Phosphorus Runoff from Surface and Subsurface Fertilizer Applications in No-till and Strip-till Fields with Minimal Slope Gradient in Central Illinois

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INTRODUCTION

While P is essential for agricultural systems, it also controls eutrophication in freshwater systems (Carpenter et al., 1998; Kauppi et al., 1993; Kimmell et al., 2001; Kleinman and Sharpley, 2003; McDowell et al., 2001; Sharpley and Rekolainen, 1997). The Environmental Protection Agency (EPA) (1996) identified eutrophication as the major cause of impairment for recreation, drinking, and industrial water quality. Several reports have also indicated that agriculture is an important contributor of P to fresh waters (Carpenter et al., 1998; Kimmell et al., 2001; United States Geological Survey, 1999). Public concern and political pressure to deal with nutrient sources have grown due to hypereutrophic dead zones in the Gulf of Mexico and Pfiesteria piscicida (presumably responsible for harmful algal blooms) outbreaks in inland US waters (Burkholder and Glasgow, 1997; Kimmell et al., 2001; Satchel, 1997; Turner and Rabalais, 1994; USEPA, 1997). While Nitrogen (N) also contributes to eutrophication, P is considered the limiting nutrient for algal growth in surface waters (Kimmell et al., 2001; Parry, 1998; Sharpley et al., 1994).

Regular inputs of P fertilizer or manure surpassing the crop nutrient requirements contribute to increased levels of soil P (Daverede et al., 2003; Sharpley et al., 1994; McDowell et al., 2001). This increase is most pronounced in conservation tillage systems where P applications on the soil surface contribute to P stratification with higher P concentrations in the surface than the subsurface (Holanda et al, 1998). The increased P levels in the soil surface can increase P loads from agricultural lands if runoff events occur. Multiple factors can influence the load of P in runoff water. In general, the loss of P through runoff water is enhanced by the application of P fertilizer or manure, and could be affected by the timing, method of application, rate, form of fertilizer, and its placement (Kimmell et al., 2001; McDowell et al., 2001). Other factors playing a role include the runoff volume, sediment loss, depth of mixing of the soil, rainfall, slope, temperature, soil type, tillage, and soil cover (Daverede et al., 2003; Kimmell et al., 2001; McDowell et al., 2001).

Research on P runoff in relation to P management through tillage and fertilizer placement is somewhat limited and to a certain extent contradicting. A study reported that conventional-till produced more sediment loss in comparison to chisel-till and no till (Andraski et al., 1985). Mueller et al. (1984) reported increased total P loss in no-till compared to tillage with manure incorporated with chisel-till. Barisas et al. (1978) reported increased soluble P content in reduced tillage systems, but credited the findings to plant residue nutrient leaching and minimal fertilizer incorporation to the soil. Mixed reports on tillage treatment and soluble P were reported by Seta el al. (1993), where increased soluble P loss was encountered with conventional-till in comparison to no-till, but there were no significant differences in soluble P losses between no-till and chisel-till. Researchers have found that conservation tillage decreases runoff volume in comparison to intensive tillage systems (Blevins et al., 1990; Seta el al., 1993). On the other hand, other researchers determined that conservation tillage had greater runoff volume in comparison to conventional tillage (Lindstrom and Onstad, 1984; Gaynor and Findlay, 1995). Since P runoff is affected by different variables, it is possible that differences in results in the literature are caused by rainfall differences and intensities, slope of the area, existent soil moisture, soil texture, and infiltration rates (Kimmell et al., 2001).

