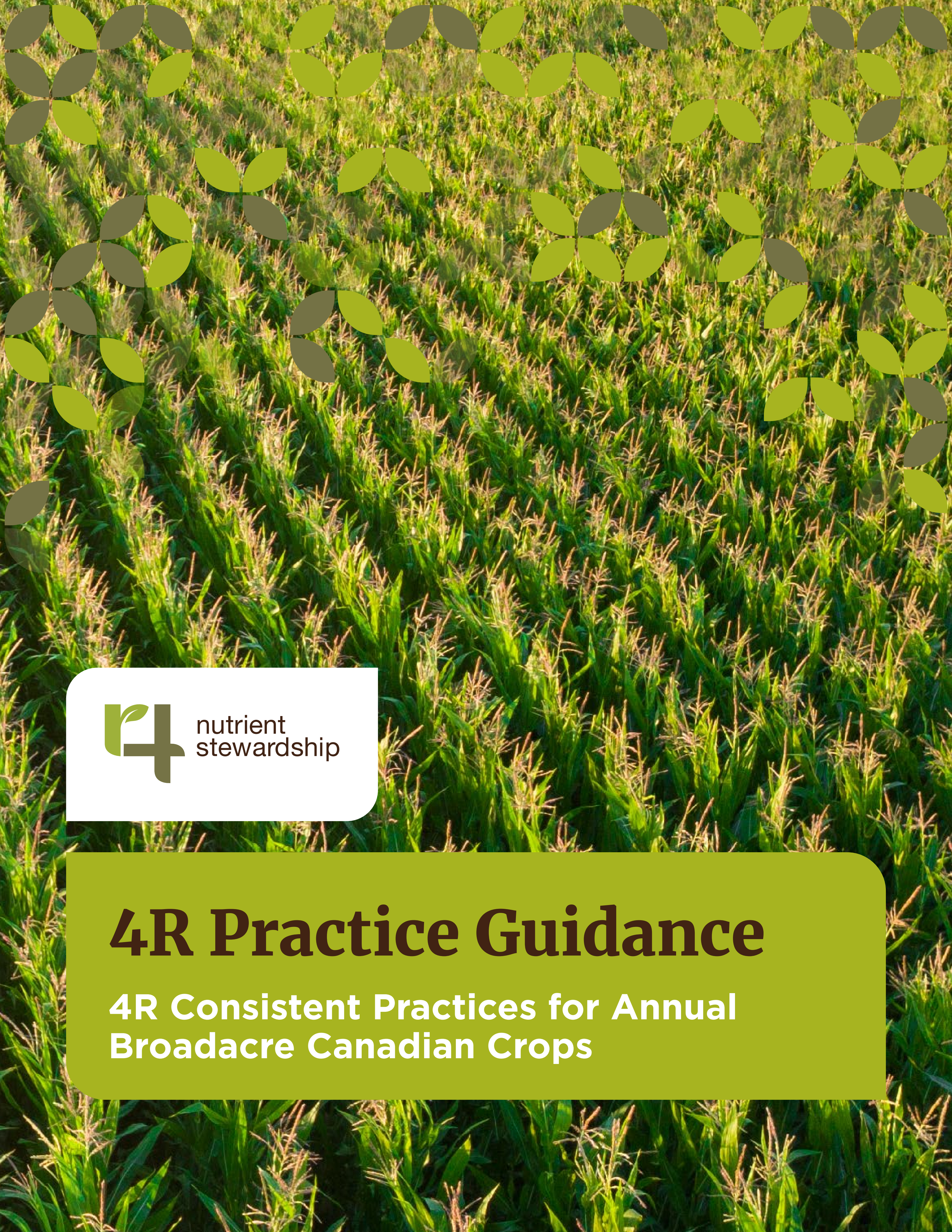

nutrient stewardship

4R Practice Guidance

4R Consistent Practices for Annual Broadacre Canadian Crops

Table of Contents

4R Consistent Practices for Annual Broadacre Canadian Crops

Purpose

The purpose of this document is to identify 4R consistent practices for Canadian cropping systems. It also identifies what would generally be considered less sustainable practices or those inconsistent with 4R principles.

The primary target audience for this document is the crop advising community made up of individuals dealing directly with producers on nutrient management issues. By helping to define 4R practices, this document will be useful to fertilizer retailers and crop advisors in developing 4R Nutrient Management Plans and providing appropriate Right Source @ the Right Rate, Right Time, and Right Place® recommendations to their farm customers. The nutrient management community should also find it useful in further development of the 4R Designation or Certification Programs which includes training of crop advisors, certification of retailers, and tracking of acres under 4R management.

The best management practice (BMP) guidance provided in the attached tables are provided for information and training purposes; they are not intended to replace the auditable standards under the Ontario's 4R Certification or Prince Edward Island 4R Certification Programs.

Introduction

The Canadian fertilizer industry implemented the 4R Nutrient Stewardship Program to ensure that fertilizers and other nutrient sources are managed sustainably. Awareness of 4R has been steadily increasing among farmers and their crop advisors over the past decade. Increasing interest in developing and implementing 4R Plans has led to questions concerning what are considered best management practices (BMP).

Furthermore, considerable ongoing research in nutrient management, development of new technologies, and sustainability requirements in the marketplace have all advanced since the previous guidance document was released. While there is no single right answer to the BMP question, Fertilizer Canada established a 4R Integrity Working Group in 2024 to review and update the previous version of this document including expanding the scope to cover more crops and additional nutrients in more regions of Canada. The current version should be considered a living document, and the current set of tables may be added to or modified over time as more information becomes available and additional crops or cropping systems are added.

The guidance included in this version covers nitrogen (N), phosphorus (P), potassium (K) and sulphur (S); the four nutrients most commonly applied as fertilizer in Canadian cropping systems. Tables are used to organize BMPs and are attached in the appendices. BMPs for N and P are organized by crop and are broken into dry and humid regions to account for the substantial role climate plays in nutrient use efficiency. BMPs for K and S are more generalized across crops and regions. Manure as a nutrient source is a special case as manure applications are regulated by provincial governments with requirements for rate, time, and place practices varying by province. While generalized manure application practices consistent with 4R principles have been included users are encouraged to familiarize themselves with the regulations in their province when making recommendations on manure use.

The 4R Nutrient Stewardship Program uses scientific principles to guide the development of 4R practices for different cropping systems (Table 1). While what is Right varies with cropping system, available fertilizer products and application technology; there is an underlying concept that practices selected will balance among economic, environmental, and social considerations. Furthermore, the 4Rs are not independent but highly interrelated and when developing practices for one of the Rights, consideration needs to be given to the other Rights. Consequently, best management practices are not stand alone but should be considered as an integrated system of practices that work together toward the goal of improving nutrient use efficiency and reducing nutrient losses from the cropping system.

Table 1. Key Scientific Principles Guiding the Development of BMPS for Nutrient Application.[1]

Right Source	Right Rate
1. Consider Rate, Time and Place	1. Consider Source, Time and Place.
2. Supply nutrients in quantifiable and available forms.	2. Address variability in crop response.
3. Use climate-smart forms.	3. Assess plant nutrient demand.
4. Use recycled forms where feasible.	4. Assess soil nutrient supply.
5. Consider biological inoculants.	5. Predict fertilizer use efficiency.
6. Suit soil physical and chemical properties.	6. Consider soil resource impacts.
7. Recognize synergisms among nutrient elements and sources.	7. Consider economics and the law of diminishing returns.
8. Recognize blend compatibility of materials.	
9. Recognize benefits and sensitivities to associated elements.	
10. Control effects of non-nutritive elements.	

1 SPRPN. 2022. Furthering 4R Nutrient Stewardship. Issue Brief 03. Scientific Panel on Responsible Plant Nutrition, Paris, France: 10. https://sprpn.org/wp-content/uploads/2022/01/IB03_English.pdf.

Table 1. Key Scientific Principles Guiding the Development of BMPS for Nutrient Application.[1]

Right Time	Right Place
1. Consider Source, Rate and Place	**1.** Consider Source, Rate and Time
2. Address changes in nutrient need through the growing season.	**2.** Place nutrients to avoid loss.
3. Assess timing of plant uptake.	**3.** Consider where plant roots are growing.
4. Assess dynamics of soil nutrient supply.	**4.** Consider soil chemical reactions.
5. Recognize dynamics of soil nutrient loss.	**5.** Suit the goals of the tillage system.
6. Evaluate logistics of field operations.	**6.** Manage spatial variability.

Growers are at different starting points when they enter a 4R program. The use of performance levels within each Right provides guidance to growers and their crop advisors on practices along a good, better, best progression for the crops and conditions in their region. Performance levels also allow growers to qualify their nutrient management practices as 4R consistent and consequently sustainable against an independent standard. Finally identifying excluded practices, those inconsistent with 4R principles, helps the cropping community move away from practices that are not sustainable.

Currently the international 4R community is using three performance levels basic, intermediate, and advanced.

The general progression is based on the following concepts:

- **BASIC –** Practices are generally consistent with 4R principles and meeting the basic requirements for all four Rights establishes the minimum threshold for 4R consistent nutrient management. A significant proportion of growers may already have these in place or are willing to move to them in the short-term (1-2 years). Current adoption rates may be up to 50% of cropped area in a region.
- **INTERMEDIATE –** Practices are fully consistent with 4R principles and may be transitional to advanced practices. Adoption of intermediate level practices may occur over the medium-term (1-3 years) particularly when they involve investment in new technology. Current adoption rates may be in the range of 20-50% for cropping systems in a region.
- **ADVANCED –** Practices are fully consistent with 4R principles and may be considered aspirational and/or best in class. There should be a sufficient level of current adoption to ensure that the practices specified are practical and possible to implement on-farm. A current adoption rate of ~5% reflects "proof of concept" that the practice can have a reasonable chance of being agronomically and economically feasible. Adoption of a full suite of advanced level practices on an individual farm may occur over a longer time frame (3-6 years) particularly when they involve investment in new technology.

When determining what practices to include in each performance level, the working group considered the crops, the regional climate, and other localized factors such as soil types. Consequently, there is an element of risk-based flexibility in determining what practices are acceptable for the different performance levels. This means that practices that are Right for a set of crops in one region may not be Right in another. This allows the same practice to be included at a higher performance level when there is sufficient regional evidence to demonstrate low risk and excluded when the evidence indicates high risk. For example, late fall band-application of ammonium-based nitrogen sources is considered acceptable at the basic level in the cold dry winter climate of the Canadian Prairies but not in warmer wetter winter regions like Southern Ontario. The generalized concepts for improvement are shown in Table 2.

Table 2. Improvement concepts for moving up levels.

LEVEL	SOURCE	RATE	TIME	PLACE
BASIC	Measured, assured, or reliably estimated nutrient content. Known mode of action.	Field specific – the rate is set considering the unique factors in each field.	Reduce timings with higher risk of nutrient loss.	Exclude high risk placement, low efficiency placements.
INTERMEDIATE	Enhanced efficiency sources (if available) in situations where agronomic, economic, or environmental benefits accrue from their use.	Rate adjusted for subfield variation in soil supply, crop demand, and risk of off-site movement.	Move application timing closer to period of highest crop demand.	Concentrate placement below the soil surface.
ADVANCED	Enhanced efficiency sources in all but low risk situations.	Rate optimized for subfield variation.	Multiple applications to synchronize timing with crop demand and growing season conditions.	Concentrate placement below the soil surface in optimal configuration with rooting zone.

In addition to adherence to 4R principles and the performance level concepts provided above several additional assumptions were made when developing the practice suites presented here.

COMPLIES WITH EXISTING REGULATIONS: Although regulations are in some cases explicitly referenced in the practice suites, the general assumption is that practices picked are/will be compliant with regulations. This is particularly important where the geographic area covered by the practices spans more than one province or territory.

LIMITED TO NITROGEN, PHOSPHORUS, POTASSIUM AND SULPHUR FERTILIZER: These are the most common nutrients added as fertilizer in Canadian cropping systems. Nitrogen and phosphorus are also the nutrients that tend to contribute to environmental issues when not well managed. Guidance on micronutrient fertilizer use is not provided and is not currently being considered.

PROVIDE GENERAL GUIDANCE ON MANURE USE: Manure is an important nutrient source particularly in regions where animal agriculture is concentrated. Cropping systems where manure is regularly applied as a nutrient source have different management requirements than systems that are managed with commercial fertilizer alone. These differences include considerations such as developing phosphorus rates based on more than one year of crop uptake; accounting for ongoing nitrogen mineralization in the years following the year of application; and developing time and place practices around spreading and incorporation that meet provincial regulations. General guidance on 4R consistent practices for managing manure application is included in this version and will continue to be refined as the 4R system evolves. Agronomists and growers are encouraged to follow 4R principles when developing manure management plans within the frameworks provided by provincial regulations.

AIMED AT SPECIFIC ENVIRONMENTAL ISSUES: While improving efficiency and return on fertilizer investment is an important economic aim of 4R in all cropping systems, practices were also selected based on their potential to reduce GHG emissions, ammonia emissions, movement of nitrate-N to groundwater, and movement of N and P to surface waters. The relative importance of these environmental impacts varies with region and cropping system and the BMPs have been adjusted to account for regional differences in risk.

EFFICIENCY INCREASES WITH PERFORMANCE LEVEL: Moving from basic to advanced follows a trajectory of improved nutrient use efficiency and increased management intensity. Although source, rate, time and place practices don't necessarily all change from one level to the next, the changes that are made should lead to higher efficiency overall for each level in the progression. Some of the common themes across cropping systems are shown in Table 2.

FLEXIBLE TO ACCOMMODATE UNUSUAL CIRCUMSTANCES: 4R plans are directional and based on adaptive management. Initially growers developing 4R Plans may not meet the basic thresholds for one or more of the rights. Growers improve over time by adopting 4R consistent practices and reach a higher level of performance in their nutrient use. Growers may need to break from their intended 4R practices on occasion to accommodate unusual circumstances caused by inclement weather, equipment limitations, lack of product etc. Temporary adoption of practices at a lower performance level than planned or non 4R practices due to uncontrollable factors will in some cases be unavoidable. This may temporarily exclude fields or farms from sustainability programs (for example, 4R Designated Acres) that use a minimum 4R threshold as basis for participation.

General Guidance vs Specific Program or Protocol Requirements

The tables that follow provide general guidance and are organized to help crop advisors and producers pick a path to improvement over time. 4R Plans and suites of BMPs may be used in various regulatory or voluntary sustainability efforts to determine program eligibility. The most notable example of this is Alberta's ***Quantification Protocol for Agricultural Nitrous Oxide Emission Reductions*** more commonly known as NERP. This protocol is part of the regulated carbon offset market in Alberta. NERP and its voluntary carbon market equivalent ***Protocol for Reducing Fertilizer Nitrous Oxide Emissions in Canadian Agricultural Croplands*** use ***4R Nitrogen Stewardship Plans*** as a basis for determining eligibility and a Basic, Intermediate, and Advanced tier system in estimating the nitrous oxide reductions.

The BMPs used in these protocols tend to be more prescriptive than the BMPs provided in this guidance document. The protocol BMPs are organized in suites of practices such that all BMPs at a given level must be implemented to achieve basic, intermediate or advanced status. **Note that following the guidelines in this document when developing a 4R Plan may not qualify a grower for Alberta's *Quantification Protocol for Agricultural Nitrous Oxide Emission Reductions* (NERP) or *Protocol for Reducing Fertilizer Nitrous Oxide emissions in Canadian Agricultural Croplands*.** Refer to the specific practice requirements listed in the protocols when developing 4R Plans for farms enrolled in an offset or inset project.

The Practice Tables

4R BMPs are provided in tabular form in Appendices A through E. For cereals and oilseeds, nitrogen and phosphorus BMPs are partitioned into dry and humid region tables that correspond to the Prairie Provinces and Ontario and east respectively.

