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Correlating Soil Test Phosphorus Losses in Runoff

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CORRELATING SOIL TEST PHOSPHORUS IN CAPTINA SILT LOAM TO PHOSPHORUS LOSSES IN RUNOFF

Technical Completion Report
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ABSTRACT

Phosphorus in agricultural runoff is often a major cause of accelerated eutrophication of lakes and streams. Previous research has indicated that the amount of dissolved P (DP) in runoff is directly related to P content of the surface soil. Decades of fertilizer application at rates exceeding those of crop uptake have elevated soil test P (STP) levels in areas of intensive crop and livestock production, making this the major source of DP loss in runoff. The objective of our experiment was to relate STP content of Captina silt loam to P concentration and loss in runoff, and determine which STP method correlates best to P levels in runoff. The 57 grass plots used in this study had a wide range of STP levels. A representative soil sample was composited from the 0-2 cm depth of each plot, and STP content was determined by Mehlich III, distilled water, and iron oxide paper strip extraction methods. Simulated rain was applied at 100 mm h^{-1}. Runoff samples were filtered and analyzed for DP content. Regression methods showed STP (regardless of extraction method) was directly related to runoff DP, but extractions with distilled water or iron oxide paper strips gave results that correlated most closely with runoff DP concentrations. Because plot runoff totals were highly variable, total DP load did not correlate well with STP.

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INTRODUCTION

Surface runoff from agricultural land is one of the major causes of accelerated eutrophication in lakes and streams. In fact, in recent reports to Congress, the U.S. Environmental Protection Agency identified agricultural nonpoint source (NPS) pollution as the major source of stream and lake contamination preventing attainment of the water quality goals identified in the Clean Water Act (USEPA, 1988).

In most cases, accelerated eutrophication of lakes and streams is caused by the addition of excessive amounts of nitrogen (N) and phosphorus (P) (Levine and Schindler, 1989). Exchange of N between the atmosphere and surface water is difficult to control and many blue-green algae are able to utilize atmospheric N. As a result, P is most often the element limiting accelerated eutrophication. Programs aimed at minimizing lake eutrophication from agricultural NPS pollution should therefore emphasize controlling P inputs to surface water. In the late 1970s, the International Joint Commission (IJC) between the U.S. and Canada recommended this approach for managing NPS pollution in the Great Lakes Basin (Rohlich and O'Connor, 1980). More recently, Florida water quality management programs dealing with NPS pollution have focused on P (Little, 1988). In Holland, the national strategy for minimizing NPS pollution, especially eutrophication due to animal wastes, is to limit entry of P into both surface and groundwater (Breeuwsma and Silva, 1992). Recent review papers by Sharpley et al. (1994) and Daniel et al. (1994) also identified the importance of developing P management strategies to limit surface water eutrophication from agricultural nonpoint pollution.

Sources of runoff P in an agricultural watershed are many and varied, but the greatest potential for accelerated eutrophication occurs in regions with intense animal manure production (Duda and

Finan, 1983). Generally, the manure is land-applied as pasture fertilizer and application rates are based on nitrogen needs of the forage, with little consideration given to forage P requirements or the potential for eutrophication. While most manure has high concentrations of P, the P requirement of plants is usually very low relative to the N requirement. For example, if manure is used to meet N needs for fescue production in Northwest Arkansas, an excess of 40, 37, and 17 kg ha^{-1} of P is applied using poultry, swine, or dairy manure, respectively (Huneycutt et al., 1988; ASAE, 1991; USDA-SCS, 1992). The P excesses are even greater if application rates are adjusted for N losses (e.g., volatilization). Thus, the inherent characteristics of animal manures and nutrient uptake of crops can promote P build-up. Decades of such fertilizer application at rates exceeding those of crop uptake have elevated soil test P (STP) levels in areas of intensive crop and livestock production. For example, 65% of the soils tested in Delaware were in the high to excessive P range (Sims, 1992).

Previous research has indicated that the P content of surface soil can directly influence the amount of dissolved P (DP) in runoff from that soil (Sharpley et al., 1977; Sharpley et al., 1978; Sharpley et al., 1994; Daniel et al., 1994). Because STP and runoff DP concentrations are related, a threshold level of STP exists that can result in runoff which is sufficiently high in DP to cause eutrophication. This link is not unexpected and must be considered in developing P management strategies that limit eutrophication but sustain high crop production. In fact, the ubiquitous contribution of runoff P from soils with elevated STP levels is potentially a more important and difficult to manage source of DP than improper land application of manure. For example, Edwards et al. (1993) monitored natural runoff from fescue-pasture watersheds where soils tested by Mehlich III extraction were in the excessive (above 150 mg kg^{-1}) STP range.

