

4R nutrient stewardship – are we there yet?

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4R nutrient stewardship is an innovative approach to best management practices (BMPs) for fertilizer. It ensures that the right source (or product) is applied at the right rate, in the right place, and at the right time (Roberts, 2007; Bruulsema et al., 2009). In the lead article of a 5-part series on 4R Nutrient Stewardship in the American Society of Agronomy's Crops and Soils magazine, Bruulsema et al. (2009) wrote "*This simple concept can help farmers and the public understand how the right management practices for fertilizer contribute to sustainability for agriculture. Getting practices "right" depends on important roles played by many partners including farmers, crop advisers, scientists, policymakers, consumers, and the general public.*" The concept of 4R stewardship not only provides structural stability to our own management decisions, but also offers us a simple and effective means of communicating to those outside agriculture about how our management contributes to sustainability. To truly be "right" practices must be site-specific for the crop, field, and for the zone within the field. Yet, the scientific foundation upon which 4R nutrient stewardship is built and that leads us to nutrient BMPs is universal.

Sustainable nutrient management supports cropping systems that contribute to the economic, social, and environmental elements of sustainability. Considering the increasing societal demand for food, fiber and fuel, global financial stress, and growing concerns over impacts on water and air quality, simultaneous improvement of productivity and resource use efficiency is an essential goal for agriculture. Globalization has linked the challenges of increasing productivity and improving efficiency. Striving to improve efficiency without also increasing productivity simply increases pressure to produce more on other lands and those lands may be less suited to efficient production. Likewise, the squandering of resources to maximize productivity resulting in increased environmental impact puts more pressure on other lands to reduce environmental impact while meeting productivity needs.

The 4R nutrient stewardship framework

The seeds for the 4R framework were planted more than 20 years ago by Thorup and Stewart (1988) when they wrote "This means using the right kind of fertilizer, in the right amount, in the right place, at the right time." Figure 1 is a schematic representation of the 4R nutrient stewardship framework based on the concepts described by Thorup and Stewart (Bruulsema et al., 2008). At its core are the 4Rs – application of the right nutrient source at the right rate, right time, and right place. Best management practices are the in-field manifestation of these 4Rs.

The 4Rs are shown within a cropping system circle because they integrate with agronomic BMPs selected to achieve crop management objectives. Those farm-level crop management objectives contribute toward the larger economic, social and environmental goals of sustainable development. Furthermore, the 4Rs cannot truly be realized if problems exist with other aspects of the cropping system. Science and experience clearly show that the impact of a fertilizer BMP on crop yield, crop quality, profitability and nutrient loss to water or air is greatly influenced by other agronomic (plant population, cultivar, tillage, pest management, etc.) and conservation practices (terracing, strip cropping, residue management, riparian buffers, shelter belts, etc.). Practices defined with sufficient specificity to be useful in making on-farm fertilizer use decisions, often are "best" practices only when in the appropriate context of other agronomic and conservation BMPs. A fertilizer BMP can be totally ineffective if the cropping system in which it is employed has other serious inadequacies.

Around the outer circle of the 4R framework are examples of performance indicators. A balanced complement of these indicators can reflect the influence of nutrient BMPs on accomplishment of the goals of sustainable development. Stakeholder input into performance indicators is an essential part of the process.

