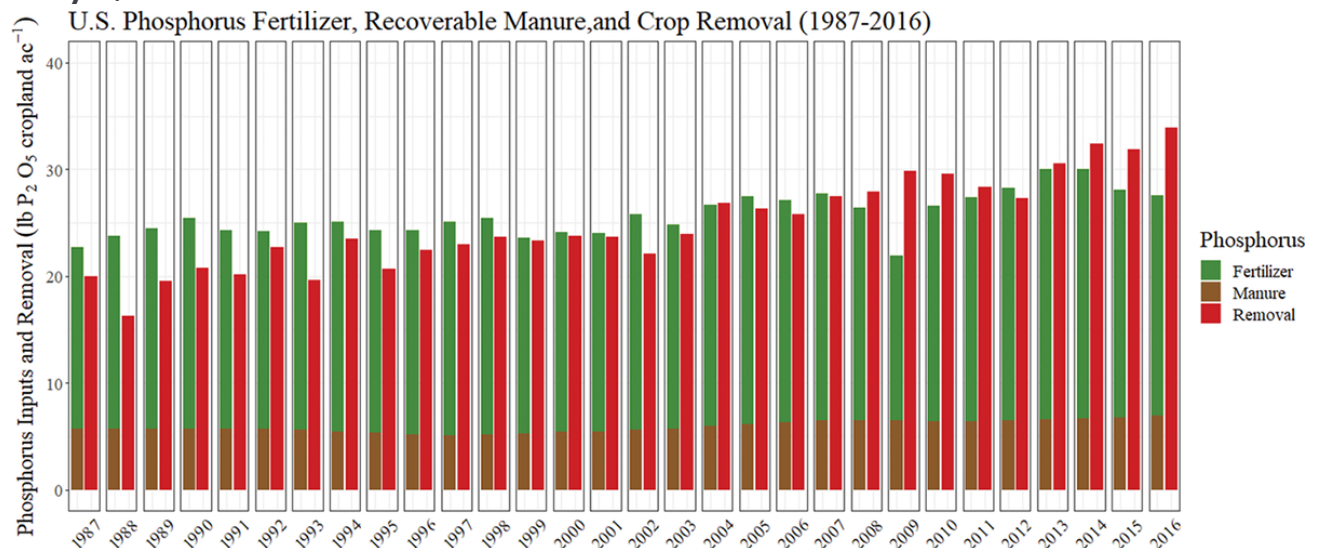




Phosphorus use trends to inform 4R nutrient stewardship and reducing losses from cropland

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July 6, 2021



Phosphorus (P) loss pathways should be considered in the context of how management strategies interact with soil and field characteristics.

Investigations of P use, soil test P, and P use efficiency have provided some

help in navigating through the plight of reducing P losses while maintaining profitable yield levels. The extent to which tillage practices and cover crops are utilized should inform P management strategies and how agronomic, economic, and environmental success are attained.

This article is [part of a series](#) from The Fertilizer Institute, highlighting some of the latest 4R research.

Abbreviations:

- **PPF,** • phosphorus partial factor productivity;
- **PUE,** • phosphorus use efficiency;
- **STP,** • soil test phosphorus.

Managing phosphorus (P) for optimum crop production has many commonalities with reducing P loss to surface waters as both are attainable through improved phosphorus use efficiency (PUE) and soil management. However, preventing losses of both sediment-bound P (particulate) and soluble P may require contrasting management strategies and have conflicting reports of efficacy. Management practices such as P application strategy and tillage practices have long been identified as influential on the susceptibility for a system to lose P. The reemergence of using cover crops to reduce soil erosion and maintain growing plants for a longer period in cropping systems

presents both opportunities and challenges to managing P. In many cases, modifying a P management strategy is needed if considerable reductions in P loss combined with yield optimization are to occur. Investigations of P use, soil test P (STP), and PUE have provided some help in navigating through the plight of reducing P losses while maintaining profitable yield levels. Additionally, the spatial pattern of tillage practices and cover crop adoption in the conterminous U.S. is described below.

Phosphorus Loss Factors

Most P loss with surface runoff from farm fields is driven by how soil- and field-specific properties interact with hydrology. It is common to characterize P lost from farm fields as sediment-bound or soluble. Detachment of soil particles and subsequent erosion moves sediment-bound P across landscapes and into water bodies, and overland flow transports soluble P within and away from crop fields. Factors that influence the zone of interaction between precipitation and surface soil naturally affect P loss with surface runoff. Many studies have connected soil/field characteristics and P management strategies with increased losses of P with surface runoff, and generally those losses are seen as a function of landscape position, STP, vegetation, soil texture, and applied P (McDowell & Sharpley, 2001).

Many state P loss indices that guide application parameters of fertilizer and manure take these factors into consideration (Osmond et al., 2017), and widely used models that estimate P loss require them for input parameters (Sharpley et al., 2017). Though often independent of P application strategy, tillage system can affect P loss potential greatly but is not in the framework for the discussion here (Li et al., 2011; Tiessen et al., 2010). While surface runoff receives the lion's share of the attention in many cases, P leaching is a critical loss pathway in some systems and can be an important challenge towards mitigating P loss and water quality impairment (Smith et al., 2015). These

leaching losses can be exacerbated by downward movement of higher soil P concentrations and artificial drainage. Components of 4R nutrient stewardship—right source, rate, timing, and placement of P—are just as influential for P leaching considerations as losses with surface runoff (Kleinman et al., [2015](#)).