Mean annual DP concentrations in the runoff ranged from 1.25 to 2.6 mg L^{-1}, with elevated STP levels responsible for the major (65 to 90%) portion of the annual DP loss, even when a major runoff event occurred 1 d after application of manure. The persistent nature of STP makes this source of runoff DP especially problematic.

Lacking clear eutrophic standards and research data, some states (OH, MI, WI, and AR) have used a subjective process, based on STP levels adequate for crop production and those "perceived" to bring about eutrophic runoff, to identify a general threshold STP level for management purposes (Sims, 1992). Unfortunately, no research base exists that relates these threshold levels directly to runoff water quality.

PURPOSE AND OBJECTIVES

An experiment was conducted to begin developing a research base for best management practices (BMPs) related to STP levels in northwestern Arkansas. In this experiment, STP content of Captina silt loam plots was determined by three different extraction methods: Mehlich III, distilled water, and iron oxide-impregnated paper strip. At present, the Mehlich III chemical extractant is commonly used for STP analysis in soil testing laboratories because it can conveniently extract several elements simultaneously. However, the Mehlich III method was developed to assess fertility status of soil for crop production, not to predict runoff water quality. Therefore, distilled water, which dissolves less P, may be the most appropriate STP extractant for predicting runoff DP. The third method utilized small strips of filter paper coated with iron oxide to extract soil P. Experiments have shown that the P reacting with the iron oxide closely approximates the amount of P actually available for use by growing algae (bioavailable P)

(Sharpley, 1993). This method may give the best estimate of the potential for accelerated eutrophication resulting from a soil's STP level. Captina silt loam is fairly representative of soils in this region which regularly receive surface applications of poultry manure, and often contain high levels of STP. The objective of this experiment was to investigate whether P concentration and loss in runoff were related to the STP content of Captina silt loam, and determine which STP method best accounts for P levels in runoff.

MATERIALS AND METHODS

The 57 plots used for this study were located at the University of Arkansas Agricultural Experiment Station at Fayetteville on a Captina silt loam (fine-silty, siliceous, mesic Typic Fragiudult) established in fescue (Festuca arundinacea Schreb.). Each plot was 1.5 x 6 m with a uniform slope of approximately 5%, borders to isolate plot runoff, and a self-cleaning flow collector as described by Edwards and Daniel (1992).

Sharpley et al. (1978) found that STP levels correlate best with runoff DP when the soil sample is taken only from the top layer of soil, preferably the 0-1 cm depth. Miller et al. (1993) confirmed that the top 2 cm of the soil profile has the greatest impact on P concentrations in runoff, so soil cores for this study were taken from the 0-2 cm depth. A representative soil sample was collected from each plot, and consisted of a composite of 10 cores (2.54 cm diameter) taken randomly from the plot surface for a total of approximately 120 g of soil. This provided an adequate amount of soil for analysis with minimal damage to the plot surface.

To reduce runoff variability due to antecedent moisture conditions, low intensity irrigation was used to bring the plots to uniform moisture conditions just prior to simulated rainfall. A simulator described by Edwards et al. (1992) was used to generate 30 minutes of runoff from each plot by applying simulated rain at an intensity of 100 mm h^{-1}.

Discrete samples were taken manually at 5-minute intervals during the runoff event. The volume of each discrete sample and the time required to collect it were recorded and used to calculate the mean flow rate and total runoff volume for the 5-minute interval. This information was used in conjunction with runoff DP analysis data, to determine the total DP load in the runoff from each plot. A subsample of each discrete sample was filtered (0.45 μm pore diameter) in the field to remove particulate P. All soil and runoff samples were stored in the dark at 4°C until they were analyzed.

The STP content of each soil sample was determined by three different extraction methods: Mehlich III, distilled water, and iron oxide-impregnated paper strip as described by Sharpley (1993). In our experiment, regression methods of statistical analysis were used to determine which STP method gave results that correlated most closely (had the most significant correlation coefficient) with runoff DP concentrations from the same plots. Runoff DP was quantified by the molybdenum-blue method for determination of P in water samples (Murphy and Riley, 1962); bioavailable P (BAP) in the runoff was quantified by the iron-oxide impregnated paper strip method (Sharpley, 1993). The average DP concentration in all of the runoff from a given plot was determined by using concentration and flow-rate data to calculate a flow-weighted mean concentration.

PRINCIPAL FINDINGS AND SIGNIFICANCE

The mean rainfall application required to produce 30 min of continuous runoff from each plot was 62.5 mm (CV = 9.7%). The mean surface runoff from the plots was 27.0 mm (CV = 40.4%). As these CV (coefficient of variance) values indicate, the total amount of runoff was highly variable among the plots, ranging from a low of 4.6 mm for plot 205 to a high of 47.6 mm for plot 603. The runoff variability was probably caused primarily by differences in infiltration rate, especially macropore flow. As the runoff event progressed, increasing soil water content reduced the infiltration rate and the amount of runoff increased steadily, from a mean of 2.6 mm during the first 5-min interval to 5.4 mm during the last 5 min of runoff.

