4R Phosphorus Fertilizer Management in the Northern Great Plains

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2019 is the 350th anniversary of the discovery of phosphorus by Hennig Brandt in 1669
Historical Background: The Red Book


http://canadianagronomist.ca/resource/the-red-book/
Red Book II ... the Sequel? ... only P, so far

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

Cynthia Grant and Brian Grant

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https://fertilizercanada.ca/nutrient-stewardship/4r-research-network/
Characteristics of the Northern Great Plains

- Runs from north part of Nebraska to northern limits of agriculture in Canada
- Cold winters with snow
- Annual precipitation from 300 to 500 mm, but highly variable
  - Drought is often limiting
- Grassland, aspen parkland and mixed-wood forest
- Soils are generally high in organic matter
Environment and Cropping System Drive P Management Decisions On Northern Great Plains

- Cold soils in spring
- Short growing season
- Often high pH carbonated soils
- Snow-melt runoff
- Reduced tillage
- Movement towards diversified rotations
- High-yielding cultivars
Chapter 1 – Background for 4R Nutrient Stewardship

✓ Right rates
✓ Right sources
✓ Right placement
✓ Right timing

In a cohesive combination suited to the crop and the environment
Chapter 2 – Role of Phosphorus for Crop Production

- Phosphorus is critical from the earliest stages of crop growth
  - Energy transfer (ATP)
  - Component of cell membranes
  - Genetic material (DNA)
- Promotes photosynthesis, root development, tillering, early flowering, seed production, and uniform ripening
- Taken up only as “ortho-P” (H$_2$PO$_4^-$ or HPO$_4^{2-}$)
  - Moves to root mainly by diffusion, over very short distances
P Deficiency

... purpling of leaves / stems
P deficiency can Lead to Stunted Growth and Reduced Yield
Chapter 3 - P Behaviour in Soil

- Very small concentrations of P in solution
- Most soil P is retained strongly by precipitation and immobilization in soil solids, and adsorption to soil surfaces
- Release for crop uptake is affected by soil, plant & environmental factors

Other Soluble Forms
(eg. chelates)

Free Ions in Soil Sol’n
Orthophosphate
($\text{H}_2\text{PO}_4^-$, $\text{HPO}_4^{2-}$)

Atmosphere
Fertilizer P
eg. MAP, APP

Crop Residues,
Livestock Manures,
Municipal Waste

Plant Roots

Root Membranes

Mass Flow
Diffusion
(Root Interception)

Soil Solution

Precipitation/Dissolution
Immobilization/Mineralization

Soil Solids & Surfaces

Bulk Solids
(Inorganic and Organic)
DCPD, OCP, HA, FA
Organic P

pH & aeration
Master Variables

Other Soluble Forms
(eg. chelates)

Adsorption/Desorption

Soil Surfaces
(Inorganic and Organic)
Majority of Soils on Northern Great Plains Are Deficient in P

Percent of Samples Testing Below Critical Levels for P in 2015

International Plant Nutrition Institute 2016
Canola Response to P in Western Manitoba

No Starter P

25 lb P2O5 applied as MAP

25 bu/acre

35 bu/acre

15 lb NW MKP per ac, equiv. to ~ 10 ppm Olsen P

Courtesy of John Heard
Chapter 4 - Environmental and Sustainability Concerns Related to P Fertilization

- Small amounts of P loss cause large problems with water quality
- Most P loss in NGP is dissolved P during snowmelt
- Careful management of P rate, placement and timing is critical for reducing the risk of P loss to surface water
- Cadmium content in P fertilizer is also a concern ... for human health
Lake Winnipeg is a concern in the Lake Winnipeg Watershed.

