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Societies

4R management of phosphorus fertilizer in the Northern Great Plains

By Megan Sever

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One-pass planting and fertilizing in Manitoba. Photo by Don Flaten.

Soil scientists Don Flaten and Cynthia Grant recently put together a comprehensive reference for phosphorus fertilizer management across the Northern Great Plains. This article summarizes their findings on managing this nutrient using the 4R approach of right rate, source, placement, and timing.

Agriculture in the Northern Great Plains is very different from what it was 30 years ago,” says soil scientist Don Flaten, a professor at the University of Manitoba. Thirty years ago, most fields were fully tilled, continuous cropping rotations were uncommon, and very few people were aware of how phosphorus runoff affects water quality. Farms were mostly small. Over the last couple of decades, we’ve seen the widespread implementation of reduced-tillage systems, intensification of crop rotation cycles along with introduction of new crops and high-yielding cultivars, and the development of new fertilizers and new ways to apply them. We’ve also become more tech-savvy and learned more about the environmental effects. Farm size has significantly increased while the number of farms has decreased. In addition, we’ve seen increases in the proportion of land that is rented rather than owned. So, Flaten says, whether you’re looking at crop selection, tillage type, yield potential, technology, or even who owns the farmland, the agricultural landscape across the Northern Great Plains has changed.

Because of all those developments, Flaten, and fellow soil fertility scientist Cynthia Grant decided to put together a comprehensive reference for phosphorus fertilizer management across the Northern Great Plains. In 2019, they published a 255-page “science-based report for phosphorus fertilizer management for crop advisers to provide better advice to farmers” and to tell scientists where gaps in research—and thus opportunities for further research—exist (view the report at <https://bit.ly/3lBAe34>).

“We decided to dive into the literature, and we engaged partners from all over the Northern Great Plains who supplied us with information from papers and reports and books and all sorts of different sources,” Flaten says.

Flaten, who retired January 1, says this report (and the abbreviated version published in the *Journal of Environmental Quality* at <https://bit.ly/2KYye3f>) is a “legacy project” for him and Grant, who recently retired from Agriculture and Agri-Food Canada. “We wanted to do our part to pass information on to the next generation of agronomists and soil scientists.”

Below, you’ll find a summary of the findings as well as further thoughts from Flaten and Tom Bruulsema, chief scientist for Plant Nutrition Canada.

Why Phosphorus Is Necessary in the Northern Great Plains

The Northern Great Plains, for purposes of this report, encompasses the arable portions of Manitoba, Saskatchewan, Alberta and northeastern British Columbia in Canada, and the agricultural parts of South Dakota, North Dakota, Montana, northeastern Wyoming, and northwestern Nebraska.



In the Northern Great Plains, crops need starter fertilizer in the spring. This photo shows corn's response to starter P early in the season (photo on the left, with the corn on the left having received starter P compared with the corn on the right that served as the control) and at midseason (photo on the right, with the control plot in the middle clearly not as tall as the corn surrounding it that had received starter P). Photos by Magda Rogalsky (left) and Don Flaten (right).

The region has long, cold winters and short, warm summers, and is prone to drought. Although climate change is making weather more erratic, it hasn't affected agriculture in the area too much so far, Flaten says. In truth, he says, "we have such a variable climate, or variable weather, that I think farmers in the Northern Great Plains have to be prepared for snowstorms in September or October and they have to be ready for late spring frost and early fall frost. So, it is not as if they have been dealing with a very uniform and consistent climate in the first place." Nonetheless, he adds, "we know that the trend for extreme weather is probably going to intensify, so it's still important to have a system that's robust and resilient and that you can make work under a wide variety of circumstances."

Most soils in the Northern Great Plains do not have enough phosphorus for agriculture. In addition, the cold winters and short growing season mean that crops need help getting started. So growers have been using phosphorus starters in this region for 100

years.

Phosphorus is essential for plant processes. It moves to plant roots by diffusion over very short distances. That's because phosphorus doesn't move much in the soil, Flaten says. Thus, phosphorus needs to be placed near the seed.

