PRAIRIE 4R NUTRIENT MANAGEMENT SPECIALTY GUIDE

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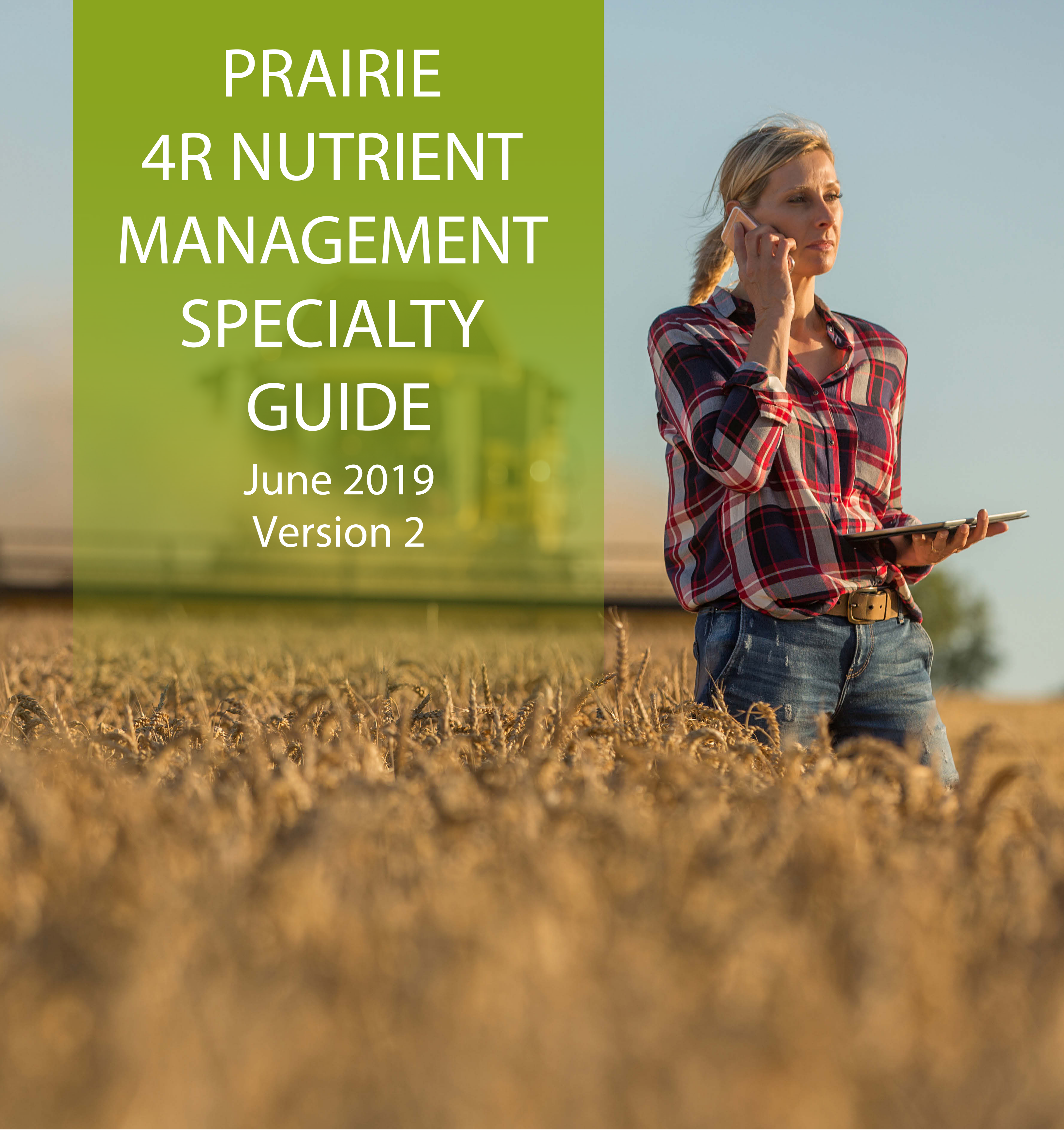

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4R nutrient stewardship

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Thank you to our sponsor, Fertilizer Canada, for their support in developing the original and revised version 2.0 of this Prairie 4R Nutrient Management Certified Crop Advisor (4R NMS-CCA) Study Guide. A special thanks to our the lead writer, Dan Heaney, for his time, experience and commitment to 4R Nutrient Stewardship and the development of this study guide for 4R NMS-CCA candidates.