- Lake Winnipeg is the 10th largest freshwater lake in the world.
- Watershed area of about 1,000,000 km² largely in the Northern Great Plains.
  - Northern Great Plains area is 1,300,000 km².
- Severe eutrophication due to excess P inputs.
Spring Snowmelt Drives P Loss on Northern Great Plains

• In Northern Great Plains, unlike other areas where erosion dominates, most loss occurs during spring snow-melt, which accounts of 80% of runoff

• Runoff from snow-melt over frozen ground leads to little erosive loss and more dissolved P loss
  – P will dissolve from surface P in soil and in vegetation
  – Some traditional soil and water conservation practices that reduce water erosion may increase the loss of dissolved P in Northern Great Plains watersheds

• Reduce P concentration at soil surface to reduce P losses
Right rate
- Right source
- Right placement
- Right timing

In a cohesive combination suited to the crop, economics, and environment
P Rate can be Managed for Short- or Long-term Sustainability

**Short-term sustainability**
- Rate chosen based on short-term economic yield response in the year of application
  - Often seed-place a low rate of P
  - May deplete soil P over time
- Suitable for short-term land tenure
- Where fertilizer costs are high relative to crop prices

**Long-term sustainability**
- Target applications to reach and maintain target soil test
  - Build on low-P soils
  - Deplete on high-P soils
- Long-term economics considers residual P value
- Suitable for long-term land tenure
- If P costs are low relative to crop prices
Soil tests Form the Basis for P Rates Recommendation

Appendix Table 17. Phosphorus recommendations for field crops based on soil test levels and placement.

<table>
<thead>
<tr>
<th>Soil Phosphorus (sodium bicarbonate or Olsen P test)</th>
<th>Cereal</th>
<th>Corn Sunflower</th>
<th>Canola Mustard Flax</th>
<th>Buckwheat Fababean</th>
<th>Potatoes</th>
<th>Peas Lentils Field beans</th>
<th>Soybeans¹</th>
<th>Legume forages</th>
<th>Perennial grass forages</th>
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<tbody>
<tr>
<td>ppm</td>
<td>lb/ac</td>
<td>Rating</td>
<td>ppm</td>
<td>lb/ac</td>
<td>Rating</td>
<td>ppm</td>
<td>lb/ac</td>
<td>Rating</td>
<td>ppm</td>
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<td>0</td>
<td>VL</td>
<td>40</td>
<td>40</td>
<td>S¹</td>
<td>40</td>
<td>20</td>
<td>S¹</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>L</td>
<td>40</td>
<td>40</td>
<td>B³</td>
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<td>S¹</td>
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<td>S¹</td>
<td>10</td>
<td>0</td>
<td>S¹</td>
<td>30</td>
</tr>
</tbody>
</table>
Yield Response to P is Highly Variable from Year to Year ... and from One Crop Phase to Another

Critical Soil Test P Thresholds Are Not Exact

- Alberta data show a critical level of 20-25 ppm for average of 10% response
- Above this level, only maintenance (crop removal) application would be required
- ... but the variability was large

Ross McKenzie, Alberta Agric.
Critical Soil Test P Thresholds Are Not Exact

- Given the large variability, a probability approach may be more realistic than a “response curve”

Karamanos, 33 site years in AB, SK, MB 1988-1995
### Applying “Safe” Rate of Seed-Placed P in Short-Term Sufficiency Program Can Deplete Soil P

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield bu/ac</th>
<th>P Removal lb</th>
<th>Seed Limit P_2O_5 ac⁻¹</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>60</td>
<td>35</td>
<td>30</td>
<td>-5</td>
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<tr>
<td>Canola</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>-20</td>
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<tr>
<td>Soybeans</td>
<td>40</td>
<td>32</td>
<td>10</td>
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<td>Barley</td>
<td>80</td>
<td>38</td>
<td>50</td>
<td>+12</td>
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<td>Flax</td>
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<td>0</td>
</tr>
<tr>
<td>Peas</td>
<td>50</td>
<td>38</td>
<td>20</td>
<td>-18</td>
</tr>
<tr>
<td>Oats</td>
<td>100</td>
<td>29</td>
<td>50</td>
<td>+21</td>
</tr>
</tbody>
</table>

*Rates are based on disk or knife openers with a 1 in. spread, 6 to 7 in. row spacing and good to excellent soil moisture*
Rotations Are Shifting to More Crops that Are Sensitive to Seed-placed P