The average DP concentration in runoff declined steadily during the course of the runoff event, from 1.732 mg L^{-1} during the first 5-min interval to 0.498 mg L^{-1} during the last 5 min of runoff. This decline may be attributed primarily to the dilution effect of increasing runoff volumes during the event, including some water which never came in direct contact with the soil surface. Also, some decline in runoff DP concentration may have occurred as DP already in the soil solution was washed out early in the runoff event. The mean volume-weighted DP concentration for the entire runoff event from each plot ranged from a low of 0.306 mg L^{-1} in plot 401 to a high of 1.809 mg L^{-1} in plot 204. The BAP concentration in runoff was slightly higher than DP, ranging from 0.368 mg L^{-1} in plot 401 to 2.182 mg L^{-1} in plot 204.

The STP values obtained using Mehlich III extractant solution ranged from 54 to 490 mg kg^{-1} and showed a significant (α=0.001) direct correlation (r^2 = 0.722) to DP levels in plot runoff (Fig. 1). However, the correlation was much closer when STP was extracted by distilled water (r^2 = 0.824 in Fig. 2) and iron-oxide paper strip (r^2 = 0.819 in Fig. 3). The STP extracted by iron-oxide paper strips (23-170 mg kg^{-1}) was greater than STP extracted by distilled water (14-110 mg kg^{-1}), and may give a better estimate of the P that will support algal growth (Sharpley, 1993).

For BAP concentrations in runoff, the r^2 values of their correlation to STP levels were 0.717, 0.815, and 0.822 for the Mehlich III, distilled water, and iron-oxide paper strip STP extractions, respectively (Fig. 4, 5, and 6). These correlations were similar to those obtained for DP in runoff and were also very significant (α=0.001). Again runoff P correlated more closely to STP extracted by distilled water or iron-oxide paper strips than by Mehlich III extractant.

Dissolved phosphorus loss (load) during the runoff event ranged from 43.4 g ha^{-1} in plot 205 to 472.8 g ha^{-1} in plot 305, and BAP loss ranged from 54.2 g ha^{-1} in plot 205 to 542.0 g ha^{-1} in plot 305. Large differences in infiltration rate resulted in high variability of total runoff among the plots. Therefore, although the concentrations of both DP and BAP in runoff showed good correlation to STP, the P load in the runoff did not correlate well with STP, whether measured as DP (Fig. 7) or BAP (Fig. 8).

CONCLUSIONS

The results of this study provide further evidence of a direct relationship between soil P levels and DP (or BAP) concentration in runoff from the soil surface. In this experiment, with soil samples taken only from the surface layer of soil (0-2 cm deep), the direct relationship was apparent regardless of which STP method and runoff P method were used. However, STP correlated much more closely to runoff P when extracted with distilled water or iron-oxide paper strips rather than Mehlich III extractant. The form of

P extracted (DP or BAP) from runoff had very little, if any, effect on the correlation between STP and runoff P.

The DP concentrations in runoff from all plots declined as flow rates increased during the course of the runoff event. Because total runoff amounts varied greatly among plots, no correlation was observed between STP and total DP loss.

Distilled water and iron-oxide paper strips were the most effective STP extractants used in this study to predict DP and BAP concentrations in runoff. However, time or economic constraints may sometimes require the use of the less effective Mehlich III STP method to make such predictions. Although the distilled water extractant was equally effective at predicting DP and BAP losses, the iron-oxide paper strip detects slightly higher levels of P, and may better quantify the P that will actually contribute to accelerated eutrophication.