As noted above, most studies have been focused on determining the effect of conservation vs. conventional tillage systems on P runoff. Relatively less has been done to compare differences in P runoff within different conservation tillage practices. Specifically, studies that compared no-till to strip till are scarce. The few available studies have been done in sandy soils or for productions systems that are very different from Illinois agriculture (Franklin et al., 2007; Truman et al., 2007). The only studies done in Illinois to compare no-till and strip-till were done in fields with substantial slope gradients and to study only the effect of tillage as no fertilizer treatments were applied (Harschi, et al., 1995; McIssac et al., 1991). A substantial portion of agricultural land in Illinois is in the 0 to 2% slopes category. While the potential for runoff is lower in "flat" landscapes, the effect of conservation tillage practices (no-till and strip-till) along with P application rate and placement method has not been evaluated for such landscapes. Also, in the last few years we have observed firsthand that large precipitation events can cause substantial soil erosion and water runoff even in very "flat" ground. These facts would indicate that research in this "flat" landscapes should be a priority. A few manuscripts recently published from our work in Illinois (Farmaha et al., 2011, 2012a, 2012b; Fernández and White, 2012) indicate some of the benefits associated with strip-till over no-till for corn and soybean production. In addition, in another publication (Fernández and Schaefer, 2012) we discussed the benefits of deep banding fertilizer to reduce surface P levels without negatively impacting corn and soybean yields. In all these recent studies, we have mentioned as a possible hypothesis that the potential for P runoff may be reduced with deep banding of fertilizer in no-till and strip-till systems. Obviously, research is needed to quantify the effect of conservation tillage and P fertilizer placement on P runoff.

MATERIALS AND METHODS

Original study setup

The study is being ~~was~~ conducted in commercial fields at three locations near Pesotum, Illinois (East Central Illinois). Soils in all three sites are~~were~~ a combination of Drummer silty clay-loam soil (fine-silty, mixed, mesic Typic Endoaquoll) and Flanagan silt loam (Fine, smectitic, mesic Aquic Argiudolls). Each of these sites had no prior history of banded fertilizer placement and fields were chisel plowed after corn and field cultivated after soybean in years before the study. Soil analysis of composite samples collected from the top 7-inch layer showed organic matter ranged from 3.0 to 3.5 % across sites, cation exchange capacity (CEC) ranged from 17 to 30 meq. of charge/100 g; and pH ranged from 5.1 to 6.3. Except for tillage and P and K fertilization, the crops were managed as recommended for the region.

The study was conducted on a corn-soybean rotation with 30-inch row spacing in all sites and for both crops. All three sites had soybeans during the 2007 growing season before the start of the study, thus corn was the first crop planted after treatment establishment. Plot size was 20 x 500 ft and treatments remained in the same plot for the duration of the study. The study was set up as a split-plot arrangement in a randomized complete-block design with two replications. The main (whole) plot included three tillage/fertilizer placement treatments: no-till/broadcast (NTBC); strip-till/broadcast (STBC); and strip-till/deep-placed (STDP). The split-plot treatments were blends of P_2O_5 and K_2O made to create seven P-K fertilizer treatments with a control receiving no P or K (0-0 or check). The six additional rates were established in 23 lb P_2O_5 and K_2O / ac increments starting with a blend of 46 lb P_2O_5 / ac and 46 lb K_20 / ac.

Strip-till operations were done always in the fall and corn was planted on the location of the strips the following spring. The soybean crop was also planted on the same crop-row position as corn but no tillage operations were performed for soybean. The location of the tillage and the banded fertilizer was maintained constant by using RTK satellite navigation technology (+/- 1-inch accuracy) (Trimble® Field Manager ™Software) with two GPS receivers, one mounted on the tractor and the other mounted on the tillage bar. Strip-till was performed on 30-inch row-spacing using a strip-till toolbar (DMI, Model 4300) that formed a residue-free berm approximately 2- to 3-inch tall and 10-inch wide and disturbed the soil approximately 7 to 7.5 inches deep. There was no soil disturbance before planting in the NTBC treatment.

Fertilizer treatments were also applied every two years in the fall before corn planting starting in fall 2007. Broadcast applications were done with a drop spreader (10T Series, Gandy, Owatonna, MN). For the STBC treatment, broadcast applications were performed after the strip-till operation. For the STDB treatment, the fertilizer was banded 6-inch below the soil surface during the tillage operation using a Gandy Orbit Air applicator (Model 6212C, Gandy, Owatonna, MN). Fertilizer sources were triple superphosphate (TSP) (0-45-0) as the P source, and KCl (0-0-60) as the K source. All corn plots received a total of 180 lb N /ac. To minimize variability, the same equipment and operator were employed to perform strip-tillage and nutrient placement at all three locations.

