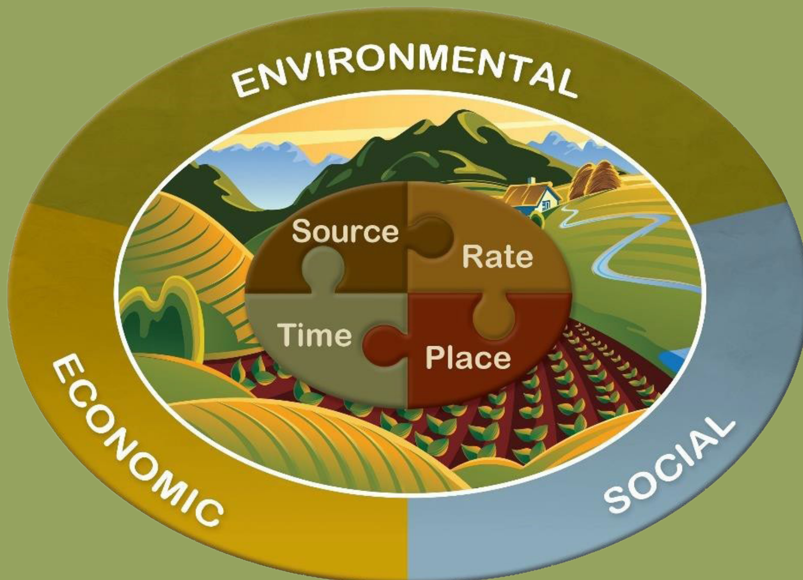
4R Management of Phosphorus Fertilizer in the Northern Great Plains: A Review of the Scientific Literature



July 3, 2019

Cynthia Grant and Don Flaten University of Manitoba

A project funded by:
Fertilizer Canada with the support of the North American 4R Research Fund

Front Cover Figure: The 4R nutrient stewardship concept defines the right source, rate, time, and place for plant nutrient application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the soil-plant ecosystem (http://www.ipni.net/ipniweb/portal/4r.nsf/article/communicationsguide)

4R Management of Phosphorus Fertilizer in the Northern Great Plains: A Review of the Scientific Literature

July 3, 2019

Cynthia Grant and Don Flaten
University of Manitoba

The overall purpose of this review is to assemble and summarize the existing science base for 4R management of P fertilizer (“right” source, “right” rate, “right” time and “right” place for fertilizer application) for crop production in the Northern Great Plains region of North America. In addition, this review identifies key gaps in knowledge and priorities for future research on this topic.

However, it’s important to note that this review does not address management of livestock manures, composts, biochars, or other amendments that are not generally regarded as conventional fertilizers, even though these amendments may play important roles in management of P fertility in soil and P nutrition in crops. Furthermore, this review does not address soil and water management beneficial management practices, which complement nutrient management practices for maintaining soil and water quality.

In this full version of the review, each chapter provides five perspectives on the chapter’s topic, including:

- a list of key messages
- a short, approximately 2 page overall summary of the chapter
- detailed information for the review
- a list of knowledge gaps
- a list of references for readers that want further information.

There is also a summary version of the review that does not include the detailed information and list of references.

Many of the aspects of P behaviour and management are highly interrelated and may be repeated within and between chapters, where those aspects are important to the understanding of the issue. This redundancy is intentional and it is included to provide readers who access only specific sections of the publication with the background material needed.

Input was provided from a wide range of contributors and the final product has been reviewed for content and accuracy by a technical review panel (see Acknowledgements), whose contributions are greatly appreciated.

Outline of the Review

Introductory Material
- Overall purpose and outline of the review
- Introduction
- Acknowledgements
- Units and abbreviations

1. Background of 4R Nutrient Stewardship
   - History
   - Background and principles

2. Role of P in Crop Production
   - Functions of P in plants
   - P accumulation in plants
   - Effects of P deficiency

3. P Behaviour in Soil
   - The phosphorus cycle
   - What happens when P fertilizer is added to the soil?
   - Residual value of fertilizer P
   - Assessing P use efficiency

4. Environmental and Sustainability Concerns Related to P Fertilizer
   - P loss to surface water and eutrophication
   - P depletion in soils
   - Cadmium loading to soil

5. Phosphorus Fertilizer Rates
   - Strategies for managing rates of P fertilization
     - Short term sufficiency
     - Long term sustainability
   - Use of soil testing as the basis for selecting rates of P
   - Selecting rates of P applications in the long-term sustainability strategy
   - Selecting rates of P application in a short-term sufficiency strategy
   - Differences in P response among crops
   - Site specific management