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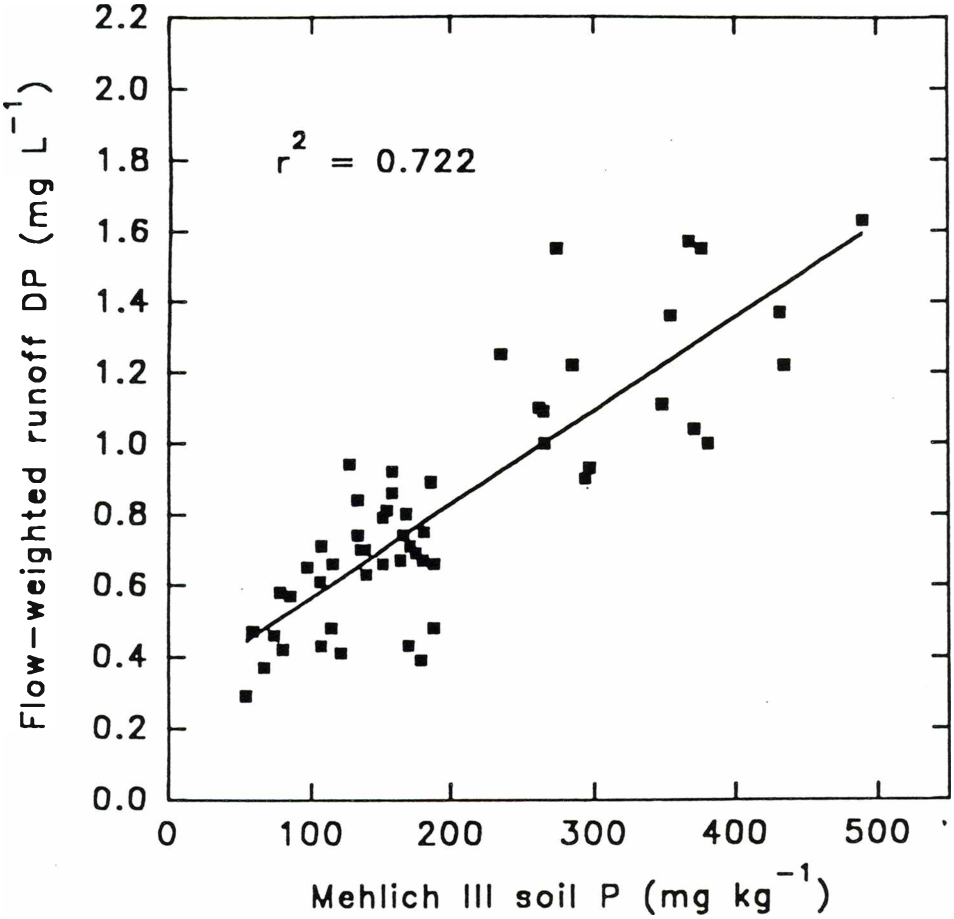

Fig. 1. Relationship between Mehlich III extractable P in Captina surface soil and dissolved P in runoff.

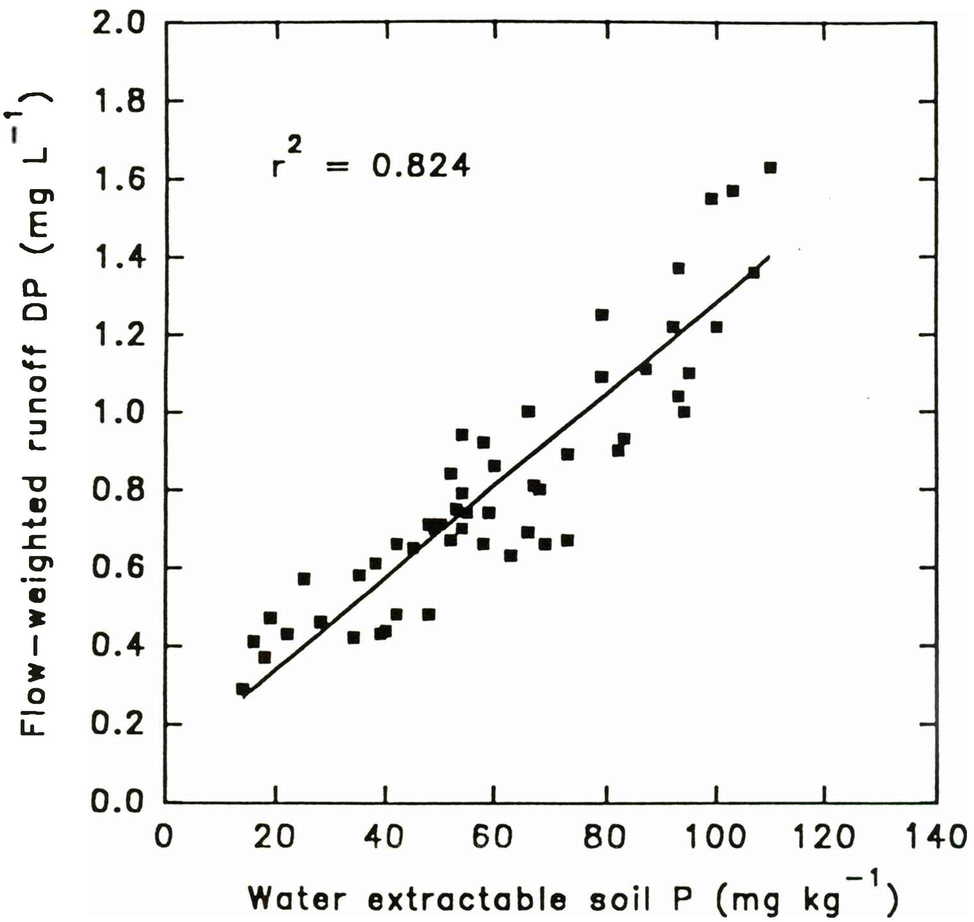

Fig. 2. Relationship between water extractable P in Captina surface soil and dissolved P in runoff.