British Columbia contains both dry areas in the BC Peace River and interior and humid regions in the lower mainland and on Vancouver Island. Local knowledge of the average growing season precipitation to evapotranspiration ratio (dry ≤ 1 > humid) can be used to decide which tables are more appropriate. Nitrogen and phosphorus BMPs for potatoes are national in scope and are differentiated based on whether production is rainfed or irrigated. A similar pan-Canadian approach is used for N and P practices for pulses and soybean as well as general guidelines for N and P when applying manure to annual cropping systems. Finally, tables of potassium and sulphur BMPs have been added.

Using the Tables

Although every application of fertilizer requires decisions about source, rate, time, and place; not all management practices meet 4R criteria. Certain practices are inconsistent with 4R principles as they are likely to lead to poor agronomic performance and deleterious environmental outcomes. Before looking up BMPs by crop and region-specific practices, users are encouraged to review the 4R excluded practices tables (Appendix A). In the body of each table, BMPs are stated as concisely as possible to avoid clutter with footnotes providing clarification and interpretation on appropriate use of the BMP.

The tables are organized into basic, intermediate, and advanced BMPs. It is expected that 4R Plans may contain a mixture of levels on a farm both within a crop and among different crops. To be considered 4R consistent a 4R Plan requires a minimum of basic BMPs for source, rate, time, and place. From there progress is made by selecting the next best practice to adopt for improvement based on the economic, agronomic, and logistical restraints of the farm as well as consideration of pertinent environmental issues.

Abbreviations and Glossary

Table 3 provides a key to common terms abbreviated in this document. Abbreviations are also noted in first use of the term in the text.

Table 3. Abbreviations used in Appendix Tables

ABBREVIATION	TERM
AA	Anhydrous ammonia (82-0-0)
AN	Ammonium nitrate (34-0-0)
APP	ammonium polyphosphate (a fluid fertilizer, 10-34-0 to 11-37-0)
AS	Ammonium sulphate (21-0-0-24)
BMP	Best management practice
CAN	Calcium ammonium nitrate (27-0-0)
CN	Calcium nitrate (15.5-0-0)
DAP	Diammonium phosphate (18-46-0)
DI	Double inhibitor (urease and nitrification)
GHG	Greenhouse gas
K	Potassium
MAP	Monoammonium phosphate (11-52-0; N can range from 10 to 12%, P2O5 from 49 to 61%)
NERP	Nitrous Oxide Emission Reduction Protocol (see glossary for disambiguation)
N	Nitrogen
NI	Nitrification inhibitor
P	Phosphorus
S	Sulphur
TSP	Triple superphosphate (0-46-0)
UAN	Urea ammonium nitrate (28-0-0 to 32-0-0)
UI	Urease inhibitor
VR	Variable rate

Table 4 provides information on the meaning of various terms used in this document. The meaning of additional terms used in the various appendix tables may be found in the footnotes attached to each table.

Table 4. Terms used in the Appendix Table.

TERM	DEFINITION
AMMONIUM BASED FORMULATION	Any fertilizer which releases more than two-thirds of its N in the ammonium form. For example, urea is considered an ammonium-based fertilizer since the product of urea hydrolysis is ammonium.
BASIC VARIABLE RATE	Nutrients are varied at the sub-field level in accordance with qualitative assessment of field variability.
BROAD ACRE CROP	Crops grown on a large scale on farms typically with expansive acreage and large equipment. Canadian examples include wheat, canola, corn and soybean.
BROADCAST	Fertilizer or other material applied to the soil surface in a widely distributed manner.
CO-BAND	Banding two or more nutrients together using two or more sources.
FIELD SPECIFIC RATES	4R treats each field as a unique cropping system. Field specific rates accounts for substantive differences in yield potential and added nutrient requirements due to variations in soil supply and/or yield limiting factors when setting rates.
CROP MODELS	In the context of 4R, crop models are computer models capable of predicting cropping system variables important to nutrient management decisions such as weather, crop stage, nutrient demand or nutrient availability. They can include mechanistic, stochastic, or statistical approaches including the emerging field of big data analytics and artificial intelligence. Acceptable models will have been calibrated and validated for the geography and cropping systems in which they are being used.
DOUBLE (OR DUAL) INHIBITORS (DI)	Fertilizer products or additives that contain a urease and a nitrification inhibitor.
DRY SOIL REGION	Regions with a growing season moisture deficit in most years. Normal growing season precipitation is less than potential evapotranspiration.

Table 4. Terms used in the Appendix Table.

TERM	DEFINITION
ENHANCED EFFICIENCY FERTILIZERS (EEF)	Fertilizer sources or products that enhance the availability of fertilizer nutrients by maintaining the nutrients in available form and/or preventing losses from the cropping system. Common technologies used in nitrogen EEFs, for example, include polymer coatings, nitrification inhibitors, and urease inhibitors.
FROZEN GROUND OR SOIL	Soil conditions such that injection, banding or nutrient incorporation through tillage are not possible at the time of nutrient application, and in the case of tillage will not be possible within the next 48 hours as a result of frozen conditions.
GRID SAMPLING	A soil sampling protocol in which samples are taken at preassigned points on a regular grid within a field.
HUMID SOIL REGION	Regions without a growing season moisture deficit in most years. Normal growing season precipitation is equal or greater than potential evapotranspiration.
NITRIFICATION INHIBITORS (NI)	Fertilizer additives that inhibit the microbial conversion of ammonium to nitrate. Products in this class are typically used to reduce denitrification and leaching. They provide co-benefits through the mitigation of direct and indirect nitrous oxide emissions.
PRIMARY NITROGEN (N) SOURCE	Product used primarily to meet nitrogen requirement of the crop. Typically, a high analysis N fertilizer such as anhydrous ammonia or urea.
SNOW COVERED GROUND OR SOIL	When soil surface cannot be seen because of snow cover. Fall application can occur after early snowfall if the accumulated snow melts and the soil remains unfrozen.
SUBSURFACE SOIL SAMPLE	Typically, a 6-24 or 12-24 inch sample depending on surface sampling depth. In some cases, a 6-12 and 12-24 sampling is used. Soil test N and S have generally been calibrated to a depth of 24 inches (surface plus subsurface). Labs can adjust values when the full 24-inch depth cannot be reached due to soil conditions or other limitations.
SUFFICIENCY AND/ OR SUFFICIENCY RECOMMENDATION	Recommendations based on Liebig's Law of the Minimum. Sufficiency recommendations are designed to meet the nutrient needs of the current crop by supplying those nutrients that are yield limiting.
SURFACE SOIL SAMPLE	Typically, a 0-6 inch or a 0-12 inch soil sample. Soil test P and K has generally been calibrated to a 0-6 inch sample in Canada.

Table 4. Terms used in the Appendix Table.	
TERM	DEFINITION
TOP DRESS	Applying fertilizer to the soil surface after the crop has been seeded and more typically after emergence.
UREASE INHIBITOR (UI)	Fertilizer additives that inhibit the action of the urease enzyme that catalyzes the conversion of urea to ammonium. Products in this class are used to reduce ammonia volatilization.
VARIABLE RATE (VR)	A precision agriculture technique that adjusts the amount and type of fertilizer applied based on variations in yield potential at the subfield level.
ZONE SAMPLING	A stratified random sampling protocol based on dividing the field into management or production zones based on satellite imagery, electrical conductivity maps, yield maps, soil maps and/or other information and then sampling each zone separately.

Appendix A – 4R Excluded Nitrogen and Phosphorus Fertilizer Practices

The practices outlined in the tables below are not consistent with 4R principles for Right Source, Rate, Time, and Place. These practices should generally be avoided for annual small grains, oilseeds, pulses, soybeans, corn and other broad acre annual crops in Canada. Reduced nutrient use efficiency and increased environmental risk are the main criteria for excluding practices.

Farmers and agronomists are urged to move away from these practices whenever possible. Fields are excluded from participating in 4R Designation, 4R Certification, and 4R Climate Smart programs and projects during the portion of the crop cycle in which the listed practices are used.

Poor nitrogen fertilizer management can result in substantial losses from the cropping system reducing yields, crop quality, land use efficiency, and profitability. Nitrogen losses through volatilization, leaching, and denitrification contribute to direct and indirect emissions of nitrous oxide, a potent greenhouse gas. Movement of nitrogen to surface and groundwater impairs ecosystem function and reduces water quality for human or animal consumption. Practices that increase the risk of nitrogen loss are economically, socially, and environmentally unsustainable.

Phosphorus losses from fertilizer occur primarily through runoff and erosion. While phosphorus losses are seldom economically or agronomically significant in terms of yield and profitability, once phosphorus leaves the land and enters surface water, it can severely compromise water quality through eutrophication. The resulting off-farm impacts includes promoting algae blooms (including toxic blue-green algae) in rivers and lakes and oxygen depletion resulting in fish die-offs. Compromised water quality from phosphorus loading also increases the cost of water treatment for downstream users.

4R Excluded Practices in the Dry Soil Regions of Canada

The dry soil regions of Canada are those areas where the average growing season precipitation to potential evapotranspiration ratio is less than one (P/PE < 1). Based on the National Ecological Framework for Canada the dry soil regions include the crop producing areas of the Canadian Prairie Provinces, the BC Peace River region, and parts of the Okanagan valley. Dry soil regions tend to have a moisture deficit during the growing season and are typically at lower moisture in the fall compared to spring. In much of the region, soils generally freeze in late fall or early winter and remain frozen at depth until spring. This reduces but does not completely stop nitrogen losses over the winter including direct and indirect nitrous oxide emission. As annual runoff is generally low phosphorus losses are generally low. However, nitrogen and phosphorus losses can spike during the spring thaw and runoff period as snow melts and soil surface layers are saturated over frozen layers deeper in the profile.

Note: The footnotes attached to the table below provide additional context on why the practice is excluded.

Table A1. Fertilizer Nitrogen Practices Inconsistent with 4R Principles — Annual Crops in Dry Soil Regions (Prairie and Boreal Plain Ecozones).

SOURCE	RATE	TIME	PLACE
APPLIES NITRATE-BASED FORMULATIONS *in fall including UAN, CN, or AN.*[2]	Sets same N rate for all fields regardless of yield potential and soil supply.[3]	Applies N on frozen soil or snow-covered ground.[4]	Broadcasts unprotected N in fall.[5]
NEVER INOCULATES PULSE/SOYBEAN.[6]	Does not account for N release from preceding legume crop.[7]	Applies fertilizer N in the fall before the soil cools below 10 C.[8]	Broadcasts unprotected urea or UAN before seeding or before crop emergence without adequate incorporation.[9]
USES PRODUCTS INCLUDING COMPOSTS AND MANURES *with unknown N content and/or unknown release characteristics.*[10]	Does not account for N contribution from previous manure applications.[11]		Uses insufficient banding depth resulting in high ammonia volatilization losses.[12]

2 Urea Ammonium Nitrate and calcium nitrate are poor choices for fall application. Nitrate is susceptible to high overwinter losses through denitrification and leaching ammonium-based sources (including urea) convert more slowly when applied to cool soils and limit nitrate accumulation reducing risk of loss.

3 The rate for the primary N source should be varied by field when there are substantial differences in yield potential and/or expected soil supply based on an assessment of factors such as field history, soil test N, previous crop, soil characteristics, grower knowledge and professional judgement. Consider varying rate by field when yield potential among fields varies by more than 15% and/or expected soil supply varies by more than 15 lb N/acre.

4 Application of fertilizer N on frozen or snow-covered ground can lead to excessive runoff losses and early spring denitrification in the saturated layer above frozen soil at depth. Frozen ground is defined: When soil conditions are such that injection, banding or nutrient incorporation through tillage are not possible at the time of nutrient application, and in the case of tillage will not be possible within the next 48 hours as a result of frozen conditions. Snow-covered ground is defined: when soil cannot be seen because of snow cover. Fall application can occur after early snowfall if the accumulated snow melts and the soil remains unfrozen.

5 Fall Broadcast has low nitrogen use efficiency largely due to overwinter losses from denitrification and leaching. Exceptions: Fall broadcast of NP source (e.g. MAP, DAP, APP or AS) at appropriate rates as a phosphorus or sulphur source with incorporation is acceptable at the basic level for most crops.

6 Best Management Practice at the advanced level is to inoculate all pulse and oilseed legumes every year they are planted. Acceptable practice at the basic level is to inoculate if the crop has not been grown in the field in the past three years. Note that not inoculating puts the crop at risk in soils where *Rhizobium* or *Bradyrhizobium* inoculum does not persist between crop cycle or falls below levels required for robust nodule formation. Fields are not spatially uniform and survival of nitrogen fixing organisms in soil may be compromised by a number of factors including poor nodule formation on the previous crop, variations in soil acidity, prolonged saturation or drying of the soil profile. Exception: dry beans are poor nitrogen fixers and are typically fertilized; inoculation is optional.

7 The contribution of a previous legume crop to plant available nitrogen needs to be considered when seeding into pulse or soybean stubble, perennial or annual forage legume residue, and terminated legume containing cover crops. The contribution to crop to be seeded can vary significantly (0-150 lb N/acre) based on legume type, yield, and moisture conditions. Agronomists should consult locally relevant sources when estimating N contribution.

8 The standard for fall soil cooling is maximum daily soil temperature at 5 cm depth is below 10°C for 3 consecutive days. Soil temperature can be approximated from air temperature using the following formula: Soil Temp = 0.6287*MaxDailyAirTemp + 0.3339. Note that using this equation a soil temp of <10°C corresponds to a max air temp of < 15.4°C. If using air temperature as a data source for the Alberta Nitrous Oxide Reduction Protocol or 4R Climate Smart Protocol the standard is max air temperature below <15°C for five consecutive days before the onset off fall application.

9 Surface broadcast of urea can result in high ammonia volatilization losses particularly under warm windy conditions on soils with basic soil pH (>7). Note that the initial conversion of urea typically increases the pH surrounding the urea granule even when broadcast on neutral or acidic soils (≤7). As the local pH rises above 7 the equilibrium between ammonia and ammonium shifts to ammonia. Incorporate broadcast urea to a minimum depth of 2 inches. Use of harrows as primary incorporation implement or relying on the seeding implement to incorporate previously broadcast urea may result in high ammonia volatilization losses.

10 Agronomists should understand the behavior of N products based on reliable estimates of N content and release rates before recommending novel products and organic N sources such as manures and composts. Use of book values to estimate N content of manure is acceptable at the basic level. Manure testing is considered a more advanced practice.

11 Manure applications may supply significant amounts of N to crops for 2-3 years following application depending on factors such as manure source and form, N content, original application rate, etc. Consult relevant sources when estimating manure N contributions such as the *Nutrient Management Guide* *(https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11920/$FILE/nutrient-management-planning-guide.pdf)*.

12 Shallow banding of unprotected urea sources or anhydrous ammonia can result in excessive ammonia volatilization losses. Losses can be reduced by using a urease inhibitor or a polymer coated urea source. Note that nitrification inhibitors combined with too shallow placement can increase ammonia volatilization losses. Agronomists should consider soil texture, temperature, and moisture conditions when recommending incorporation and banding depths and consult locally relevant information related to appropriate banding depths for their clients.

Table A2. Fertilizer Phosphorus Practices Inconsistent with 4R Principles - Annual Crops in Dry Soil Regions (Prairie and Boreal Plain Ecozones).

SOURCE	RATE	TIME	PLACE
USES PRODUCTS INCLUDING COMPOSTS AND MANURES *with unknown P content and/or unknown release characteristics.*[13]	Sets rates without reference to recent soil test.[14]	Applies P on frozen soil or snow-covered ground.[15]	Broadcasts P without incorporation on land without conducting risk assessment of potential loss to surface waters, or where assessment shows high risk.[16]
	Applies fertilizer P in excess of crop removal rates to fields with high soil test P values and low probability of response and/or uses rates exceeding regulatory limits.[17]		Exceeds recommended seedrow placement rates for P source and crop type.[18]

13 Agronomists should understand the behavior of P products based on reliable estimates of P content and release rates before recommending novel products and organic P sources such as manures and composts. Use of book values to estimate P content of manure is acceptable at the basic level. Manure testing is considered a more advanced practice.

