ABSTRACT

The disposition of fall-applied fertilizer P (30 kg P ha⁻¹) to winter wheat (Triticum aestivum L.) on four Southern Plains soils was investigated over a 4-yr period under field conditions, using ³²P as a tracer. Wheat was harvested 70 d after planting and P fertilization. An average increase in wheat dry-matter yield (0.86–1.94 Mg ha⁻¹) and Bray-1 P content of 0–50 mm surface soil (8.4–34.4 mg kg⁻¹) was observed following each fertilizer P application over the 4 yr. The major proportion of applied fertilizer P at wheat harvest remained in the soil as inorganic P (60–76%) with little conversion to organic P (8–15%). The proportion as Bray-1 P ranged from 17 to 51%, decreasing with an increase in P sorption capacity of the soil. With consecutive fertilizer applications the proportion of fertilizer P as Bray-1 P increased. Little movement of fertilizer P was observed below the 50-mm depth (3–7%). Recovery of fertilizer P by winter wheat decreased with consecutive fertilizer applications, ranging from 23 to 9% of that applied. The recovery was inversely related to the residual Bray-1 P content of surface soil (Bray-1 P content prior to each fertilizer application). Thus, although dry-matter yield of winter wheat increased with consecutive fertilizer applications, fertilizer P recovery decreased as residual P made an increasing contribution to uptake of P by winter wheat. Consideration of residual soil P levels may, thus, reduce costly maintenance fertilizer P applications.

Additional Index Words: Bray-1, inorganic P, organic P, ³²P, radioactive tracer, Triticum aestivum L.


With the increased cost of fertilizers and current interest in minimizing environmental pollution, maximum utilization of applied fertilizer is important. As a result, there has been an increasing use of fertilizer disposition studies (Menzel and Smith, 1984). By application of tracer techniques to studies of fertilizer utilization, the relative amounts of native and applied nutrients that are taken up by crops, in addition to soil fixation and immobilization can be estimated.

Considerable research has been conducted on the fate of fertilizer N in soil using ¹⁵N for a wide range in crops as reviewed by Allison (1966) and Vose (1980), including winter wheat (Triticum aestivum L.) (Olsen et al., 1979; Olsen and Swallow, 1984). Few field studies have investigated the disposition of fertilizer P tagged with ³²P, however, due to the short half-life of the isotope (14.3 d). Research by Nelson et al. (1947), Spinks and Barber (1947), and Ulrich et al. (1947) investigated the utilization of fertilizer P by grapes (Vitis L.), corn (Zea mays L.), potatoes (Solanum tuberosum L.), and tobacco (Nicotiana tabacum L.). No information is available on the disposition of applied fertilizer P (using ³²P) for winter wheat, although this crop is of agronomic importance in the Southern Plains area. For example, 3.2 × 10⁶ ha of land in Oklahoma is in winter wheat (averaged for 1981–1983), representing 73% of Oklahoma’s cropland (USDA, 1984).

The objective of this study was to investigate the disposition of ³²P labeled fertilizer P, fall-applied to winter wheat ('TAM 105') over a 4-yr period under field conditions in the Southern Plains.

MATERIALS AND METHODS

Undisturbed cores of four agriculturally important soils were collected from Bryan County, south-central Oklahoma, in April 1981. These soils are Bernow (fine-loamy, siliceous, thermic Glossic Paleudalfs), Houston Black (fine, montmorillonitic, thermic Udic Pellusterts), Muskogee (fine-loamy, mixed, thermic Typic Argiudolls), and Teller (fine-loamy, mixed, thermic Udic Argiudolls). Four square, open-ended Al casings (300-mm wide by 600-mm deep, with 5-mm wall thickness) were placed in the ground with the aid of a trenching machine at each location and the encased soil columns were carefully removed and relocated in a secured field area at the Durant laboratory. The casing walls extended 25 mm above the soil surface to prevent any runoff or run-on.

After the plots (cores in casings) had been allowed to settle for approximately 24 weeks, all the 0- to 50-mm topsoil was removed from each plot, air dried, passed through a 2-mm sieve, and mixed thoroughly. Fertilizer P (30 kg P ha⁻¹ as Ca(HPO₄)₂·H₂O), N, and K (100 kg N and 279 kg K ha⁻¹ as KNO₃) were applied in solution (50-mL plot⁻¹) to soil from two of the four plots for each soil type. Radioactive P (³²P) was also applied in the solution, with each plot receiving approximately 7.4 × 10⁶ Bq (2μCi). The two remaining plots of each soil received N and K only and will be subsequently referred to as the check treatments. The soil was thoroughly mixed again, returned to the field plot, and wheat planted. Molten wax was poured down the inside of each casing to ensure no soil discontinuities and preferential water movement. The procedure of top soil removal and fertilizer addition was repeated in September of each year. Water was sprayed on the plots to supplement natural rainfall and maintain soil-water content above wilting point.