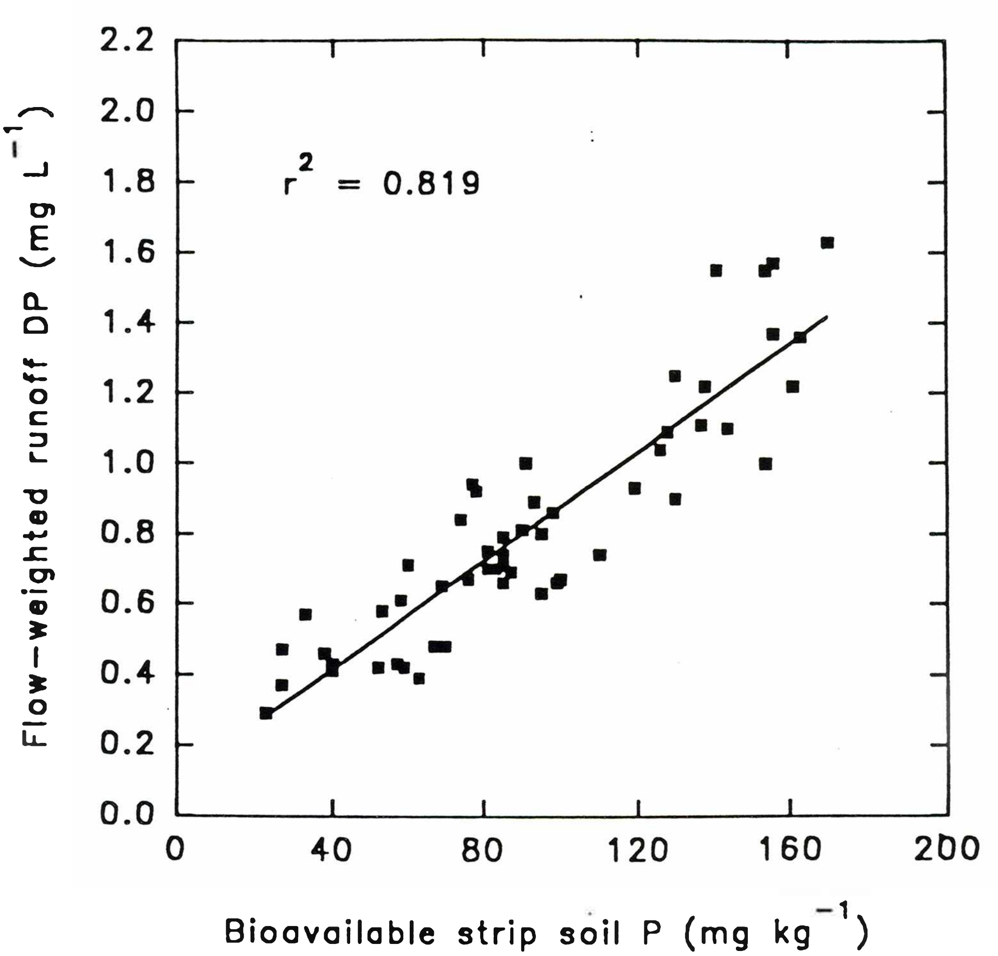

Fig. 3. Relationship between bioavailable strip extractable P in Captina surface soil and dissolved P in runoff.