- Increased acres of canola, soybeans and corn,
  - High rates of P removal
  - Limited amount of P can be placed in the seed row, without risk of toxicity
- Decreased barley and wheat acres
  - Less opportunity to place high rates of P with seed
- Yields of all crops have increased
  - Greater removal of P in the grain
- Soil P can be depleted over time
Crops Respond to P Fertilizer and P Fertility, so Depleted Soil P can Decrease Crop Yield Potential

Average Olsen soil test P for all rates of seed placed P after 5 years

- 8 ppm
- 4 ppm
- 5 ppm

Amount of P b'cast initially (lb P$_2$O$_5$/ac)

- 163
- 82

Optimum yield was higher with moderate rather than very low soil test P

Wagar et al. 1986
Solutions to the Phosphorus Deficit

• Side-band or mid-row band to move P away from the seed
• Manage P through the rotation by increasing P in other less sensitive crops
• Use a long-term sustainability program, to maintain soil P at target levels
  – Broadcast or band higher levels of P when needed
Long term sustainability strategy to move soil P levels into an optimum range over time

- **Buildup range**: If low, may want to build by applying fertilizer or manure P in excess of crop removal.
- **Maintenance range**: If near optimum, can balance input and removal.
- **Drawdown range with starter P only**: If excess, can draw down by using only starter P.

Adapted from OMAFRA Soil Fertility Handbook

- **10-20 ppm Olsen soil test P**

Soil P Level:
- VL
- L
- M
- MH
- H
- H+

P Rate relative to Removal:
Olsen P Reflects P Balance in Alberta and Manitoba Soils after 8 years of P Applications in a Durum-Flax Rotation

- Olsen P increased with high P rates
- Olsen P declined when no P applied
- At 40 lb phosphate/acre/year, Olsen P was maintained at most sites
- Surplus P to raise Olsen P by 1 ppm:
  - 16-23 lb $P_2O_5$/ac at Carman
  - 29-32 lb $P_2O_5$/ac at Carstairs
  - 27-35 lb $P_2O_5$/ac at Brandon
  - 21-25 lb $P_2O_5$/ac at Ft. Sask.
  - 32-41 lb $P_2O_5$/ac at Phillips
- Most rapid change in light-textured, poorly buffered soils

Grant et al. unpublished
Key Messages for Selecting the Right Rate of P

Avoid excess P depletion or accumulation

- Deficits can reduce P fertility & long-term productivity
- Surpluses can increase risk of P loss and eutrophication
- Target Olsen P levels of around 15 ppm
  - Build levels in cereal years, with side- or mid-row band applications, or with manure
  - Consider a maintenance strategy when target soil test P levels are attained
  - Add only starter P if soil test P exceeds target levels
Right Source

- Right rate
- Right source
- Right placement
- Right timing

In a cohesive combination suited to the crop, economics, and environment
Traditional Phosphate Fertilizers

1. Rock phosphate (highly insoluble, but rec. for organic)
2. Triple super phosphate or TSP (eg. 0-45-0)
3. Monoammonium phosphate or MAP (eg. 11-52-0)
4. Ammonium polyphosphate or APP (eg. 10-34-0)
Monoammonium Phosphate (MAP)

- Monoammonium phosphate is the standard fertilizer source for Western Canada
  - Inexpensive to manufacture
  - Easy to handle granule
  - Analysis in the range of 11-52-0
- Performs better than calcium phosphates on calcareous soils
  - Ammonium in formulation enhances efficiency on high pH, calcareous soils
- Less toxic than DAP for seed placement

Wheat Grain Yield Response to MAP and MCP in Saskatchewan (1939-1943)

https://www.ipni.netpecifics-en
Ammonium Polyphosphate or APP (eg. 10-34-0)

- A reasonably popular form of liquid P fertilizer
- Poly-P is not immediately available to plants but is quickly split into ortho-P by soil’s phosphatase enzymes
- Reactions and effectiveness similar to MAP in NGP
Products that Attempt to Improve P Use Efficiency

• Use of more crop available forms
  – Ammoniated phosphates
  – Dual banding N and P fertilizer together
  – Fluids vs. dry/granular
  – Liquid orthophosphates vs. polyphosphates

• Reduce soil retention
  – Avail

• Release P gradually to match plant uptake
  – Polymer coated MAP and struvite

• Inoculants that release P in rhizosphere or improve plant access to P
  – Provide *(Penicillium bilaii)*
  – Mycorrhizae
What Else is In the Band?

