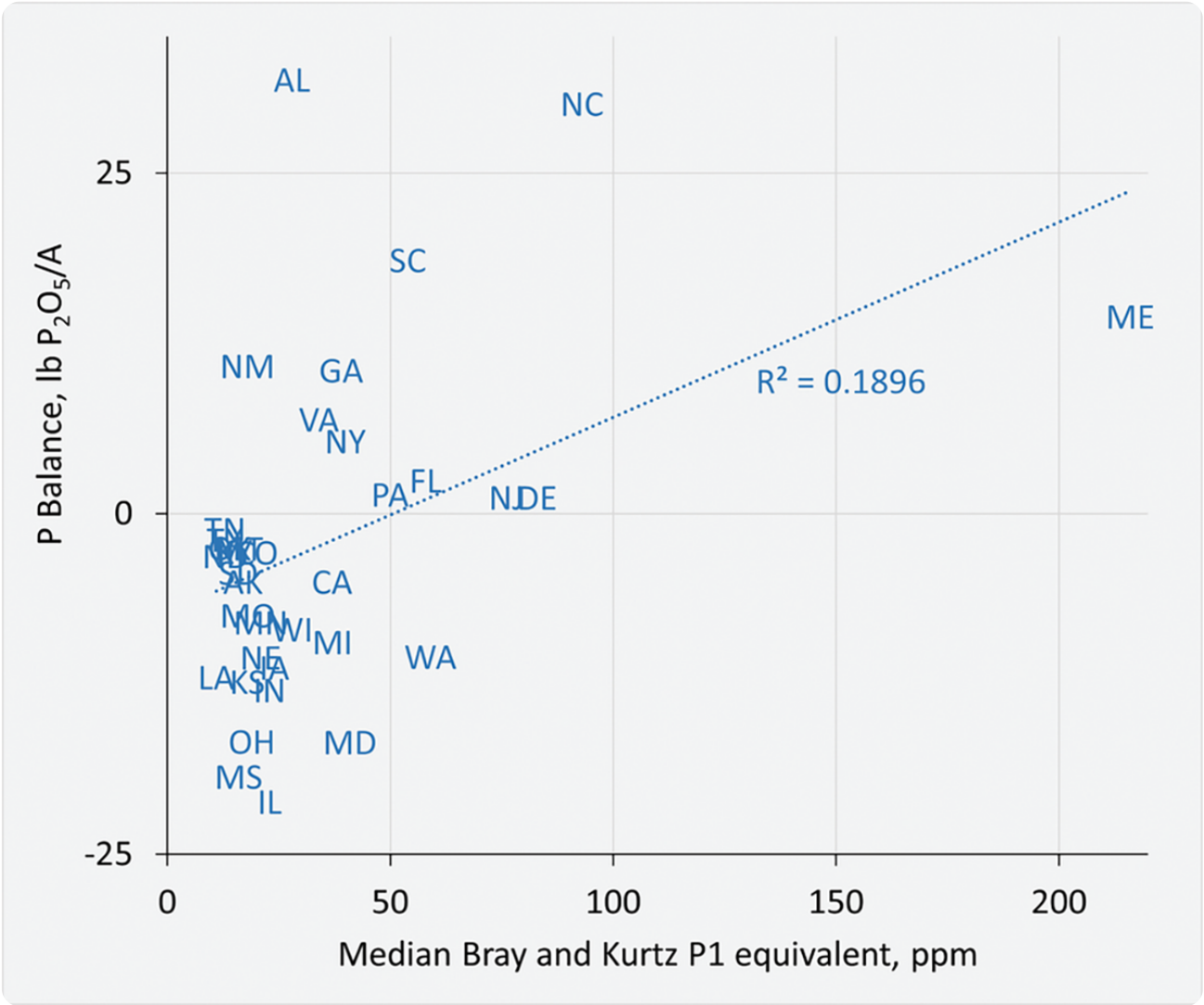
Science Societies

Evaluating impacts of 4R nutrient stewardship

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Nutrients are essential for plant and animal agriculture and comprise a large portion of its outputs. The starting point for assuring beneficial impacts is the adaptive management built into 4R Nutrient Stewardship. To manage adaptively means to evaluate impacts in your decision cycle. The metrics you evaluate need to reflect impacts important to your local farming system. Farther-reaching impacts of crop nutrition include water quality, air quality, carbon footprint, biodiversity, food security, human nutrition, farm livelihoods, and circularity. By better documenting the decision cycle, our current and past practices, and their relation to impacts, the industry has the opportunity to build public trust.

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

Impacts of nutrient stewardship reach far and extend broadly. Nutrients are essential for plant and animal agriculture and comprise a large portion of its outputs. But the starting point for assuring beneficial impacts is the adaptive management built into 4R Nutrient Stewardship.

To manage adaptively means to evaluate impacts in your decision cycle. The metrics you evaluate need to reflect impacts important to your local farming system. Three key 4R outcome metrics important to almost every farm are crop productivity, soil

health, and nutrient use efficiency (Fixen, 2020). The three relate directly to nutrient stewardship practices, complement each other well, and connect to the farther-reaching impacts of crop nutrition. Applying the right source of nutrients at the right rate, time, and place boosts a cropping system's productivity while maintaining soil health and optimizing nutrient use efficiency.

Fertilizer inputs make cropping systems more productive. They increase yields and can also increase the nutrient density of crops. Of course, many other crop management factors also influence yield and quality. The same can be said for the health of soils. Soil health depends on maintaining nutrient reserves as well as practicing soil conservation. Nutrient use efficiency, in the same manner, is influenced by applying the right source of nutrients at the right rate, time, and place but can be influenced just as much by any management factor affecting yield as well as by the health of the soil.