Research and best practices have shown that the most efficient sources of phosphorus fertilizers in the region are ammonium phosphates. They have also shown that the agronomically and environmentally most beneficial way to deliver the phosphorus to the seeds is banding the starter in or near the seed row—at least for the Northern Great Plains, Flaten says.

"With the cold soils/short growing season and the importance of early-season phosphorus for the crops that we grow, we see substantial benefits for placing phosphorus in bands, and to do that precisely, it works best if we do that at planting," he says.

Basically, the goal is sustainably efficient nutrient use—providing the optimum amount of fertilizer to the growing crop at the time it's required, in the most cost-efficient manner, with the least environmental risk, Flaten and Grant wrote. That approach has a name: 4R nutrient stewardship.

The Complex Challenge of 4R Nutrient Stewardship

The 4Rs focus on nutrient application, Bruulsema says. "In a nutshell, the 4R nutrient stewardship concept is all about connecting the source of nutrients that you're applying, and the rate, timing, and placement, to sustainable outcomes for everyone involved, starting with the farmer and moving up through the whole food value chain, ending up with the consumer," he says.



Monoammonium phosphate, a granular fertilizer, is the most common phosphorus fertilizer source in the Northern Great Plains. Photo by Don Flaten.

The Rs are: the right fertilizer rate, right fertilizer source, right timing, and right placement. The goal is to consider the economic, social, and environmental impacts of all choices for each field.

“It is a combination of art and science in the sense that there are many individual scientific components built on sound science fundamentals for sources, rates, placement, and timing of phosphate fertilizer

application,” Flaten says. “But how to fit all of

those pieces of the puzzle together in a way that suits a particular field in a particular year for a particular crop is a complex challenge.”

Right Rate

“The rate of phosphorus fertilization should be selected to ensure that the crop can access the phosphorus that it requires as it is needed to optimize crop growth,” wrote Flaten and Grant in the *Journal of Environmental Quality* (JEQ). Components of the right rate involve proper assessment of the nutrient demand and soil nutrient supply, plus economics, among other factors.

An easy way to think of this is: Phosphorus out should match phosphorus in. But it’s more complicated than that, Flaten says, as not all soils need phosphorus added at the rate of removal to maintain fertility levels. Other soils, he says, may need phosphorus added at rates greater than removal to maintain phosphorus fertility. To determine the

necessary rate, you first need to know what you're working with, so start with a soil test. The most appropriate soil tests vary significantly from region to region, so farmers should work with local agronomists to determine the best option. General best practices for testing in the Northern Great Plains include testing in the top 6 inches, once per year, usually in the fall, Flaten says. That's because phosphorus doesn't usually change much from fall to spring in this region.

Once you know the initial soil phosphorus level, the next question is whether your fertility goals are aimed for the short term or long term. "Short term" means you're trying to "optimize net returns in the year of application," Flaten and Grant wrote in JEQ. "Long term" means you're thinking about soil health and fertility year after year.

Next, consider your crop and its needs, plus what other nutrients are in the soil or what you're going to add. Other nutrients can have direct effects on phosphorus availability and uptake. Then, think about what type of phosphorus fertilizer you're using and where you're placing the phosphorus—basically bringing in the other three Rs. For example, some crops, like canola and flax, are very sensitive to injury from seed-placed fertilizer, so in-row banding a high rate of phosphate fertilizer could cause stunted growth or yield loss.

Right Source

In the Northern Great Plains, choosing a fertilizer source must be driven by soil characteristics and how nutrients and their sources fit together, Flaten and Grant wrote in JEQ. Phosphorus and nitrogen often play nicely together—ammonium nitrogen in a phosphate fertilizer helps encourage phosphorus uptake, Flaten says. But phosphorus and calcium, if placed together on a high-pH soil, form less-soluble compounds, making it harder for a plant to get the necessary phosphorus. “The effectiveness of various fertilizer sources will therefore be affected both by their initial content of plant-available phosphorus and by the type and speed of reaction of the soluble phosphorus with soil constituents,” Flaten and Grant wrote.



