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When It Rains, It Pours: Extreme Precipitation & Nutrient Loss, Part 2

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January in the Midwest, a portion of the calendar that conjures memories of bitter cold, biting winds, and often snow. The holiday season was, however, unusually warm and fell well short of those remembrances of winters past (see e.g., Kraker, January 4, 2024). According to the National Oceanic and Atmospheric Administration (NOAA), including the National Weather Service (NWS), the outlook for winter 2023-2024 will be impacted by the continuing grip of a strong El Niño system. The result is likely higher temperatures than normal across much of the U.S, but mixed impacts on precipitation: possibly wetter-than-normal in the south; drier-than-normal in the north, including less snow (Becker, December 13, 2023; Johnson, November 30, 2023; L'Heureux and Brettschneider, October 26, 2023; NOAA, NWS, November 16, 2023). In the previous article for this series, we discussed the background on nutrient losses from farming and the impacts of extreme precipitation on those losses (*farmdoc daily*, December 7, 2023). Today's article dives deeper into the issue with a focus on phosphorus.

Background

As discussed previously, the key findings from research generally align with intuition, common sense, and experience (*farmdoc daily*, December 7, 2023). Nutrient losses almost all happen during heavy rains and snow melt. Farming practices and soil conditions at the time of precipitation, moreover, create the conditions for nutrient loss; excess nutrients on bare and frozen ground are very vulnerable to being lost. Therefore, while farmers cannot control the weather, they can control important aspects of the conditions in their fields that can lead to nutrient losses when precipitation falls. This holds true for phosphorus.

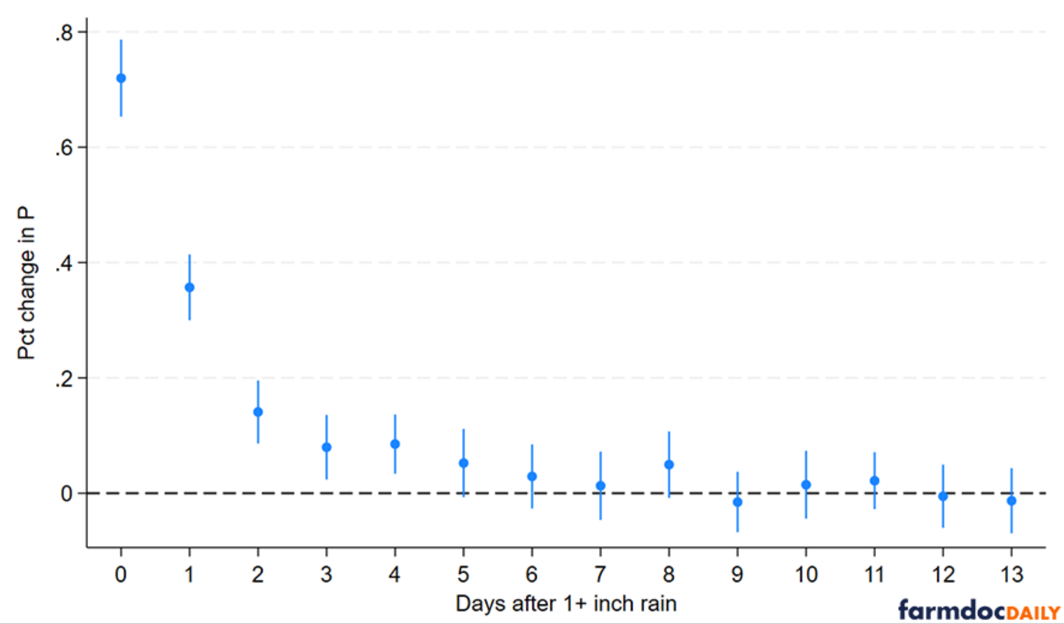
Phosphorus (P) is an essential element for life, including plant life; phosphorus fertilizer has traditionally come from sedimentary rocks (phosphate rock) and manure, but in recent years has increasingly been in the form of ammonium phosphates (see e.g., Margenot and Lee, 2023; Leon, Nakayama and Margenot, 2023; Hertzberger, Cusick and Margenot, 2021; Margenot et al., 2019; Johnston et al, 2014; Ashley, Cordell and Mavinic, 2011; Cordell, Drangert and White, 2009). Phosphorus moves through its cycle (and as such, our ecosystems) very slowly; sedimentized phosphorus that has bound to soil may remain in that soil for decades or even a century. Plants feed on phosphorus in the soils, but only small amounts are dissolved and available to plants, leading to limitations on growth and yields. The combination of the capacity of soils to fix P compared to the low use efficiency of most crops also results in surplus P that accumulates over time (Schneider et al., 2019; Zhu, Li and Whelan, 2018; Motew et al., 2017; Gentry et al., 2007). Again, the nutrients that remain in the soils after harvest are the most susceptible to being lost due to precipitation events.