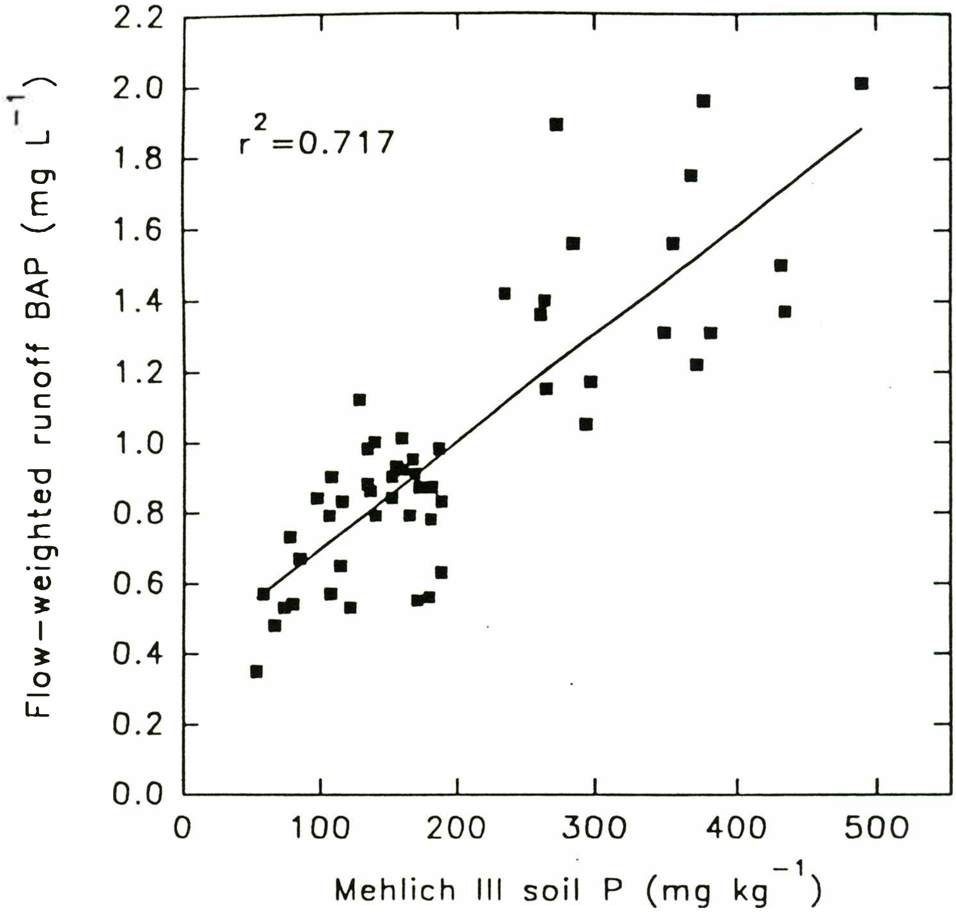

Fig. 4. Relationship between Mehlich III extractable P in Captina surface soil and bioavailable strip P in runoff.

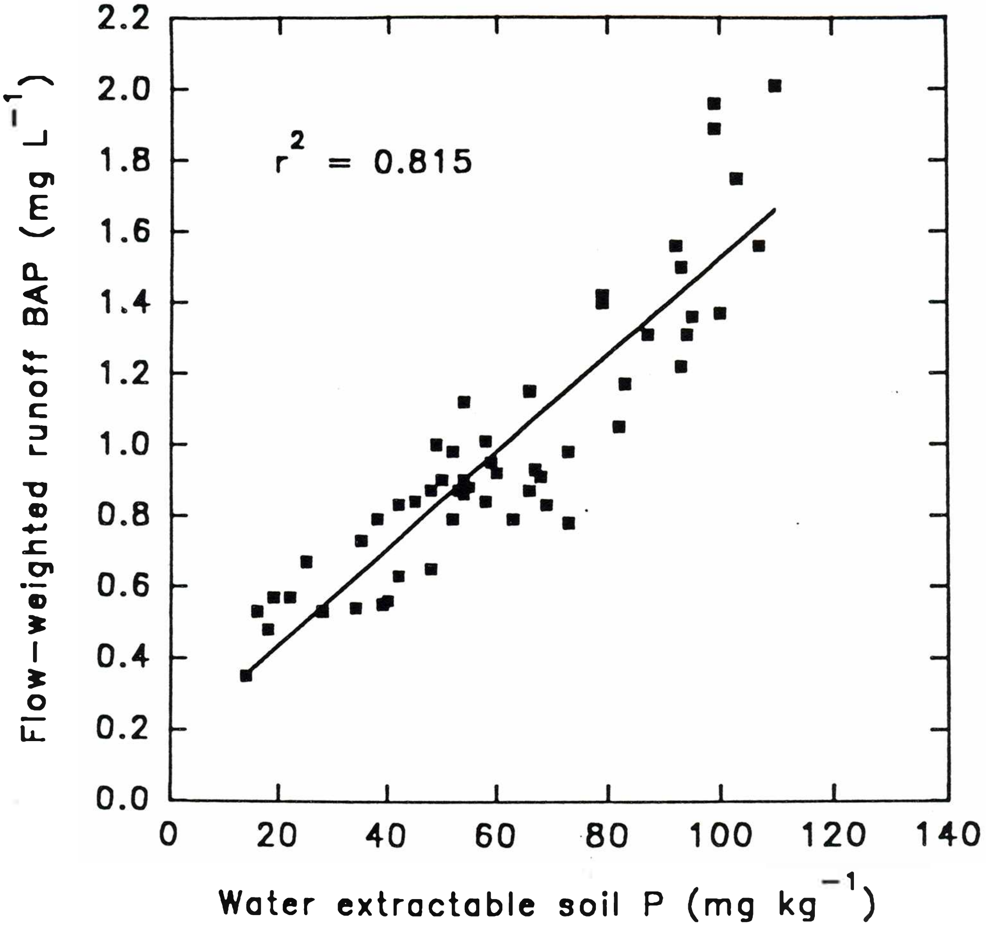

Fig. 5. Relationship between water extractable P in Captina surface soil and bioavailable strip P in runoff.