<u>P runoff study setup</u>

Starting in fall 2013 after soybean harvest, three fertilizer treatments from the original study (0, 92, and 161 lb P_2O_5 acre^{-1}and K_2O acre^{-1}) were selected for P runoff measurements. Because of treatment application since 2007, by fall 2013 the plots had a large gradient of soil surface P test levels, which made these plots ideal to accomplish the objectives of this study. In these plots, the fertilizer rates were reduced to half the amount but with annual applications; thus, the total amount of fertilizer remained the same over a corn-soybean cycle. Similarly, the tillage/placement operations remained constant except that they are done on a yearly basis.

We followed similar procedures to Daverede et al. (2003) for rainfall simulation and runoff sample collection and analysis. In the center of each treatment area a microplot (5 x 6.5 ft) was established by installing metal borders on 3 sides with a collection tray on the 4th side. The microplots were installed to be representative of the field with the long sides placed in the middle of a strip-till track. Soil samples next to the micro-plot area were collected at 0-4 and 4-8 inch depths for Bray-P analysis. During the rainfall simulation event 0-1 inch depth soil samples consisting of 12 cores were collected adjacent to the microplot for Bray-P analysis. Installation of microplot and rainfall simulation began one week after fertilizer application. Rainfall simulation started in early November 2013 but was disrupted by inclement weather until December. Thus, samples were collected only in one of the three locations. Runoff water from a 30-minute runoff event was collected from each micro-plot at 5 minute intervals (up to 500 ml) with an additional 1-liter sample collected after the rainfall simulation event. The runoff samples were analyzed for dissolved reactive phosphorus (DRP) and total phosphorus (TP.) Analysis of algal-available P (AAP) is not yet completed. Sediment from each sample was quantified. The length of rainfall simulation to initial runoff was recorded. The entire volume of runoff was recorded to calculate P load. Village of Tolono water supply was used for rainfall simulation. Water samples were collected from each source tank load for contaminant analysis.

In the spring of 2014 rainfall simulation will be performed and runoff samples will be collected prior to planting at all three locations. The micro-plots will be moved to a new location within the plots for the next rainfall simulation event in the spring. Yield data will be collected from the crop in the fall of 2014. In 2014 all three fields will be planted in corn. Following application of P and K treatments in the fall of 2014 rainfall simulation will be repeated at each site. Appropriate statistical analysis will be used to analyze the data.

RESULTS AND DISCUSSION

As noted above samples were collected from the two replications at one of the three locations. Thus, this report includes only preliminary data that has not been fully analyzed statistically. For this report concentrations of the 5 minute interval sampling were combined over the 30 minute runoff event. In addition, DRP samples were analyzed from the liter-sample collected after the 30 minute runoff event.

Dissolved reactive P (DRP) concentrations combined over the 30-minute rainfall simulation runoff period (Figure 1) showed greater DRP concentrations for broadcast P applications regardless of the tillage method (no-till or strip-till) compared to when the P fertilizer is banded in the subsurface (ST DP). For both DRP combined over the 30-minute rainfall simulation runoff period (Figure 1) and for DRP from runoff during the 30 minute period after rainfall simulation (Figure 2) when P is broadcast on the soil surface, soil disturbance with strip-till appeared to increase DRP concentrations relative to the no-till system where no soil disturbance occurred.