14 Annual soil testing is not required for P management as soil test P levels tend to remain relatively stable in the short-term. Testing some fields every year and individual fields at least every 4 years is the recommended best practice.

15 Phosphorus applied on frozen or snow-covered ground is at risk of loss and can be transported into surface waters as soluble or particulate P during spring runoff or following heavy spring rains. Frozen ground is defined: When soil conditions are such that injection, banding or nutrient incorporation through tillage are not possible at the time of nutrient application, and in the case of tillage will not be possible within the next 48 hours as a result of frozen conditions. Snow-covered ground is defined: when soil cannot be seen because of snow cover. Fall application can occur after early snowfall if the accumulated snow melts and the soil remains unfrozen.

16 Surface applied P has low efficiency. P is immobile in soil and can get stranded at or near the surface. Surface applied P can be transported into surface waters. Note that P losses may not result in noticeable declines in economic or agronomic performance, but they can have a significant impact on water quality.

17 As soil test P levels rise above the critical value, the likelihood of a yield response diminishes and the environmental risk of P loss to surface waters increases. Soil test methods vary in the amount of P they extract, and critical levels vary by crop. Follow local or regional guidelines for interpreting P soil tests and set rates at or below crop removal or eliminate P applications when soil test values are in the range where a yield response is unlikely. Also be aware of regulatory limits on soil test P which vary by province. Refer to manure tables for manure as P source.

18 Excess seedrow P can cause seedling damage and low emergence due to the salt effect. This can be further compounded when using blends containing N and/or K and/or S in addition to P. Seedrow application of urea in combination with P risks ammonia toxicity in addition to the salt effect. Consider crop type, soil type, soil moisture, and seed bed utilization based on fertilizer spread and row spacing when recommending seedrow placed P rates alone or in combination with other fertilizers. In cases, where safe seedrow placement cannot meet P requirements use other placement methods in combination with or instead of seedrow placement.

4R Excluded Practices in the Humid Soil Regions of Canada

The humid soil regions of Canada are those areas where the average growing season precipitation to potential evapotranspiration ratio is greater than or equal to one (P/PE ≥ 1). Based on the National Ecological Framework for Canada the humid soil regions include the crop producing areas of Ontario, Quebec, the Atlantic Provinces, and parts of British Columbia. Humid soil regions tend to have only minor moisture limitations during the growing season and drought years are less frequent than in dry regions. Soils typically enter the winter in a moist condition. Soils may or may not freeze or may not freeze very deeply over winter. Winter runoff may move surface applied nutrients off fields and saturated soil may contribute to overwinter nitrogen losses through denitrification. Runoff, soil saturation, and leaching may all occur during the growing season following heavy rains.

Note: The footnotes attached to the table below provide additional context on why the practice is excluded.

Table A3. Fertilizer Nitrogen Practices Inconsistent with 4R Principles — Annual Crops in Humid Soil Regions (Mixedwood Plains & Atlantic Maritime Ecozones).

SOURCE	RATE	TIME	PLACE
NEVER INOCULATES PULSE/SOYBEAN.[19]	Sets same N rate for all fields regardless of yield potential, nutrient demand, and soil supply.[20]	Applies N on frozen soil or snow-covered ground.[21]	Broadcasts unprotected urea or UAN before seeding or before crop emergence without adequate incorporation.[22]
USES PRODUCTS INCLUDING COMPOSTS AND MANURES *with unknown N content and/or unknown release characteristics.*[23]	Does not account for N release from preceding legume crop.[24]	Applies primary N Source in Fall.[25]	Uses insufficient banding depth resulting in high ammonia volatilization losses.[26]
	Does not account for N contribution from previous manure applications.[27]		

19 Best Management Practice at the advanced level is to inoculate all pulse and oilseed legumes every year they are planted. Acceptable practice at the basic level is to inoculate if the crop has not been grown in the field in the past three years. Note that not inoculating puts the crop at risk in soils where *Rhizobium* or *Bradyrhizobium* inoculum does not persist between crop cycle or falls below levels required for robust nodule formation. Fields are not spatially uniform and survival of nitrogen fixing organisms in soil may be compromised by a number of factors including poor nodule formation on the previous crop, variations in soil acidity, and prolonged saturation or drying of the soil profile. Exception: dry beans are poor nitrogen fixers and are typically fertilized; inoculation is optional.

20 The rate for the primary N source should be varied by field when there are substantial differences in yield potential and/or expected soil supply based on an assessment of factors such as field history, soil test N, previous crop, soil characteristics, grower knowledge and professional judgement. Consider varying rate by field when yield potential among fields varies by more than 15% and/or expected soil supply varies by more than 15 lb N/acre.

21 Application of fertilizer N on frozen or snow-covered ground can lead to excessive runoff losses and early spring denitrification in the saturated layer above frozen soil at depth. Frozen ground is defined: When soil conditions are such that injection, banding or nutrient incorporation through tillage are not possible at the time of nutrient application, and in the case of tillage will not be possible within the next 48 hours as a result of frozen conditions. Snow-covered ground is defined: when soil cannot be seen because of snow cover.

22 Surface broadcast of urea can result in high ammonia volatilization losses particularly under warm windy conditions on soils with basic soil pH (>7). Note that the initial conversion of urea typically increases the pH surrounding the urea granule even when broadcast on neutral or acidic soils (≤7). As the local pH rises above 7 the equilibrium between ammonia and ammonium shifts to ammonia. Incorporate broadcast urea to a minimum depth of 2 inches. Use of harrows as primary incorporation implement or relying on the seeding implement to incorporate previously broadcast urea may result in high ammonia volatilization losses.

23 Agronomists should understand the behavior of N products based on reliable estimates of N content and release rates before recommending novel products and organic N sources such as manures and composts. Use of book values to estimate N content of manure is acceptable at the basic level. Manure testing is considered a more advanced practice.

24 The contribution of a previous legume crop to plant available nitrogen needs to be considered when seeding into pulse or soybean stubble, perennial or annual forage legume residue, and terminated legume containing cover crops. The contribution to the crop to be seeded can vary significantly (0-150 lb N/acre) based on legume type, yield, and moisture conditions. Agronomists should consult locally relevant sources when estimating N contribution.

25 Fall-application of primary N sources in humid regions of Canada can lead to substantial overwinter N loss through leaching and denitrification. Soils may not freeze or may not freeze very deeply over winter. Winter runoff may move surface applied nutrients off fields and saturated conditions may contribute to overwinter nitrogen losses.

26 Shallow banding of unprotected urea sources or anhydrous ammonia can result in excessive ammonia volatilization losses. Losses can be reduced by using a urease inhibitor or polymer coated urea source. Note that nitrification inhibitors combined with too shallow placement can increase ammonia volatilization losses. Agronomists should consider soil texture, temperature, and moisture conditions when recommending incorporation and banding depths and consult locally relevant information related to appropriate banding depths for their clients.

27 Manure applications may supply significant amounts of N to crops for 2-3 years following application depending on factors such as manure source and form, N content, original application rate, etc. Consult relevant regional sources when estimating manure N contributions.

Table A4. Fertilizer Phosphorus Practices Inconsistent with 4R Principles — Annual Crops in Humid Soil Regions (Mixedwood Plains & Atlantic Maritime Ecozones).

SOURCE	RATE	TIME	PLACE
USES PRODUCTS INCLUDING COMPOSTS AND MANURES *with unknown P content and/or unknown release characteristics.*[28]	Sets rates without reference to recent soil test.[29]	Applies P on frozen soil or snow-covered ground.[30]	Broadcasts P without incorporation on land without conducting risk assessment of potential loss to surface waters.[31]
	Applies fertilizer P in excess of crop removal rates to fields with high soil test P values and low probability of response and/or uses rates exceeding regulatory limits.[32]		Exceeds recommended seedrow placement rates for P source and crop type.[33]

28 Agronomists should understand the behavior of P products based on reliable estimates of P content and release rates (solubility) before recommending novel products and organic P sources such as manures and composts. Use of book values to estimate P content of manure is acceptable at the basic level. Manure testing is considered a more advanced practice.

29 Annual soil testing is not required for P management as soil test P levels tend to remain relatively stable in the short-term. Testing some fields every year and individual fields at least every 4 years is the recommended best practice.

30 Phosphorus applied on frozen or snow-covered ground is at risk of loss and can be transported into surface waters as soluble or particulate P during spring runoff or following heavy spring rains. Fall application of P products can occur after early snowfall if the accumulated snow melts and the soil remains unfrozen. Frozen ground is defined: When soil conditions are such that injection, banding or nutrient incorporation through tillage are not possible at the time of nutrient application, and in the case of tillage will not be possible within the next 48 hours as a result of frozen conditions. Snow-covered ground is defined: when soil cannot be seen because of snow cover.

31 Surface applied P has low efficiency. P is not mobile in soil and can get stranded at or near the surface. Surface applied P can be transported with runoff into surface waters. Note that P losses may not result in noticeable declines in economic or agronomic performance but they can have a significant impact on water quality.

32 As soil test P levels rise above the critical value, the likelihood of a yield response diminishes and the environmental risk of P loss to surface waters increases. Soil test methods vary in the amount of P they extract, and critical levels vary by crop. Follow local or regional guidelines for interpreting P soil tests and set rates at or below crop removal or eliminate P applications when soil test values are in the range where a yield response is unlikely. Also be aware of regulatory limits on soil test P which vary by province. Refer to manure tables for manure as P source.

33 Excess seedrow P can cause seedling damage and low emergence due to the salt effect. This can be further compounded when using blends containing N and/or K and/or S in addition to P. Seedrow application of urea in combination with P risks ammonia toxicity in addition to the salt effect. Consider crop type, soil type, soil moisture, and seed bed utilization based on fertilizer spread and row spacing when recommending seedrow placed P rates alone or in combination with other fertilizers. In cases, where safe seedrow placement cannot meet P requirements use other placement methods in combination with or instead of seedrow placement.

Appendix B - 4R Nitrogen and Phosphorus Practices for Annual Crops in Dry Regions

The Prairie and Boreal Plain ecozones of Manitoba, Saskatchewan, Alberta and the Peace River Region of British Columbia are considered dry regions based on a precipitation to potential evapotranspiration ratio of less than 1.

The climate throughout the region is semi-arid. Growing season moisture deficits occur throughout the region tending to be greater and more prevalent in the brown and dark brown soils zones of Southern Saskatchewan and SE Alberta compared to the black and gray soil zones. Soil moisture is typically depleted by the end of the growing season with partial to total recharge of the profile occurring from post-harvest to planting the following year. Stored soil moisture at seeding is consequently an important parameter to consider when setting yield goals and fertilizer rates. Soils tend to freeze and remain snow covered from late fall until spring most years. Southern Alberta can be an exception to this where warm dry chinook winds can sublimate the snow cover at any time during the winter period. Runoff during the spring thaw is the major mechanism of edge of field nutrient losses. Fertilizer best management practices are aimed at preventing losses through internal and external pathways and increasing nutrient availability in time and space to match crop demand. Nitrogen Best Management Practices for the Dry Regions of Canada

Nitrogen is a common limiting factor for annual crop production in Western Canada affecting both yield and crop quality. Best management practices are designed primarily to improved nitrogen use efficiency and prevent loss through volatilization, denitrification, and leaching. A co-benefit of improved NUE is reduced emissions of nitrous oxide and potent greenhouse gas.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

BMPs for Spring Cereal and Oilseeds in Dry Regions

Table B1. 4R Nitrogen BMP for Spring Cereal and Oilseeds in Dry Soil Regions — Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Ammonium-based formulation for fall (except UAN).[34]	Set field scale N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations.[35]	Apply N after soil cools in fall.[36]	Broadcast and incorporate within 24 hours using tillage to a minimum depth of 2 inches.[37]
	Any N fertilizer source in spring or in season.			Fall broadcast for spring seeded crops of primary N source must be EENF.[38]
		Soil test every 4 years or less to assess residual N at depth.[39]	Apply N in spring before seeding.	Fall or early spring broadcast of NP or NS sources is allowed at P rate and/or S rate for planned crop.[40]

34 There are different approaches to developing nitrogen recommendations for spring cereals and oilseeds including yield goal or N balance methods based on the Stanford equation, regional response curves, and process-based crop modelling. Additionally, scientifically validated AI based recommendation systems have been under development for the past decade and are starting to become available at the field level. In selecting appropriate methods ensure that 4R principles were considered during method development and that the method chosen has been validated for the crop and region. When setting N rates consider field specific yield history and yield potential in relation to other fields on farm to maximize ROI on fertilizer dollars.

35 Available moisture is often limiting in Prairie crop production. Consider variations in stored soil moisture, probability of precipitation, potential for shortfalls in growing degree days, frost free period and other potential variations in weather and climate when setting yield goals and N rates. Note that considering of weather and climate variability is a foundation practice and applies to all source, rate, time, place decisions at all levels of the BMP matrix.

36 The standard for fall soil cooling prior to application of a primary N source is a maximum daily soil temperature below 10°C at 5 cm depth for 3 consecutive days. Soil temperature can be approximated from air temperature using the following formula
Soil Temp = 0.6287*MaxDailyAirTemp + 0.3339.
Note that using this equation a soil temp of <10°C corresponds to a max air temp of < 15.4°C.

Table B1. 4R Nitrogen BMP for Spring Cereal and Oilseeds in Dry Soil Regions — Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
INTERMEDIATE	Use enhanced efficiency forms of ammonium-based fertilizers in high moisture, high risk situations.[41,42]	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[43]	Apply N in spring at seeding.	Apply primary N source in subsurface bands/ injection.
	OR Use nitrate sources (AN, CAN, CN) where main risk is ammonia volatilization.[44]	Set subfield management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations.		Spring broadcasting of primary N source more than 14 days before planned seeding date must be EENF.[45]
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.		

37 Rainfall may preclude the need for incorporation if received within 24 hours following broadcast application of urea. A minimum of 0.25 inches (7 mm) on coarse textured soils and 0.50 inches (13 mm) on medium or fine textured soils of precipitation is required to move urea to sufficient depth to prevent volatilization.

38 Fall broadcast tends to be 20% less efficient than fall banded N and 40% less efficient than spring banded N. The main loss pathways are denitrification and leaching/runoff during spring thaw. While broadcasting in fall may be necessary to accommodate the logistics of field operations an EENF should be used to reduce overwinter losses and loss. Note early spring broadcasting of primary N source would generally be considered as more than 14 days before planned seeding date.

39 Random sampling without GPS tagging of core locations is acceptable at the basic level but GPS tagged core locations are best practice as they allow better comparison of trends over time. Acceptable minimum depth combinations 0-6 & 6-24 inch or 0-12 & 12-24 inch. The soil test for N is the nitrate test and nitrate is subject to denitrification and leaching losses. Since nitrate is mobile it can move deeper into the rooting zone and accumulate. Best practice is to sample every field, every year. Sampling for N less often is acceptable at the basic level provided some fields on the farm are sampled every year such that individual fields are tested at least once within a 4-year cycle.

40 Fall application of ammonium phosphate products including MAP, DAP, and APP are allowable at the P rate for the following spring crop. Fall-application of ammoniated or other phosphate fertilizers to cover multiple cropping years is excluded due to the higher risk of N and P loss. Fall application of AMS, AMTS or other NS sources is allowed at the S rate for the following spring crop.

41 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate to the situation after assessing the risk of loss. EENF products that can be blended with conventional products should contain a minimum of 50% EENF to qualify at the intermediate level. Rate, time, and place modifications may need to be considered depending on product.

42 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils, and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which EENF source (nitrification inhibitor, urease inhibitor, double inhibitor, or controlled release) is most likely to prevent loss.

43 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

44 Ammonium nitrate, calcium ammonium nitrate, and calcium nitrate greatly reduce or eliminate the risk of volatilization losses. They are consequently acceptable sources when volatilization is considered the main loss mechanism. Note that nitrate containing products increase the risk of losses through denitrification and leaching.