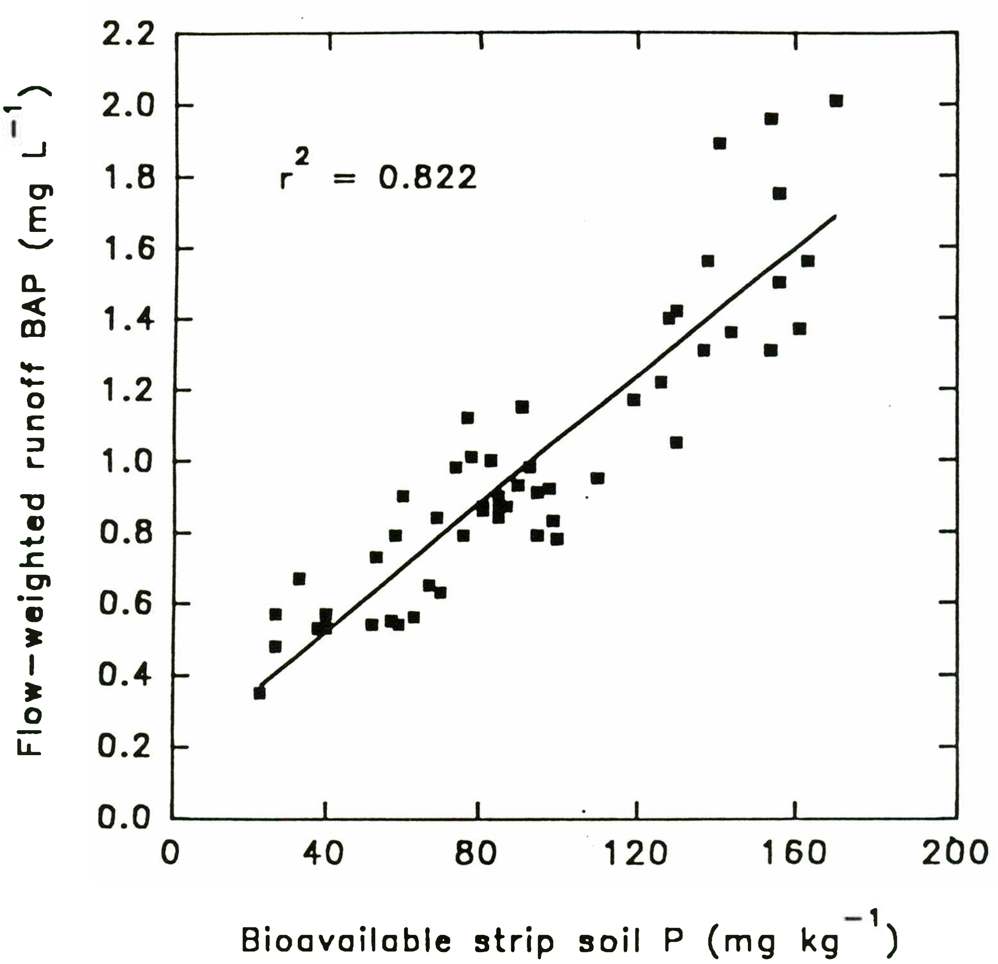

Fig. 6. Relationship between bioavailable strip extractable P in Captina surface soil and bioavailable strip P in runoff.