Discussion

The discussion that follows reviews what happens to phosphorus levels in surface water when it rains. The discussion works through recent research that tracked phosphorus concentrations in surface water quality readings for over a decade in Wisconsin, with readings both before and after the precipitation events (Skidmore et al., 2023). In general, phosphorus spikes more after extreme precipitation in areas with: (1) more development; (2) more crop agriculture; (3) and more livestock agriculture (of any scale). Each of these are sources of phosphorus. It is also important to note that a significant amount of the spike in phosphorus is unexplained by current activity. It is likely that unexplained phosphorus is due to residual and legacy sources of phosphorus—residual in that it has accumulated in agricultural soils from past applications; legacy, which might be phosphorus accumulated over longer time frames and larger scales, possibly from natural processes in addition to human activity (see e.g., Zhou and Margenot, 2023). An example of phosphorus not explained directly by farm applications is that resulting from streambank erosion, which includes natural processes that are also impacted by human activities (see e.g., Margenot et al., 2023; Zhou and Margenot, 2023).

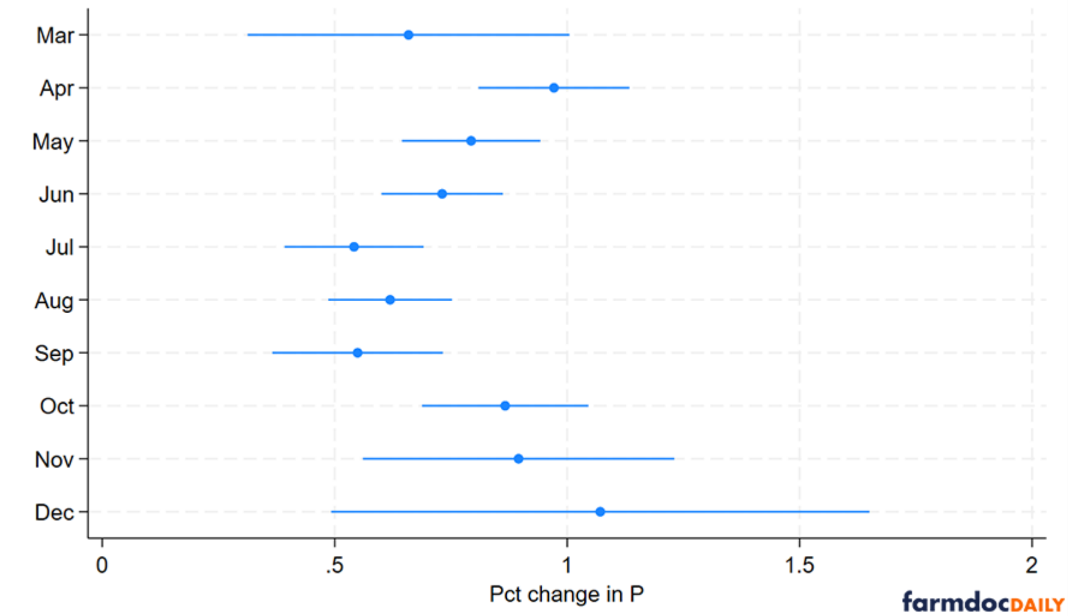
In short, the levels of phosphorus in surface water increased substantially with increased precipitation (Skidmore et al., 2023). Surface water quality readings on a day with one half to one inch of rain found phosphorus concentrations that increased by 42% compared to a baseline day with less than half an inch of rain. If there were one to two inches, those readings increased by 67%, and if there were more than two inches, phosphorus in surface water more than doubled (104% increase). Simply comparing days with more or less than an inch of rain, phosphorus concentrations also remained elevated for over a week after a day where precipitation occurred. Figure 1 graphs the percent increase (where 1 corresponds to a 100% increase) in phosphorus for the two weeks following a day with more than an inch of rainfall.