Phosphorus and Cover Crop Management Trends

In assessing the effects of P management and cover crops on losses with surface runoff, it is helpful to summarize P use trends over time and the extent to which cover crops are being incorporated into U.S. cropping systems. Overviews of fertilizer and manure P use, harvest P removal, soil test P levels, and PUE will help to set the stage.

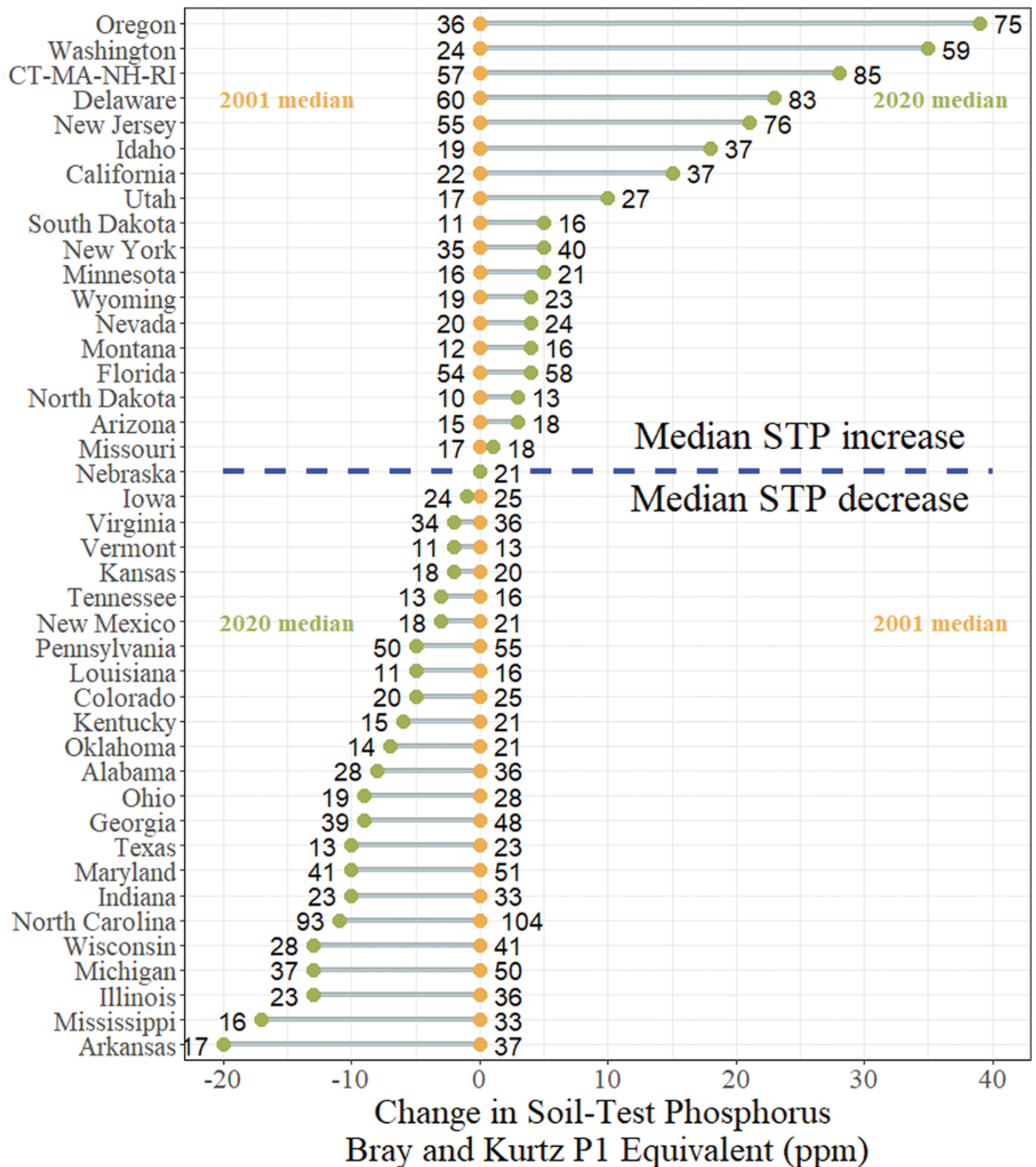
While unintended P loss from crop fields as surface runoff may constitute considerable losses, the removal of P in harvested portions of crops from agricultural land represents the largest annual outflux. Additionally, estimated crop P removal is a common component of P fertilization recommendations when STP levels are either within or above the agronomic critical concentrations for respective areas and crops. Crop removal of P_2O_5 has increased from 19.9 lb P_2O_5 ac⁻¹ in 1987 to 33.9 lb P_2O_5 ac⁻¹ in 2016 across all U.S. cropland (Figure [1](#)), equivalent to 2.26 million tons more P_2O_5 leaving crop fields and to be considered when estimating the P balance of cropping systems (TFI, [2021](#)). Yield levels drive major differences in crop removal of P over time; however, P content of harvest crops can vary regionally.