6. Phosphorus Fertilizer Sources, Additives and Microbial Products
   - Traditional sources of P fertilizer
     - Phosphate rock
     - Commercial phosphate fertilizers
   - Fertilizer special formulations, additives and coatings
   - Reclaimed and by-product sources of phosphorus
   - Microbial products

7. Phosphorus Fertilizer Placement
   - Efficiency of band versus broadcast application
   - Effect of band position
   - Seedling toxicity issues related to seed-placed phosphorus
   - Dual banding of N and P fertilizer

8. Phosphorus Fertilizer Timing
   - Importance of early season supply
   - Requirement for P supply during grain fill/flowering
   - Factors affecting early-season supply of P to the plant
   - Implications for P fertilizer management

9. Creating a Cohesive 4R Management Package for Phosphorus Fertilization
   - The 4R package - fitting the pieces together
   - Agronomic drivers for phosphorus management on the Northern Great Plains
     - Tillage system and crop sequence
     - Crop type, rotation and yield
     - Weed competition
     - Effects of other nutrients
   - 4R management of P fertilizer for the environment

Introduction

Key Messages:

- The cold soils at planting and short growing season of the Northern Great Plains affect P dynamics and 4R nutrient stewardship
- Changes in management practices such as widespread adoption of reduced tillage systems, introduction of new crops and high-yielding cultivars, intensification and extension of crop rotations and development of new fertilizer products affect P management
- The main purpose of this review is to provide a strong science base to ensure that “4R” management of P fertilizer (i.e., “right” source, “right” rate, “right” time and “right” place for fertilizer application) is agronomically, economically and environmentally sustainable

The Northern Great Plains includes the arable portions of the Canadian provinces of Manitoba, Saskatchewan, Alberta and northeastern British Columbia as well as the agricultural regions of South Dakota, North Dakota, and Montana; plus parts of northeastern Wyoming and northwestern Nebraska (Figure 1) (Barker and Whitman 1988; Padbury et al. 2002). According to Padbury et al. (2002), the northern boundary of this region is the northern limit for agriculture in North America, although the rich agricultural region of the Peace River district in northern British Columbia and Alberta technically lies outside of the Northern Great Plains. The climate of the northern Great Plains is continental, with long, cold winters and short, warm summers; insufficient moisture is often a major limiting factor for crop yield.

Over the past several decades there have been substantial changes in farming practices on the Northern Great Plains, including widespread adoption of reduced tillage systems, introduction of new crops and high-yielding cultivars, intensification and extension of crop rotations, development of new fertilizer products, increased appreciation of the role of microbial interactions in phosphorus dynamics, and growing concerns about climate change and the effects of P on water quality (Grant and Flaten 2019). As cropping systems, technology and societal demands evolve over time, nutrient management practices must also evolve to address concerns and take advantage of emerging opportunities.

In dryland farming systems on the Northern Great Plains, economically and environmentally sustainable agronomic management of phosphorus requires science-based application of “4R” nutrient stewardship principles (i.e., “right” source, “right” rate, “right” time and “right” place for fertilizer or manure application (Bruulsema 2017; Bruulsema et al. 2009; Flis 2018)). One of the challenges associated with the “4R” nutrient stewardship program is to ensure that farmers and agronomists have the “right” science-based information to make good decisions about their nutrient management practices. The last comprehensive literature review of P fertilizer management in the Prairies was published by the Canadian Society of Soil Science in 1993, as part of the “Impact of Macronutrients on the Crop Responses and Environmental Sustainability on the Canadian Prairies” … also known as “The Red Book” (Rennie et al. 1993). The Red Book has been a valuable source of scientific information on macronutrients for students, scientists and agronomists. Unfortunately, the P review in that book has historically been available only in hard copy and it does not include the substantial quantity of additional P fertility research that has been conducted over the last 25 years. The lack of inclusion of recent research is of a serious limitation because of the great changes in agronomic practices in western Canada over the last three decades.