Concentrations of DRP increased with increasing P fertilizer rate (Figures 3 and 4). This finding illustrates the importance of P management, both in terms of soil P level and P fertilization rate, in minimizing the negative impact of P to the environment when runoff occurs. These data show that it is possible to reduce the amount of DRP by not applying more fertilizer (92 lb P_2O_5/acre over two years for this particular location) than what is needed to maintain an adequate fertility level. However, equally important it is to point out that even when an appropriate P fertilizer rate is used to maintain adequate fertility, in a runoff event the amount of P exiting the field will be higher than if no P fertilizer is applied. This illustrates that even when the best possible management practices are used, it is not reasonable to expect no negative impact on the environment. Interaction of tillage/fertilizer placement and P fertilizer rate shows that instead of broadcast applications, sub-surface banding P fertilizer with strip-till can be a viable alternative to minimize P runoff when P fertilizer applications are needed.

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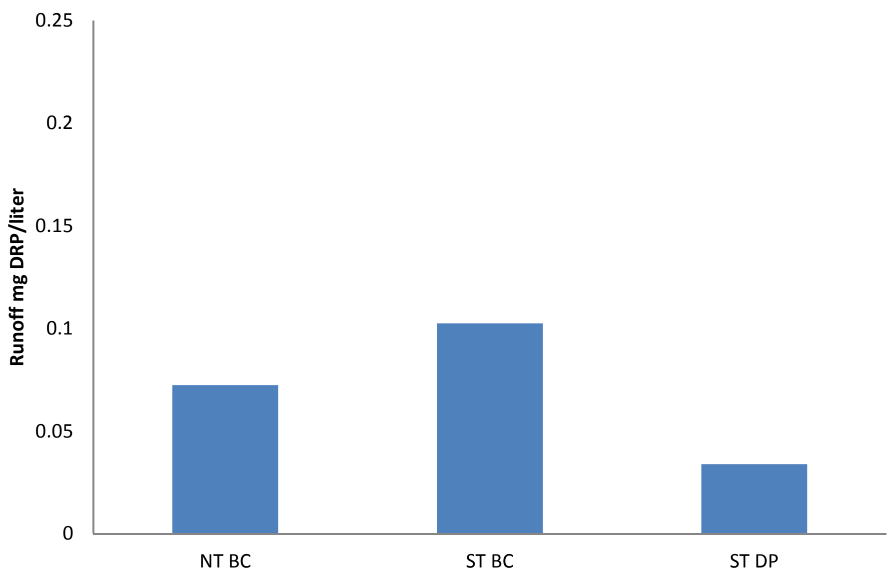

Figure 1. Combined concentration of dissolved reactive P in runoff at 5, 10, 15, 20, 25, 30 minute collection intervals as affected by tillage/fertilizer placement method averaged across P fertilizer rate.

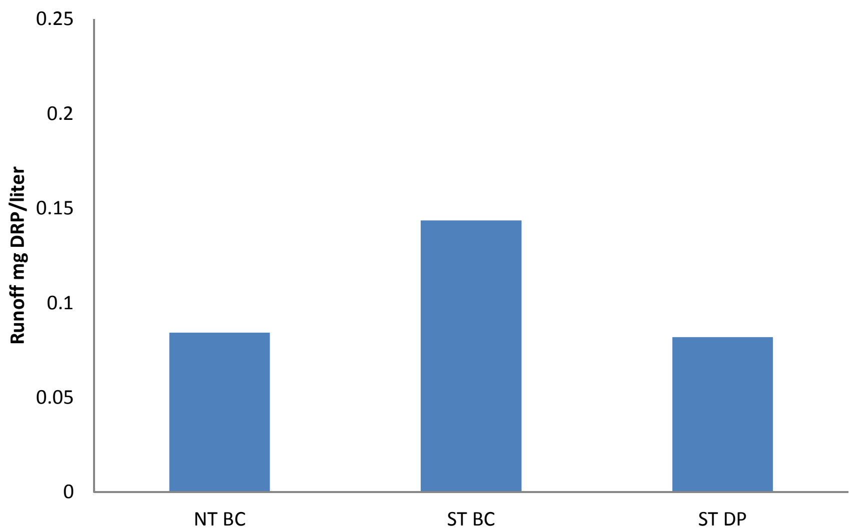

Figure 2. Dissolved reactive P concentration in liter-sample collected at end of 30 minute runoff event as affected by tillage/fertilizer placement method averaged across P fertilizer rate.