45 Broadcasting the primary N source in spring before seeding increases the risk of N losses. Assess what factors are relevant when assessing risk and which EENF source is most likely to prevent loss.

Table B1. 4R Nitrogen BMP for Spring Cereal and Oilseeds in Dry Soil Regions — Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Use enhanced efficiency forms of ammonium fertilizers in all situations except low risk.[46]	Develop sub-field management zones based on quantitative analysis of field variability.[47]	Split apply N using a combination of spring application at or before seeding and in-season application as required to meet optimal rate.[48]	Apply primary N source in subsurface bands/ injection.
			AND Apply in season N within optimal window for crop uptake.[49]	Use EENF forms of surface banded urea and UAN in season or use nitrate-based products.[50]
		Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications.		

46 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate for the situation after assessing the risk. EENF products that can be blended with conventional products should contain a minimum of 70% EENF to qualify at the advanced level. Note that for in-season surface applications nitrate sources (AN, CAN, CN) are acceptable where main risk is ammonia volatilization.

47 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates should be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

48 Split applications can potentially reduce nitrous oxide emissions; however, research in Western Canadian cropping systems suggests that splitting N application between at or before time of seeding and in-season doesn't necessarily improve yield and/or quality. When using split application best practice is to apply at least two thirds of N rate at seeding and the balance in-season early in the phase of rapid vegetative growth. Under dry seeding conditions, split application can be used as a hedge against in season drought. The in-season application would only be applied if moisture conditions improve.

49 Cereals are generally not yield responsive beyond stem elongation. Canola may be responsive up to early flowering.

50 Nitrate based products are acceptable for surface application in-season as they reduce ammonia volatilization relative to ammonium-based products and denitrification and leaching risk tends to be low in-season on the Prairies in most years.

Table B1. 4R Nitrogen BMP for Spring Cereal and Oilseeds in Dry Soil Regions — Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED *(cont.)*	Use enhanced efficiency forms of ammonium fertilizers in all situations except low risk.[46]	Apply N using digitized/ automated prescriptions for predetermined management zones	AND Apply in season N within optimal window for crop uptake. [49]	Use EENF forms of surface banded urea and UAN in season or use nitrate-based products.[50]
		AND/OR Use in-season sensing or estimation of crop N requirements using proximal or remote sensing technologies, crop modelling, or pre-side dress N tests to set in-season N rates.		Reduce overlap using section control or other appropriate technology on fertilizer application equipment.[51]
		AND/OR Use post-harvest nitrate test in combination with N uptake estimates to calculate N balance.[52]		

51 Reducing overlap lowers fertilizer and seed costs. Section control's effectiveness varies depending on field dimensions and obstacles.

52 Advanced management of N rates should include one or more of the in-season and post-season assessment approaches to provide feedback on accuracy of N rate.

Table B2. 4R Phosphorus BMPs for Spring Cereal and Oilseeds in Dry Soil Regions – Prairies and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (4 years or less) to establish P baseline.[53]	Apply P in fall or co-apply with N after soil cools.[54]	Broadcast and incorporate to a minimum depth of 2 inches.[55]
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.[56]	Set field specific rates considering differences in yield potential and soil test values among fields.[57]		
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Apply P in spring before seeding.	Band/inject or co-band in fall or in spring prior to seeding or mid-row band at seeding (with consideration for mobility issues if banded with high rates of N or in cool soils).[58]
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.	Vary P in-field in relation to yield potential variations and/or N rates and/or differences in soil test P.[59]		
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through benchmark, zone or grid sampling.	Apply P in spring at seeding.	Place with seed at safe rates based on crop, seed bed utilization, and total product load.[60]
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.	Vary P by management zone independently from N.		Side-band at seeding.

53 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method.

54 Co-application of N and P in fall must meet source, rate, place requirements for both N and P.

55 Surface applications of P (with the exception of in season rescue P) must be incorporated to reduce risk of loss to surface waters and prevent surface stranding. Broadcast and incorporation is acceptable at the basic level with consideration of poor efficiency when broadcast is used on fields with low to medium soil tests values. Note that harrowing after application may not provide sufficient depth of incorporation to ensure availability or prevent runoff loss.

56 Consider product solubility and effects of soil characteristics such as soil pH on phosphorus release rates when using lower solubility products such as rock phosphate or struvite as a P source.

57 Rates should be set following provincial guidelines based on soil test and crop types, unless documented on-farm data show reasonable expectation of improved crop yield with a reasonable expectation of no increased risk to water or quality by utilizing 4R principles. Adopt a draw down strategy in zones that test very high in P by setting rates less than annual crop removal.

58 Midrow banding P may delay seedling access in cold soils. Co-banding P with higher rates of N (>70 lb N/acre) in the midrow may delay root access to P as N moves out of the band and creates a fertilizer reaction zone that is temporarily toxic due to high salt and/or ammonia.

59 Consider applying build rates in fields/zones that are deficient or very deficient in P. Apply only removal or sufficiency rates in zones that are marginal or optimal in P. Adopt draw down strategy in fields that test very high in P.

60 In situations where P rates required for optimal yield exceed safe rates for seed row placement, place additional required P away from seed.

BMPs for Corn in Dry Regions

Table B3. Nitrogen BMPs for Corn in Dry Soil Regions – Prairie and Boreal Plains Ecozones.

<table>
<tr><th>LEVEL</th><th>RIGHT SOURCE</th><th>RIGHT RATE</th><th>RIGHT TIME</th><th>RIGHT PLACE</th></tr>
<tr><td rowspan="4">BASIC</td><td rowspan="3">Ammonium-based formulations for fall (UAN excluded due to nitrate content).[61]</td><td rowspan="3">Set field scale N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications[62] as well as annual weather variations.[63]</td><td rowspan="2">Apply N after soil cools in fall.[64]</td><td>Broadcast and incorporate within 24 hours using tillage to a minimum depth of 2 inches.</td></tr>
<tr><td>Fall broadcast of primary N source must be EENF.[65]</td></tr>
<tr><td rowspan="2">Apply N in spring before seeding.</td><td rowspan="2">Fall or early spring broadcast of NP sources is allowed at P rate for corn.[66]</td></tr>
<tr><td>Any N fertilizer in spring or in-season.</td><td>Soil test every 4 years or less to assess residual N at depth.[67]</td></tr>
</table>

61 Ammonium-based formulations contain two-thirds or more of the nitrogen as ammonium OR convert to ammonium when applied to soil (for example, urea and anhydrous ammonia). Although UAN meets this two-thirds criterion, it is excluded from fall application because the 25% nitrate content increases the risk of over winter N loss through denitrification and leaching.

62 There are different approaches to developing nitrogen recommendations for spring cereals and oilseeds including yield goal or N balance methods based on the Stanford equation, regional response curves, and process-based crop modelling. Additionally, scientifically validated AI based recommendation systems have been under development for the past decade and are starting to become available at the field level. In selecting appropriate methods ensure that 4R principles were considered during method development. When setting N rates consider field specific yield history and yield potential in relation to other fields on farm to maximize ROI on fertilizer dollars.

63 Available moisture is often limiting in Prairie crop production. Consider variations in stored soil moisture, probability of precipitation, potential for shortfalls in growing degree days, frost free period and other potential variations in weather and climate when setting yield goals and N rates. Note that considering of weather and climate variability is a foundation practice and applies to all source, rate, time, place decisions at all levels of the BMP matrix.

64 The standard for fall soil cooling prior to application of a primary N source is a maximum daily soil temperature below 10°C at 5 cm depth for 3 consecutive days. Soil temperature can be approximated from air temperature using the following formula:
Soil Temp = 0.6287*MaxDailyAirTemp + 0.3339.
Note that using this equation a soil temp of <10°C corresponds to a max air temp of < 15.4°C.

65 Fall broadcast tends to be 20% less efficient than fall banded N and 40% less efficient than spring banded N. The main loss pathways are denitrification and leaching/runoff during spring thaw. While broadcasting in fall may be necessary to accommodate the logistics of field operations an EENF should be used to reduce overwinter losses and loss. Note early spring broadcasting of primary N source would generally be considered as more than 14 days before planned seeding date.

66 Fall application of ammonium phosphate products including MAP, DAP, and APP are allowable at the P rate for the following spring crop. Fall-application of ammoniated or other phosphate fertilizers to cover multiple cropping years is excluded due to the higher risk of N and P loss.

Table B3. Nitrogen BMPs for Corn in Dry Soil Regions – Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
INTERMEDIATE	Use enhanced efficiency forms of ammonium-based fertilizers in high moisture, high risk situations.[68, 69]	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[70]	Apply N in spring at seeding.	Apply in subsurface bands/ injection.
	OR Use nitrate sources (AN, CAN, CN) where main risk is ammonia volatilization.[71]	Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications. Apply N according to qualitative estimates of in-field variability.		
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.		

67 Random sampling without GPS tagging of core locations is acceptable at the basic level but GPS tagged core locations are best practice as they allow better comparison of trends over time. Acceptable minimum depth combinations 0-6 & 6-24 inch or 0-12 & 12-24 inch. The soil test for N is the nitrate test and nitrate is subject to denitrification and leaching losses. Since nitrate is mobile it can move deeper into the rooting zone and accumulate. Best practice is to sample every field, every year. Sampling for N less often is acceptable at the basic level provided some fields on the farm are sampled every year such that individual fields are tested at least once within a 4-year cycle.

68 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate to the situation after assessing the risk of loss. EENF products that can be blended with conventional products should contain a minimum of 50% EENF to qualify at the intermediate level. Rate, time, and place modifications may need to be considered depending on product.

69 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils, and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which EENF source (nitrification inhibitor, urease inhibitor, double inhibitor, or controlled release) is most likely to prevent loss.

Table B3. Nitrogen BMPs for Corn in Dry Soil Regions – Prairie and Boreal Plains Ecozones.

<table>
<tr><th>LEVEL</th><th>RIGHT SOURCE</th><th>RIGHT RATE</th><th>RIGHT TIME</th><th>RIGHT PLACE</th></tr>
<tr><td rowspan="5">ADVANCED</td><td rowspan="5">Use enhanced efficiency forms of ammonium fertilizers in all situations except low risk.[72]</td><td>Develop sub-field management zones based on quantitative analysis of field variability.[73]</td><td rowspan="2">Split apply N using a combination of spring application at or before seeding and in-season application as required to meet optimal rate. [74]</td><td>Apply before or at seeding using subsurface bands/ injection.</td></tr>
<tr><td>Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications.</td><td rowspan="3">Apply subsurface bands/injection in-season using specialized equipment.[75]</td></tr>
<tr><td>Apply N using digitized/ automatic prescriptions for predetermined management zones.</td><td rowspan="3">AND

Apply N in season within optimal window for crop uptake.[76]</td></tr>
<tr><td>AND/OR

Use in-season sensing or estimation of crop N requirements using proximal or remote sensing technologies, crop modelling, or pre-side dress N tests to set in-season N rates.</td></tr>
<tr><td>AND

Use post-harvest nitrate test in combination with N uptake estimates to calculate N balance.[77]</td><td>Surface apply in-season using protected N sources.[78]</td></tr>
</table>

70 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

71 Ammonium nitrate, calcium ammonium nitrate, and calcium nitrate greatly reduce or eliminate the risk of volatilization losses. They are consequently acceptable sources when volatilization is considered the main loss mechanism. Note that nitrate containing products increase the risk of losses through denitrification and leaching.

72 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate for the situation after assessing the risk. EENF products that can be blended with conventional products should contain a minimum of 70% EENF to qualify at the advanced level. Note that for in-season surface applications nitrate sources (AN, AS, CAN, CN) are acceptable where main risk is ammonia volatilization.

73 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates should be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

74 Split applications can potentially reduce nitrous oxide emissions; however, research in Western Canadian cropping systems suggests that splitting N application between at time of seeding and in-season doesn't necessarily improve yield and/or quality. When using split application best practice is to apply at least two thirds of N rate at seeding and the balance in-season during the phase of rapid vegetative growth. Under dry seeding conditions, split application can be used as a hedge against in season drought. The in-season application would only be applied if moisture conditions improve.

75 In-season nitrogen can be placed subsurface using equipment designed to apply anhydrous ammonia, aqua ammonia, or urea ammonium nitrate between corn rows. Depth of placement should be sufficient to prevent volatilization which will vary depending on soil texture and moisture as well as weather conditions during and after application.

76 Split application applies a portion of the required fertilizer N closer to or in the window of maximum crop uptake. Best practice for corn would be to apply approximately two-thirds of recommended total rate at or before seeding and the balance within the V6 to V10 growth stage window. The split application approach allows the decision to omit or reduce the last one-third if circumstances change. For example, if yield potential is limited due to drought or other factors prior to V6.

77 Advanced management of N rates should include one or more of the in-season and post-season assessment approaches to provide feedback on accuracy of N rate.

78 Surface placement of granular products in season can be broadcast or dribble banded. Liquid products can be surface banded using Y-drops or streamer nozzles. Use of high coverage nozzles like flat fan should be avoided as they can result in extensive damage to leaves and high N losses. Surface application increases risk of volatilization loss when using urea or urea or UAN. Best practice at the advanced level is to use a protected N source such as UI inhibited urea or UAN, DI urea, or controlled release urea. When using EENF sources keep in mind that dry surface conditions may delay release of N and movement into the rooting zone. Nitrate sources are an acceptable choice when the main risk is volatilization loss.

Table B4. 4R Phosphorus BMPs for Corn in Dry Soil Regions – Prairie and Boreal Plains Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (4 years or less) to establish P baseline.[79]	Apply P in fall or co-apply with N after soil cools.[80]	Broadcast and incorporate to a minimum depth of 2 inches.[81]
		Set field specific rates considering differences in yield potential and soil test values among fields.[82]		
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Apply P in spring before seeding.	Band/inject or co-band in fall or in spring prior to seeding or mid-row band at seeding (with consideration for mobility issues if banded with high rates of N or in cool soils).[83]
		Vary P in-field in relation to yield potential variations and/or N rates and/or differences in soil test P.[84]		
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through benchmark, zone or grid sampling.	Apply P in spring at seeding.	Place with seed at safe rates based on crop, seed bed utilization, and total product load.[85]
		Vary P by management zone independently from N.[86]		Side-band at seeding.

79 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method.

80 Co-application of N and P in fall must meet source, rate, place requirements for both N and P.

81 Surface applications of P (with the exception of in season rescue P) must be incorporated to reduce risk of loss to surface waters and prevent surface stranding. Broadcast and incorporation is acceptable at the basic level with consideration of poor efficiency when broadcast is used on fields with low to medium soil tests values. Note that harrowing after application may not provide sufficient depth of incorporation to ensure availability or prevent runoff loss.

82 Rates should be set following provincial guidelines based on soil test and crop types, unless documented on-farm data show reasonable expectation of improved crop yield with a reasonable expectation of no increased risk to water or quality by utilizing 4R principles. Adopt a draw down strategy in zones that test very high in P by setting rates less than annual crop removal.

83 Midrow banding P may delay seedling access in cold soils. Co-banding P with higher rates of N (>70 lb N/acre) in the midrow may delay root access to P as N moves out of the band and creates a fertilizer reaction zone that is temporarily toxic due to high salt and/or ammonia.

84 Consider applying build rates in fields/zones that are deficient or very deficient in P. Apply only removal or sufficiency rates in zones that are marginal or optimal in P. Adopt draw down strategy in fields that test very high in P.

85 Corn has high P requirements. In situations where P rates required for optimal yield exceed safe rates for seed row placement, place additional required P away from seed.

86 Varying P independently from N may require special equipment or extra passes over the field. It should be considered when there are large differences in soil test P within a field indicating increased risk of P loss to surface waters and/or potentially poor return on phosphorus fertilizer. Also consider when portions of the field require substantially higher P rates than the field average to optimize yield.

Appendix C - 4R Nitrogen and Phosphorus Practices for Annual Crops in Humid Regions

The Mixed Wood Plains and Atlantic Maritime ecozones of Ontario, Quebec, and the Atlantic Provinces comprise the major agricultural areas of Eastern Canada. These are considered humid regions based on a precipitation to potential evapotranspiration ratio greater than 1.

