ABSTRACT

The transport of bioavailable P (BAP) in agricultural runoff can stimulate freshwater eutrophication. Previous research has shown that the amount of P removed by Fe-oxide impregnated paper strips (Fe-oxide strips) is related to the growth of Selenastrum capricornutum in laboratory incubations. As only one algal type was used, additional assays were conducted to determine if Fe-oxide strips can estimate the potential bioavailability of P in runoff to Anabaena, Ankistrodesmus, and Euglena, which are common in eutrophic waters of the Southern Plains. Algal growth was related \( (P > 0.001) \) to the amount of P extracted from runoff sediment by Fe-oxide strips. For a given strip P content of runoff sediment, algal cell count increased in the order Anabaena, Euglena, Selenastrum, and Ankistrodesmus. Thus, the amount of P removed from runoff by Fe-oxide strips, estimates the BAP content of runoff that may be potentially available for uptake by several common freshwater algae.

The transport of BAP in agricultural runoff can stimulate freshwater eutrophication (Schindler, 1977). Bioavailable P represents orthophosphate P in dissolved (DP) and particulate (PP) attached to eroding soil material, that can be taken up by algae. Recently, Sharpley et al. (1982) reported BAP can range from 20 to 90% of the total P (TP) transported in runoff as a function of agricultural management. In addition, several studies have found little reduction in lake productivity with decreased TP input and attributed this to an increased bioavailability of P entering (Young and DePinto, 1982). Thus, measurement of BAP transport in runoff should improve our ability to evaluate the inputs of agricultural management on eutrophic response of lakes.

Standard methods to measure BAP involve lengthy algal assays culturing Selenastrum capricornutum with sediment samples (Miller et al., 1978). Rapid extraction methods using NH\(_4\)F and NaOH have been proposed (Hegemann et al., 1983; Sharpley et al., 1991). These methods have not been widely used, however, because of limitations in relating P extracted by chemicals bearing no resemblance to runoff or lake water composition, to in-lake bioavailability of P. Thus, Sharpley (1993) proposed the use of Fe-oxide strips to estimate BAP, as the growth of Selenastrum was found to be related to the Fe-oxide strip P content of runoff. The method uses runoff as the support medium and the strips act as a sink for P. Thus, the method may simulate algal P availability more closely than chemical extraction.

As only one algal type was used by Sharpley (1993), additional assays were conducted to see if the Fe-oxide strip method is valid for other algae. Therefore, this study investigates the use of Fe-oxide strips to estimate the potential availability of P in runoff to several freshwater algae (genera: Anabaena, Ankistrodesmus, and Euglena). Data for Selenastrum (Sharpley, 1993) is included for comparison. The four algae are commonly found in eutrophic farm ponds and lakes in the Southern Plains (Menzel et al., 1989; Troeger, 1978).

MATERIALS AND METHODS

Runoff Collection and Analysis

Characteristics of nine agricultural watersheds representing management practices in the Southern Plains, are presented in Table 1. The watersheds encompass a range of sizes (2–6 ha), soils (Alfisols, Inceptisols, and Mollisols), and slopes (1–9%). Fertilizer P was only applied to E5 (22 kg P ha\(^{-1}\)), C1 (50 kg P ha\(^{-1}\)), and C2 (22 kg P ha\(^{-1}\)) in 1987 at rates determined by soil test recommendations. More detailed information on watershed management is given by Sharpley et al. (1992).

Runoff was measured using calibrated flumes equipped with water-level recorders. Five to 15 samples are collected during each runoff event, composited in proportion to flow to provide a single representative flow-weighted sample, and stored at 277 K. Runoff samples from four events in May and June, 1986 and three events in May and June 1987, were combined and sediment concentrated by centrifugation and decantation. The resultant slurries were stored at 277 K. The sediment concentration of each slurry was determined by evaporation (378 K) to dryness.