Surface soil samples (0–50 mm) were taken at 2-d intervals initially and less frequently later as changes in soil P warranted. Soil-water content was determined gravimetrically on each sample at air dryness and the sample then retained for chemical analyses. Seventy days after planting and fertilization, the wheat was harvested. Above ground wheat (shoot) was cut from each plot and below ground wheat (root) was collected from composited cores (four on each plot) taken in 50-mm increments down to 600 mm. The core holes were filled with fresh soil. The core samples were spread in thin layers to air-dry and to facilitate hand-removal of roots (Smith et al., 1982). Each root free soil sample was mixed thoroughly, and an appropriate subsample was taken for analysis. The roots were lightly washed, dried at 65°C, and finely ground (60 μm). Dry matter production of wheat shoot and root was determined on an air-dry basis.

Total P (TP) content of soil was determined by perchloric acid digestion (Olsen and Sommers, 1982) and inorganic P (IP) by acid (0.5 M H₂SO₄) extraction (Walker and Adams, 1958). Organic P (OP) was calculated as the difference between TP and IP. Bray-1 P (BP) was determined by the method of Bray and Kurtz (1945). The concentration of ³²P in each TP, IP, and BP soil extract was measured in dupli-
Table 1. Physical and chemical properties of the soils (0-50 mm).

<table>
<thead>
<tr>
<th>Soil</th>
<th>Clay content</th>
<th>Organic C content</th>
<th>pH</th>
<th>Total mg kg⁻¹</th>
<th>Inorg. mg kg⁻¹</th>
<th>Org. mg kg⁻¹</th>
<th>Bray mg kg⁻¹</th>
<th>P sorption index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bernow fsl</td>
<td>8</td>
<td>0.71</td>
<td>6.3</td>
<td>196</td>
<td>87</td>
<td>107</td>
<td>9</td>
<td>318</td>
</tr>
<tr>
<td>Houston Black e</td>
<td>50</td>
<td>2.21</td>
<td>7.9</td>
<td>420</td>
<td>255</td>
<td>165</td>
<td>4</td>
<td>755</td>
</tr>
<tr>
<td>Muskogee 1</td>
<td>29</td>
<td>0.86</td>
<td>6.0</td>
<td>296</td>
<td>109</td>
<td>186</td>
<td>14</td>
<td>370</td>
</tr>
<tr>
<td>Teller</td>
<td>22</td>
<td>0.85</td>
<td>6.3</td>
<td>292</td>
<td>174</td>
<td>118</td>
<td>7</td>
<td>436</td>
</tr>
</tbody>
</table>

Results and Discussion

Soil Phosphorus

Little movement of applied P was measured below 50 mm (Fig. 1), uptake of P by winter wheat from below the 50-mm soil depth was mainly from soil native P. Discussion of P levels will, therefore, be restricted to the 0-50 mm soil layer unless noted otherwise. Physical and chemical properties of the surface soils are presented in Table 1.

An increase in the BP content of surface soil (0-50 mm) was observed following fertilizer P addition (Fig. 2). The BP content of check soil remained fairly constant and as levels were similar for each soil, average values are given in Fig. 2. The TP and IP content of surface soils behaved similarly to BP content following fertilizer P addition, while OP content of both check unfertilized and fertilized soil remained constant during the study period (data not presented). The
maximum BP value following P fertilization increased each year of the study. Over the 4 yr, the maximum BP value increased from 95.6 to 133.0, 56.7 to 115.0, 94.1 to 124.2, and 57.8 to 125.6 mg kg⁻¹ for Bernow, Houston Black, Muskogee, and Teller, respectively, equivalent to increases of 39, 103, 32, and 117% (Fig. 2). The subsequent decrease from the maximum BP content indicates annual removal by plant uptake and conversion to less soluble forms.

Phosphorus Uptake and Wheat Dry-matter Yield

Due to the short half-life of the radiotracer ³²P (14.3 d), and the fact that nearly 75% of the P uptake by wheat occurs during the first 60 d of growth (Tucker, 1968), wheat was harvested 70 d after planting and P fertilization. In the following discussion, therefore, wheat yield and P uptake refers to that which occurred during the first 70 d of growth.

The TP content of wheat grown on all check soils, except Bernow, was similar (Table 2). An increase in TP content of both wheat shoot and root was measured following fertilizer P application. No significant difference in TP content of wheat shoot and root from check and fertilized soil existed among years, even though BP content increased with consecutive fertilizer P applications (Table 2). Apparently, soil type rather than BP content had a greater effect on TP content of winter wheat. An increase in TP content of winter wheat with fertilizer P application has also been observed by Ginrich (1964), Leikam et al. (1983), and Stibbe and Kafkafi (1973).

