of Fe-P$_i$ was actually higher in the buffer than in the crop field. This was probably related to the somewhat higher OM level in the buffer and subsequent P bonding to the humic acid through Fe bridges (Gerke and Hermann 1992). Percentage Fe-P$_i$, Ca-P$_i$, and Res-P$_i$ were significantly ($p = 0.05$) higher in the buffer than in the crop field in the 0–5-cm sample, but percentage labile-P$_i$ and Al-P$_i$ were greater in the crop field in 0–5- and 0–10-cm samples. The fact that a greater percentage of P$_i$ in the crop field was in more labile forms reflects the regular application of manure. The percentage Fe-P$_i$ was higher in the buffer regardless of sampling depth.

Within each sampling location (crop field or buffer), there were differences in extractable P$_i$ concentration with depth for the most available P$_i$ forms (Tables 2 and 3). Labile P$_i$, Al-P$_i$, and Fe-P$_i$ were significantly different for each sampling depth in the crop field with extractable P$_i$ decreasing as sampling depth increased. In the buffer, however, only the Fe-P$_i$ was different for all three depths. Labile P$_i$ and Al-P$_i$ were different in the 0–5-cm depth but not in the 0–10- and 0–15-cm depths in the buffer. Additionally, in the crop field, as a percentage of TP$_i$, both labile P$_i$ and Al-P$_i$ decreased as sampling depth increased (Table 3). Clearly, the data show that P$_i$ has accumulated in the upper 5 cm of both the crop field and the adjacent buffer. Accumulation of P in the surface soil of agricultural fields to which fertilizer or manure has been applied has been reported in the literature (Royer et al. 2003; Malhi et al. 2003; Hountin et al. 2000). Surprisingly, we could find only one report of P accumulation in the surface horizon of conservation buffers. In that study (Cooper and Gilliam 1987), the authors reported significant accumulations of total P in the upper 3 cm of riparian area soils adjacent to cropland. They concluded that the increase was a function of silt and clay deposition within the riparian area. It is important to note that the riparian area studied by Cooper and Gilliam (1987) was actually a riparian forest, which extended over a significant area (approximately 185 ha).

Although Ca-P$_i$ was the largest fraction in both locations, and across all depths there was no difference among sampling depths at either location. However, Ca-P$_i$ did represent an increasing portion of TP$_i$ as sampling depth increased (Table 3). The fact that differences were found in the 0–5- and 0–10-cm layer samples and not in the 0–15-cm samples suggests that choice of sampling depth may significantly affect conclusions about soil P distributions and subsequent inferences made concerning the potential for buffer areas to act as a sink for P.

Organic Phosphorus Fractions

Total P$_o$ content was larger than TP$_i$ content in both the crop field and buffer, regardless of sampling depth. As expected, the difference between TP$_i$ and
Table 4. Organic phosphorus (Po) sequentially extracted from labile, biomass, moderately labile, fulvic acid (FA), humic acid (HA), and nonlabile soil P fractions (total organic P (TPo) is the total of the six Po fractions)

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (cm)</th>
<th>Labile-Po (mg P kg(^{-1}))</th>
<th>Biomass-Po (mg P kg(^{-1}))</th>
<th>Mod labile-Po (mg P kg(^{-1}))</th>
<th>FA-Po (mg P kg(^{-1}))</th>
<th>HA-Po (mg P kg(^{-1}))</th>
<th>Nonlabile-Po (mg P kg(^{-1}))</th>
<th>TPo (sum) (mg P kg(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>0–5</td>
<td>13.6Aa</td>
<td>19.0Aa</td>
<td>14.7Ab</td>
<td>193.9Aa</td>
<td>72.0Aa</td>
<td>108.7Aa</td>
<td>421.9Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>14.9Aa</td>
<td>13.0Aa</td>
<td>16.0Aa</td>
<td>186.3Aa</td>
<td>79.7Aa</td>
<td>121.0Aa</td>
<td>430.9Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>17.1Aa</td>
<td>9.6Aa</td>
<td>19.8Aa</td>
<td>182.6Aa</td>
<td>84.2Aa</td>
<td>120.7Aa</td>
<td>434.0Aa</td>
</tr>
<tr>
<td>Buffer</td>
<td>0–5</td>
<td>20.7Aa</td>
<td>16.5Aa</td>
<td>30.8Aa</td>
<td>175.4Aa</td>
<td>81.1Aa</td>
<td>148.8Aa</td>
<td>473.3Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>14.2Aa</td>
<td>13.5Aa</td>
<td>27.9Aa</td>
<td>175.5Aa</td>
<td>86.0Aa</td>
<td>111.4Ba</td>
<td>428.4Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>16.0Aa</td>
<td>6.2Aa</td>
<td>24.7Aa</td>
<td>173.5Aa</td>
<td>83.7Aa</td>
<td>111.2Ba</td>
<td>415.3Aa</td>
</tr>
</tbody>
</table>