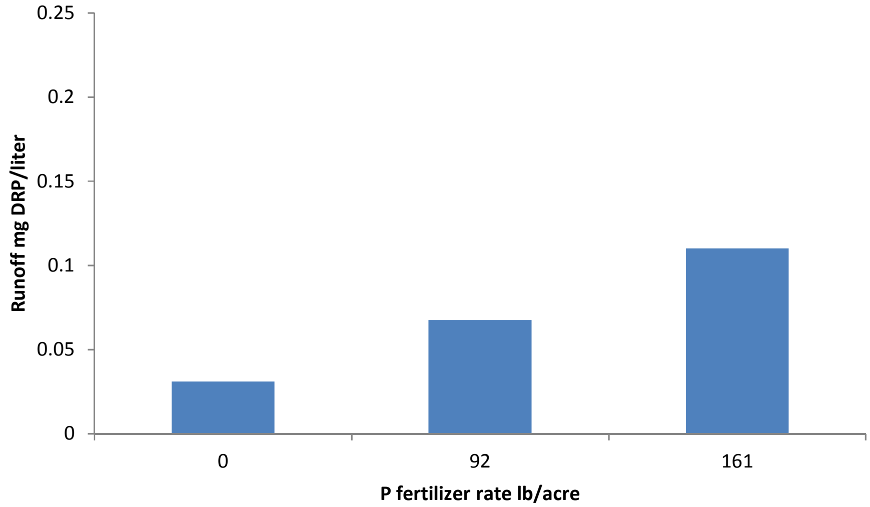
0.25
0.2
0.15
0.1
0.05
0
Runoff mg DRP/liter
0
92
161
P fertilizer rate lb/acre

Figure 3. Combined concentration of dissolved reactive P in runoff at 5, 10, 15, 20, 25, 30 minute collection intervals as affected by P fertilizer rate averaged across tillage/fertilizer placement method. Note that in fall 2013 the P fertilizer rate was reduced in half.

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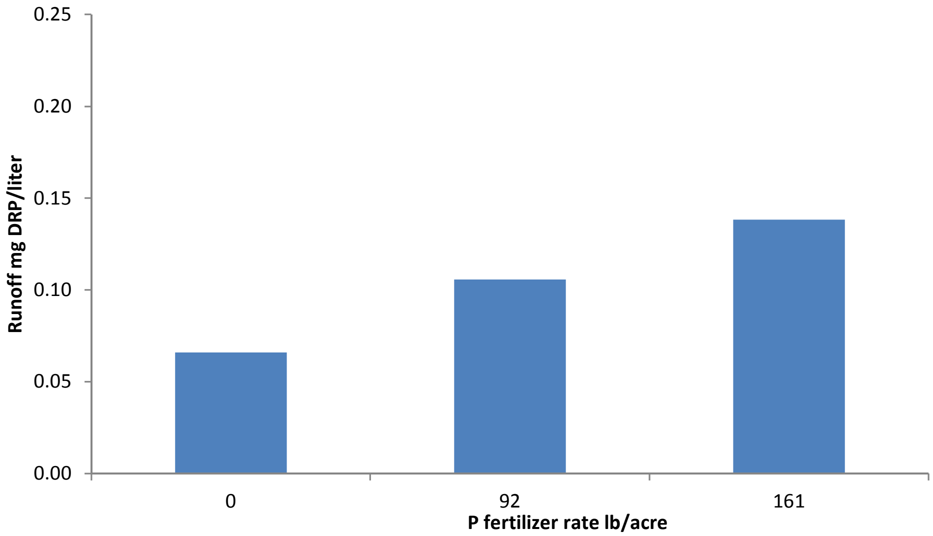

Figure 4. Dissolved reactive P concentration in liter-sample collected at end of 30 minute runoff event as affected by P fertilizer rate averaged across tillage/fertilizer placement method. Note that in fall 2013 the P fertilizer rate was reduced in half.