The relationship between dry-matter yield of wheat and its P content, for both check and fertilized soils, was linear and highly significant at the 0.01% level (Fig. 3). Deviations from the linear regression of Fig. 1 indicate the extent to which yield-determining factors other than P supply may have influenced wheat yield (Black and Scott, 1956; Smith et al., 1982). Phosphorus content accounted for 83% of the variability in wheat yield. Soil-water content was maintained near field capacity during wheat growth by irrigation and the linearity of Fig. 3 discounts luxury-P consumption. Consequently, variation in wheat yield was dominated by soil P supply and, thus, the data can be used to investigate fertilizer P disposition in terms of soil fertility.

The dry-matter yield of wheat (shoot plus root) on soil receiving no fertilizer P application was greater for Muskogee than for the other soils (Table 2). No consistent difference in dry-matter yield for check soil was found between treatment years. With the application of fertilizer P, an increase in yield was observed each year when compared to the check soil (Table 2).

![Fig. 3. Total dry-matter yields of winter wheat in relation to P content of winter wheat.](image-url)
Table 3. Distribution of fertilizer P in soil and wheat 70 d after P fertilization and planting.†

<table>
<thead>
<tr>
<th>Soil</th>
<th>Year</th>
<th>Total</th>
<th>Inorganic</th>
<th>Organic</th>
<th>Bray</th>
<th>Shoot</th>
<th>Root</th>
<th>Movement‡</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bernow</td>
<td>1981</td>
<td>73.8</td>
<td>60.2</td>
<td>13.6</td>
<td>37.1</td>
<td>20.2</td>
<td>2.7</td>
<td>5.3</td>
<td>102.0</td>
</tr>
<tr>
<td></td>
<td>1982</td>
<td>72.4</td>
<td>61.1</td>
<td>11.3</td>
<td>40.4</td>
<td>2.7</td>
<td>2.7</td>
<td>5.3</td>
<td>97.3</td>
</tr>
<tr>
<td></td>
<td>1983</td>
<td>77.0</td>
<td>66.9</td>
<td>10.1</td>
<td>46.5</td>
<td>2.7</td>
<td>2.7</td>
<td>5.9</td>
<td>98.7</td>
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<tr>
<td></td>
<td>1984</td>
<td>71.6</td>
<td>63.6</td>
<td>8.0</td>
<td>50.7</td>
<td>2.7</td>
<td>2.7</td>
<td>3.5</td>
<td>97.1</td>
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<td>85.4</td>
<td>76.1</td>
<td>9.3</td>
<td>16.6</td>
<td>2.2</td>
<td>4.4</td>
<td>103.7</td>
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<td></td>
<td>1982</td>
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<td>70.4</td>
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<td>20.4</td>
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<td>3.5</td>
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<tr>
<td>Teller</td>
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<td>62.9</td>
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<td>26.2</td>
<td>3.6</td>
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<td>33.4</td>
<td>4.1</td>
<td>4.1</td>
<td>94.4</td>
<td></td>
</tr>
</tbody>
</table>

† Vertical columns (i.e., between soil types) designated by the same letter are not significantly different at the 5.0% level, as determined by analysis of variance.
‡ Movement of added fertilizer P below the 50-mm depth 70 d after P fertilization and planting.

Fig. 4. Relative dry-matter yield of winter wheat (P-fertilized yield/check yield) for each year of study.

The response of wheat dry-matter yield to fertilizer P application was greater for Bernow than the other soils (Fig. 4). This may result from the fact that Bernow was the least fertile soil in terms of TP, IP, OP, and BP content, when fertilizer P was not applied. In addition, Bernow had the lowest clay content, suggesting a lower capacity to resupply soil solution P as used by the crop. Because of these factors, the check yields decreased each year from 1982 to 1984, thereby accentuating the increase in relative yield with time for the Bernow soil (Fig. 4). The Teller soil behaved similarly but not to the same degree. As no significant difference in BP content of subsurface soil was found, variation in surface soil BP content accounted for differences in wheat yield. Although a general increase in response of wheat yield to fertilizer P was observed with consecutive applications, this was not significant, except for Bernow in 1983 and 1984 (Fig. 4). In fact, wheat yield was related to the maximum BP content of surface soil following each fertilizer P addition (Fig. 5). The difference in wheat yield among soils at similar BP contents may result from more favorable soil physical conditions for plant growth in the loamy Muskogee and Teller, compared to the sandy Bernow and clayey Houston Black soils. In addition, BP may not estimate P availability to the same degree in each soil.

