The question about the origin of the idea of 4R—the right source at the right rate, the right time, and in the right place—is a common one. There are several references that are mentioned when this comes up, but I’d like to highlight three—from 1988, 1994, and 1997.

In 1988, Thorup and Stewart stated that there was a need to develop strategies that include maximum economic yield, optimum fertilizer use efficiency, and minimum degradation of the environment. They also mentioned that achieving this goal would require both careful management practices at the farm and clear-sightedness in legislative assemblies. Stepping through source, rate, time, and place, Thorup and Stewart (1988) discussed the challenge of changing nutrient recommendations with increased yields, and the impact of changing practices on nutrient use efficiency. For example, the summary of available research at the time indicated that maximum crop response to applied phosphorus could only be expected if sufficient nitrogen was supplied or available nitrogen was present in the soil (Thorup and Stewart, 1988).

In 1994, Pierce and Robert discussed site-specific management for agriculture that “is about doing the right thing, at the right time, in the right place, in the right way.” This paper discussed the pros and cons of the adoption and development of site-specific management tools, such as remote sensing and sensors. They stated, for example, that using a practice such as grid-based soil sampling can capture the variation in soil fertility that is not related to soil map units (Pierce and Robert, 1994). A grid size of 330 (2.5 ac) ft was mentioned as frequently used in 1994; however, it was also recognized that crop

**4R history and recent phosphorus research**

Where did the 4R idea come from? This article looks at a few of the early sources and how those concepts relate to current challenges facing phosphorus management. **Earn 0.5 CEUs in Nutrient Management** by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/564.

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yields are not always correlated to the variation seen in grid soil tests (Pierce and Robert, 1994). Sensors, such as yield monitors, were mentioned, and the challenge of evaluating the data collected by the sensors was a concern then (Pierce and Robert, 1994) and still is today. For example, in the 2017 Dealership Survey by CropLife magazine, the service of yield monitor data analysis is offered by only 55% of the dealers (Erickson and Lowenberg-Deboer, 2017).

Given these were concepts of the 1980s and 1990s, why do we keep talking about and studying the 4R framework and concepts? Constant changes in technology, genetics, and equipment are a big part of the challenge. In 1988, education and encouragement to try new practices were cited as the biggest challenges to increased adoption of practices that optimize fertilizer use (Thorup and Stewart, 1988). Additionally, Pierce and Robert (1994) stated that education and training on assessing and interpreting spatial variability in agriculture were lacking. The profitability of site-specific management, how it affects the environment, and the socioeconomic considerations—its accessibility to all farm sizes—were raised as questions in 1994. All of the above continue to be questions and challenges today as the technology and farm demographics evolve.

Finally, there are differences in the rate of adoption across practices. For example, in 1988, it was predicted by soil scientists that by 2010, 95% of the crop acres in the United States would be under conservation or minimal tillage practices (Thorup and Stewart, 1988). However, the USDA Economic Research Service (ERS) reported that in 2010–2011, roughly 40% of combined acreage of corn, soybean, wheat, and cotton were in no-till/strip-till, with adoption rates higher for some crops (e.g., soybeans) and some regions (Wade et al., 2015). Meanwhile, site-specific services, such as soil sampling with GPS and field mapping with GPS have grown to 78 and 75% of retailers, respectively, offering these services in 2017 (Erickson and Lowenberg-Deboer, 2017).

Relating to current research

In 1997, Larson et al. looked deeper at the use of site-specific management as a route to optimize crop production while maintaining soil and water quality compared with conventional uniform field management. It was stated that the placement of phosphorus fertilizer may greatly influence the amount of phosphorus lost, and when good management practices, such as amounts, timing, and placement of fertilizers, and tillage systems are applied on a precision basis, movement of phosphorus off the land can be minimized (Larson et al., 1997). Research continues on phosphorus management to decrease phosphorus loss to address water quality concerns. With changes in tillage practices and the introduction of equipment that offers more fertilizer placement and tillage options, the interactions of placement and loss continue to be a challenge to understand.

Discovering the best combination of practices for each field and across the landscape takes both controlled (rainfall simulation) and edge-of-field monitoring studies. Rainfall simulation research has shown decreases in dissolved reactive phosphorus (DRP) loss in surface and subsurface drainage (Smith et al., 2016; King et al., 2018; Williams et al., 2018). When subsurface loss was simulated through rainfall and pan lysimeter collection, injecting phosphorus fertilizer decreased DRP loss by 66%. Incorporation of phosphorus fertilizer through tillage decreased DRP loss by 75% compared with surface application of phosphorus fertilizer (Williams et al., 2018). Banding MAP fertilizer decreased phosphorus surface runoff loss in a rainfall simulated study by 95% (Smith et al., 2016). When 4R practices were evaluated across 19 paired edge-of-field sites (38 fields), no significant difference in DRP surface or subsurface loss was found between surface broadcast and subsurface placement of fertilizer (King et al., 2018). Total phosphorus loss in surface and subsurface drainage was slightly lower but not significantly different between surface broadcast and subsurface placement (King et al., 2018). The high level of variation in the measurements among fields influenced these comparisons. Pooling all 38 fields where site-specific characteristics (such as phosphorus application rate, soil test phosphorus, slope, soil type, and organic or inorganic fertilizer) were different makes it
difficult to find overall differences in practices versus site-specific differences. When more years of data are available for each site and practices are compared between the paired fields, controlling for the other site-specific management factors, analysis may result in significant differences (King et al., 2018).

When optimizing fertilizer use through site-specific management, it is important to consider all of the site-specific characteristics as well as the fertilizer source, rate, time, and place (Thorup and Stewart, 1988; Pierce and Robert, 1994; Larson et al., 1997). Soil test phosphorus concentration is an important site-specific characteristic for determining phosphorus fertilizer rate and examining the likelihood for phosphorus loss from the site. Across the 38 fields in the edge-of-field study, increased soil test phosphorus concentration increased DRP loss, especially when above 75 ppm (or mg/kg) Mehlich III (King et al., 2018). Additionally, when rates of phosphorus application from organic or inorganic fertilizer were at or below recommended rates, based on soil test results, the likelihood of excess phosphorus loss from fields decreased compared with fertilizer application rates greater than recommendations (King et al., 2018).

Conclusions and continued research

The advantage of using the 4R framework to make nutrient management decisions is the adaptability to site-specific conditions. Actively making decisions on the right source, at the right rate, at the right time, and in the right place, while considering site-specific characteristics like soil type, soil test concentrations, slope, and edge-of-field resource concerns, has the greatest potential for reduced environmental impact and improved economic performance. Research needs to continue on stacking 4R in-field practices and the addition of conservation practices to determine the outcomes and create tools for consultants and producers to determine the best set of 4R and conservation practices for a site-specific approach. &

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Drift [continued from p. 29]

References


Drift [continued from p. 29]

References


Soil organic matter [continued from p. 8]

References


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References