The climate throughout the region tends to be humid. Soil moisture is typically fully recharged within the profile during the period from post-harvest to planting the following year. Surface and subsurface drainage is used extensively in some regions to manage excess moisture. Leaching of nitrate and drainage effluent can be major sources of N to groundwater and surface water. Runoff is a major mechanism of edge of field losses of N and P. Fertilizer best management practices are aimed at preventing losses through internal and external pathways and increasing nutrient availability in time and space to match crop demand. Although growing season precipitation normally exceeds potential evapotranspiration (P/PE > 1), differences in crop available moisture is an important factor in yield variation from year to year.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

BMPs for Corn in Humid Regions

Table C1. Nitrogen BMPs for Corn in Humid Soil Regions — Mixedwood Plains & Atlantic Maritime Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Any N fertilizer with guaranteed analysis.	Set field scale N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications.[87]	Apply N in spring before seeding. *Note: N from NP sources (MAP, DAP APP) allowed for fall at P rate.*[88]	Broadcast and incorporate within 24 hours using tillage to a minimum depth of 2 inches.
INTERMEDIATE	Any N fertilizer with guaranteed analysis. *Plus*	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[89]	Apply N at seeding.	Apply in subsurface bands/injection.
	Use enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) in high moisture, high risk situations.[90]	Set sub-field management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications.		

Table C1. Nitrogen BMPs for Corn in Humid Soil Regions — Mixedwood Plains & Atlantic Maritime Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Use enhanced efficiency fertilizers (nitrification inhibitors, urease inhibitors, or controlled release) in all situations except low risk.	Develop sub-field management zones based on quantitative analysis of field variability. [91]	Split apply N using a combination of spring application at or before seeding and in-season application as required to meet optimal rate.[92]	Apply primary N source in subsurface bands/injection.
		Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications.		Apply subsurface bands/injection in-season using specialized equipment.[93]
		Apply N using digitized/automatic prescriptions for predetermined sub-field management zones.		
		AND/OR Use in-season sensing or estimation of crop N requirements using proximal or remote sensing technologies, crop modelling, or pre-side dress N tests to set in-season N rates.		Use EENF forms of surface banded urea and UAN in season or use nitrate-based products.[94, 95]
		AND/OR Use post-harvest soil nitrate testin combination with N uptake estimates to calculate N balance. Or use corn stalk nitrate test to assess N rate.[96]		

87 Approaches to developing nitrogen recommendations for corn including yield goal or N balance methods based on the Stanford equation, regional response curves, and process-based crop modelling. Additionally, scientifically validated AI based recommendation systems have been under development for the past decade and are starting to become available at the field level. In selecting appropriate methods ensure that 4R principles were considered during method development. When setting N rates consider field specific yield history and yield potential in relation to other fields on farm to maximize ROI on fertilizer dollars. OMAFA's *Agrisuite* platform contains an example of a N calculator that is consistent with 4R Principles.

88 Fall-application of primary N sources is an excluded practice in humid regions of Canada. Fall application of ammonium phosphate products including MAP, DAP, and APP are allowable at the P rate for corn. Fall-application of ammoniated or other phosphate fertilizers at rates aimed at meeting the need of a subsequent crop like soybeans increases the risk of N and P loss.

89 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

90 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which enhanced efficiency N source is most likely to prevent loss. Note that a nitrate source such as ammonium nitrate, calcium nitrate, or calcium ammonium nitrate may be an appropriate choice to reduce volatilization from in-season applications when the risk of loss through denitrification and leaching is low.

91 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates can be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

92 Split application applies a portion of the required fertilizer N closer to or in the window of maximum crop uptake. Best practice would be to apply one to two-thirds of recommended total rate at or before seeding and the balance within the V3 to V13 growth stage window. The split application approach allows the decision to omit or reduce the in-season application if circumstances change. For example, if yield potential is limited due to drought or other factors prior to V6.

93 In-season nitrogen can be placed subsurface using equipment designed to apply anhydrous ammonia, aqua ammonia, urea ammonium nitrate, or granular nitrogen products between corn rows. Depth of placement of ammonia and urea based products should be sufficient to prevent volatilization which will vary depending on soil texture and moisture as well as weather conditions during and after application.

94 Nitrate-based products are acceptable for surface application in-season as they reduce ammonia volatilization relative to ammonium-based products and denitrification and leaching risk tends to be lower in-season when the crop is actively growing.

95 Surface placement in season increases risk of volatilization loss when using urea or ammonium-based sources. Best practice at the advanced level is to use a protected N source such as UI inhibited urea or UAN, DI urea, or controlled release urea. When using controlled release granular sources keep in mind that dry surface conditions may delay release of N and movement into the rooting zone. In season surface application may be performed using streamer nozzles, Y drops, dribble banders, or emerging technologies such as robotic applicators.

96 Advanced management of N rates should include one or more of the in-season and post-season assessment approaches to provide feedback on accuracy of N rate.

Table C2. Phosphorus BMPs for Corn in Humid Soil Regions – Mixedwood Plains & Atlantic Maritime Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (4 years or less) to establish P baseline.[97]	Broadcast P in fall.	Broadcast and incorporate to a minimum depth of 2 inches.
		Set field specific rates considering differences in yield potential and soil test values among fields.[98]		Broadcast without incorporation is allowed in situations where the risk of phosphorus loss to surface water has been demonstrated to be low or very low according to a recognized phosphorus loss assessment tool.[99]
		P rate when using fall applied NP sources (MAP, DAP, APP) should be set such that co-applied N rate does not exceed 35 lb N/acre.[100]		
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Band P in fall. Band P in spring before seeding.	Band/inject or co-band with other nutrients in fall using conservation techniques such as minimum tillage or strip tillage.
		Vary P in-field in relation to yield potential variations and/or N rates and/or differences in soil test P.		Band/inject or co-band with other nutrients prior to seeding.
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Apply P in spring at seeding.	Place with seed at safe rates for corn considering seed bed utilization, and total product load.
		Vary P by management zone independently from N.[101]		Side-band at seeding.

97 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method.

98 Rates should be set following provincial guidelines based on soil test and crop types, unless documented on-farm data show reasonable expectation of improved crop yield with a reasonable expectation of no increased risk to water or quality by utilizing 4R principles. Adopt a draw down strategy in zones that test very high in P by setting rates less than annual crop removal.

99 Not all parts of the landscape contribute phosphorus loss to surface waters. Recommending broadcasting without incorporation within the 4R framework requires a risk assessment using an assessment approach that is recognized as appropriate for the region (e.g., the Phosphorus Loss Assessment Tool for Ontario (PLATO) available on Agri suite). Note that risk can be reduced in some situations by choosing low or lower solubility products like struvite or reactive rock phosphate.

100 Maximum rates for fall applied P when limited by 35 lb N/ac co-application are 164, 89, 119 lb P2O5/acre respectively for the common ammoniated P sources MAP, DAP, and APP.

101 Varying P independently from N may require special equipment or extra passes over the field. It should be considered when there are large differences in soil test P within a field indicating increased risk of P loss to surface waters and/or potentially poor return on phosphorus fertilizer. Also consider when portions of the field require substantially higher P rates than the field average to optimize yield.

BMPs for Winter Wheat in Humid Regions

Table C3. Nitrogen BMPs for Winter Wheat in Humid Soil Regions – Mixedwood Plains & Atlantic Maritime Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Any N fertilizer with guaranteed analysis for spring application.[102]	Set field scale N rates using a recognized N calculator or recommendation system that accounts for realistic yield and protein goals, soil N supply characteristics, previous legume crops, and previous manure applications.	Apply primary N source as soon as practical in spring.	Broadcast granular fertilizer or topdress liquid (UAN) using streamer nozzles or dribble banding equipment.
INTERMEDIATE	Use enhanced efficiency forms of ammonium-based fertilizers (urease inhibitors, double inhibitors or controlled release) in high moisture, high risk situations.[102, 103] Or	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[104]	Apply required N as topdress in the spring, as close as practical to Feekes 5 or Zadoks 30 growth stage.	Broadcast granular EENF forms of urea or use nitrate-based products.[105, 106] or Apply UAN treated with a UI or DI in season using dribble banding equipment or streamer nozzles.
	Use nitrate sources (AN, CAN, CN) where main risk is ammonia volatilization.[107]	Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield and protein goals, soil N supply characteristics, previous legume crops, and previous manure applications.		

102 Winter wheat requires adequate P following germination and emergence in order to form a viable crown that will improve chance of winter survival. N rates at seeding should be minimal as excess N may increase fall vegetative growth and reduce winter survival. MAP is the preferred source of ammoniated phosphates for seeding application to winter wheat.

103 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which enhanced efficiency N source is most likely to prevent loss.

Table C3. Nitrogen BMPs for Winter Wheat in Humid Soil Regions – Mixedwood Plains & Atlantic Maritime Ecozones.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Use enhanced efficiency forms of ammonium-based fertilizers (urease inhibitors, double inhibitors or controlled release) in all situations except low risk.[102]	Develop sub-field management zones based on quantitative analysis of field variability.[108] Set management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield and protein goals, soil N supply characteristics, previous legume crops, and previous manure applications.	Split apply N using a combination of spring top dress as soon as practical and a second spring application by Feekes 7 or Zadoks 32 growth stage.[109]	Broadcast granular EENF forms of urea or use nitrate-based products.[110, 111] or Apply UAN treated with a UI or DI in season using surface banding equipment.[112]

104 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off or reducing N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

105 Nitrate based products are acceptable for surface application in winter wheat as they reduce ammonia volatilization relative to urea and denitrification and leaching risk tends to be lower in-season when the crop is actively growing.

106 Surface placement increases risk of volatilization loss when using urea. Best practice at the advanced level is to use a protected N source such as UI inhibited urea or UAN, DI urea, or controlled release urea. Note that using a nitrification inhibited urea alone in surface applications increases volatilization losses. When using controlled release granular sources keep in mind that dry surface conditions may delay release of N and movement into the rooting zone.

107 Ammonium nitrate, calcium ammonium nitrate, and calcium nitrate greatly reduce or eliminate the risk of volatilization losses. They are consequently acceptable sources when volatilization is considered the main loss mechanism. They increase the risk of losses through denitrification and leaching.

108 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates can be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

109 Feekes 7 or Zadoks 32 (second node detected) is the stage of winter wheat growth where yield response to added N starts to diminish. N added beyond this stage up to Feekes 9 or Zadoks 39 may still increase protein which may be desirable in hard winter wheat varieties.

110 Nitrate based products are acceptable for surface application in winter wheat as they reduce ammonia volatilization relative to urea and denitrification and leaching risk tends to be lower in-season when the crop is actively growing.

111 Surface placement increases risk of volatilization loss when using urea. Best practice at the advanced level is to use a protected N source such as UI inhibited urea or UAN, DI urea, or controlled release urea. Note that using a nitrification inhibited urea alone in surface applications increases volatilization losses. When using controlled release granular sources keep in mind that dry surface conditions may delay release of N and movement into the rooting zone.

112 Appropriate application equipment may include streamer nozzles or dribble banders. Nitrogen uptake is primarily through the roots methods that place a greater proportion of the fertilizer on the soil as opposed to the plants will improve uptake and reduce plant damage.

Table C4. Phosphorus BMPs for Winter Wheat in Humid Soil Regions – Mixedwood Plains & Atlantic Maritime Ecozone.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (4 years or less) to establish P baseline.[113]	Apply P in fall before or at seeding.	Broadcast and incorporate to a minimum depth of 2 inches.
		Set field specific rates considering differences in yield potential and soil test values among fields.[114]		
		P rate when using fall applied NP sources (MAP, DAP, APP) should be set to meet P requirement and avoid excess N.[115]		
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Apply P in fall before or at seeding.	Band/inject or co-band with other nutrients prior to seeding.
		Vary P in-field in relation to yield potential variations and/or projected N rates and/or differences in soil test P.		
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Apply P in fall at seeding.	Seed place at safe rates based on crop, seed bed utilization, and total product load.
		Vary P by management zone independently from projected N rate.		Side-band at seeding.
				Midrow band at seeding.

113 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method. Ensure the lab chosen is familiar with testing agricultural soils and has a robust QA/QC program in place and participate in inter-laboratory comparison programs such as the ALP or NAPT.

114 Rates should be set following provincial guidelines based on soil test and crop types, unless documented on-farm data show reasonable expectation of improved crop yield with a reasonable expectation of no increased risk to water or quality by utilizing 4R principles. Adopt a draw down strategy in zones that test very high in P (approaching or exceeding 60 ppm) by setting rates less than annual crop removal.

115 Excess N can reduce overwinter survival. Fall applied P produces a 20 lb N/ac co-application at rates of 46, 25, 33 lb P2O5/acre respectively for MAP, DAP, and APP. MAP is the preferred choice of ammoniated phosphates when aiming to limit N availability in fall.

Appendix D - 4R Nitrogen and Phosphorus Practices for Annual Legumes in All Regions

Annual legume crops include the grain legumes or pulses (field pea, lentil, chickpea, fababean, dry bean, fenugreek, grasspea, lupin) and oilseed legumes. Soybean is the major oilseed legume grown in Canada. Including annual legumes in the crop rotation can reduce N fertilizer requirements over the course of the rotation and reduce nitrous oxide emissions.

Annual legumes form symbiotic relationships with nitrogen fixing soil bacteria. The efficiency of nitrogen fixation varies widely among crop types. Faba beans may fix well over 100 lb N/ac and soybeans average 160 lb N/ac, while dry beans may fix less than 20 lb N/ac. Except for dry bean, most pulses and soybean get sufficient N from fixation in combination with N from endogenous soil sources to fully meet their needs.

As the plant root system develops, the nitrogen fixing bacteria invade plant root hairs and form nodules where the enzyme nitrogenase reduces atmospheric dinitrogen (N2) to ammonia (NH3). The genera involved are *Rhizobium sp* (family *Rhizobaiaceae*) and *Bradyrhizobium sp* (family *Nitrobacteraceae*). Although there is some cross over, different crop species require different species of *Rhizobium* or *Bradyrhizobium* in-order-to form nodules. Soils may contain wild strains of nitrogen fixers that will nodulate crops, but these even when present may not be effective in meeting crop N demand. Inoculating with an effective strain either through seed coating or in furrow application of granular or liquid products ensures that sufficient inoculant is present to drive robust nodule formation. Once a crop has been grown in a field several times, enough residual inoculum may be present for robust nodule formation and use of inoculants may not be required. However, inoculum survival depends on factors such as soil moisture, temperature, tillage and crop rotation. Soil pH is particularly important and survival from season to season may not occur in acidic soils. Nodulation and fixation may also be suppressed by high levels of available N in soil. Keep in mind that factors like pH may vary substantially across a field and survival may be highly variable at the subfield level.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

Commercial inoculants contain a stabilized population of nitrogen fixing bacteria, but these are still living organisms. Some general best practices to ensure inoculant remains viable and improve probability of successful nodulation include:

Table D1. General 4R Best Management Practices for Inoculating Annual Legumes.
Buy fresh inoculant every season and don't use past the expiration date.[116]
Make sure N-fixing species matches the crop type.[117]
Store inoculants and inoculated seed in cool dark place avoid exposure to sunlight.[118]
Avoid using treated water when mixing or diluting inoculants.[119]
When treating seed on farm, inoculate within 24 hours of seeding.[120]
Ensure inoculant is compatible with other seed treatment products.[121]
Ensure rate and source of seed row fertilizer is safe for inoculant.[122]
Check fields for active nodules four to six weeks after planting.[123]

116 The viability of inoculant products declines over time. Using stale dated product may lead to inoculation failure.

117 Pulses fall into inoculation groups that share specificity for Rhizobium sp. Peas, lentils, and faba beans require R. leguminosarum. Chickpeas are matched to *R. cicero*, and dry beans *R. phaseoli*. Soybeans require *Bradyrhizobium japonicum*.