Clay content of each sediment sample was determined by pipette analysis, following dispersion with sodium hexametaphosphate (Gee and Bauder, 1986). The sediment slurries were sterilized by autoclaving at 394 K and 100 Pa prior to P analysis and algal assay inoculation. Phosphorus was extracted from 0.2 g sediment with 30 mL of 0.5 M NH\(_4\)F (pH 7.0) for 1 h; 100 mL of 0.1 M NaOH for 17 h; and one Fe-oxide strip on an end-over-end shaker. Iron-oxide strip methodology is described below. Total P content of each sediment sample was determined by digestion with perchloric acid (Olsen and Somsers, 1982). The concentration of P was measured on neutralized filtrates of all extracts by the colorimetric method of Murphy and Riley (1962). Autoclaving did not affect the amount of P extracted by the above methods, suggesting P bioavailability was similar before and after sterilization.

Iron-oxide strips were prepared by immersing filter-paper circles (15-cm diam., Whatman\(^1\) no. 541) in a 10% (w/v) solution of FeCl\(_3\)-6H\(_2\)O. The paper circles were then air dried and immersed in 2.7 M NH\(_4\)OH solution to convert FeCl\(_3\) to Fe oxide. Immersion in NH\(_4\)OH was carried out as rapidly as possible to avoid uneven oxide deposition on the paper (Lin et al., 1991). After the paper circles were air dried, they were cut into strips 10 by 2 cm and stored for subsequent use.

One Fe-oxide strip was shaken with 0.1 g of sediment in 40 mL of deionized distilled water for 16 h on an end-over-end shaker at 298 K. The strip is then removed, rinsed free of adhering particles, and dried. Phosphorus retained on the strip is removed by shaking the strip end-over-end with 40 mL of 0.1 M H\(_2\)SO\(_4\) for 1 h, and following neutralization is measured by the method of Murphy and Riley (1962). For runoff, the Fe-oxide strip method involves shaking one strip with 50 mL of runoff.

Algal Assay

Anabaena, Ankistrodesmus, Euglena, and Selenastrum were cultured in provisional algal assay procedure (PAAP) medium

Abbreviations: BAP, bioavailable phosphorus; DP, dissolved phosphorus; PP, particulate phosphorus; TP, total phosphorus; PAAP, provisional algal assay procedure.

SHARPLEY: ALGAE AVAILABLE PHOSPHORUS IN AGRICULTURAL RUNOFF

Table 1. Management of the watersheds and selected characteristics of runoff sediment collected.

<table>
<thead>
<tr>
<th>Watershed</th>
<th>Year</th>
<th>Management†</th>
<th>Clay</th>
<th>Strip P‡</th>
<th>NH₄F</th>
<th>NaOH</th>
<th>Total P mg kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>El Reno, OK</td>
<td>E5</td>
<td>1986</td>
<td>CT wheat</td>
<td>44</td>
<td>69</td>
<td>5</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td>E6</td>
<td>1986</td>
<td>CT wheat</td>
<td>49</td>
<td>101</td>
<td>4</td>
<td>125</td>
</tr>
<tr>
<td></td>
<td>E7</td>
<td>1986</td>
<td>CT wheat</td>
<td>43</td>
<td>99</td>
<td>5</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td>E8</td>
<td>1986</td>
<td>NT wheat</td>
<td>45</td>
<td>101</td>
<td>6</td>
<td>148</td>
</tr>
<tr>
<td>Ft. Cobb, OK</td>
<td>C1</td>
<td>1986</td>
<td>Peanut - sorghum rotation</td>
<td>45</td>
<td>42</td>
<td>3</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>1986</td>
<td>Peanut - sorghum rotation</td>
<td>44</td>
<td>108</td>
<td>4</td>
<td>161</td>
</tr>
<tr>
<td>Woodward, OK</td>
<td>W2</td>
<td>1986</td>
<td>Native</td>
<td>46</td>
<td>233</td>
<td>15</td>
<td>265</td>
</tr>
<tr>
<td></td>
<td>W3</td>
<td>1986</td>
<td>Grass</td>
<td>42</td>
<td>210</td>
<td>12</td>
<td>233</td>
</tr>
<tr>
<td></td>
<td>W4</td>
<td>1987</td>
<td>NT wheat</td>
<td>50</td>
<td>193</td>
<td>13</td>
<td>213</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1987</td>
<td>Grass</td>
<td>53</td>
<td>231</td>
<td>16</td>
<td>251</td>
</tr>
</tbody>
</table>

