Sustainable Phosphorus Management: Defining 4R Practices

By Heidi Peterson and Tom Bruulsema

Phosphorus (P) use efficiency in the U.S. has improved dramatically since the 1980s (NuGIS, 2019), yet eutrophication and other nutrient-related water quality issues, commonly used as measurable indicators of sustainability, have persisted. Our landscapes have become more complex. For example, since the 1960s we have been experiencing an increase in the frequency of high intensity precipitation events (Melillo et al., 2014), compounded by the addition of artificial subsurface drainage networks and high residue management practices. To overcome the P challenges confronting U.S. agriculture, it is important to begin at the nutrient source.

Phosphorus can be supplied to crops through mineral fertilizers, manures, and other organic residues (e.g., biosolids, plant residues). When P is applied to the soil, only 10 to 15% is taken up, or recovered, by the crop the first year (Roberts and Johnston, 2015). Phosphorus must be dissolved in the soil solution to be taken up by crops, typically as orthophosphate ($H_2PO_4^{2-}$ and HPO_4^{2-}) and soluble organic P compounds. The quantity of the P form supplied will vary between source with some that is: (1) readily plant available in a labile, soluble P form; (2) weakly adsorbed to mineral surfaces and slowly available; or (3) strongly adsorbed, non-labile P considered unavailable. To meet crop productivity needs, the supply of weakly bound labile-P must be maintained to continuously resupply the pool of solution P as it is being used by the crop. Organic P forms can be converted into plant-available P through mineralization. Inorganic P pools can also replenish the soil solution through soil P minerals dissolving into the soil solution or desorption of P attached to soil particles such as clay or minerals containing iron (Fe) or aluminum (Al).

Phosphorus can be transported with runoff flowing across an agricultural field or can infiltrate into the soil in the dissolved or particulate forms. Phosphorus loss is determined by complex interactions amongst physical, chemical, and biological variables. To effectively manage the pool of available P for crop production while minimizing P losses to water, P application practices should follow the 4R Nutrient Stewardship framework to ensure that the right nutrient source is applied at the right rate, at the right time, and in the right place (IPNI, 2012). "Right" is defined in terms of managing the fertilizer application to ensure alignment with economic, social, and environmental goals, resulting in a more sustainable cropping system (**Figure 1**).

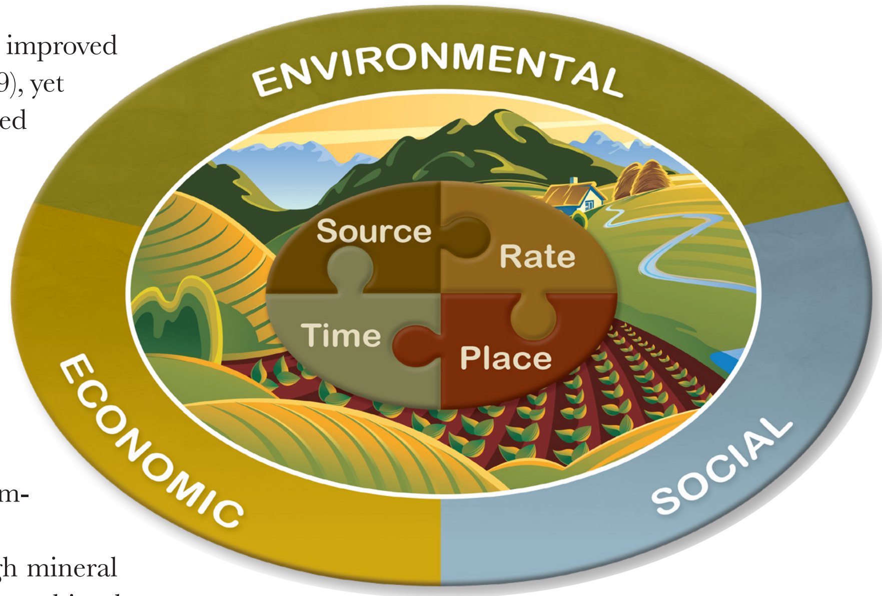

Figure 1. The 4R Nutrient Stewardship concept defines the right source, rate, time, and place for fertilizer application based on stakeholder desired economic, social, and environmental outcomes.

Understanding that each field system is unique, 4R Nutrient Stewardship connects the management of crop nutrition to sustainable production, keeping in mind the progress toward achieving target goals on key performance metrics. These metrics may include farm productivity, P use efficiency, improved water quality, or maintaining optimum soil test levels. It integrates adaptive management as an ongoing process of developing improved practices for efficient production and resource conservation.

The Right P Source

Selection of the right source must consider the rate, time, and placement of the P application and is dependent

SUMMARY

Sustainability assurance programs seek clear definitions of 4R phosphorus practices that support continued improvement in both water quality and crop yields. Increasing phosphorus use efficiency is not enough. Site-specific practices addressing region-specific challenges are required.

KEYWORDS:
4R Nutrient Stewardship; adaptive management; use efficiency

ABBREVIATIONS AND NOTES:
P = phosphorus; N = nitrogen; K = potassium

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upon the nutrient content, its solubility, and whether it is regionally available. Most mineral fertilizers are highly soluble and can contain different quantities of P, in addition to N, K, and other essential crop nutrients. Manure is an organic P source, which tends to be less soluble and much less concentrated than the P found in mineral fertilizers. When applied to the soil, organic nutrients mineralize over time, releasing nutrients that may be susceptible to loss through runoff; however, its variability in P content and interaction with other nutrients, such as Al, Fe, or calcium (Ca), can make it more difficult to manage than mineral fertilizers (Sharpley et al., 2004).