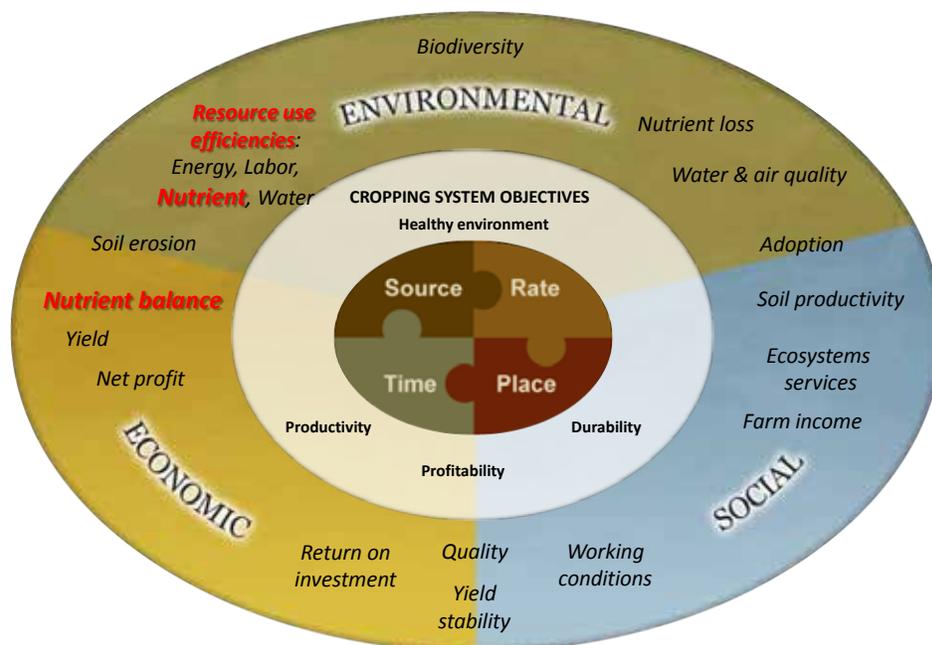


Figure 1. The 4R nutrient stewardship framework.

Science-based framework principles

The 4R nutrient stewardship framework is based on universal scientific principles that lead to nutrient BMPs. The principles serve as a guide to practices with the highest probability of supporting the management objectives of the cropping system and more broadly, the economic, social, and environmental goals of sustainable development (Table 1).

Table 1. Key scientific principles used in developing practices for determining right source, rate, time, and place (Bruulsema et al., 2009).

Category	Examples of key scientific principles
Source	Ensure a balanced supply of essential nutrients, considering both naturally available sources and characteristics of specific products, in plant-available forms.
Rate	Assess soil nutrient supply and plant demand.
Time	Assess dynamics of crop uptake, soil supply, and logistics of field operations. Determine timing of nutrient loss risks.
Place	Recognize root-soil dynamics. Manage spatial variability within the field to meet site-specific crop needs and to limit potential losses from the field.

The role of adaptive nutrient management

Scientific truths are seldom permanent but change as scientific knowledge grows. Likewise, BMPs are dynamic and evolve as science and technology expands our understanding and opportunities, and practical experience teaches the astute observer what does or does not work under specific local conditions. Thorup and Stewart in the same paper quoted earlier wrote in 1988: “Research performed on university farms and by professional researchers on farmer’s fields are extremely valuable. However, they do not necessarily relate directly to every farmer’s fields. Soils

have tremendous variability from one farm to another. Cultural practices vary markedly from one farmer to another. Even climatic factors can vary significantly over very short distances. All of these factors affect possible responses from fertilizer programs. All of this means that the farm operator who survives in the 1990s and beyond is going to have to experiment a little on his own, keep accurate records, be flexible to government programs, world market price fluctuations and soil and water conservation needs.” Though the term did not yet exist, these agronomists were describing adaptive nutrient management.

Figure 2 (Fixen, 2005) illustrates schematically the process of adaptive nutrient management where science-based decision support facilitates the integration of multiple site-specific factors and input from stakeholders into a recommendation for right source, rate, time, and place. That recommendation leads to a management decision and associated action. With time the productivity, profitability and environmental impacts are known and resource use efficiency can be determined. With additional time the durability of the system utilizing the practices in place becomes evident and that collective experience is fed back into the decision making process, allowing for better future predictions of right source, rate, time, and place. In theory, every pass through the cycle has the potential to result in better decisions and more appropriate actions.