- P availability is increased by ammonium in the band
  - Ammoniated P fertilizers (e.g. MAP, APP) outperform other P fertilizers
  - Adding urea or ammonia to MAP bands (dual banding) increases fertilizer P uptake when fertilizer is banded away from seed
- P availability is delayed when banded with high rates of N
  - Typical rates of N will delay P uptake for several weeks due to band toxicity
- Some starter P should be placed in seed row when “dual banding” N and P
  - Allow early season access to P
Fluid vs. Dry Fertilizers

- Under arid, highly calcareous conditions in Australia, fluid forms of P are more available than dry:
  - Water moving toward dissolving granule carries Ca to the fertilizer
  - Ca precipitates P and leads to small reaction zone
  - Fluid forms increase reaction zone and allow greater root uptake
- Similar benefit has not shown up in tests in Manitoba and is unlikely in humid areas
No Difference Between Dry MAP & Fluid APP in Wheat Yield Over Three Years at Two Sites Near Brandon

• Similar results in previous studies by Racz and in later studies on canola, durum wheat and soybean

• Soils in MB trials were much more humid and less calcareous than the 70% calcium carbonate in the Australian trials
Struvite

- Commercial struvite (e.g., Crystal Green) is recovered from wastewater.
- Represents an important step towards sustainable use of recycled P.
Overall recovery of P from struvite and coated MAP in wheat and canola was similar to uncoated MAP (11-52-0) in clay loam and sand.

What About Microbial Products?

Two major products sold in western Canada

- Provide (or Jumpstart and part of TagTeam)
- Mycorrhizal inoculants
- Little evidence found in the literature of reliable benefits of inoculants on crop yield or P uptake
  - Mycorrhizal populations are very important but native populations may be adequate
  - If application rates are reduced to below crop removal when these products are used, it will increase the P deficit ... the imbalance between crop removal and P applied
Key Messages for Selecting the Right Source of P

- MAP (eg. 11-52-0) and APP (eg. 10-34-0) are the standard fertilizer sources for the Northern Great Plains
  - Ammonium enhances efficiency on high pH, calcareous soils
  - Dual banding with ammonium N can improve P efficiency
- No evidence of significant agronomic difference between orthophosphate and polyphosphate
- Fluids and dry formulations perform similarly on the Northern Great Plains
- Novel P fertilizer formulations or use of microbial products have generally not shown increased effectiveness over MAP and APP under field conditions on the Northern Great Plains
- Recycled P products such as struvite offer improvements in long term sustainability
Chapter 7, 8 - Right Placement and Timing

- Right rate
- Right source
- Right placement
- Right timing

In a cohesive combination suited to the crop, economics, and environment
Principles of Phosphorus Nutrition that Affect P Placement and Timing

- **P is needed early in growth**
  - Plants must have adequate supply in first 3-6 weeks

- **Phosphorus will not move far through the soil**
  - Movement is limited to a few mm

- **Adequate P needs to be near the seed-row so the plants can access it early in the season**
Placement Will Vary with Sustainability Approach and Rate of Application

• Broadcast applications can work agronomically with high application rates or if background soil P levels are high
  – Provides adequate supply of P to seedling from bulk soils
  – Enables long-term maintenance of P balance
  – But leads to accumulation of P at surface, especially under reduced tillage systems ... increases risk of runoff losses

• Banding improves efficiency when using lower rates of application
  – For short-term sustainability approach
Banding Improves P Availability

- Slows tie-up of P in soil
  - Important on high pH, carbonated soils of NGP
  - Having some N in the band is beneficial
- Bands must be placed where roots will contact them early in season
  - Seed-placed
  - Side-banded
- Some plant roots proliferate in bands
  - Fertilizer bands provide high concentration
  - More roots in the band increase uptake
- Amount that can safely be placed with the seed varies with crop type
Banding Near Seed-Row Important on Cold Soils & Short Growing Season of Northern Great Plains