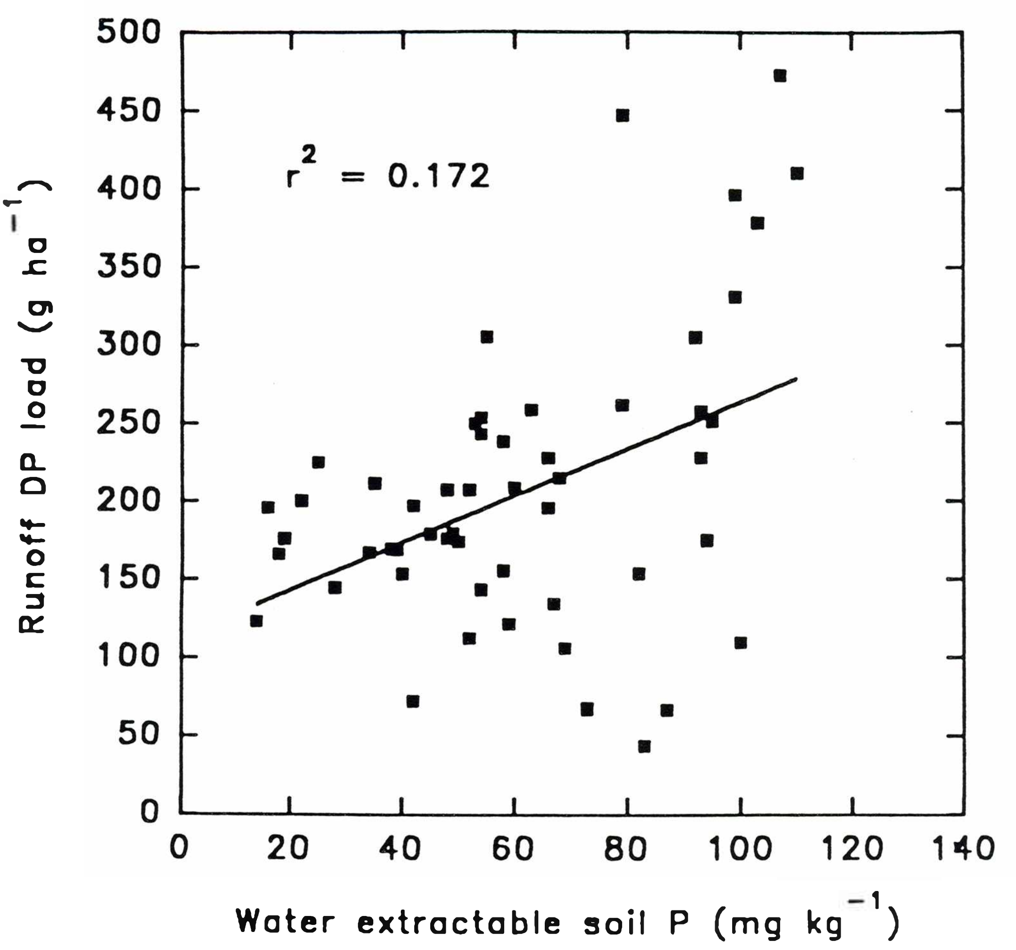

Fig. 7. Relationship between water extractable P in Captina surface soil and DP load in runoff.

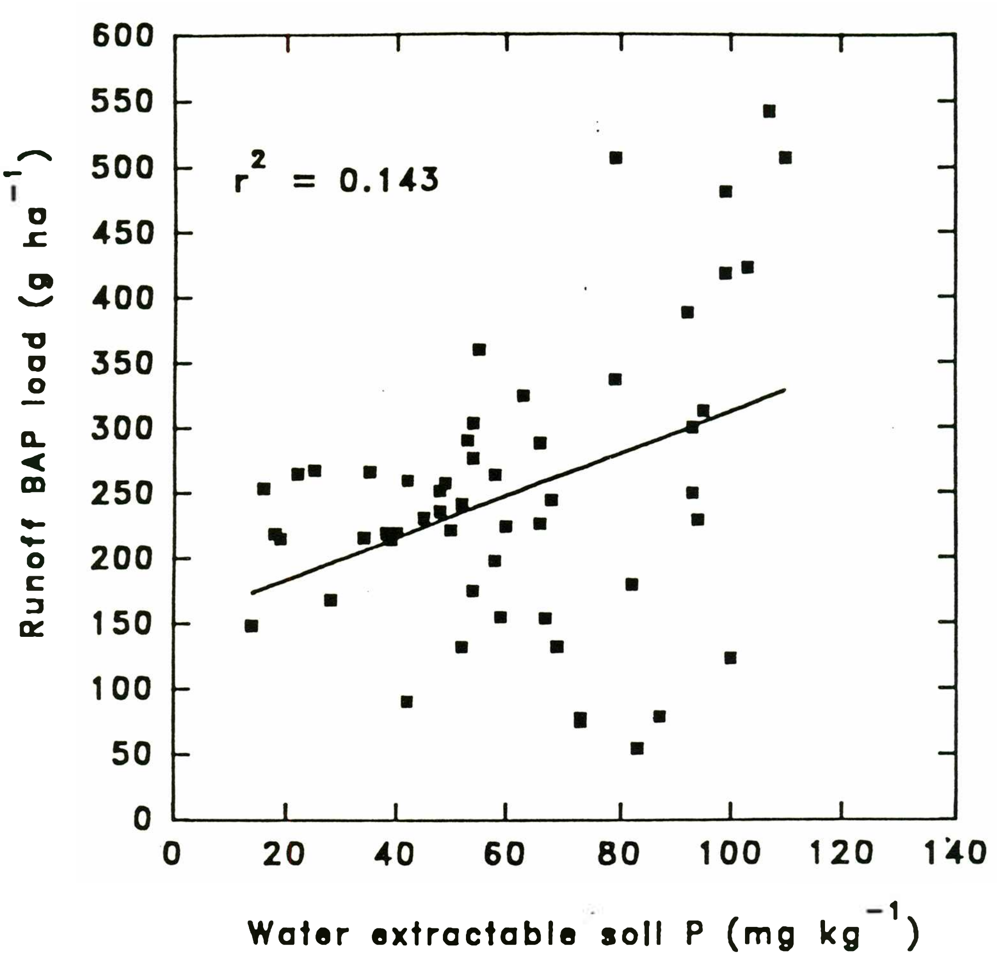

Fig. 8. Relationship between water extractable P in Captina surface soil and BAP load in runoff.