118 The bacteria in inoculant products can be killed by heat and the ultraviolet radiation in sunlight.

119 Water treatments such as chlorine are used to disinfect water and may sterilize or partly sterilize the inoculant resulting in failure.

120 Viability of the inoculate tends to decline following on-farm treatment. Treating as close to seeding as possible helps ensure viability is maintained.

121 When co-treating seed or using seedrow application of fungicide or insecticide check labels for compatibility.

122 Fertilizer placed at high rates in furrow with inoculant may kill the bacteria through the salt effect or ammonia toxicity. Mixing granular inoculant with granular fertilizer in the applicator will result in inoculation failure.

123 Checking for nodules early is important in verifying successful formation of the nitrogen fixing system particularly when relying on residual soil inoculum. Nodules appear near the crown of the root system with seed applied inoculants and along the lateral roots with furrow applied products. Active nodules are pink inside. Seven to fourteen nodules per plant at first flower typically indicates adequate nodulation. In situations where plants have poor nodulation and show signs of N deficiency, rescue N fertilizer can be applied up to initiation of pod formation.

Nitrogen BMPs for Pulses and Soybean

Table D2. 4R Nitrogen BMPs for Pulses and Soybean.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Inoculate with appropriate *Rhizobium or Bradyrhizobium* strain, if crop has not been grown in the field previously.[124]	Apply inoculant at label rates.[125]	Apply inoculant at time of seeding.	Apply granular inoculant in seed row or side-band.[126]
	Consider soil and climate factors as well as crop interval to determine if inoculation is required when crop has been grown in a field previously.[127]			Follow label directions for seed coating.
	Dry Beans – Typically fertilized see separate table.			Fall or early spring broadcast of NP sources is allowed at P rate for planned crop.[128]
INTERMEDIATE	Inoculate with appropriate *Rhizobium or Bradyrhizobium* strain, if crop has not been grown in the field in the past 3-5 years.[129]	Double inoculate with appropriate *Rhizobium or Bradyrhizobium* strain, if crop has not been grown in the field previously.[130]	Same as Basic.	*Same as Basic except fall broadcast not allowed for NP sources.*
ADVANCED	Inoculate with appropriate *Rhizobium or Bradyrhizobium* strain every time crop is grown in the field.[131]	*Same as Intermediate.*[132]	*Same as Basic.*	*Same as Intermediate.*

124 Effective nodulation requires the presence of sufficient inoculum in the rooting zone early in the growing season. The Rhizobium species (Bradyrhizobium for soybean) must match the crop type. Some pulse crops may be inoculated by wild strains or residual inoculum in the soil from previous crops. Soil conditions particularly acid pH, soil moisture, and temperature as well as crop rotation effect Rhizobium survival and nodulation success.

125 A significant percentage of bacteria in the inoculant may die off following application before they can infect emerging plant roots. Cutting rates may result in an insufficient number of viable organisms for robust nodule formation.

126 Follow seed place fertilizer limits for pulse and soybean crops considering seed-bed utilization, soil texture and soil moisture. Side-banding inoculant with higher rates of fertilizer may result in inoculation failure. Placing inoculant in midrow band is not recommended as it delays nodule formation.

127 Factors to consider when assessing the likelihood of viable population in soils include time interval from previous planting of the crop or crop in same inoculant group, nodulation (good or poor) of most previous crop, soil pH, intervening conditions of drought or excess moisture, and variability in survival conditions within or between fields.

128 Fall application of ammonium phosphate products including MAP, DAP, and APP are allowable at the P rate for the following spring legume crop. Note that excess available N can suppress nitrogen fixation.

129 Guidelines for frequency of reinoculation in fields that have previously grown an annual legume in the same vary by crop and region.

130 Using two forms of inoculant, for example granular and seed treated, ensures robust nodulation when the crop has not been grown previously in the field. Double inoculation is generally not advantageous when the crop was planted in the field in the past four years and the previous crop was well nodulated.

131 Inoculating every year that the crop is grown in a field reduces risk of sub-optimal yields due to poor nodulation and subsequent nitrogen deficiency. While inoculum can survive in soil for extended periods in the absence of the host crop, several factors can reduce survival including poor nodulation of the previous crop, soil acidity, prolonged soil saturation, and/or extended drought. Survival may not be uniform across fields with poor survival occurring, for example, in low areas where water ponds or areas of lower pH. Research suggests that inoculating every time the crop is seeded tends to have a positive effect on yield and ensures that there is sufficient numbers of viable organisms present to ensure robust nodule formation. Yield increases required to cover the cost of inoculation vary be crop and crop price but are typically less than 1 bu/acre.

132 Some researchers have shown a need for small amounts of fertilizer N in high yielding soybean varieties under excellent growing conditions. In these circumstances N-fixation, remobilization of N within the plant and endogenous soil supply may be insufficient to meet N demand during the seed-filling period.

Nitrogen BMPs for Dry Beans

Dry beans (Phaseolus vulgaris encompasses a wide range of phenotypes and associated market classes, including kidney, navy, great northern, and pinto beans. Dry beans are relatively inefficient nitrogen fixers and are typically fertilized in commercial production to increase yield. Optimizing nitrogen supply requires a balancing between fixation capacity, soil supply, and fertilizer. Dry beans can be grown as a row crop or solid seeded depending on available equipment and other crops in the rotation. The production system used may limit time and place choices.

Table D3. 4R Nitrogen BMPs for Dry Beans.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Fertilize dry beans using ammonium-based formulation for fall (except UAN)[133] or any N fertilizer source in spring or in season.[134]	Set field scale N rates based on realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications[135] as well as annual weather variations.[136]	Apply N after soil cools in fall allowed in dry regions (no fall N application in humid regions).[137]	Broadcast and incorporate within 24 hours using tillage to a minimum depth of 2 inches.
	Inoculate with appropriate *R. phaseolus* strain under conditions that favour N-fixation.[138]	Soil test for N when conditions suggest residual N may be present in significant quantities.		Fall broadcast for spring seeded crops of primary N source must be EENF and limited to dry regions.[139]
			Apply N in spring before seeding.	Fall or early spring broadcast of NP sources is allowed at P rate for planned crop.[140]

133 Ammonium-based formulations contain two-thirds or more of the contained nitrogen as ammonium OR convert to ammonium when applied (for example, urea and anhydrous ammonia). UAN is excluded from fall application because the nitrate content increases the risk of over winter N loss through denitrification and leaching.

134 Dry beans nodulate but are relatively poor nitrogen fixers. Estimates vary but fixation typically provides less than 50% of N required for optimal yield. The balance of N required is derived from soil or N fertilizer. Prairie soils tend to contain wild Rhizobium strains that can form nodules with dry beans and yield response to inoculation is variable. Note that in high residual N situations soil derived N in combination with fixation may provide sufficient N without fertilizer. Fertilizer N rates above 50 lb N/acre may also suppress fixation.

135 There are different approaches to developing nitrogen recommendations for dry beans including yield goal or N balance methods based on the Stanford equation and regional response curves. In selecting appropriate methods ensure that 4R principles were considered during method development.

136 Available moisture is often limiting in crop production. Consider variations in stored soil moisture, probability of precipitation, potential for shortfalls in growing degree days, frost free period and other potential variations in weather and climate when setting yield goals and N rates.

Table D3. 4R Nitrogen BMPs for Dry Beans.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
INTERMEDIATE	Use enhanced efficiency forms of ammonium-based fertilizers in high moisture, high risk situations.[141, 142] *OR* Use nitrate sources (AN, CAN, CN) where main risk is ammonia volatilization.[143]	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[144]	Apply N in spring at seeding.	Apply primary N source in subsurface bands/ injection.
		Set subfield management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations.		Spring broadcasting of primary N source more than 14 days before planned seeding date must be EENF.[145]
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.		
ADVANCED	Use enhanced efficiency forms of ammonium fertilizers in all situations except low risk.[146]	Develop sub-field management zones based on quantitative analysis of field variability.[147]	Split apply N using a combination of spring application at or before seeding and in-season application as required to meet optimal rate.[148]	Apply primary N source in subsurface bands/ injection.
			AND Apply in season N within optimal window for crop uptake.	Use EEFN forms of surface banded urea and UAN in season or use nitrate-based products.[149]

137 Dry regions are the Prairie and Boreal Plain ecozones of Western Canada and have normal precipitation to potential evapotranspiration ratios of less than 1. The standard for fall soil cooling prior to application of a primary N source is a maximum daily soil temperature below 10°C at 5 cm depth for 3 consecutive days. Soil temperature can be approximated from air temperature using the following formula:

Soil Temp = 0.6287*MaxDailyAirTemp + 0.3339. Note that using this equation a soil temp of <10°C corresponds to a max air temp of < 15.4°C.

138 Growers should consider inoculating dry bean in neutral soils (pH 6.0-8.0) with low soil test N and high mineralization potential. Additional N fertilizer rates can potentially be reduced or eliminated when dry bean is inoculated under favorable conditions.

139 While broadcasting in fall may be necessary to accommodate the logistics of field operations an EEFN should be used to reduce overwinter losses and loss. Note early spring broadcasting of primary N source would generally be considered as more than 14 days before planned seeding date.

140 Fall application of ammonium phosphate products including MAP, DAP, and APP is allowable in all regions at the P rate for the following spring crop. Fall-application of ammoniated or other phosphate fertilizers to cover multiple cropping years is excluded due to the higher risk of N and P loss.

141 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate to the situation after assessing the risk of loss. EEFN products that can be blended with conventional products should contain a minimum of 50% EENF to qualify at the intermediate level. Rate, time, and place modifications may need to be considered depending on product.

142 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils, and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which EEFN source (nitrification inhibitor, urease inhibitor, double inhibitor, or controlled release) is most likely to prevent loss.

143 Ammonium nitrate, calcium ammonium nitrate, and calcium nitrate greatly reduce or eliminate the risk of volatilization losses. They are acceptable sources when volatilization is considered the main loss mechanism. Note that nitrate containing products increase the risk of losses through denitrification and leaching.

144 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

145 Broadcasting the primary N source in spring before seeding increases the risk of N losses. Assess what factors are relevant when assessing risk and which EEFN source is most likely to prevent loss.

146 Agronomists should select an Enhanced Efficiency Nitrogen Fertilizer (EENF) with demonstrated efficacy and appropriate for the situation after assessing the risk. EEFN products that can be blended with conventional products should contain a minimum of 70% EENF to qualify at the advanced level. Note that for in-season surface applications nitrate sources (AN, CAN, CN) are acceptable where main risk is ammonia volatilization.

147 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates should be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

148 Split application applies a portion of the required fertilizer N closer to or in the window of maximum crop uptake. Best practice would be to apply two-thirds of recommended total rate at or before seeding and the balance to coincide with maximum N demand. The split application approach allows the decision to omit or reduce the last one-third if circumstances change. For example, if yield potential is limited due to drought or other factors. Split applications can potentially reduce nitrous oxide emissions; however, it doesn’t necessarily improve yield and/or quality. NOTE: In season application of N can be used to ensure yield goals in inoculated beans that failed to nodulate.

149 Nitrate based products are acceptable for surface application in-season in situations where ammonia volatilization is the major risk for loss.

Phosphorus BMPs for Pulses (Including Dry Bean) and Soybean

Table D4. 4R Phosphorus BMPs for Pulses (Including Dry Bean) and Soybean.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (4 years or less) to establish P baseline.[150]	Broadcast P in fall or co-apply with N (dry bean) after soil cools.[151]	Broadcast and incorporate to a minimum depth of 2 inches.[152]
		Set field specific rates considering differences in yield potential and soil test values among fields.[153]		
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling (4 years or less).	Band P in fall or co-band with N (dry bean) after soil cools.[154]	Band/inject or co-band with other nutrients in fall using conservation techniques such as minimum tillage or strip tillage.
		Vary P in-field in relation to yield potential variations and/or N rates and/or differences in soil test P.[155]	Apply P in spring before seeding.	Band/inject or co-band with other nutrients prior to seeding.
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through benchmark, zone or grid sampling.	Apply P in spring at seeding.	Place with seed at safe rates based on crop, seed bed utilization, and total product load.[156]
		Vary P by management zone independently from N.		Side-band at seeding.
				Midrow band at seeding.

150 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method.

151 Co-application of N and P in fall must meet source, rate, place requirements for both N and P. Fall application of primary N sources on fields intended for dry bean production is not a 4R BMP in humid regions.

152 Surface applications of P (except for in season rescue P) must be incorporated to reduce risk of loss to surface waters and prevent surface stranding. Broadcast and incorporation is acceptable at the basic level with consideration of poor efficiency when broadcast is used on fields with low to medium soil tests values. Note that harrowing after application may not provide sufficient depth of incorporation to ensure availability or prevent runoff loss. Recommending broadcasting without incorporation within the 4R framework requires a risk assessment using an assessment approach that is recognized as appropriate for the region (e.g., the Phosphorus Loss Assessment Tool for Ontario (PLATO) available on Agri suite). Note that risk can be reduced in some situations by choosing low or lower solubility products like struvite or reactive rock phosphate.

153 Rates should be set following provincial guidelines based on soil test and crop types, unless documented on-farm data show reasonable expectation of improved crop yield with a reasonable expectation of no increased risk to water or quality by utilizing 4R principles. Adopt a draw down strategy in zones that test very high in P by setting rates less than annual crop removal.

154 Co-application of N and P in fall must meet source, rate, place requirements for both N and P. Fall application of primary N sources on fields intended for dry bean production is not a 4R BMP in humid regions.

155 Consider applying build rates in fields/zones that are deficient or very deficient in P. Apply only removal or sufficiency rates in zones that are marginal or optimal in P. Adopt draw down strategy in fields that test very high in P.

156 In situations where P rates required for optimal yield exceed safe rates for seed row placement, place additional required P away from seed. Consider potential impact on inoculant when applying P in seedrow.

Appendix E – 4R Nitrogen and Phosphorus Practices for Intensive Potato Production in All Regions.

Nitrogen BMPs for Rainfed Potato Production

Rainfed production is the predominant form of potato cultivation in Eastern Canada. Prince Edward Island produces 40% of the potatoes grown in Eastern Canada.

New Brunswick, Quebec, and Ontario produce the remaining 60%. Rainfed acreage in Western Canada is generally restricted to seed and table potatoes, while processing potatoes are predominantly grown under irrigation.

Runoff of P resulting in compromised surface water quality is a significant issue in the major rainfed production areas. Leaching of nitrate, in addition to contributing to indirect nitrous oxide emissions, are a threat to groundwater quality. This is a particular concern in PEI due to the provinces coarse textured soils and total reliance on groundwater for domestic and industrial water supply. Nitrous oxide emissions from fertilizer use in potato production contribute less than 3% of the total emissions from agriculture soils. While only a percentage of Canadian cropland is occupied by potatoes, they are a high value crop and there are increasing demands from the marketplace requiring sustainable production. Fertilizer best management practices are aimed at preventing losses through internal and external pathways and increasing nutrient availability in time and space to match crop demand. Optimizing N and P practices for potato production requires a balance between crop quality, profitability, and environmental protection.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

Table E1. 4R Nitrogen BMPs for Rainfed Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Any N fertilizer with guaranteed analysis.[157]	Apply based on nitrogen balance or provincial guidelines for yield goals.	Apply N in fall after the soil cools (dry regions only).[158]	Band fall N (dry regions only).
		Set field specific rates based on previous yield history and soil types.	Apply nitrogen in spring before seeding.	Broadcast and incorporate with-in 24 hours using tillage to a mini-mum depth of 2 inches allowed for spring.
		Adjust for variety following provincial guidelines or guidance from processor or agent.		
INTERMEDIATE	Any N fertilizer with guaranteed analysis.	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[159]	Apply nitrogen in spring at seeding.	Apply Primary N source at or before seeding using subsurface bands/injection.
	Use EENF (nitrification inhibitors, urease inhibitors, or controlled release) in high moisture, high risk situations.	Set subfield management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations.		
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.[160]		
		Adjust for variety following provincial guidelines or guidance from processor or agent.		