Considering the three key metrics together helps the manager seek sustainable synergies. Overemphasis on nutrient use efficiency can lead to nutrient-depleted soils and foregone productivity. Overemphasis on productivity can lead to poor nutrient use efficiency. But when source, rate, time, and place decisions are evaluated by all three metrics, the combinations that produce the most sustainable results are favored for adoption.

Nutrient use efficiency attracts increasing attention in today's sustainability dialogue. Serving as one of the key metrics of crop nutrition, it reflects responsible management and relates to risks of nutrient loss. It is as complex as the cropping systems to which it applies, and yet it reflects only partially the outcomes we expect from applying nutrients.

Nutrient Use Efficiency Complexity

On first glance, nutrient use efficiency appears deceptively simple. An efficiency in most uses is a simple ratio of output to input. Divide nutrients out by nutrients in, and you have a number. But complexities multiply when it's applied to agriculture (Congreves et al., **2021**).

First, approaches differ in defining the system out of which and into which the nutrients are flowing. Is it a field, a farm, a country, or the world? Soil surface, or farm gate? A single cropping season, a whole year, or a whole crop rotation? Nutrient use efficiency is a property of a system, not of any one single fertilizer or crop cultivar. So the system boundaries need to be defined carefully.

Second, which of the following do you consider as outputs: the harvested crop, the whole crop, the nutrients in either, the nutrients over and above the uptake that would have occurred without the input in question, the nutrients retained in the soil, those returned to the air, and those leaving the field with the drainage water or with eroded soil?

Third, which of the following inputs do you include or ignore: fertilizer, manure, deposition from the air, biological nitrogen fixation, and mineralization from the soil? Putting all these options together, hundreds of possible combinations could provide a ratio of outputs to inputs. Not only that, many of the outputs and inputs aren't measured and reported and can only be estimated.