General best practices for testing your soil in the Northern Great Plains include testing in the top 6 inches, once per year, usually in the fall. Photo by Udayakumar Sekaran.

Although struvite (from liquid manure or municipal wastewater) is growing in popularity due to the environmental benefits of recycling a waste stream, monoammonium phosphate, a granular fertilizer, is the most common phosphorus fertilizer source in the Northern Great Plains. Ammonium polyphosphate is the most common liquid fertilizer in the region. “Another one of the granular ammonium phosphate fertilizers that is more popular in the U.S. than Canada is diammonium phosphate,” Flaten says. “But it has a much higher risk of seedling toxicity [than monoammonium phosphate] if it is applied in the seed row. And because we have these cold soils and short growing season challenges, we want to apply the phosphate

in the seed row.”

Thus, he says, best practices indicate that “monoammonium phosphate is generally a better source to go with because it has less seedling toxicity risk.”

Right Placement



Broadcasting is good for building up background levels of phosphorus in the soil; however, in the Northern Great Plains, Don Flaten advises against doing it in the fall as it carries a risk of running off as snowmelt in the spring. Photo courtesy of Adobe Stock/Dusan Kostic.

The right placement is almost as complicated as finding the right rate. These two components go hand in hand and vary based on the crop, Flaten says. The goal of the right placement is to maximize agronomic efficiency and avoid toxicity. The question for placement is: Do you broadcast or do in-row or near-row banding?

Broadcast is good for building up background levels of phosphorus in the soil, Flaten says, but otherwise, in the Northern Great Plains,

banding is the way to go. Optimal placement is affected by everything from time of seeding and weather conditions to soil conditions (including nutritional and moisture content) and field topography. Type of crop also matters: “For a row crop like corn, with 30-inch spacings between corn rows and a large amount of fertilizer in each band, we’d want some separation between the corn seed and the phosphate fertilizer, so we’d go 2 inches away,” Flaten says. For most other crops grown in this region, however, he says, best practices indicate banding closer than 2 inches and likely in the seed row.

Right Timing

In the Northern Great Plains, crops need starter fertilizer in the spring. Placement in the seed row at planting is most important, especially for cold, low-phosphorus soils.

“We’re not too keen on applying phosphate fertilizer in the fall, especially fall broadcast [applications], because a large portion of our runoff in the Northern Great Plains occurs at snowmelt in the spring,” Flaten says. If applied in the fall, he says, especially if broadcast, phosphorus “has a risk of running off, which is an agronomic loss, but even more important, the consequences of downstream water quality can be severe. It takes only a little bit of phosphorus to cause big problems with water quality.”

Whether you need to also apply a late-season phosphorus fertilizer depends largely on the initial phosphorus level in the soil and the timing of plant nutrient uptake. If soils are severely depleted, plants might benefit from a foliar application, “but it’s usually best to apply phosphorus fertilizer to the soil, at planting,” Flaten says.

So, what do the tenets of the 4Rs look like in practice?

The 4Rs in Practice: Choices

Many different factors affect the choices farmers make within each of the 4Rs. For example, whether you own or rent a field might affect your chosen rate of phosphorus application, Flaten says. If you own a field and intend to keep it in the family for the long term, you tend to think about longer-term sustainability in phosphorus placement—year after year phosphorus content in fields, keeping rates relatively even—than if you’re renting or preparing for retirement, he says. If you’re thinking more short term, you might aim for phosphorus sufficiency in each field each year.

Another factor is the type of tillage, which affects many different issues. For example, with reduced or no tillage, crop debris left on the soil insulates it, keeping it warmer in the fall and winter but slightly cooler in the spring and summer. Those temperature

changes also affect soil moisture content. Another issue is stratification—for example, lots of phosphorus in the top few inches, where it is placed, and deeper soils devoid of phosphorus—which can occur if the organic debris is never tilled into the ground and you use broadcast phosphorus fertilizer or you band but do very little tilling. “But the research that I have seen from the Canadian prairies shows that the crop’s root system is also very active in those surface soils, partly because of the reduced tillage, and if there’s more moisture and more root growth in the surface soil, it seems to compensate for the stratification.”