Figure 1. Percent Change in Phosphorus Concentration for Two Weeks after a Day with More Than One Inch of Precipitation. Coefficients Should Be Interpreted as Percents by Multiplying by 100 (e.g., 0.8 Corresponds to an 80% Increase)



The highest runoff from an inch of rain results from precipitation from October to December and March to April, which aligns with previously discussed concerns about nutrients in soils that are bare (after harvest) and frozen. Figure 2 graphs the percent increase in phosphorus in all surface water readings on a day with more than an inch of precipitation compared to one with less than an inch based on the month in which the precipitation occurred. While phosphorus increases by 50% in response to an inch of rainfall in summer months, it nearly doubles in winter and spring.

Figure 2. Percent Increase in Phosphorus on a Day With More Than an Inch of Precipitation Based on Day in Which the Precipitation Occurs. Coefficients Should Be Interpreted as Percents by Multiplying by 100 (e.g., 0.8 Corresponds to an 80% Increase)



The immediate transportation of phosphorus occurs in streams and rivers, which is not surprising because they function as water highways for humans as well as nutrients. Rivers and streams are how nutrients applied in the Midwest can reach the Gulf of Mexico, contributing to the hypoxic or dead zone in those waters. Research has found, however, that the dynamics of nutrient concentration differ in important ways between rivers and streams versus lakes and reservoirs (Manning et al., 2020). To further an understanding of nutrient loss, this recent research separated readings based on whether they were in a river or stream or a lake or reservoir. Notably, the readings produced no evidence that lake or reservoir concentrations increased in the immediate aftermath of precipitation events. By comparison, river and stream P concentrations experienced an 80% spike after an inch of rain compared to 57% overall.

Short-term spikes in phosphorus from more extreme precipitation do not wash out of the system throughout the season. End-of-season phosphorus levels are higher in years with more extreme precipitation events. An additional day with more than an inch of rain in January to August results in 6% higher phosphorus concentrations in September to December. The additional phosphorus arrives in lakes and reservoirs by the end of season. An additional event with greater than one inch of precipitation increases end-of-season phosphorus by 9% in rivers and streams and by 6% in lakes and reservoirs (Skidmore et al., 2023).

In terms of conservation practices, the research found significant evidence that short-term and end-of-season phosphorus spikes are lower in areas with more cover cropping. A little goes a long way; a watershed in which just ten percent of the cropped area was planted in winter cover crops experienced a 36% lower phosphorus spike, compared to one with no winter cover crops. The benefits of cover crops carry over to end-of-season P levels as well. An additional 5% of cropped area planted to cover crops offsets an additional day with more than an inch of rain. These findings further support the conclusions that cover crops are a key to both water-smart and climate-smart agriculture and generally align with previous research finding positive impacts from conservation practice adoption (see e.g., Margenot et al., 2017). In line with common sense and intuition, keeping the soil surface covered during the vulnerable periods between crop seasons is important to reducing nutrient and soil losses due to weather events.

Conclusion

The basic conclusion is that continuing business-as-usual will likely combine with increased extreme precipitation to result in increasing levels of phosphorus in surface waters. And, again, while some matters are out of the farmer's hands, there are practices that can help reduce losses—losses that cost both the farmer and the general public. Cover crops, conservation tillage, and buffer strips are often emphasized as climate-smart for their sequestration potential, but they pay a double dividend. They make our systems resilient to extreme weather and allow farmers to keep producing while mitigating the relationship between agriculture and runoff. This is going to be more valuable as extreme weather becomes the norm. Recognition that phosphorus is already in our soils and our systems adds further importance to the adoption of conservation practices. What already happened is out of the hands of today's farmers, but they can protect against future losses due to precipitation with good soil-health practices. Conservation is becoming more important to protect farmers' bottom lines, improve soil health, and invest in the natural resources vital to production, as well as to protect water quality against nutrient losses.

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