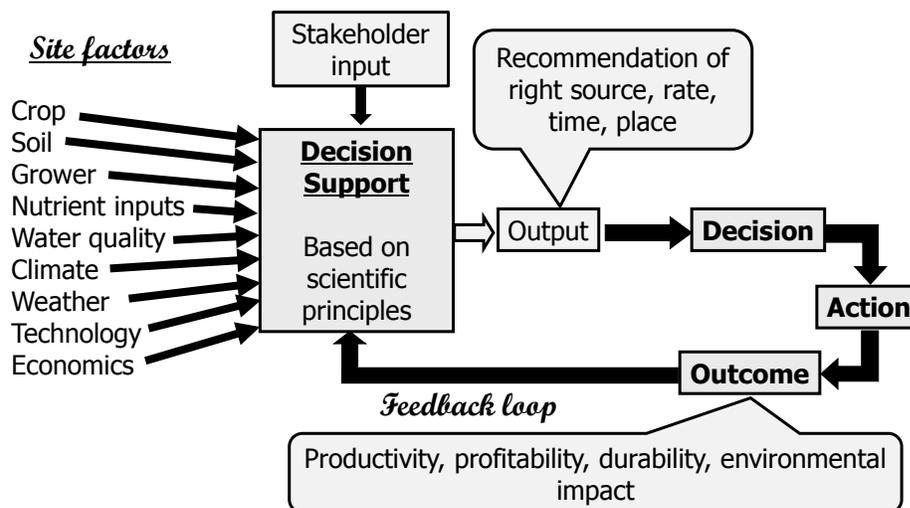


Figure 2. The role of adaptive management in 4R nutrient stewardship.

Consideration of the many possible site factors that can influence the exact nature of fertilizer BMPs reveals why local flexibility is critically important. For example (Fixen, 2007):

- Crop factors usually include yield potential and crop value and in some cases tissue nutrient concentrations or leaf color as several crop cultural practices can influence nutrient management;
- Soil factors often involve soil nutrient supplying indices or other physical, chemical or biological properties that influence nutrient cycling and crop growth;
- Grower factors might include land tenure, availability of capital, opportunity costs, the experience/ education of the farmer and local advisers, or philosophical nutrient management objectives;
- Nutrient input factors incorporate information on sources available such as commercial forms or nutrient-containing wastes, fertilizer costs and application costs;
- Water quality factors might include restrictions on nutrient application in riparian zones or near other water bodies or considerations due to ground water quality;
- Climate factors drive some types of model-based support systems while others respond to near real-time

weather information for a specific growing season and short term weather forecasts;

- What relevant technologies are available at the site in question may certainly influence definition of best practices. For example, in-season refinement of N application rate and timing may be best accomplished with electronic sensor technology in some cases and leaf color charts in others.
- Economic factors beyond those tied directly to the grower can impact nutrient decisions.

The dynamic nature of site-specific fertilizer BMPs and importance of local flexibility present a significant challenge to mandated fertilizer BMP adoption. Mandates may speed adoption, but may also result in loss of beneficial fine-tuning based on local expertise and the adaptive management process.

Is 4R Nutrient Stewardship at work in Iowa?

So, have we got it all right in Iowa? The answer to this question clearly lies at a farm level. However, we can use some recent aggregate data sets from two IPNI projects to evaluate tendencies in Iowa and the surrounding Corn Belt for at least the “rate” component of the 4Rs. One project, named NuGIS, utilizes data from multiple sources to create a nutrient use GIS for the U.S. (IPNI, 2010a). It covers a 20-year period but because Agriculture Census data are used in some balance determinations, most results are at 5-year intervals. The second project is the 2010 North American soil test summary, one in a series of summaries that IPNI periodically conducts with the cooperation of private and public soil testing laboratories (IPNI, 2010b).

The NuGIS model was used to estimate N, P and K balance for Iowa, expressed as removal to use ratios and balance per acre (Table 2). Both these expressions could be considered part of the set of performance indicators illustrated in Figure 1. All three nutrients show increasing efficiency trends in Iowa. The inference for N is that N efficiency has been improving over time since more of the N used in cropping systems appears to be captured by crops. However, these expressions do not take changes in soil N into account. The trends for P and K also reflect increasing efficiency of nutrient use. However, with P and K the desirability of these changes is dependent on soil fertility and whether it is remaining at optimum levels. The balance estimates clearly show the effect of reduced fertilizer use in 2009.

Table 2. State level nutrient balance in Iowa, 1987 to 2009.