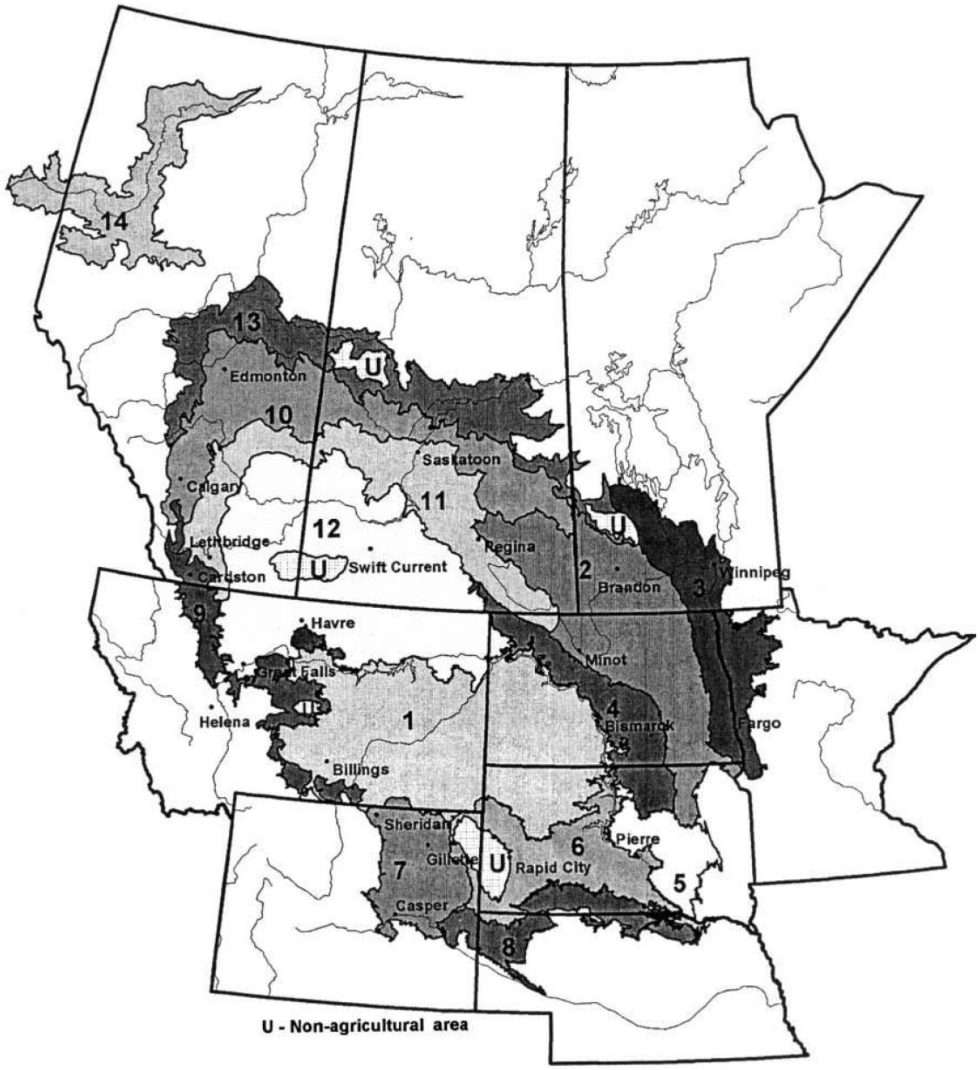


Figure 1. Agroecoregion of the Northern Great Plains (Padbury et al. 2002)

References

Barker, W. T. and Whitman, W. C. 1988. Vegetation of the northern Great Plains. Rangelands 10(6):266-272.

Bruulsema, T. 2017. 4R Phosphorus management practices for major commodity crops of North America. Pages 12. International Plant Nutrition Institute, Norcross, GA.

Bruulsema, T., Lemunyon, J. and Herz, B. 2009. Know your fertilizer rights. Crops and Soils 42(2):13-18.

Flis, S. 2018. 4R history and recent phosphorus research. Crops and Soils 51(2):36-47.

Grant, C.A. and Flaten, D.N. 2019. 4R management of phosphorus fertilizer in the northern Great Plains. J. Environ. Qual. Accepted April 2019. doi:10.2134/jeq2019.02.0061

Padbury, G., Waltman, S., Caprio, J., Coen, G., McGinn, S., Mortensen, D., Nielsen, G. and Sinclair, R. 2002. Agroecosystems and land resources of the Northern Great Plains. Agronomy Journal 94:251-261.

Rennie, D., Campbell, C. and Roberts, T. 1993. Impact of macronutrients on crop responses and environmental sustainability on the Canadian prairies-a review. Ottawa, ON: Can Soc Soil Sci.