As the most important indicator of both P fertility and potential P loss, an evaluation of STP over time is a useful exercise. Soil test P trends over time in the U.S. corroborate the observations seen for crop removal. The [2020 North American Soil Test Summary](#), in conjunction with past summaries, indicates many U.S. states are observing lower median STP levels from 2001 to 2020 (TFI, [2021](#)). While median STP has decreased from 27 ppm in 2001 to 23 ppm Bray and Kurtz P1 equivalent in 2020,

Canadian STP levels have seen a contrasting trend from 2001 to 2020, showing an increase from 25 to 28 ppm, respectively. While these trends are of interest for national insights, regional- and state-specific changes better inform changes in soil P dynamics in relation to agronomic and environmental concerns. For example, Ohio has seen a decrease in STP from a statewide median of 28 ppm in 2001 to 19 ppm in 2020. This is a considerable decrease in a state where agronomic P management has been a hot topic for some time. Contrastingly, STP in Minnesota has increased from 16 ppm in 2001 to 21 ppm in 2020.

Figure 2 shows trends of median STP from 2001 to 2020 for U.S. states with at least 2,000 soil samples submitted to soil test summaries during that same time. Yellow points indicate the 2001 value, and green points indicate the 2020 median STP value. These shifts in median STP values can inform the agronomy community where further investigation may be needed to understand if changes in STP levels are in the direction that helps or hinders agronomy productivity or mitigates environmental concerns. A median STP value is also better understood in relation to the STP critical level (concentration) used in each respective geography. Figure 3 shows percent of soil P samples testing below the STP critical level for each state in 2001, 2020, and as before, the x-axis indicates the change from 2001 to 2020. States located below the blue dotted line indicate a reduction in soil samples testing below the STP critical level (Figure 3). In many cases, the states that indicated an increase in median STP in Figure 2 logically showed a reduction in the frequency soil samples below the STP critical level in Figure 3. In many cases, the agronomic STP critical level used in Figure 3 is considered for indices or assessments of sites for potential P loss (Osmond et al., 2017). While these data represent state-level aggregation, diving into the trends of median STP values or the frequency of samples below the critical level in farm fields will inform where management tweaks can provide benefits.

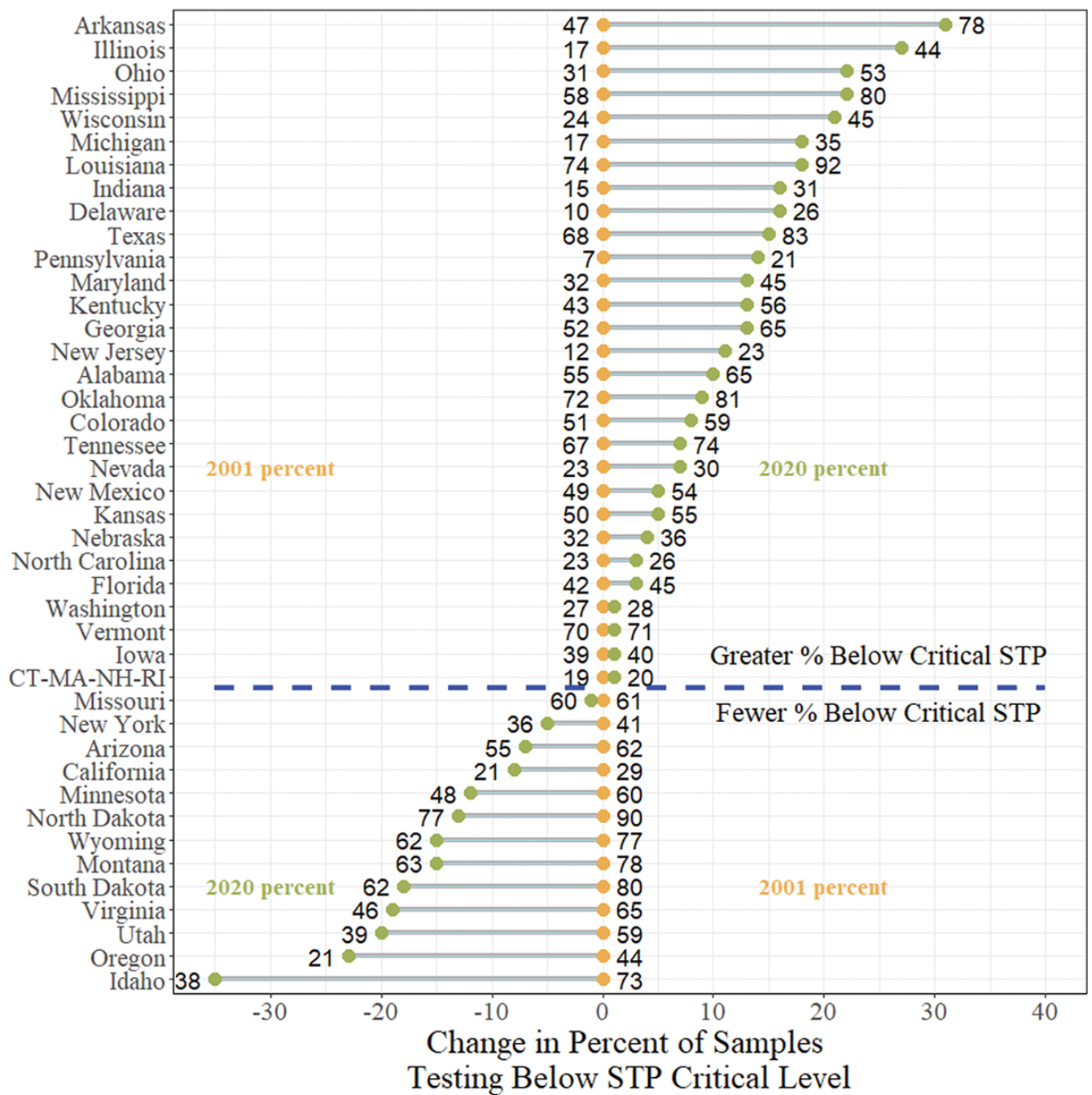
Median Soil-Test Phosphorus Change 2001 to 2020



Data: 2020 North American Soil Test Summary

Figure 2, Median soil test phosphorus change (2001–2020).