Year	Removal to use ratio ¹			Balance ² , lb/A		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
1987	0.74	1.06	0.93	+39	-2	+4
1992	0.71	1.06	0.92	+44	-2	+4
1997	0.81	1.29	1.08	+33	-10	-4
2002	0.86	1.33	1.17	+22	-12	-8
2005	0.86	1.32	1.12	+27	-14	-7
2006	0.84	1.33	1.16	+31	-14	-9
2007	0.82	1.31	1.11	+34	-14	-6
2008	0.79	1.13	1.07	+39	-6	-4
2009	0.90	1.85	1.54	+18	-27	-22

¹ The ratio of nutrients removed in harvested portions of crops to the sum of N fixed by legumes (for N only) fertilizer applied and nutrients from recoverable manure based on Ag Census livestock inventory and NRCS procedures for estimating recoverability. ² (N fixation + fertilizer applied + recoverable nutrients – crop removal)/planted acres.

The NuGIS interactive web tool can also be used to view nutrient balance expressions on watershed scale for census years. In Figure 3, P and K removal to use ratios over the last 20 years are compared for much of the Corn Belt. The images show the widespread occurrence of increasingly negative P and K balances in this region.

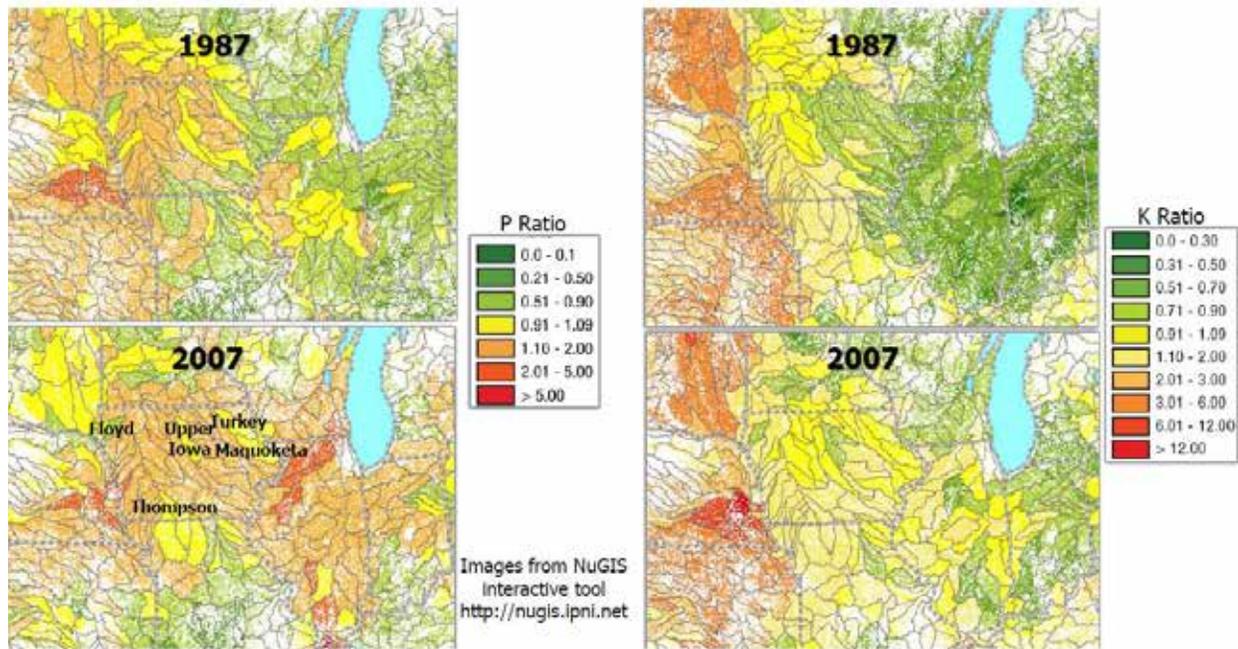


Figure 3. P and K removal to use ratios by 8-digit watersheds for 1987 and 2007 (IPNI, 2010).

The P and K balance trends for Iowa and surrounding states create questions about soil fertility trends in the region that can, at least in part, be addressed by the 2010 soil test summary when compared to the previous summary conducted in 2005 (Table 3). As one would predict based on the balance relationships, the median soil tests for P and K declined over the last 5 years, -3 ppm and -11 ppm respectively. Thus, in 2010, ½ the soil P tests in IA were below 22 ppm P and 161 ppm K. As these medians are near critical levels, close attention to P and K management and investment in sound soil testing programs are called for and likely to offer significant economic returns. Though the P median was 22 ppm, 15% of the samples tested above 50 ppm.