• P encourages crop maturity which is an asset for short growing season

• Cold soils reduce P availability
  – Lower P solubility and movement
  – Slower root growth

• Banding P near the seed at the time of seeding improves availability when P availability is low

Greater chance of response to starter P with early seeding on cold soils
Starter P may increase yield with cold soils and early seeding even on relatively high P soils

+10 kg/ha Seed row P$_2$O$_5$

No starter P

Fall band 70-30-10-10 on whole field

Photo: Aaron Baldwin, Cargill
Excess Seed-placed Monoammonium Phosphate Can Cause Seedling Damage in Canola and Other Crops

- Toxicity is mainly related to salt effect from N portion of MAP or APP fertilizer
  - Blending with S can increase damage
- Toxicity will be affected by soil characteristics and weather
- Similar damage can also occur with soybean and flax

![Graph showing % Emergence and Stand Density vs. Kg Phosphate per Hectare and Phosphate (kg ha⁻¹)]

J. Schoenau
Seed-Placed MAP Can Cause Seedling Damage in Sensitive Crops, eg. Canola at Portage la Prairie

20 lbs P$_2$O$_5$/ac as MAP (11-52-0) with disc openers at 12 inch spacing

No seedrow P applied
Seedling Damage was Reduced by Struvite and Controlled Release Phosphate

- Struvite and coated MAP reduce the risk of seedling toxicity
- Lower salt and ammonium concentration in seed-row
- Can also move band away from seed

Katanda et al. 2019
Agron. J. 111:390–396
Banding P Below Surface Reduces Risk of Environmental Losses

- Broadcasting P is agronomically inefficient and leaves soluble P on the surface prone to run-off
  - Especially with conservation tillage
  - Especially with fall application
- P banded in soil increases P efficiency and reduces P accumulation near soil surface
- Environmentally beneficial because P is placed under soil surface after spring snowmelt runoff
- Agronomically beneficial, especially in cold soils in areas with short growing season
Runoff losses for P applied at 100 lbs MAP (11-52-0) per acre in laboratory studies were 50 times greater for broadcast P than for P banded 1 cm below the soil surface (Smith et al. 2016).
Key Messages for Selecting the Right Placement and Timing for P Fertilizer

• Plants need P from their earliest growth stages
  – P fertilizer should be applied when and where the crop can access it early in the season.
• Cold soils in the early spring can restrict root growth and P availability, limiting early season P supply to crops
• Band application near the seed-row can improve P efficiency
  – Banding slows soil reactions that reduce P availability
  – Place P bands where plant roots will intercept them in early growth
• Broadcast P at the soil surface is agronomically less efficient than in-soil bands and increases the risk of P runoff
• In-soil banding is agronomically and environmentally beneficial for P applications on the Northern Great Plains
Chapter 9 – Creating a Cohesive 4R Management Package for Phosphorus Fertilization

- Right rate
- Right source
- Right placement
- Right timing

In a cohesive combination suited to the crop, economics, and environment
4R P Management on Northern Great Plains

- Environment and management system drive 4R practices on Northern Great Plains
- Cold soils at planting restrict P availability and root growth
  - Benefits of banding in or near seed-row increase
- Snow-melt drives P losses through dissolved P movement in runoff
  - Reduce P concentration at the soil surface
  - Benefits of banding at seeding
- Diversification and intensification increases P removal
  - Balance P input with off-take to avoid excess accumulation or depletion of P over time
Employing the science-based principles of 4R P fertilizer stewardship is vital for sustainable crop production.

The most efficient sources of P fertilizer for this region are ammonium phosphates.

Long term sustainable crop production requires P fertilizer rates that match crop removal.

Banding P fertilizer in or near the seed-row is agronomically and environmentally beneficial.

- Right source
- Right rate
- Right placement
- Right timing
P Management – The next 350 Years?

- P is a finite resource
  - Whether timeframe is 50 years or several hundred
- P is required to feed the growing world population
- Every unit of P must be used and reused efficiently for long-term sustainability
  - Efficient fertilizer use
  - Reduction of P losses from agricultural systems
  - Capture and recycling of P in waste streams and animal manures

Sustainability is the P challenge for the next 350 years
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