Change of Soils Below STP Critical Level 2001 to 2020



Data: 2020 North American Soil Test Summary

Figure 3, Change in the percentage of soil samples testing below the agronomic phosphorus critical level (2001–2020).

Phosphorus use efficiency can be used to describe the ability of a system to convert P inputs to measurable outputs such as yield or P removal. Phosphorus partial factor

productivity (PFP) is the pound of crop harvested per pound of P_2O_5 applied. Figure 4 shows PFP of P for corn, cotton, soybean, and wheat from 1964 to 2018 in the U.S. While each crop has an increasing trend for this period, significant breaks in the data for corn, soybean, and wheat indicate from 1964 to 1974 a decreasing PFP trend was occurring (Figure 4). From 1975 to 2018, PFP of P for corn, cotton, soybean, and wheat increased 102 (1.8 bu), 11, 29 (0.5 bu), and 75 (1.2 bu) lb crop lb $P_2O_5^{-1}$, respectively. Though explanations for this increasing trend since the mid-1970s could be many, this increase coincides with an expanded effort to use soil test recommendations to guide P fertilization practices. Additional PUE terms, such as the ratio of P removed to P applied in cropland acres, indicate improvements in U.S. cropping systems to convert P inputs to tangible outputs. Figure 1 shows that the ratio of crop removal to inputs (fertilizer and manure) of P_2O_5 for U.S. cropland has shifted from 1987 to 2016. Prior to 2004, a general accumulation of P was occurring (removal < application) with a partial nutrient balance below 1.0. However, from 2008 to 2016, the ratio has changed to indicate a partial nutrient balance above 1.0, indicating greater removal of P than that being applied (Figure 1).

Cover crop acres and percent of cropland acres having cover crops has increased substantially around the U.S. National acreage increased over 5 million (from 10.2 to 15.4 million) acres from 2012 to 2017 for the conterminous U.S. (USDA-NASS, 2019). This represents an increase of 2.6 to 3.9% of conterminous U.S. acreage having a cover crop present. States leading the way in adoption increase were Iowa, Missouri,

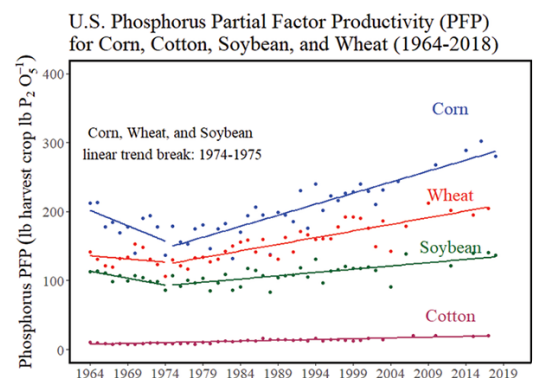
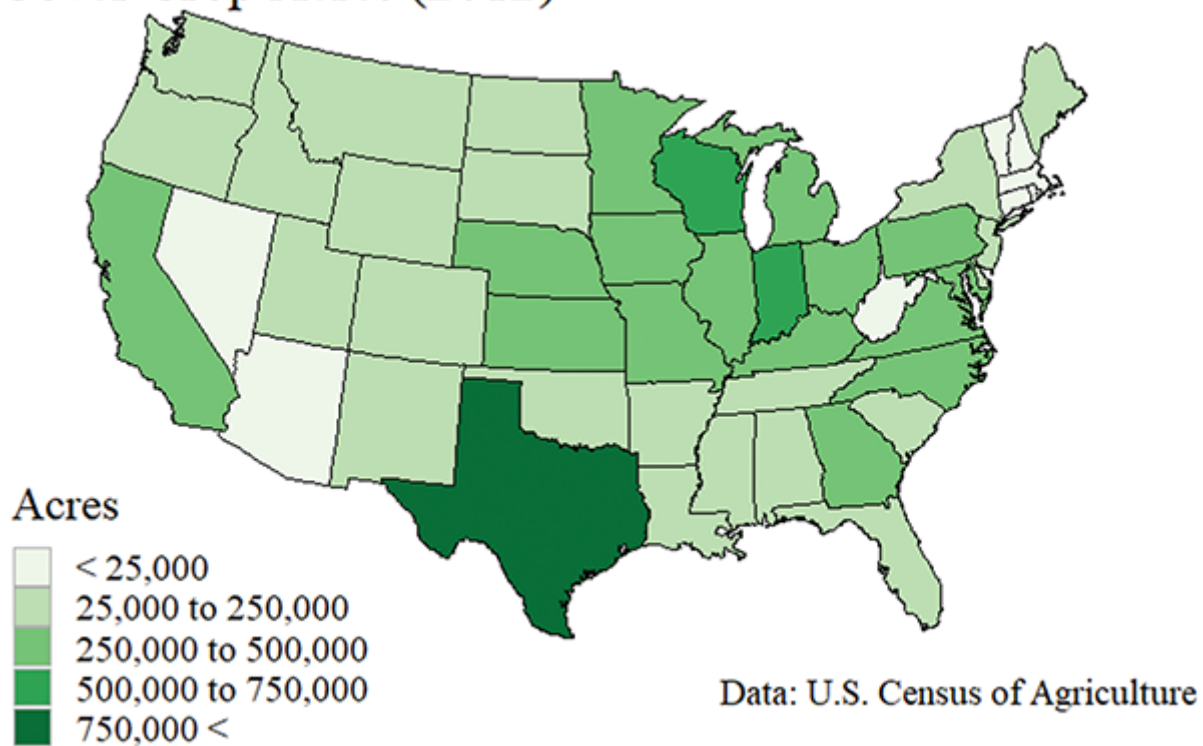