Table 3. Soil test summary results for selected states, 2010 (IPNI, 2010).

State(s)	Samples ¹	Bray P1, ppm		Soil K, ppm		Soil S ³		DTPA Zn ⁴		pH Median
		Median	Change ²	Median	Change ²	Samples	%	Samples	%	
IA	775	22	-3	161	-11	362	16	172	40	6.5
IL	225	26	-10	179	+1	202	16	35	19	6.4
MN	217	18	0	160	+4	139	14	61	50	6.7
NE	363	18	-4	320	-44	275	15	243	44	6.4
Corn Belt	3,028	22	-6	159	-11					6.5
N Amer	4,483	25	-6	149	-5	2,459	13	1,412	37	6.4

¹ Thousands of samples tested for P.

² Change in median level from 2005.

³ Thousands of samples tested for S and % below 3 ppm calcium phosphate equivalent S or 6 ppm Mehlich 3 equivalent S.

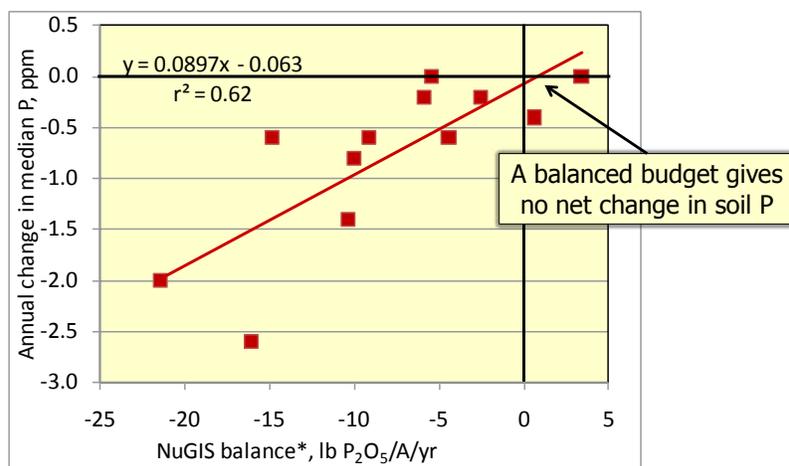
⁴ Thousands of samples tested for Zn and % below 1 ppm DTPA equivalent Zn.

The 2010 summary also showed that 16% of the samples tested for S from Iowa fell in the lowest category in the summary, consistent with surrounding states (Table 3). Across North America, 13% tested in this category, compared to 4% in 2005, indicating a decline in soil S levels, consistent with reports of increasing S deficiencies in several regions, including Iowa. A high percentage of samples also tested below 1 ppm Zn.

The intensity of soil sampling and relatively uncomplicated nutrient budgets of the Corn Belt provide an opportunity for analysis of aggregate data not possible in other regions of the country. One such analysis is the regression of nutrient balance on change in soil test levels. For P, 62% of the variation in change in state median soil test P level is explained by state P balance (Figure 4). The resulting regression line essentially passes through the origin indicating that when P use is equal to P removal by crops, over the last 5 years no change in soil test P level occurred. Though some general relationships between K balance and soil test K change were apparent (major declines in the West where the balance is highly negative), nutrient balance alone was not a good indicator of observed changes in soil test K since only 9% of the variability in soil change was explained by K balance (data not shown).

Summary

In the practical world, sustainable agriculture is less of a condition than it is a direction. None of us can see far enough into the future to know what is sustainable. What we can do is strive in our management, our advising, and our research to create systems that are more sustainable than those of the past. Continuous improvement is an essential ingredient for sustainability and 4R nutrient stewardship can serve as the foundation for the continuous improvement of nutrient management. The aggregate data discussed here indicate that nutrient relationships on the farms they represent are changing, and one can infer that they need to continue to change with the direction needed being farm and field dependent. 4R nutrient stewardship offers a useful framework to guide those changes towards more sustainable systems.



*NuGIS is a GIS nutrient balance model (IPNI, 2010).

Figure 4. Annual change in median soil P level for 12 Corn Belt states as related to state P balance (fertilizer + recoverable manure - crop removal), 2005-2009.

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