Acknowledgements

This review was funded by Fertilizer Canada with the support of the North American 4R Research Fund from April 2018 to June 2019. The authors were assisted with contributions of literature from:

Chris Holzapfel, IHARF
Alan Moulin, AAFC Brandon
Ramona Mohr, AAFC Brandon
Shabtai Bittman, AAFC Agassiz
S. S. Malhi, Retired AAFC
Ray Dowbenko, Retired Agrium/Nutrien
Jay Goos, NDSU
Fran Walley, U. of Sask
Tom Jensen, IPNI
Garry Hnatowich, SK ICDC
Rigas Karamanos, Koch
Dan Heaney, Fertilizer Canada consultant
Con Campbell, Retired AAFC
John Heard, MB Ag
Tom Bruulsema, IPNI
Taryn Dickson, Canola Council of Canada
Paul Fixen, Retired IPNI
Daryl Domitruk, MB Pulse & Soybean Growers
Jeff Schoenau, U. of Sask
Henry Wilson, AAFC Brandon
Steve Crittenden, AAFC Brandon
Mervin St. Luce, AAFC SPARC
Clain Jones, Montana State University
Patrick Carr, Montana State University
David Franzen, NDSU
Ross McKenzie, Retired AB Ag
Diane Knight, U. of Sask
Geza Racz, U of MB (Prof. Emeritus)
Len Kryzanowski, Alberta Agriculture
Les Henry, U of Sask (Prof. Emeritus)
Jeff Jacobsen, Montana State U. (Prof. Emeritus)
Lyle Cowell, Nutrien
Stewart Brandt, Northeast Ag. Research Fdn.
Murray Hartman, Alberta Agriculture
Eric Bremner, Western Ag Innovations

In addition, the "review" was "reviewed" by a Technical Advisory Group, which included:

John Heard (Manitoba Agriculture Crop Nutrition Specialist, Carman, MB)
Ross McKenzie (retired Alberta Agriculture Agronomy Research Scientist, Lethbridge, AB)
Lyle Cowell (Nutrien agronomist, Tisdale, SK and co-author of 1993 review chapter on P)
Jeff Schoenau (Professor, Soil Fertility, U. of Saskatchewan)
Rigas Karamanos (Senior Agronomist, Koch Fertilizer Canada)
Les Henry (Professor Emeritus, U. of Saskatchewan)
Len Kryzanowski (Alberta Ag. & Forestry)
Tom Bruulsema (Vice-President, International Plant Nutrition Institute (IPNI))
Amanda Giamberardino (Fertilizer Canada, ex officio)

Unit Conversions

Generally, within this document, the measurements are in imperial units (e.g., lbs or bushels per acre). However, most of the scientific literature used for this document report measurements in S.I. or metric units. The following factors can be used to convert between these types of units.

Convert	to	Multiply First Column by	Comments
Acres	Hectares	0.402	
Pounds	Kilograms	0.454	
Inches	Centimeters	2.54	
Pounds per acre	kg/ha	1.12	
Canola (bu/acre)	kg/ha	56.0	
Wheat (bu/acre)	kg/ha	67.3	
Barley (bu/acre) 48 lb bu	kg/ha	53.8	
Flax (bu/acre)	kg/ha	62.8	
ppm	lb/acre in six inches	2	Assumes that bulk density is uniform and high, at 1.33 g/cm^3
P	P_2O_5	2.29	
P_2O_5	P	0.44	

Definitions of Concentrations

ppm = mg L^{-1} or mg/L if reported as concentration in solutions (e.g., in water) or
mg kg^{-1} or mg/kg if reported as concentrations per unit of mass (e.g., in soil)

ppb = µg L^{-1}

Abbreviations

4R	applying the right nutrient source at the right rate, right time and in the right place
ADP	adenosine diphosphate
AMF	arbuscular mycorrhizal fungi
APP	ammonium polyphosphate liquid fertilizer (e.g., 10-34-0)
ATP	adenosine triphosphate
BMP	beneficial management practice
Cd	cadmium
DCP	dicalcium phosphate
DCPD	dicalcium phosphate dihydrate
DNA	deoxyribonucleic acid
DAP	diammonium phosphate granular fertilizer (e.g., 18-46-0)
FA	fulvic acid
HA	humic acid
HFA	mixture of humic and fulvic acid
KS	potassium sulphate granular fertilizer (e.g., 0-0-50-18S)
LDH	layered double hydroxide
MAP	monoammonium phosphate granular fertilizer (e.g., 11-52-0)
MCP	monocalcium phosphate
N	nitrogen
NADP	nicotinamide adenine dinucleotide phosphate
NADPH	reduced form of nicotinamide adenine dinucleotide phosphate
NMR	nuclear magnetic resonance (spectroscopy)
OCP	octacalcium phosphate
P	phosphorus
P_i	inorganic phosphorus
P_o	organic phosphorus
PUE	phosphorus fertilizer use efficiency
RNA	ribonucleic acid
SBU	seedbed utilization
SSP	single or “ordinary” superphosphate granular fertilizer (e.g., 0-20-0-10S)
STP	soil test phosphorus
TSP	triple super phosphate granular fertilizer (e.g., 0-45-0)