Disposition of Fertilizer Phosphorus

The proportion of applied fertilizer P as surface soil TP and IP decreased during the 70 d following fertilizer application and planting of wheat (Fig. 6), due to plant uptake and conversion to OP. As no consistent difference in the proportion of fertilizer P in these forms was observed between years, average values are given. The proportion of fertilizer P as BP not only decreased during each annual 70-d period, due to plant uptake and conversion to unavailable forms, but declined between 1981 and 1984 as well (Fig. 7). Bernow and Houston Black are given as examples with the BP content of Muskogee and Teller decreasing similarly. The application of fertilizer P had no consistent effect on the distribution of applied P in TP, IP, or OP.
forms between years in surface soil at harvest (Table 3). The proportion of fertilizer P as BP in surface soil increased with annual fertilizer applications (Table 3). Only the BP content following the third (1983) and fourth (1984) fertilizer application, however, were significantly greater than that after the first application (1981). Although no difference in the proportion of fertilizer P as TP, IP, or OP was observed among soils (Table 3), the proportion as BP was inversely related to the P sorption capacity of the individual soils (Fig. 7). A decrease in fertilizer P uptake by rye grass (*Lolium perenne* L.) and winter wheat with increasing clay content observed by Dean et al. (1947) and Stibbe and Kafkafi (1973), respectively, may also be associated with an increasing P sorption.

The proportion of fertilizer P in the wheat shoot decreased with consecutive fertilizer P applications, although no consistent difference in the root was observed (Table 3). The decrease in proportion of fertilizer P in the shoot may result from a greater contribution of residual fertilizer P to uptake of P by wheat with consecutive fertilizer applications. This is consistent with the linear decrease in proportion of wheat P (shoot plus root) derived from fertilizer with increasing residual BP content of each surface soil (Fig. 8). Residual BP from the previous year is represented by the BP content of surface soil prior to each fertilizer application and wheat planting. In addition, the proportion of wheat P derived from fertilizer (Fig. 8) was negatively correlated with inorganic P content ($R^2 = 0.97$) and P sorption index ($R^2 = 0.93$) of the soil (Table 1). Inorganic P and BP may represent quantity factors, in terms of P supply to wheat and P sorption index represent the capacity of the soil to buffer changes in available P content.

Earlier studies have reported recovery of fertilizer P to be greater on P-deficient soils. For example, Nelson et al. (1947) reported that potatoes recovered 50% of fertilizer P applied (30 kg ha$^{-1}$) to a low native-P soil (17 kg ha$^{-1}$ as modified Truog) and only 10% on high native-P soil (53 kg ha$^{-1}$ as modified Truog) in North Carolina. Similarly, swedes (*Brassica napobrassica* Mill.) recovered about 20 and 15% of fertilizer P applied at rates of 18 and 35 kg ha$^{-1}$, respectively, in several Scottish studies as summarized by Black (1968). In addition, Dean et al. (1947) concluded that the recovery of fertilizer by ryegrass from three different soils was inversely related to relative P-fertility status of the soils.

The movement of fertilizer P through the soil profile was small (Table 3), avg 5.1, 5.3, 3.4, and 4.8% for Bernow, Houston Black, Muskogee, and Teller, respectively. Because of the small downward movement plus restriction of runoff loss of P by the casing walls, the recovery of $^{32}$P was good. Consequently, the likelihood of the applied fertilizer P under this prevailing practice to contribute soluble P to the groundwater of the area is negligible.
SUMMARY

The results of this 4-yr study of the disposition of fall-applied fertilizer P (30 kg ha$^{-1}$ yr$^{-1}$) to four Southern Plains soils under winter wheat, show that although only 9 to 23% of the applied fertilizer P was recovered by the crop, dry-matter yield increased each year with fertilizer application. Total uptake of P by wheat was relatively constant from one year to the next. Thus, in the present study, the 30 kg ha$^{-1}$ fertilizer application is adequate to give a maximum wheat yield response initially, and maintenance rates of P in succeeding years could possibly be reduced below 30 kg P ha$^{-1}$ without yield reductions. Consistent with earlier studies on corn, potatoes, and swedes (Black, 1968; Dean et al., 1947; Nelson et al., 1947), the recovery of fertilizer P by winter wheat was inversely related to the residual P-fertility status of the soil. Although the yield of winter wheat increased with consecutive fertilizer P applications, crop uptake of fertilizer P decreased. Consequently, as residual P builds up in the soil making an increasing contribution to P uptake by winter wheat, fertilizer P efficiency decreases. Consideration of residual P levels in the soil may, thus, reduce costly maintenance fertilizer P applications.

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REFERENCES