Table E1. 4R Nitrogen BMPs for Rainfed Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Any N fertilizer with guaranteed analysis.	Develop sub-field management zones based on quantitative analysis of field variability.[161]	Split primary nitrogen sources between an initial application before or at seeding and one or more in-season applications.	Apply initial application of primary N source in subsurface bands/injection.
	Use EENF (nitrification inhibitors, urease inhibitors, or controlled release) in all situations except low risk.[162]	Set subfield management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations		Surface apply in-season using an EENF.
		Apply N using digitized/ automated prescriptions for predetermined management zones.	Apply all primary N source in season prior to hilling.[163]	Surface apply all primary N in-season using an EENF followed by immediate hilling.
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.		
		Adjust for variety following provincial guidelines or guidance from processor or agent.		
		Monitor N in-season using technologies such as crop sensors, satellite or UAV imagery, crop nitrogen demand modelling, field scouting, and/ or petiole testing.		

157 There is some evidence of yield response when potatoes are fertilized with a nitrate as opposed to an ammonium-based N source. Nitrate sources increase the risk of N loss through denitrification and leaching but reduce the risk of volatilization. Assess likely mechanism of loss and consider the effects of placement and timing when using nitrate sources.

158 Dry regions are those with growing season precipitation to potential evapotranspiration ratio of less than 1 (P/PE < 1). The major potato growing areas in the Prairie Province meet this requirement. The standard for fall soil cooling prior to application of a primary N source is a maximum daily soil temperature below 10°C at 5 cm depth for 3 consecutive days. Soil temperature can be approximated from air temperature using the following formula:

Soil Temp = 0.6287*MaxDailyAirTemp + 0.3339.

Note that using this equation a soil temp of <10°C corresponds to a max air temp of < 15.4°C.

159 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

160 Soil test N test is a useful predictor of available N. In dry regions. sample in fall after the soil has cooled or in spring. In more humid regions, sample in spring prior to planting. In humid regions, fall soil test N is less useful as a predictor of available N for the following spring crop but can be used in a post-harvest assessment of N balance. Sample as soon as feasible following harvest.

161 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates should be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

162 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils, and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which EEFN source (nitrification inhibitor, urease inhibitor, double inhibitor, or controlled release) is most likely to prevent loss.

163 Delaying primary N application until hilling improves NUE and yield provided there is sufficient available N to support early growth. Sources of N for early season growth may include ammoniated phosphorus (MAP, DAP, APP) products applied at or before seeding, previous manure applications, and soil N.

Nitrogen BMPs for Irrigated Potato Production

Irrigated potato acreage is concentrated in Alberta with Manitoba and Saskatchewan increasing production as more irrigated acres become available. Irrigation removes or substantially reduces the risk of moisture limiting yields. Nutrients, most commonly nitrogen, can be delivered through the irrigation system. Fertigation allows in-season adjustment of nitrogen rates in response to increased or decreased demand, market expectations, and water availability.

Table E3. 4R Nitrogen BMPs for Intensive Irrigated Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Any N fertilizer with guaranteed analysis.[164]	Set rates based on nitrogen balance or provincial guidelines for yield goals.	Apply nitrogen in spring before planting.[165]	Broadcast in spring and incorporate within 24 hours using tillage to a minimum depth of 2 inches.
		Set field specific rates based on previous yield history and soil types.		
		Adjust for variety following provincial guidelines or guidance from processor or agent.		
INTERMEDIATE	Any N fertilizer with guaranteed analysis.	Develop sub-field management zones based on qualitative assessment of field variability such as observed landscape position and soil variability.[166]	Split primary N applications between pre-plant and at hilling.	Broadcast and incorporate first application of primary N source before planting. AND Surface apply in-season application(s) using an appropriate EENF.[167]
	Use EENF (nitrification inhibitors, urease inhibitors, or controlled release) in high moisture, high risk situations.[168]	Soil test each field every year using georeferenced (GPS) soil tests (Dry Regions).[169]		
		Adjust for variety following provincial guidelines or guidance from processor or agent.		

Table E3. 4R Nitrogen BMPs for Intensive Irrigated Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Any N fertilizer with guaranteed analysis.	Develop sub-field management zones based on quantitative analysis of field variability.[170]	Apply all primary N source in season prior to hilling.[171]	Apply initial application of primary N source in subsurface bands/injection.
	Use EENF (nitrification inhibitors, urease inhibitors, or controlled release) in all situations except low risk.	Set subfield management zone N rates using a recognized N calculator or recommendation system that accounts for realistic yield goal, soil N supply characteristics, previous legume crops, and previous manure applications as well as annual weather variations.		Surface apply all primary N in-season using an appropriate EENF followed by immediate hilling.
		Apply N using digitized/automated prescriptions for predetermined management zones.	Split primary nitrogen sources between before planting and one or more in-season fertigation applications.	
		Soil test one or more management zones in each field every year using georeferenced (GPS) soil tests.		
		Monitor N in-season using technologies such as crop sensors, satellite or UAV imagery, crop nitrogen demand modelling, field scouting, and/or petiole testing.		Apply N through fertigation according to crop needs as determined by petiole testing (or other validated assessment approach) and with corresponding reduction of N before planting.[172]

164 There is some evidence of yield response when potatoes are fertilized with a nitrate as opposed to an ammonium-based N source. Nitrate sources increase the risk of N loss through denitrification and leaching but reduce the risk of volatilization. Assess likely mechanism of loss and consider the effects of placement and timing when using nitrate sources.

165 Potato planters do not have the capacity to co-apply large amounts of N at planting. Typically P is applied at planting in the furrow.

166 A qualitative VR approach is considered acceptable in moving from basic to intermediate Rate BMPs. This can range from switching off N application in areas of low yield potential to manually adjusting rates referencing predetermined zone maps. The main difference from intermediate to advanced is the methods used at the intermediate level are based on observation and subjective classification rather than systematic interpretation of geospatial data.

167 Nitrate based products are acceptable for surface application in-season as they reduce ammonia volatilization relative to ammonium-based products and denitrification and leaching risk tends to be low in-season. Assess risk of leaching and denitrification prior to application of nitrate based products.

168 Risk of N loss is largely controlled by weather and soil conditions. Risk of volatilization loss from urea products is increased under warm windy conditions, application on higher pH soils, and inadequate incorporation depth particularly in coarse textured or dry soils. Risk of loss through denitrification and leaching occurs under wet conditions. All three processes plus nitrification contribute to direct or indirect nitrous oxide emissions. Assess what factors are relevant when assessing risk and which EEFN source (nitrification inhibitor, urease inhibitor, double inhibitor, or controlled release) is most likely to prevent loss.

169 In dry regions (Prairies) soil test for N to a minimum depth of 24 inches in the fall or spring prior to the potato year.

170 The difference between VR at the advanced compared to intermediate level is that sub-field management zones are derived through a data driven process. Management zones can be set before field operations start based on data derived from grid sampling, remote or proximal sensing, previous season yield maps, and/or soil maps. Rates should be set for individual management zones and adjusted in season before application based on remote or proximal sensing combined with crop models or interpretive algorithms. Alternatively, N can be varied in real-time using crop or soil sensing technology attached to application equipment.

171 Delaying primary N application until hilling improves NUE and yield provided there is sufficient available N to support early growth. Sources of N for early season growth may include ammoniated phosphorus (MAP, DAP, APP) products applied at or before planting, previous manure applications, and soil N.

172 Ensure sufficient irrigation water is applied to move N into the rooting zone.

Phosphorus BMPs for Rainfed and Irrigated Potato Production

Table E2. 4R Phosphorus BMPs for Rainfed and Irrigated Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use P fertilizer with guaranteed analysis.	Use recent soil test (≤ 3 years) to establish P baseline.[173]	Apply P in spring before seeding.	Broadcast and incorporate to a minimum depth of 2 inches.[174]
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.[175]	Account for P present in manure/compost.		
		Follow provincial guidelines to meet sufficiency levels.		
		Set field specific rates considering differences in yield potential and soil test values among fields.		
		Reduce P rates where P Saturation Index and soil pH indicate that P availability is not limited.[176]		

173 Soil test P is relatively stable from year to year consequently field sampling on an annual basis is not required. Best practice is to sample some fields on the farm every year such that individual fields are tested at least once within a 4-year cycle. Note that different laboratories may use different methods for determining soil test P. Agronomists should consider soil characteristics particularly soil pH when determining which phosphorus test to use and ensure that interpretation guidelines are matched to the test method chosen. A further consideration is provincial nutrient management regulations that may set soil test phosphorus limits based on a specific test method.

174 Surface applications of P (with the exception of in season rescue P) must be incorporated to reduce risk of loss to surface waters and prevent surface stranding. Broadcast and incorporation is acceptable at the basic level with consideration of poor efficiency when broadcast is used on fields with low to medium soil tests values. Note that harrowing after application may not provide sufficient depth of incorporation to ensure availability or prevent runoff loss.

175 Consider product solubility and effects of soil characteristics such as soil pH on phosphorus release rates when using lower solubility products such as rock phosphate or struvite as a P source.

176 Phosphorus saturation index is currently used in Prince Edward Island and Quebec to determine P response in potato. The PSI is a derived value using results of phosphorus and aluminum soil tests. Critical limits and probability of response vary with soil pH.

Table E2. 4R Phosphorus BMPs for Rainfed and Irrigated Potato Production.

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
INTERMEDIATE	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone, grid or benchmark sampling every 3 years or less.	Apply P in spring at seeding.	Broadcast and incorporate to a minimum depth of 2 inches (only an intermediate BMP when P is already optimal, and P rates are removal based).
		Account for P present in manure/compost.		
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.	Reduce P rates where P Saturation Index and soil pH indicate that P availability is not limited.		Side-band at seeding.
ADVANCED	Use P fertilizer with guaranteed analysis.	Assess in-field variability in P availability through zone or grid sampling.	Apply P in spring at seeding.	Apply liquid P directly on in-furrow at planting.
		Account for P present in manure/compost.		
	Use P sources capable of enhancing P availability to level of crop demand in current growing season.	Vary P by management zone independently from N.		
		Reduce P rates where P Saturation Index and soil pH indicate that P availability is not limited.		
		Apply build rates in fields/zones that are deficient or very deficient in P.		

Appendix F – 4R Practices for Potassium Fertilizer Management in All Regions

Plants take up potassium in the ionic form (K+). Potassium taken up by cereal and oilseed crops is largely recycled through crop residue return. Harvest removals increase with forage and silage crops as well as root crops such as potatoes and sugar beets. Prairie soils tend to contain abundant available potassium.

The common soil tests measure exchangeable potassium; however, interpretation needs to consider crop type. Canola, for example, is very efficient at scavenging potassium and the threshold for deficiency is at a lower soil test value than for cereals. Cereals particularly barley may respond to seed placed K even when soil tests are above the critical level. This occurs rarely and the mechanism is not well understood but seems to be more prevalent in some varieties than others.

Fertilizer potassium sources are generally chloride, sulphate, and nitrate salts which dissolve to release K+ into the soil solution. Animal manures can also be an important source of available K. Once in the soil solution, K+ undergoes exchange reactions displacing cations held on negatively charged sites on clay and organic matter. Plant available potassium held on the cation exchange complex is considered an immobile nutrient. As plants remove K+ from solution, exchangeable K is released to replenish the soil solution and diffuses to the root surface. Placement is an important consideration in managing potassium applications as low mobility can result in stratification at or near the surface. The associated anion within the fertilizer also needs to be considered as some crops are sensitive to chloride.

Potassium is frequently at suboptimal levels in Eastern Canadian soils. Prairie soils are generally well endowed with available potassium. In both regions, deficiencies tend to be more likely in sandy soils with low organic matter. Clay minerology can affect K availability. Soils high in feldspar derived smectite clays tend to fix and release K from their interlayers in response to changing soil conditions such as wetting and drying or freezing and thawing. This can result in removal of K from the available pool. Clays derived from micas, such as vermiculite and illite, fix K+ more permanently in their interlayers and are not prone to K tie up through fixation. Clay minerology varies regionally and may affect the interpretation of soil test results as well as performance of fertilizer K.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

Table F1. 4R Practices for Potassium Fertilizer Application in Annual Crop Rotations

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BASIC	Use K sources capable of enhancing K availability to level of crop demand in current growing season.[177]	Set crop specific potassium rates based on provincial guidelines and probability of response using recent soil test (≤ 4 years).[178]	Apply in fall before soils freeze.[179]	Broadcast without incorporation.[180]
	Consider effects of associated elements when selecting potassium sources.[181]	Account for K in manure applications.[182]		
INTERMEDIATE	Same as Basic.	Set field specific rates considering recent soil test (≤ 4 years) and adjusted for differential response based on crop type and soil conditions that influence K availability (low pH, coarse texture, free carbonates, soil temperature, clay minerology, and cropping history).[183]	Apply in spring before seeding for spring seeded crops. Apply in fall before seeding fall seeded crops.	Broadcast and incorporate.[184] Seed-place at or below rates to prevent seedling damage.[185]

177 Some sources may contain potassium minerals of low solubility which require higher rates to meet sufficiency needs of the crop during the current growing season.

178 Soil test K levels can decline during the growing season followed by a rise over the fall and winter. Best practice is to test each field on a three-year rotation preferably testing some fields every year and consistently sampling at the same time of year and the same point in the crop rotation. Look for soil test trends over several sampling cycles to determine if available K is being depleted. Soil test K should be interpreted based on the probability of an economic response. Application rates should be crop-specific and in the case of annual crops used for grazing cattle such as winter wheat, fall rye, or annual rye grass an imbalance of K and Mg concentrations can lead to grass tetany.

Table F1. 4R Practices for Potassium Fertilizer Application in Annual Crop Rotations

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Same as Basic.	Monitor soil levels of K at sub-field with zone or grid sampling. Apply potassium according to quantified field variability of nutrient demand using digitized prescriptions (advanced variable rate).[186]	Apply at seeding for spring or fall seeded crops.	Seed-place at or below rates to prevent seedling damage based on crop type, seed-bed utilization, soil type, and soil moisture.[187] Mid-row band.[188] Side-band.[189]

179 Fall application is generally acceptable as K is not subject to significant over winter losses when applied prior to freeze up. Potassium nitrate at higher rates may contribute to overwinter nitrous oxide emissions or nitrate leaching.

180 Broadcast without incorporation is acceptable at the basic level. Potassium is an immobile nutrient and can be stranded at the soil surface and positionally unavailable under dry conditions.

181 Muriate of potash (KCl) is the most commonly available potassium fertilizer. Crops vary in their sensitivity to the accompanying chloride ion and can be grouped into chloride loving, chloride tolerant, conditionally chloride tolerant, and chloride sensitive. Many horticultural crops fall into the sensitive groups. Chlorine is an essential element and may have beneficial effects in chlorine deficient soils particularly in areas of fields which tend to leach. Sulfate and nitrate, the other two common anions found in potassium fertilizer salts, are also essential elements and may offer opportunities for correcting KS or KN deficiencies using lower product volumes than single nutrient sources.

182 Animal manure can be an important source of plant available K. Manure ranges from 0.4 to 1% total-K depending on source and is readily available. Manure applied at rates sufficient to meet N or P requirements will generally result in K additions in excess of crop requirements.

183 Crops vary in their sensitivity to low available K. Canola for example is an efficient K scavenger and the critical threshold for crop response is considerably lower than for cereals. Potassium is largely cycled back to the cropping system through residue following grain crops. Rates may need to be adjusted upwards following high K removal crops such as alfalfa, silage, potatoes, or sugar beets. Interpretive guidelines will also vary based on the soil test method used. Use regionally appropriate soil test methods and interpretive guides when setting K rates.

184 Broadcasting with incorporation results in better positional availability than surface application. Note that broadcast applications tend to have lower nutrient use efficiency than concentrated placements.