Since P is most often supplied in blends or with other nutrient sources, nutrient interactions must also be considered. Synergisms with other nutrients and sources is also important to maintain balanced nutrition. The crop's efficiency to recover P will depend upon whether the selected source adequately provides the necessary soil P supply, balanced together with N and K. For instance, results from a 50-yr irrigated continuous corn field experiment conducted in Kansas demonstrated a strong positive interaction between N and P. Application of N at the economic optimum rate of 172 kg N/ha increased P fertilizer recovery when applied at 20 kg P/ha, from 20% without N to 63% with N (Schlegel and Havlin, 2017).


R. Derickson

Drainage ditch with water discharge from network of in-field, subsurface tile drainage lines.

The Right P Rate

Applying the right rate of P fertilizer begins with understanding the plant needs and ensuring that adequate methods are used to assess the soil nutrient supply. The spatial variability in soil nutrient concentrations and yield potential within a field due to soil texture, soil pH, past management activities, and topography must be acknowledged. Variable rate application technology, which varies the nutrient application rate according to the location within the field using geographic information systems (GIS) and global positioning systems (GPS), can improve P use efficiency and decrease the risk for runoff and leachate losses.

Crops take up nutrients in proportion to yield. Under or over applying P may result in negative production, economic, and environmental implications. The right application rate for P is often based on soil sample collection and testing, which provides an index of nutrient availability. Soil testing provides a probability of response to P inputs and guidance on the amount of fertilizer needed to maximize economic return by maintaining an optimum soil test level. Over applying P can increase the risk of loss to surface runoff and leachate, whereas drawing down soil P concentrations by harvesting biomass P at a rate that exceeds P input may result in a decline in both soil fertility and yield potential (Dodd and Mallarino, 2005). Inputs from manure, composts, and other bioproducts all contribute to the distribution of P in soils and should be properly credited to avoid over application (Pagliari et al., 2018).

The Right P Timing

Seasonal crop demand and nutrient uptake patterns should be considered when determining the right time to apply P fertilizer. Although it is often driven by the management capabilities and logistics of the producer, timing surface application of organic and inorganic P sources must be balanced with crop needs and discharge-producing precipitation events to minimize runoff and leaching loss (King et al., 2018). Edge-of-field water quality monitoring indicates that the time between P application and the first precipitation event is negatively correlated to surface runoff and

TAKE IT TO THE FIELD

Cropping systems are dynamic and require an adaptive approach to P management, which focuses on the 4Rs to optimize recovery and minimize losses.

subsurface tile P concentrations (Smith et al. 2016).

The primary concern is to avoid surface application on frozen soils and prior to precipitation events to reduce runoff and leaching loss. Although crops take up nutrients at different rates throughout the growing season, in soils with low soil test P (STP) applying a starter fertilizer at a high rate may optimize productivity (Mallarino and Bundy, 2008). Since P is essential to early plant root growth and development, application at or near planting is most effective, particularly on highly acidic or alkaline soils that have very high P fixation capacity. Although P remains in the soil, in these acidic and alkaline soils, annual applications may be necessary to adequately supply the crop needs.

The Right P Placement

The right placement of P fertilizer near the roots increases the availability to the plant since P is less mobile than N and K. This is especially important in soils with a very high P fixation capacity. Seed placement or banding P fertilizer near the root zone at lower rates in soils with low STP can maximize corn response and result in higher efficiency, although soil type and moisture conditions may impact results (Mallarino et al., 1999; Mallarino and Bundy, 2008). Subsurface placement techniques improve soil-fertilizer contact while reducing surface disturbance and reducing P runoff and leachate losses (Williams et al., 2018). Unincorporated broadcast applications may initially save time and money, especially in no-till systems, but P stratification may also occur (Baker et al., 2017). Stratification limits deeper root growth and development and increases the risk for loss through surface runoff and subsurface tile drainage. However, there is insufficient literature suggesting stratification impacts yields. Uptake of P is also influenced by soil moisture, and subsurface P placement can improve plant uptake during drought conditions by inducing deeper plant root growth, ultimately improving the plant resiliency (Hansel et al., 2017).

A Holistic Approach

Cropping systems are dynamic, and when climatic and hydrologic factors are integrated into these management decisions, it is important that the choices made evolve with the current science and technology, but also consider economic factors. The site-specific nature of 4R practices limits the degree of detail with which they can be described across large regional cropping systems. Therefore, the development of a regionally based 4R P guidance requires collaboration between agricultural scientists and stakeholders with an awareness of local farm-based implementation to ensure that the practices are both efficient and economically feasible. As new resources and tools are developed, integrating adaptive P fertilizer management into farm-level decisions will encourage the use of relevant, site-specific information to determine the right source, rate, time, and place for efficient and effective fertilizer management. **BC**


H. Peterson/IPNI

Conservation tillage and cover crops control P losses in the particulate form, but control of the dissolved form requires attention to placement and timing.

Dr. Peterson (e-mail: hpeterson@ipni.net) is Director, IPNI Phosphorus Program, Stillwater, MN, USA. Dr. Bruulsema (e-mail: tom.bruulsema@ipni.net) is IPNI Vice President (Americas) & Director of Research, Guelph, ON. Canada.

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