Stratification leads to challenges in soil testing because of the potential for hot spots or voids. Soil testing problems can lead to over- or underapplying fertilizer. Reduced tillage might also improve the long-term availability of phosphorus, Flaten and Grant noted in the review, by slowing the reaction of phosphorus fertilizer with other nutrients, like calcium and magnesium in alkaline soils and aluminum and iron in acidic soils.



Spring runoff is another factor considered in tillage and type of fertilizer application: If a lot of phosphorus is left on the soil surface because of no-till and broadcast application, snowmelt and spring storms may cause significant phosphorus runoff. That means you're both polluting the environment and wasting phosphorus. In that case, you need to think carefully about when you apply it, Flaten says.

With reduced or no tillage, crop debris left on the soil insulates it, keeping it warmer in the fall and winter but slightly cooler in the spring and summer. Photo by Rajveer Singh.

Cultivar selection and crop rotation/diversity will also affect phosphorus management decisions. For example, long-term continuous cropping leads to reductions of plant-available phosphorus unless phosphorus is added to compensate for crop removal. One thing to think about for crop rotations, Flaten says, is mycorrhizal fungi associations. Most plant species absorb more phosphorus with mycorrhizal associations. Corn, flax, and soybeans rely on these associations. But leaving a field fallow for a year or growing crops like canola that don't rely on these associations will deplete the colonies, he says. So growing corn after canola or a fallow year will restrict mycorrhizal-enhanced uptake of phosphorus, thus leading to the crops needing higher rates of fertilizer application that year. "We should be planning our crop rotation to avoid situations where a mycorrhizal-dependent crop ... [follows] a nonmycorrhizal crop or was fallow the year before," Flaten says.

The blend of other nutrients in your soils also plays a role in your choices.

Developing a Plan

Growers need to understand that 4Rs provide the framework for the collaboration between agronomists and farmers that is essential to improving agricultural sustainability, Bruulsema says.

A 4R stewardship plan involves tracking and recording all crop management practices, including details of the rate, source, time, and place of every nutrient application, according to Bruulsema. Then, you adjust every year as needed, he says. It's called adaptive management. "There's a cycle where you make all your management choices, then you implement them, put them in the field, harvest your crops, and along the way, you are also making observations—you are collecting data and assessing the outcome of the choices you made," he says. "Then the next year in the decision cycle, you use the information you've gained each year to make changes to the plans for the following year."

Farmers already do this, Bruulsema says, even if they don't use the terms "adaptive management" or "4Rs." Agronomists and crop advisers just need to start a conversation with farmers to learn what they're already doing and how they can use the 4Rs to improve, he says. The discussion often centers on rate, he says, which makes sense because rate determines the amount of cash a farmer forks over for fertilizer. Bruulsema notes that farmers want to do things well, but profitability is what keeps them in business. So, while there are changes farmers could make to timing and placement in particular that are better for the environment, these actions might be considerably more expensive and may not increase returns. "The burden of protecting the environment cannot fall entirely on the grower," he says. Everyone—all stakeholders, from the farmer to the person eating the produce—has to be involved in stewardship.

So, what's the most important message for crop advisers to tell farmers?

Bruulsema says: "Everyone can do it. Nobody's excluded." Even if your practices don't measure up to everything that's recommended, he adds, "you can be sure you're at least doing something right, and you're improving."

Flaten says, to compress the 255-page review to one sentence: “In the Northern Great Plains, you’re probably going to need band placement of an ammonium phosphate in or near the seed row at time of seeding at a rate that’s sustainable for the long-term phosphorus fertility of that soil.”

Of course, he adds, “it’s not always that simple. There may be situations where you’re going to deviate from that general rule, but that’s often going to give you the best bang for your buck and the smallest environmental footprint that’s associated with phosphate fertilization.”

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