Figure 4, U.S. phosphorus partial factor productivity (PFP) for corn, cotton, soybean, and wheat (1964–2018).

Nebraska, Illinois, Ohio, and Indiana, all having over 250,000 more cover crop acres in 2017 than 2012. Figure 5 shows the acres of cover crops in each state for the 2012 and 2017 U.S. Census of Agriculture (USDA–NASS, 2019). Texas was the state with the largest cover crop acreage in both 2012 and 2017 with the 2017 value topping more than 1 million acres. With more than 4% increases from 2012 to 2017, Rhode Island, Maine, Maryland, and Vermont had the greatest increases in the proportion of cropland acres with cover crops. Figure 6 shows the percentage of cropland with cover crops in 2012 and 2017 (USA–NASS, 2019). In 2017, states with the largest fraction of cropland with cover crops were Maryland, Delaware, and Connecticut with 29, 19, and 15% respectively. The increase in cover crop acreage represents a very large and influential change to U.S. cropping systems and their structure–function relationship.

Cover Crop Acres (2012)



Cover Crop Acres (2017)

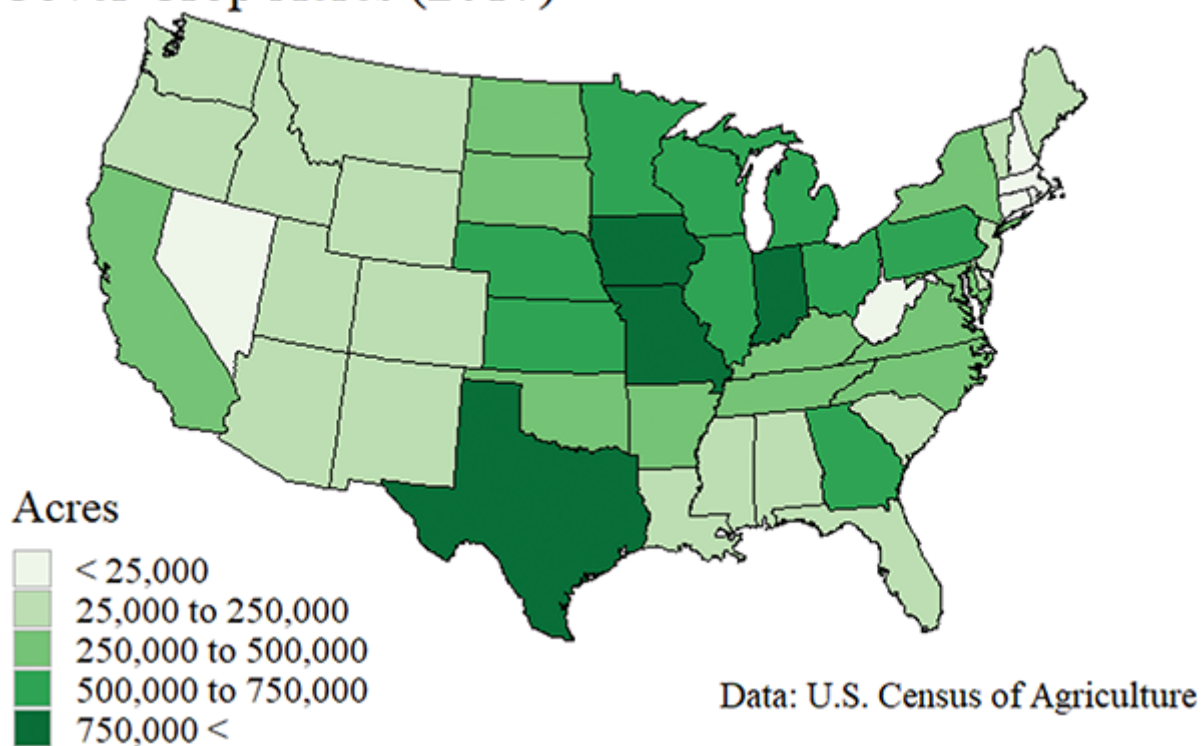
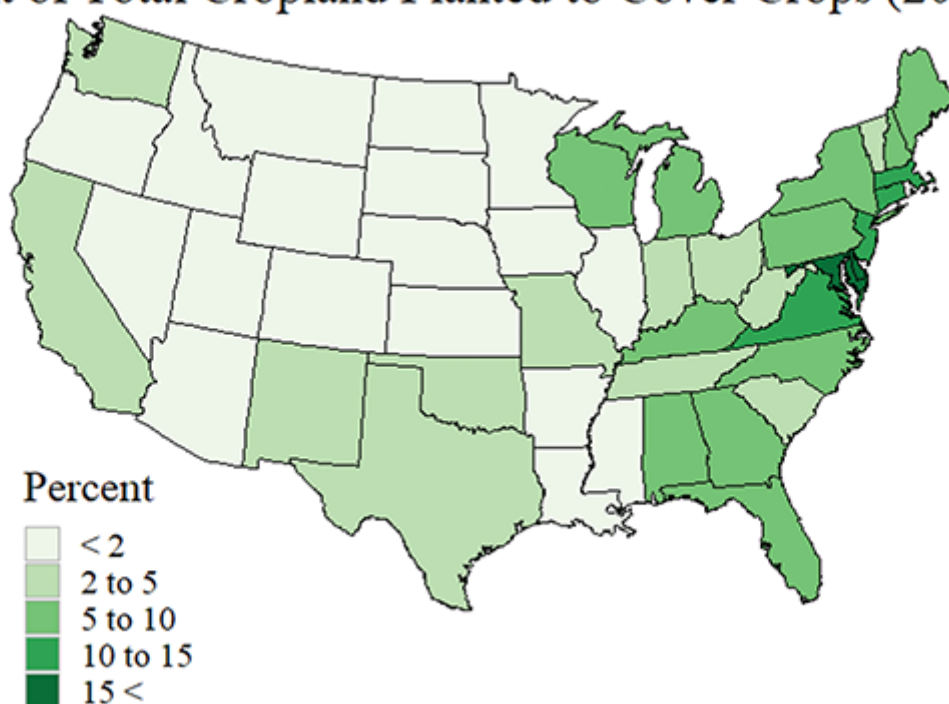
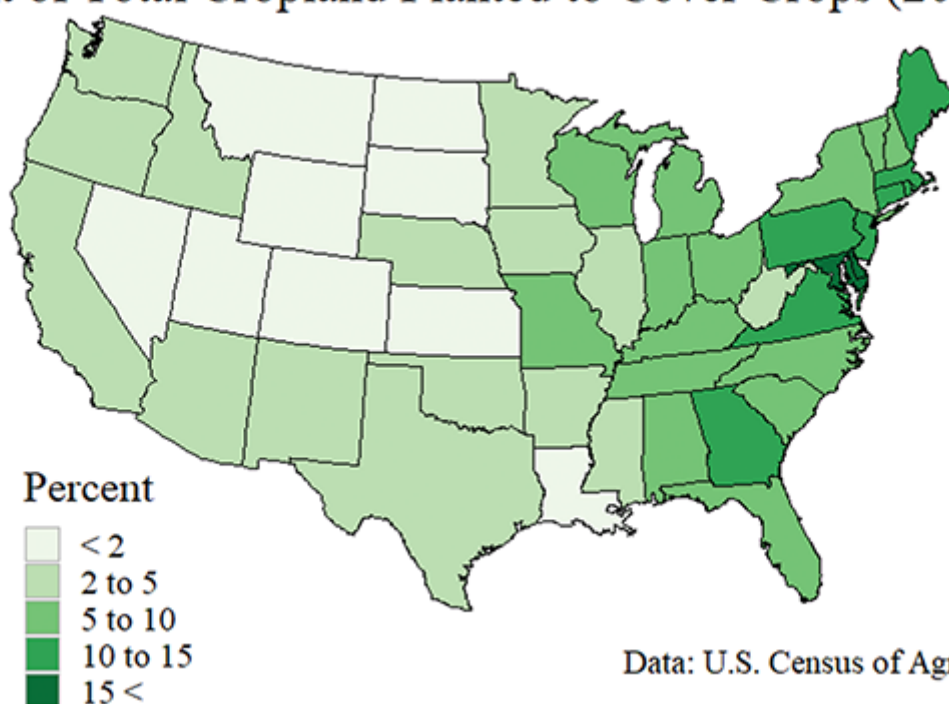


Figure 5, U.S. state cover crop acres in 2012 and 2017.

Percent of Total Cropland Planted to Cover Crops (2012)



Percent of Total Cropland Planted to Cover Crops (2017)



Data: U.S. Census of Agriculture

Figure 6, U.S. state percentage of cropland acres having cover crops planted in 2012 and 2017.

The spatial distribution of prevalent tillage practices also can inform different geographical challenges associated with P management. The extent of three tillage

practice “types” for 2017 is shown in Figure 7. The definitions of tillage practices vary, however; within the 2017 USDA Census of Agriculture, conservation tillage “leaves 30 percent or more of the soil surface covered by crop residue after planting” and “conventional tillage has 100 percent of the soil surface mixed or inverted” (USDA–NASS, 2019). Patterns in tillage system utilization not only follow commonly defined physiographic regions, but also region–specific challenges. For example, significant no–till acres reside in areas where moisture conservation and wind erosion prevention exist in the Great Plains (Figure 7). Contrastingly, regions with a high frequency of poorly drained soils in states such as Iowa and Illinois show starkly higher conventional tillage use. In many cases, these examples of tillage practice prevalence strongly relate to soil parent material and formation factors of the local region. Reviews on P losses with different tillage systems and conservation practices have been extensive (Dodd & Sharpley, 2016; Osmond et al., 2012), and the resounding conclusion that usually arises is that the interaction of inherent soil/environmental characteristics and management practices changes drastically by region. Therefore, local solutions are sought after in many cases.