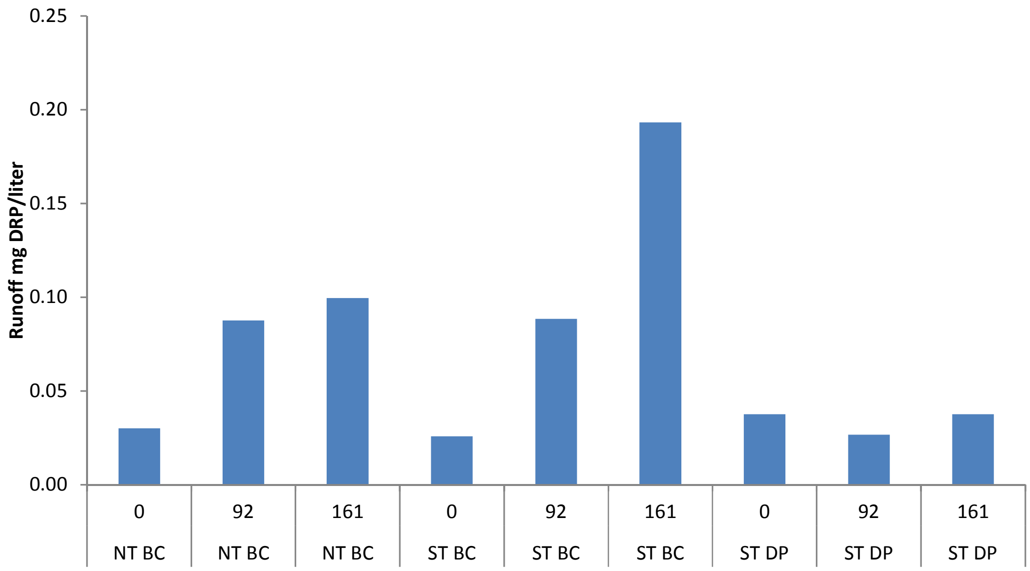

Figure 5. Combined concentration of dissolved reactive P in runoff at 5, 10, 15, 20, 25, 30 minute collection intervals as affected by tillage/fertilizer placement method and P fertilizer rate (lb/acre). Note that in fall 2013 the P fertilizer rate was reduced in half.

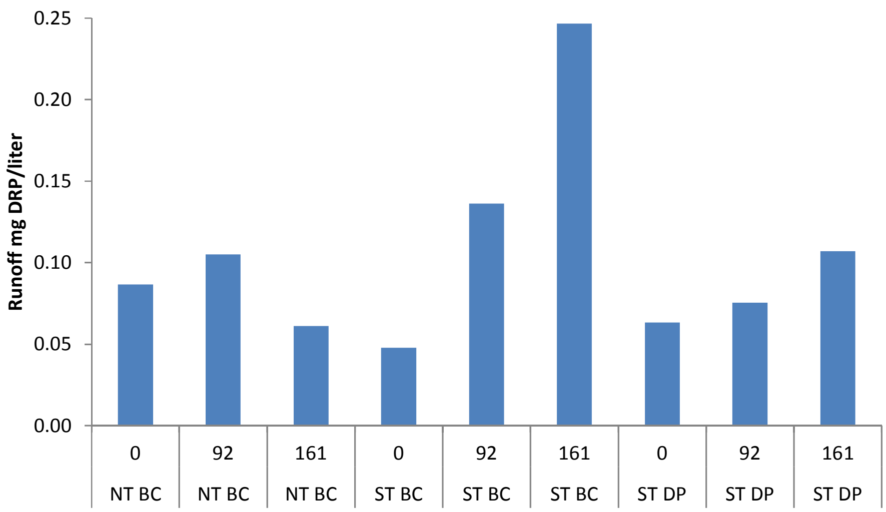

Figure 6. Dissolved reactive P concentration in liter-sample collected at end of 30 minute runoff event as affected by tillage/fertilizer placement method averaged across P fertilizer rate (lb/acre). Note that in fall 2013 the P fertilizer rate was reduced in half.