So let's look at some of the simplest estimates of nutrient use efficiency. Partial nutrient balance is defined as the nutrient in the harvested crop divided by the nutrients applied as fertilizer and manure and derived from biological nitrogen fixation. For nitrogen in crop production in the United States, NuGIS indicates that it ranged from 73 to 86% from 2012 to 2016 (TFI, **2021a**). Calculated as a balance (inputs of

fertilizer, legume fixation, and manure minus crop removal), the average nitrogen surplus ranged from 16 to 29 lb/ac. The lowest percent and the highest surplus was, of course, for 2012, a major drought year, but unfortunately, we don't get to choose which years we farm.

What happens to the rest of the nutrient applied if less is harvested than applied? "Lost to the environment" is one answer commonly given. But it doesn't tell you where in the environment. Some nutrient fates can cause harm: nitrate loss to groundwater, nitrous oxide and ammonia loss to the air, and nitrogen and phosphorus in drainage water. Some losses are benign, such as dinitrogen going back to the air though they may represent wasted dollars spent on fertilizer or energy invested in its manufacture.

Some nutrient surpluses can even be beneficial. Surplus nitrogen, when combined with high inputs of crop residues, can help increase soil organic matter (Grove et al., **2009**), and nitrogen input is required for soil carbon sequestration (van Groenigen et al., **2017**). Surplus phosphorus can be useful for correcting soils deficient in the nutrient; unfortunately, however, some large surpluses tend to occur on higher-testing soils while some deficits are more common on less fertile soils as shown by studies in Canada (Reid et al., **2019**), the North-Central region (Jones et al., **2021**), and the conterminous United States (Figure **1**). More attention is needed to get nutrient surpluses to the right place.

And what if more is harvested than applied? In most cases, mining from soil reserves is indicated, meaning depletion of soil fertility. What this means is that nutrient use efficiency doesn't always need to increase. It has an optimum level, and that level depends on the current level of the soil's fertility. It may not be a problem to "mine" for several years from a soil testing well above critical levels for phosphorus and potassium but not from lower-testing soils.

Does higher nutrient use efficiency mean higher yield? Sometimes, but not always. Corn breeding has raised grain yield and nitrogen use efficiency simultaneously over the past 70 years (Mueller et al., **2019**). The same appears to be true for wheat breeding (Guarda et al., **2004**). A singular focus on nutrient use efficiency, however, can lead to yield-reducing rate reductions.

Farther-Reaching Impacts of Crop Nutrition

What are the farther-reaching impacts of crop nutrition? These include water quality, air quality, carbon footprint, and biodiversity. Negative impacts in these areas arise from nutrient losses, and thus tend to diminish with increases in nutrient use efficiency. But sometimes, choices of source, timing, and placement can have larger direct impacts on these end points than on nutrient use efficiency alone. A good example is placing phosphorus in the soil within conservation tillage systems: it reduces loss of dissolved phosphorus by a lot more than its impact on crop nutrient uptake (Williams et al., **2018**). The "right source" choice of a nitrification inhibitor with urea, in the right circumstances, can reduce nitrous oxide emission by 20 to 40% (Thapa et al., **2016**) even though it improves yield and nitrogen use efficiency by much less (Abalos et al., **2014**). Producing higher yields enables society to spare land for nature, and specific 4R practices can protect soil biodiversity as well (SPRPN, **2021**).

Going yet further, impacts extend to food security, human nutrition, farm livelihoods, and circularity. Crop nutrition can be managed for positive outcomes in these largely societal benefits. Producing more food, and more nutritious food, contributes toward ensuring all are properly nourished. Producing with better practices and with better documentation enhances value, providing employment and economic benefit well beyond the farm gate. Circularity is an attribute sought under the banner of regenerative agriculture. These extended benefits depend on many more management

factors beyond the 4Rs, but the 4Rs make a real and essential contribution.

Crop producers, crop advisers, and agricultural input retailers already engage in adaptive management. We all play a role in communicating to society the broad and far-reaching benefits of continuously seeking the right source, rate, time, and place of nutrient application. By better documenting the decision cycle, our current and past practices, and their relation to impacts, the industry has the opportunity to build public trust.

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