*Means followed by the same letter (uppercase denotes within location differences, lowercase denotes between location differences) are not different by Fisher’s LSD (\( p = 0.05 \)).
TPo was greater in the buffer than in the crop field (Tables 2 and 4). Nonlabile P, FA-Po, and HA-Po were the largest components of Po in the soils of both the crop field and the buffer. FA-Po was positively correlated with Mehlich 3-P (r = 0.95**), but HA-Po was negatively correlated with Mehlich 3-P (r = 0.94**), suggesting that P associated with the FA fraction is more labile. Furthermore, there was a strong negative correlation between the relatively nonlabile HA-Po and FA-Po, labile-Pi, and Al-Pi (r = 0.84*, 0.97**, and 0.97**, respectively), which indicates that HA may be acting as a sink for P in this system. FA-Po was also positively correlated with silt and clay content (r = 0.87** and 0.81*, respectively) and negatively correlated with percent sand (r = 0.93**). Moderately labile Po, the next largest fraction in both the crop field and the buffer, was positively correlated with percent sand (r = 0.93**) and negatively correlated with percent silt, percent clay, Mehlich 3-P, and pH (r = 0.94**, 0.80*, 0.77*, and 0.94**, respectively). Interestingly, only biomass-Po showed any correlation with percent OM (r = 0.72*).

With the exception of the moderately labile P fraction (which was higher in the crop field in the 0–5-cm sample), there were no significant (p = 0.05) differences in Po between the crop field and the buffer. This lack of accumulation of Po was probably related to the management of the buffer, which includes periodic burning. In a study of the effect of burning on the forms of soil P, Saa et al. (1994) found that levels of NaOH extractable Po were reduced by approximately 30% as a result of a severe burn (soil surface temperature between 250 and 400°C). The general lack of differences in Po fractions between the crop field and the buffer reflects the similar levels of OM (Table 1).

Table 5. Organic phosphorus (Po) sequentially extracted from labile, biomass, moderately labile, fulvic acid (FA), humic acid (HA), and nonlabile soil P fractions as a percentage of the total Po from Table 4

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (cm)</th>
<th>Labile-Po (%)</th>
<th>Biomass-Po (%)</th>
<th>Mod labile-Po (%)</th>
<th>FA-Po (%)</th>
<th>HA-Po (%)</th>
<th>Nonlabile-Po (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>0–5</td>
<td>3.2Aa*</td>
<td>4.5Aa</td>
<td>3.5Ab</td>
<td>46.0Aa</td>
<td>17.0Aa</td>
<td>25.8Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>3.5Aa*</td>
<td>3.1Aa</td>
<td>3.7Aa</td>
<td>43.2Aa</td>
<td>18.5Aa</td>
<td>28.1Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>3.9Aa</td>
<td>2.2Aa</td>
<td>4.6Aa</td>
<td>42.1Aa</td>
<td>19.4Aa</td>
<td>27.8Aa</td>
</tr>
<tr>
<td>Buffer</td>
<td>0–5</td>
<td>4.4Aa</td>
<td>3.5Aa</td>
<td>6.5Aa</td>
<td>37.1Ab</td>
<td>17.1Aa</td>
<td>31.4Aa</td>
</tr>
<tr>
<td></td>
<td>0–10</td>
<td>3.3Aa</td>
<td>3.2Aa</td>
<td>6.5Aa</td>
<td>41.0Aa</td>
<td>20.1Aa</td>
<td>26.0Aa</td>
</tr>
<tr>
<td></td>
<td>0–15</td>
<td>3.8Aa</td>
<td>1.5Aa</td>
<td>5.9Aa</td>
<td>42.0Aa</td>
<td>20.1Aa</td>
<td>26.7Aa</td>
</tr>
</tbody>
</table>

*aMeans followed by the same letter (uppercase denotes within location differences, lowercase denotes between location differences) are not different by Fisher’s LSD (p = 0.05).
CONCLUSIONS

Phosphorus forms and their distribution were different in a continuously cropped field and an adjacent conservation reserve buffer. The most significant difference between the two locations was the higher concentration of labile Pi fractions in the surface soil of the crop field. However, there also was some accumulation of labile Pi fractions in the surface layer of the buffer, which could have a negative impact on the ability of the buffer to act a sink for P. The accumulation of labile Pi in the surface soil of the buffer was likely the result of a management system that does not include the removal of biomass. Regular mowing or burning to control weeds does not remove nutrients from the system, and burning may actually increase the available Pi content in the surface layer. The fact that soil P levels were lower and soil texture was coarser in the buffer than in the crop field suggests minimal P retention by the buffer, if P was lost from the production area. More important, the results of this study suggest that care should be taken in choosing soil sampling depths when relating the distribution of P fractions and the potential for P loss.

REFERENCES

Phosphorus Fractions in a Buffer and Production Field