† CT and NT represent conventional and no till practices. Peanuts (Arachis hypogena L.); sorghum, [Sorghum bicolor (L.) Moench]; wheat, (Triticum aestivum L.). Strip P represents bioavailable P determined by Fe-oxide strip method.

RESULTS AND DISCUSSION

The amount of P removed from runoff sediment by Fe-oxide strips ranged from 42 to 233 mg kg⁻¹ (Table 1). Although P extraction by 0.1 M NaOH was greater than Fe-oxide strips (Table 1), amounts extracted by both methods were related ($r^2 = 0.96$). In contrast, 0.5 M NH₄F extracted small amounts of P. The proportion of TP as strip P ranged from 11 to 41% (average of 27%). These runoff sediments varied in P content and were, thus, used as the source of P in assays with P-starved algae.

Algal growth was related to the amount of P extracted from runoff sediment by Fe-oxide strips (Fig. 1). The relationships were significant ($P > 0.001$) for four algal types in incubations with runoff sediment as the sole P source. The amount of DP added to the algal incubations (1 to $2 \times 10^{-5}$ mg P) was small compared with strip P levels (4 to $23 \times 10^{-5}$ mg P). For a given strip P content of runoff sediment, algal cell count increased in the order Anabaena, Euglena, Selenastrum, and Ankistrodesmus. Thus, the Fe-oxide strips provide an estimate of the potential BAP content of runoff.

In addition to strip P, 0.5 M NH₄F and 0.1 M NaOH extractable content of runoff sediment P was significantly ($P > 0.001$) related to the growth of each algal type (Table 2). As NH₄F extracted smaller amounts of P than NaOH and Fe-oxide strip (Table 1), it may provide less accurate estimates of BAP than the other two
Table 2. Coefficient of determination ($r^2$) of the linear regression between sediment P content and algal cell count after a 29-d incubation.

<table>
<thead>
<tr>
<th>Sediment P form</th>
<th>Anabaena</th>
<th>Ankistrodesmus</th>
<th>Euglena</th>
<th>Selenastrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strip P†</td>
<td>0.93**</td>
<td>0.92**</td>
<td>0.92**</td>
<td>0.95**</td>
</tr>
<tr>
<td>0.5 M NH₄F</td>
<td>0.91**</td>
<td>0.92**</td>
<td>0.94**</td>
<td>0.93**</td>
</tr>
<tr>
<td>0.1 M NaOH</td>
<td>0.74**</td>
<td>0.79**</td>
<td>0.80**</td>
<td>0.89**</td>
</tr>
<tr>
<td>Total P</td>
<td>0.62*</td>
<td>0.65*</td>
<td>0.63*</td>
<td>0.61*</td>
</tr>
</tbody>
</table>

*, ** Significance at >0.01 and 0.001 probability levels, respectively.
† Strip P determined by Fe-oxide strip method.

methods. In addition, sorption of P by CaF₂ formed during NH₄F extraction of calcareous materials and exchange of Fe-bound P by F⁻, make this extractant unsuitable for routine use (Syers et al., 1972; Williams et al., 1971). Compared with the NaOH extraction, Fe-oxide strips use actual runoff water and may thus more realistically simulate algal P uptake from runoff.

In conclusion, the amount of P removed from runoff by Fe-oxide strips, estimates the BAP content of runoff that may be potentially available for uptake by several common freshwater algae. The Fe-oxide strips, however, measure P bioavailability under optimal conditions. Thus, strip P will be a potential not quantitative estimate of BAP in runoff.

REFERENCES