185 Consider seedbed utilization based on opener type and row spacing as well as soil texture and moisture when setting seed-placed rates. If K requirement cannot be met with safe seed-placed rates place additional requirements away from seed using alternative placements or timings. Seed-place runs the risk of seedling damage if soil conditions change. Potassium rates may need to be adjusted downward for K when co-applied with N and/or P and/or S in seed row.

186 Zone or grid sampling can characterize spatial variability in K within a field. Varying K rates independent of N and/or P requires specialized equipment or a separate pass over the field.

187 Consider seedbed utilization based on opener type and row spacing as well as soil texture and moisture when setting seed-placed rates. Seed-place runs the risk of seedling damage if soil conditions change. Rates need to adjusted downward K when co-applied with N and/or P in seed row.

188 Mid-row K can become positionally unavailable early in the season in cold or dry soil soils or when co-banded with nitrogen.

189 Side banding K at seeding provides high nutrient use efficiency while reducing the risk of seedling damage.

Appendix G - 4R BMPs for Sulphur Fertilizer Management in All Regions

Managing sulphur fertility in cropping systems creates some unique challenges. The plant available form of sulphur is sulphate (SO42-). Sulphate is mobile in soil but can precipitate with calcium to form sparingly soluble gypsum. Like nitrogen, sulphur in soil can undergo oxidation and reduction transformations mediated by soil microbes.

Sulphate contains the fully oxidized form (+6) while hydrogen sulfide gas is the most fully reduced form (-2) occurring in soil. Sulphate can be leached from soil while hydrogen sulfide can be lost as gas.

Fertilizer S sources containing sulphate salts such as ammonium sulphate, potassium sulphate, potassium magnesium sulphate, and magnesium sulphate are high soluble and tend to dissolve rapidly to release S into the plant available pool. Calcium sulphate in the form of gypsum is sparingly soluble and should be considered a slow-release product when used as fertilizer. It is more commonly used in Canadian agriculture as a soil amendment to improve sodic soils. Sources containing thiosulphate (S2O32-), a partially reduced form, oxidizes relatively quickly to sulphate and are commonly used in fluid fertilizer. Elemental S° sources include different granular formulations as well as suspensions. Elemental S°oxidizes relatively slowly to the sulphate form and is generally considered a slow-release fertilizer, with the oxidation rate largely governed by the fineness of the particles and the dispersion of the granules. Additionally, there are compound S fertilizers that provide immediately available sulphate combined with elemental S° for slow release. Compound S fertilizers may also include other nutrients.

The different sources require appropriate rate, time, and place practices to effectively manage timely S availability.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

Table G1. 4R Sulphur BMPs for Fertilizer Application in Annual Crop Rotations

RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
GENERAL 4R SULPHUR MANAGEMENT PRACTICES			
Use S sources capable of enhancing S availability to level of crop demand in current growing season.	Adjust rates based on time required for available nutrient release/conversion.	Ensure timing allows for release/ conversion to available forms.	Choose placement appropriate for release/conversion, seed safety, and limiting potential loss of S or accompanying ion.
	Soil test for available S and salinity on a regular basis. [190]		
	Account for S in manure applications.[191]		
	Account for sulphate in irrigation water.[192]		
BMPS FOR ELEMENTAL SULPHUR SOURCES			
Elemental S° sources with micronized particles (< 100 μm) and containing a granule dispersal agent such as swelling clay or dispersed in a compound fertilizer matrix containing one or more additional soluble fertilizers.[193]	Set field specific rates adjusted for differential response based on crop type and soil conditions that influence S availability (low pH, coarse texture, free carbonates, soil temperature, previous use).	Apply in fall before soil freezes.	Broadcast with or without incorporation.[194]
Elemental S° in suspensions follow directions for mixing and agitation.	Consider multiple year application rates.[195]	Apply in early spring for spring seeded crops in situations where elemental S has been continually used for 2 or more years.[196]	

Table G1. 4R Sulphur BMPs for Fertilizer Application in Annual Crop Rotations

RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
BMPS FOR THIOSULPHATE SOURCES			
Thiosulphate sources.[197]	Set field specific rates adjusted for differential response based on crop type and soil conditions that influence S availability (low pH, coarse texture, free carbonates, soil temperature).	Apply in spring for spring seeded crops.	Broadcast with or without incorporation.
		Apply at time of seeding.	Band before seeding.
		Apply in-season.[198]	Band away from seed.[199]
BMPS FOR SULPHATE SOURCES			
Sulphate sources.[200]	Set field specific rates adjusted for differential response based on crop type and soil conditions that influence S availability (low pH, coarse texture, free carbonates, soil temperature).	Apply in fall before soil freezes.[201]	Consider ammonia volatilization with broadcast application of ammonium containing sources.[202]
		Apply in spring.	Band before seeding.
		Apply at time of seeding.	Band away from seed.
		Apply in season.	Apply at safe seed row rates for the crop type, opener, row spacing, soil type and moisture condition.[203]
Compound fertilizers containing Elemental Sulphur and Sulphate sources.	Set field specific rates adjusted for differential response based on crop type and soil conditions that influence S availability (low pH, coarse texture, free carbonates, soil temperature).[204]	Apply in fall before soil freezes.	Consider ammonia volatilization with broadcast application.[205]
		Apply in spring.	Band before seeding.
		Apply at time of seeding.	Band away from seed.
			Apply at safe seed row rates for the crop type, opener, row spacing, soil type and moisture condition.[206]

190 The sulphur soil test measures sulphate the plant available form in soil. In semi-arid regions sulphate levels can vary by several order of magnitude across a field due to the presence of sodium sulphate and/or magnesium sulphate and/or calcium sulphate (gypsum) in the rooting zone. A low soil test can generally be interpreted as there are significant portions of the field that are sulphur deficient particularly for high sulphur using crops like canola, pulses and soybeans. Interpretation of an adequate or high soil test value is more nuanced and should be interpreted in relation to indicators of salinity in the field. Best practice for sampling for soil test sulphur is to sample to a minimum depth of 24 inch (0-6, 6-24 or 0-12, 12-24) and measure electrical conductivity to detect salinity. Landscape directed sampling can be useful when salinity is suspected or know, sampling hilltops, mid-slopes and depressional areas separately.

191 Animal manure can be an important source of plant available S. Manure ranges from 0.25 to 0.50% total-S depending on source. Approximately half will be available in the year of application.

192 Irrigation water can be a significant source of sulphate reducing or eliminating the need for fertilizer S additions.

193 Several soil factors including pH, moisture, temperature and previous use influence elemental S° oxidation. Particle size and dispersion mechanism are also important factors. The smaller the particle size the greater the total surface area of the particles and the more rapidly they tend to oxidize. The <100 μm particles limit is used by AAPFCO for designating an elemental S° source as a slow-release fertilizer. Particles larger than the limit tend to oxidize too slowly to be useful fertilizer sources.

194 Broadcasting granular forms of elemental S° can assist with granule breakdown and dispersion of the elemental S° particles resulting in better soil contact and increased oxidation rate.

195 Due to their slow conversion to sulphate, elemental S° sources are not efficient at meeting crop demand in the initial year of applicant. This can be overcome to some extent by using higher rates. However, the population of slow growing sulphur oxidizing bacteria is often the limiting factor.

196 An appropriate strategy for introducing elemental S° is to use it in combination with a sulphate source over several growing seasons to build up the oxidizing capacity of the soil and the elemental S° reserve.

197 Thiosulphates are fluid fertilizer formulations. Thiosulphate converts to tetrathionate and then to sulphate typically over a period of one to four weeks. Consider temperature and compatibility when blending with other fluid fertilizer products or applying in combination with crop protection chemicals.

198 Consider conversion time when using thiosulphates in-season to correct S deficiency.

199 Thiosulphate is toxic to seedlings. Avoid placement in the seedrow.

200 Sulphate fertilizers are generally readily soluble and contain the plant available form of sulphur. Calcium sulphate (gypsum) is the exception and is sparingly soluble.

201 Restrict rate of ammonium sulphate to meet S requirement not N requirement when applying in fall.

202 Broadcasting ammonium containing sulphate forms without incorporation is acceptable on soils with surface pH ≤ 7.0. When surface soil pH > 7.0 broadcast and incorporate to prevent ammonia volatilization.

203 When applying sulphate fertilizers in the seedrow as part of a blend consider the total salt load of the blend.

204 When using compound fertilizers or bulk blends containing a mixture of sulphate and elemental S° sources consider conversion of elemental S° portion in relation to crop demand.

205 Broadcasting ammonium containing sulphate forms without incorporation acceptable on soils with surface pH ≤ 7.0. When surface soil pH > 7.0 broadcast and incorporate to prevent ammonia volatilization.

206 Compound fertilizers containing sulphate and elemental S° may improve seedrow safety relative to comparable rates of sulphate fertilizers. Approach cautiously when using as part of a blend and consider the total salt load of the blend.

Appendix H – 4R Practices for Manure Use in Annual Crop Rotations in All Regions

Manure and its derivatives such as compost, lagoon effluent and separated solids can be important sources of nutrients for crop production. Manure can also build soil organic matter and contribute to overall soil health. When poorly managed, manure applications can contribute to soil and water degradation, poor crop performance, and elevated greenhouse gas emissions.

Land application of manure can also create nuisance issues with neighbors including odours, flies, and biological contamination. Use of manure following 4R principles helps optimize benefits while minimizing problems.

The manure use BMPs in the tables below are generalized for annual crop production across all regions of Canada. Manure application is regulated by the provinces who set standards for rate, time, and place. Since the regulations can vary considerable among provinces, it's important for the grower and agronomist to fully understand the constraints placed on manure application by the regulatory regime in their province. The tables below provide general guidance provincial regulations may be more stringent in some cases.

Nitrogen in manure is present mostly as ammonium, and organic-N, and small amounts of nitrate. Surface application of manures containing significant amounts of ammonium combined with delayed incorporation or without incorporation can result in substantial losses of the ammonium-N portion. Losses tend to be greatest in the first 6 hours following application. Factors affecting volatilization include temperature, humidity, wind speed, and soil pH. Volatilization losses tend to be greater in soils with pH greater than 7. Incorporating surface applied solid or liquid manure immediately following application is currently the most viable option for reducing volatilization loss. Banding or injecting liquid manure is the preferred approach for preventing volatilization losses.

Note: The footnotes attached to the tables below provide additional information on the individual practices.

Table H1. 4R General Nitrogen and Phosphorus BMPs for Manure Application

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
Basic	Use book values to estimate N and P content of manure.[207]	Soil test prior to manure application.[208]	Apply manure within timelines set by provincial regulations or guidelines.[209]	Surface apply and incorporate following provincial guidelines.[210]
	Use mixing and agitation prior to and during application of liquid manure.[211]	Set field specific manure application rates based on estimated N and P release and crop demand.		Observe all required setbacks as set out in provincial regulations/ guidelines or specified in manure management plans.[212]
		Ensure manure application rates do not exceed provincial regulations/guidelines for maximum manure and/ or manure N and/or P rates or if no provincial guidelines exist to not exceed 3 years of expected crop N and P uptake.[213]		
		Consider residual N and P from previous manure applications when setting rates for subsequent crops.[214]		
INTERMEDIATE	Sample manure either before or during application and analyze manure to determine N and P content.[215]	*Basic Plus,* Vary manure applications according to qualitative estimates of in-field variability.	Apply manure after harvest following regional guidelines for timing.[216]	Surface apply followed by incorporation within 24 hours.
	Use mixing and agitation prior to and during application of liquid manure.	Identify and soil test high risk areas of fields separately.		Observe all required setbacks as set out in provincial regulations/ guidelines or specified in manure management plans.

Table H1. 4R General Nitrogen and Phosphorus BMPs for Manure Application

LEVEL	RIGHT SOURCE	RIGHT RATE	RIGHT TIME	RIGHT PLACE
ADVANCED	Base N and P content estimates on the average of multiple manure samples over several years.[217]	*Basic Plus,* Use advanced techniques such as the use of DEMs, remote or proximal sensing, and/or risk modelling applications to assess risk of loss.	Apply manure in spring before seeding.	Apply liquid manure using subsurface bands/injection.
	Use solid-liquid separation to facilitate independent management of N and P.[218]	Monitor soil levels of N and P with zone or grid sampling.	Apply manure in season.	Apply liquid manure or effluent through low pressure irrigation systems.
	Treat liquid manures with nitrification inhibitor to reduce N losses.[219]	Apply manure according to quantified field variability of risk and nutrient demand using digitized prescriptions (advanced variable rate).	Observe appropriate restrictions on crop use for manure applications to growing crops.	Surface apply solid manures with immediate incorporation.
	Compost solid manures prior to application.			Observe all required setbacks as set out in provincial regulations/ guidelines or specified in manure management plans.

207 Book values are estimates of average or typical values for nutrients and other characteristics such as solids found in manure. Book values are usually calculated using pooled data from multiple manure tests. Book values when used should match species, feed regime, and storage systems used on the farm as closely as possible.

208 Soil testing prior to manure application is a regulatory requirement in some provinces where soil test-based restrictions apply. Soil tests for N and P can be used to adjust rates and/or determine the relative value of manure among fields. Manure generally creates higher value in fields or parts of fields where soil test N and P and soil organic matter are relatively low.

209 Manure application is typically restricted under provincial regulations at certain times of year. All provinces restrict application on frozen and/or snow-covered ground as it limits opportunities for incorporation and increase risk of loss through runoff. Some provinces may have other time restrictions. Manitoba, for example, sets specific dates for fall closure and spring reopening of the application window. Ensure you understand the timing restrictions in your province when developing manure management plans.

210 Incorporation of solid or liquid manures following surface application on arable land is generally required under provincial regulations. Regulations vary by province as to how soon after application incorporation must occur, typically within 48 hours. Surface application can lead to substantial N loss through ammonia volatilization. Losses of 20-50% are common and vary depending on manure type, ammonia/ammonium content, soil pH, and weather conditions. Immediate incorporation (within 1 hour) is considered best practice and can significantly reduce N losses and increase the value of manure as a nutrient source. .

211 Mixing and agitation prior to and during application improve uniformity of distribution of solids and nutrients in the manure. This leads to more uniform distribution of nutrients across the field during application.

212 Setbacks from common water bodies, surface drains, and other features that can act as conduits of manure constituents to surface or groundwater are included in provincial regulations. Regulations may also prohibit application on steeper slopes or other erosion prone features in the landscape.

213 Manure and nutrient applications are regulated at the provincial level. Provincial limits on N and P loading vary but most are based on N or P soil test limits. Understand the regulations governing manure application in your province when developing manure management plans and using manure as a nutrient source.

214 Mineralization of N and P from manure may take place over several seasons and can be a substantial source for crops grown in subsequent years. Contributions to available N and P should be factored into the nutrient budgets for at least two years following the year of application.

215 Manure is a heterogenous material that can be challenging to sample. To collect a representative sample(s) develop a sampling plan before starting manure management activities. For possible sampling approaches consult reference materials provided by provincial governments. For example, Alberta's *Nutrient Management Planning Guide* (https://open.alberta.ca/publications/7086752).

216 In dry regions, delaying manure application until the soil cools may reduce N losses. In humid regions, this may not be practical or beneficial. Nutrients in late-applied manure may be more susceptible to loss in runoff in late fall or winter rains. Also in humid regions, soils tend to get wetter and more prone to compaction with time in the fall. Late summer application following an early harvested crop like winter wheat combined with a cover crop may be beneficial in reducing over winter N and P losses.

217 Merging results from several years of manure sampling and analysis can provide a better estimate of manure characteristics including N and P content in situations where animal feed and storage conditions have been relatively consistent.

218 Solid-liquid separation typically results in a P enriched solid fraction and a ammonia-N enriched liquid fraction. This allows for quasi-independent management of N and P when managing nutrient loading and environmental risk.

219 Nitrification inhibitors added to liquid manure can slow nitrification and reduce risk of denitrification and leaching. Note that use of NIs should be limited to subsurface placements of liquid manures as slowing nitrification in surface applied manures may lead to increased volatilizations losses.