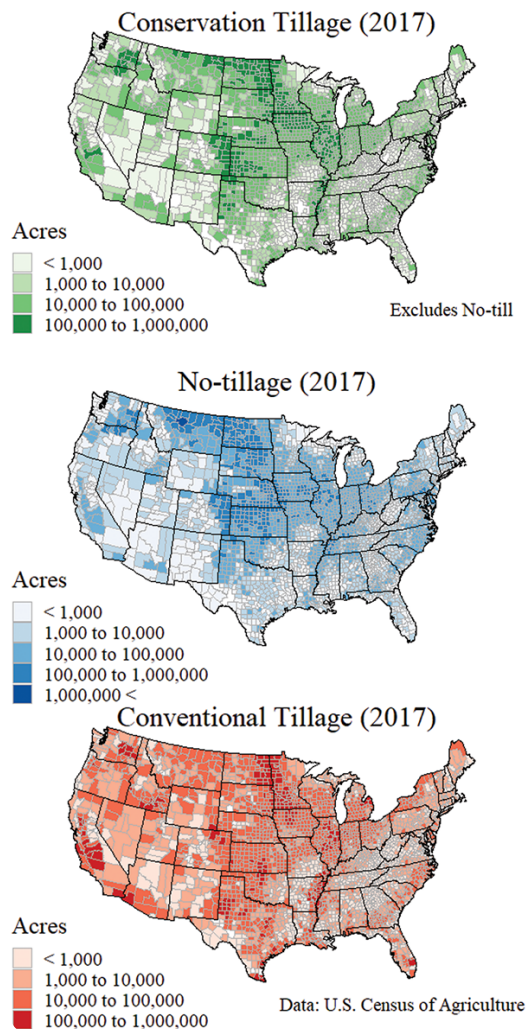


Figure 7, County-level conservation, no-till, and conventional tillage practice acres in 2017.

In the context of P management decisions for agronomic, economic, and water quality successes, the components of 4R nutrient stewardship (source, rate, timing, and placement) share an interconnectedness. For example, specific P sources will naturally direct the rate, timing, and placement that logically should be implemented. Likewise, decisions of shifting P application placement strategies will include consideration of different sources. Phosphorus source characteristics like availability, P content, solubility, and balance of other nutrients present can be useful when considering different source options. Crop demand and STP levels should inform rates of P application for optimal crop nutrition to avoid both overapplications or P deficiencies (Dodd & Mallarino, 2005). Phosphorus timing should also be guided by crop demand as

early-season P needs commonly explain crop responses to early available P (Dodd & Mallarino, 2005; Grant et al., 2001). Timing of P application continues to be integral for mitigating water quality concerns. Strong connections between applying P to frozen ground (Wendt & Corey, 1980) and strategies that do not allow enough time for soil-P reactions prior to intense runoff events or crop uptake (Allen & Mallarino, 2008; Vadas et al., 2017) point towards timing as a critical 4R component. Finally, the placement of P

fertilizers and manure may have been documented and studied the most recently in respect to P losses with surface runoff (Smith et al., [2016](#), [2017](#); Wiens et al., [2019](#)). Agronomic benefits to different placement methods vary greatly and depend on soil moisture, temperature, and chemical properties that limit bioavailability (P fixation capacity). The water quality benefits to placing P below the surface are less in question as studies in Minnesota (Timmons et al., [1973](#)), Ohio (Williams et al., [2018](#)), and Maryland (Kibet et al., [2011](#)) have all demonstrated reduced P loss with subsurface placement.

Key Takeaways

- Phosphorus loss pathways should be considered in the context of how management strategies interact with soil and field characteristics.
- Increasing trends of P removal with crop harvest are largely a function of yield increases and an influential component of field-level phosphorus budgets.
- Soil test P trends indicate an increasing frequency of soils testing below the agronomic critical level.
- Median STP trends from 2001 to 2020 corroborate a general trend of crop removal exceeding fertilizer and manure P inputs.
- The extent to which tillage practices and cover crops are utilized should inform P management strategies and how agronomic, economic, and environmental success are attained.

References

Allen, B.L., & Mallarino, A.P. (2008). Effect of liquid swine manure rate, incorporation, and timing of rainfall on phosphorus loss with surface runoff. *Journal of Environmental Quality*, **37**, 125–137. <https://doi.org/10.2134/jeq2007.0125>

Dodd, J.R., & Mallarino, A.P. (2005). Soil-test phosphorus and crop grain yield responses to long-term phosphorus fertilization for corn-soybean rotations. *Soil Science Society of America Journal*, **69**(4), 1118–1128.

<https://doi.org/10.2136/sssaj2004.0279>

Dodd, R.J., & Sharpley, A.N. (2016). Conservation practice effectiveness and adoption: Unintended consequences and implications for sustainable phosphorus management. *Nutrient Cycling in Agroecosystems*, **104**, 373–392.

<https://doi.org/10.1007/s10705-015-9748-8>

Grant, C.A., Flaten, D.N., Tomasiewicz, D.J., & Sheppard, S.C. (2001). The importance of early season phosphorus nutrition. *Canadian Journal of Plant Science*, **81**, 211–224. <https://doi.org/10.4141/P00-093>

Kibet, L.C., Allen, A.L., Kleinman, P.J.A., Feyereisen, G.W., Church, C., Saporito, L.S., & Way, T.R. (2011). Phosphorus runoff losses from subsurface-applied poultry litter on coastal plain soils. *Journal of Environmental Quality*, **40**, 412–420.

