18

Practitioner's Perspective

From Nutrient Use to Nutrient Stewardship: An Evolution in Sustainable Plant Nutrition

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The pressures challenging farming systems of today both resemble and differ from those of 75 years ago. Relative to nutrient use, a main focus in 1945 was supplying nutrients to meet crop need and to build soil fertility. While these challenges remain today, they must be met with much more attention to environmental concerns. We review here the past and project from the present to describe how the practice of plant nutrition is evolving from nutrient use to nutrient stewardship.

In 1945, a speech by Mrs. Roy C.F. Weagly, President of the Associated Women of the American Farm Bureau Foundation, was entered into the Congressional Record by Senator George Radcliffe of Maryland. She stated, "The fertility of our soil has been greatly reduced by erosion, overcropping, leaching and man's failure to return sufficient nutrient to the soil." She called for a national plant-nutrient policy to make plant-nutrient fertilizer available to all areas of the country (Congressional Record 1945).

Content review from the 1945 volume of *Better Crops with Plant Food* (a publication from the International Plant Nutrition Institute) indicates fertilizer source, rate, timing, and placement were discussed extensively, even though the term "4R nutrient stewardship" was absent. Topics also indicate a focus on identifying soils suffering fertility depletion and crops needing nutrients to boost yields.

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Some articles did also address crop quality as affected by crop nutrition and the importance of controlling soil erosion to minimize nutrient loss.

Today, the term "4R nutrient stewardship" has become ubiquitous with many stakeholders. A 2017 survey indicated 96% of crop advisors were aware of 4R terminology (Moody 2018), and the 4Rs are the basis for nutrient management efforts at the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS 2020). The 4Rs are guided by the following principles:

- Right Source—Ensure a balanced supply of essential nutrients, considering both naturally available sources and the characteristics of specific products, in plant available forms.
- Right Rate—Assess and make decisions based on soil nutrient supply and plant demand.
- Right Time—Assess and make decisions based on the dynamics of crop uptake, soil supply, nutrient loss risks, and field operation logistics.
- Right Place—Address root-soil dynamics and nutrient movement, and manage spatial variability within the field to meet site-specific crop needs and limit potential losses from the field.

The question arises: Was 4R nutrient stewardship practiced in 1945? A quote from one of the articles in the 1945 volume states, "Experience has shown that for maximum efficiency from use of fertilizers we not only must make sure we use the right amount of the right fertilizer ratio, but we must apply it at the right time and in the right place with respect to the feeding root." The context, however, was in a discussion of the merits of "plow-under" fertilizers for corn. Additionally, within the article, the word "stewardship" was used only in reference to stewardship of the soil, not of nutrients or fertilizers.

Some of what we consider new today was already in mind in 1945. A portent of precision farming, "selective service for each acre" was defined as "using the land according to its capabilities and treating it according to its needs, including application of needed soil and water conservation practices…treating these farms, fields, and acres in accordance with their needs and adaptabilities" (Sargent 1945).

While terms linked to nutrient source, rate, timing, and placement were a part of the nutrient use lexicon prior to the 1990s, it is late in the 20th century that we see a shift toward the nutrient management considerations of today. The *Journal of Soil and Water Conservation* (JSWC) database offers insight through the appearance of key terms relevant to nutrient stewardship. From 2000 to present, we see a five- to six-fold increase in the appearance of the terms "nutrient loss" and "nutrient pollution," respectively, in JSWC article text (figure 1). Noting that JSWC indexes are not as thorough nor searchable prior to 1981, it is notable that those two terms do not appear in the journal's printed index prior to 1981. Appearance of "sustainability" and "sustainable" also increase significantly between 2000 and 2020, and again neither appear in the pre-1981 journal index.

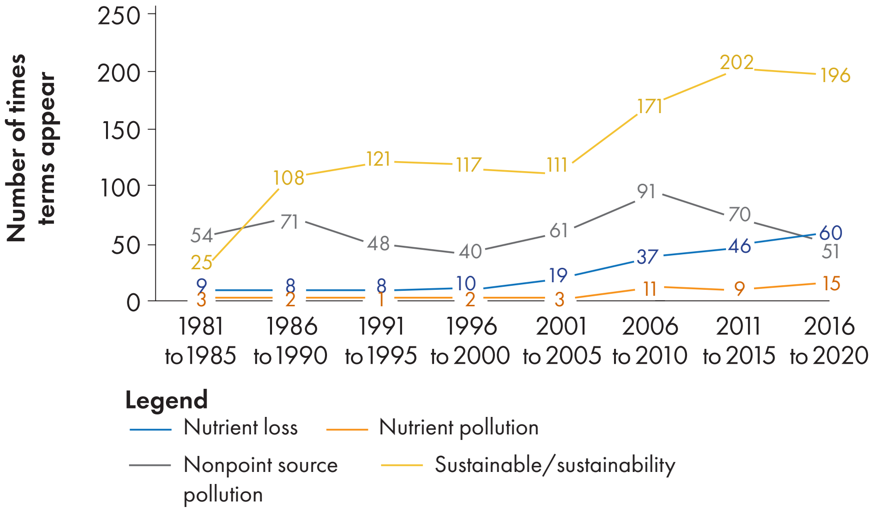
While the literature cited above shows that nutrient use around 1945 focused on building soil fertility and addressing crop deficiencies, a shift toward environmental considerations has occurred since that time. With this shift, the terms "management" and "stewardship" start to be applied to nutrients as well as to soils.