<https://doi.org/10.2134/jeq2010.0161>

Kleinman, P.J.A., Church, C., Saporito, L.S., McGrath, J.M., Reiter, M.S., Allen, A.L., ... & Joern, B.C. (2015). Phosphorus leaching from agricultural soils of the Delmarva Peninsula, USA. *Journal of Environmental Quality*, **44**, 524–534.

<https://doi.org/10.2134/jeq2014.07.0301>

Li, S., Elliott, J.A., Tiessen, K.H.D., Yarotski, J., Lobb, D.A., & Flaten, D.N. (2011). The effects of multiple beneficial management practices on hydrology and nutrient losses in a small watershed in the Canadian Prairies. *Journal of Environmental Quality*, **40**, 1627–1642. <https://doi.org/10.2134/jeq2011.0054>

McDowell, R., & Sharpley, A. (2001). Approximating phosphorus release from soils to surface runoff and subsurface drainage. *Journal of Environmental Quality*, **30**, 508–520. <https://doi.org/10.2134/jeq2001.302508x>

Osmond, D., Bolster, C., Sharpley, A., Cabrera, M., Feagley, S., Forsberg, A., ... & Zhang, H. (2017). Southern phosphorus indices, water quality data, and modeling (APEX, APLE, and TBET) results: A comparison. *Journal of Environmental Quality*, **46**, 1296–1305. <https://doi.org/10.2134/jeq2016.05.0200>

Osmond, D., Meals, D., Hoag, D., Arabi, M., Luloff, A., McFarland, M., ... & Line, D. (2012). Improving conservation practices programming to protect water quality in agricultural watersheds: Lessons learned from the National Institute of Food and Agriculture Conservation Effects Assessment Project. *Journal of Soil and Water Conservation*, **67**, 123A–128A.

Sharpley, A., Kleinman, P., Baffaut, C., Beegle, D., Bolster, C., Collick, A., ... & Weld, J. (2017). Evaluation of phosphorus site assessment tools: Lessons from the USA. *Journal of Environmental Quality*, **46**, 1250–1256.

<https://doi.org/10.2134/jeq2016.11.0427>

Smith, D.R., Huang, C., & Haney, R.L. (2017). Phosphorus fertilization, soil stratification, and potential water quality impacts. *Journal of Soil and Water Conservation*, **72**, 417–424. <https://doi.org/10.2489/jswc.72.5.417>

Smith, D.R., King, K.W., Johnson, L., Francesconi, W., Richards, P., Baker, D., & Sharpley, A.N. (2015). Surface runoff and tile drainage transport of phosphorus in the Midwestern United States. *Journal of Environmental Quality*, **44**, 495–502.
<https://doi.org/10.2134/jeq2014.04.0176>

Smith, D.R., Harmel, R.D., Williams, M., Haney, R., & King, K.W. (2016). Managing acute phosphorus loss with fertilizer source and placement: Proof of concept. *Agricultural & Environmental Letters*, **1**, 150015. <https://doi.org/10.2134/ael2015.12.0015>

TFI (2021). 2020 North American Soil Test Summary. The Fertilizer Institute, Arlington, VA. <https://nugis.tfi.org/>

TFI (2021). Nutrient Use Geographic Information System (NuGIS). The Fertilizer Institute, Arlington, VA. <https://nugis.tfi.org/>

Tiessen, K., Elliott, J., Yarotski, J., Lobb, D., Flaten, D., & Glozier, N. (2010). Conventional and conservation tillage: Influence on seasonal runoff, sediment, and nutrient losses in the Canadian prairies. *Journal of Environmental Quality*, **39**, 964–980. <https://doi.org/10.2134/jeq2009.0219>

Timmons, D.R., Burwell, R.E., & Holt, R.F. (1973). Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. *Water Resources Research*, **9**(3), 658–667.
<https://doi.org/10.1029/WRO09i003p00658>

USDA–NASS (USDA National Agricultural Statistics Service) (2019). Quick stats. <https://quickstats.nass.usda.gov/>

Vadas, P.A., Good, L.W., Jokela, W.E., Karthikeyan, K., Arriaga, F.J., & Stock, M. (2017). Quantifying the impact of seasonal and short-term manure application decisions on phosphorus loss in surface runoff. *Journal of Environmental Quality*, **46**, 1395–1402. <https://doi.org/10.2134/jeq2016.06.0220>

Wendt, R.C., & Corey, R.B. (1980). Phosphorus variations in surface runoff from agricultural lands as a function of land use. *Journal of Environmental Quality*, **9**, 130–136. <https://doi.org/10.2134/jeq1980.00472425000900010028x>

Wiens, J.T., Cade-Menun, B.J., Weiseth, B., & Schoenau, J.J. (2019). Potential phosphorus export in snowmelt as influenced by fertilizer placement method in the Canadian prairies. *Journal of Environmental Quality*, **48**(3), 586–593. <https://doi.org/10.2134/jeq2018.07.0276>

Williams, M.R., King, K.W., Duncan, E.W., Pease, L.A., & Penn, C.J. (2018). Fertilizer placement and tillage effects on phosphorus concentration in leachate from fine-textured soils. *Soil and Tillage Research*, **178** (December 2017), 130–138. <https://doi.org/10.1016/j.still.2017.12.010>

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