By 2010, the fertilizer industry had shifted its focus from solely considering soil fertility and crop needs to more broadly considering the impact of nutrient stewardship on economic, social, and environmental outcomes. These multiple outcomes include key sustainability performance areas including profitability, soil health, reduced losses to the environment, rural development, food security, land conservation, and habitat protection.

The number of tools to diagnose nutrient need and aid in nutrient application has expanded beyond soil testing and plant analysis to include sensors, crop and soil maps, global positioning system (GPS) guidance, and in-season crop models accounting for weather, as well as new fertilizer products and technologies. Dealership surveys, conducted by CropLife media and Purdue

Figure 1

Number of times the terms "nutrient loss," "nutrient pollution," "nonpoint source," and "sustainable/sustainability" appear in *Journal of Soil and Water Conservation* text between 1981 and 2020.



University, show that from 2004 to 2019, use of GPS guidance with autosteer/autocontrol has increased from 5% to 90% of respondents (Erickson and Lowenberg-DeBoer 2019). Between 1997 and 2019, variable rate fertilizer application among retailers increased from 9% to 64%. Data from The Fertilizer Institute (The Fertilizer Institute 2020b) indicate 24% of all nitrogen (N) is now applied with an enhanced efficiency fertilizer product. These products, tools, technologies, and practices are key components to implementing 4R nutrient stewardship on the ground.

The past 75 years saw great changes in nutrient balances. Nitrogen use efficiency (N removed in crop harvest as a fraction of that supplied by fertilizers, manures, and legumes) was as high as 175% in 1947 (Stanford et al. 1970), because the common use of moldboard plowing made a lot of N available from the organic matter of America's rich soils. It dipped as low as 51% in 1974 but has climbed to almost 70% today (Lassaletta et al. 2014).

Around 1945, crop harvests were removing less than one-quarter the amount of phosphorus (P) they do today. Annual P inputs, manure and fertilizer, amounted to 60% more than crop removal in 1945, remained in surplus through the 1970s and 1980s, but since 2008 have matched or fallen short of crop removals (Bruulsema et al. 2019).

Given the site specificity of 4R practice adoption and impact, a real-world example provides good insight into implementation outcomes. On a no-till corn operation in Illinois, the operator's management practices evolved from 2014 to 2018 to refine his nutrient management system (The Fertilizer Institute 2020a). As practices evolved (e.g., fine tuning the timing of N application to more closely match the crop's growth curve and refining spatial decisions for variable rate application), so did the cropping system outcomes. In addition to yields increasing across the four-year period, the cost for practice implementation decreased by \$40 to \$62 ha^{-1} (\$16 to \$25 ac^{-1}), and the N application rate decreased with increasing yield, leading to an improved N use efficiency, going from 50 to 70 kg (0.9 to 1.25 bu) of corn per kilogram (pound) of N applied. Additionally, greenhouse gas nitrous oxide emissions were reduced by 34% (based on the carbon dioxide equivalent [CO_2eq]), based on the calculation utilized by Field to Market (2018) in the FieldPrint Calculator.

Future

Optimizing nutrient use efficiency involves matching input rates as closely as possible to the needs of the system. It depends on choosing the right source, right time, and right place for each nutrient application, as well as on choosing the right crop, the right cultivar, the right pest control, and the right tillage and soil management. We project that as the products, tools, technologies, and practices described above are further fine-tuned and developed, nutrient use efficiencies will be further optimized while maintaining soil health. In addition, specific critical losses will be further reduced.

Today, the public and a broad group of agricultural stakeholders have heightened expectations of farmers and the fertilizer industry when it comes to nutrient use. The linkage of nutrient loss to algal blooms, eutrophication, ammonia loss, and nitrous oxide emissions (a potent greenhouse gas)—as well as the increased media attention on these topics—has placed an increasing focus on reducing nutrient loss to the environment. While crop production systems are considered nonpoint source, and therefore not regulated by the US Environmental Protection Agency Clean Water Act, in the last decade some states have implemented policies aimed specifically at reducing nutrient loss.

Consumer-facing retail chains and brands in the food supply chain are increasingly engaged in driving practice change on the farm. In its infancy in 2006, Field to Market (whose mission is to unite the food supply chain to deliver sustainable outcomes for agriculture) now has more than 120 regular members representing farmer, agribusiness, and conservation interest but also consumer brands such as Kellogg’s, General Mills, PepsiCo, and Coca Cola. Fertilizer decisions are still driven by production and economic performance on the farm, but environmental perspectives are now a key consideration as our mindset has evolved from one focused on nutrient use to one focused on nutrient stewardship.

As in many other aspects of agriculture, a more informed consumer base has the power to continue to drive practice change on the farm. Consequences of a changing climate will impact decision making as stakeholders grapple with associated risk. Also, given the time requirements to address environmental concerns, we’ll likely feel the pressure to address water quality and nutrient loss issues for years to come. However, we are on the forefront of new technologies, scientific discovery, and data evaluation that can lead to future nutrient management breakthroughs. Projecting forward 75 years, it will be fascinating to see what roles will be played by artificial intelligence, big data, fertilizer technologies, and knowledge of the soil microbiome in the development of tools to address the variable nutrition needs of crops within and among fields, and in response to each year’s weather.

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