NOTE TO CERTIFIED CROP ADVISORS

If this resource is being used as a study reference for the 4R NMS CCA Specialty, please note that while this guide provides information relevant to each competency area, it should not be presumed that knowledge of the material in this guide alone is sufficient for the Specialty. Depending on the background knowledge of the candidate, it may be necessary to also review and be familiar with the materials referenced.

TABLE OF CONTENT

INTRODUCTION

BACKGROUND[1]

The International Certified Crop Adviser (ICCA) Program developed the 4R Nutrient Management Specialty (4R NMS) Certification to meet the growing demand for qualified advisers with focused knowledge and skills in nutrient management. Not all CCAs do nutrient management work, many focus on other aspects of crop advising. The 4R NMS allows those CCAs who do advise on nutrient management to become more visible and recognized for their knowledge and skills. Not only can 4R Nutrient Stewardship make for better nutrient recommendations, it can help CCAs meet their clients' needs for improved water quality, environmental stewardship and sustainability.

Nutrient management is an integrated process that considers not only the agronomic aspects of soil fertility and crop nutrition, but also the social, economic, and environmental relationships with the management system. The 4R concept of nutrient management has been developed and is being implemented world-wide by industry, researchers, government agencies, farmers and farm advisers. It is centered around the goal of building a nutrient management plan that puts the right nutrient source, at the right rate, at the right time, and in the right place – the 4Rs of nutrient management. The 4R approach integrates agronomic practices with economic analysis and environmental interaction at the local field or subfield level. It also considers the social impacts for the local community and downstream stakeholders. The CCA 4R NMS is an additional specialty certification that builds on the nutrient, soil and water components of the international CCA certification. Obtaining 4R NMS certification demonstrates the CCA's proficiency in working with 4R concepts and building 4R principles into nutrient management plans.

Agronomy is a dynamic field where new discoveries and approaches continue to occur at a rapid pace. The ASA and ICCA Program encourages comments and suggestions concerning possible modifications to the first edition of the Prairie Performance Objectives for 4R Nutrient Management Specialist Exam.

Comments should be sent via email to certification@sciencesocieties.org.

The ASA and ICCA Program would like to thank the many volunteers on the Prairie CCA Exam Committee who contributed to the development of the Region 1 Performance Objectives and the questions for the exam. This type of program would not be possible without the generous donations of time and energy from industry, private consulting, government, and academia professionals dedicated to the advancement of agronomy and the ICCA program.

Fertilizer Canada has sponsored the development of the Prairie 4R Nutrient Management Specialty Guide to assist CCAs preparing for the Prairie 4R NMS exam. Fertilizer Canada would also like to thank the many volunteers who helped review and edit this study guide and have contributed to the advancement of 4R in Canada in so many ways over the past decade.

LAYOUT OF THE GUIDE

This guide follows the structure of *Region 1 Performance Objectives.* It is organized hierarchically as follows:

Proficiency Areas (PA)

Competency Areas (CA)

Performance Objective (PO)

1 Background adapted from the Foreword to the CCA 4R Nutrient Management Specialist Exam – Region 1 Performance Objectives.

When cross referencing we have generally used the format PA#, CA#, PO#. For example, Proficiency Area 3, Competency Area 3, Performance Objective 1 Discuss how the timing of soil nitrogen tests can impact test levels would be referenced as PA3, CA3, PO1.

We have followed this structure in building the guide. In the Region 1 Performance Objectives, specific points are sometimes listed (A, B, C…) under the main theme or statement of the Performance Objective. We have addressed these points individually when it made sense to do so. In some cases, it made more sense to integrate the points into a single discussion and we adjusted accordingly.

PURPOSE OF THE GUIDE

This document is intended as a study guide. It is not a comprehensive list of the detailed facts and concepts you may need to know in order to successfully challenge the 4R Nutrient Management Specialist Exam developed for the Canadian Prairies. This guide provides a basic level of information for each performance objective listed in the CCA 4R Nutrient Management Specialist Exam – Region 1 Performance Objectives, as well as tips on studying and writing the exam. It contains links to other sources that will be useful in broadening and deepening your knowledge of 4R Nutrient Stewardship generally and specifically for the Prairie Provinces including the Peace River region of British Columbia. Note that although BC is considered part of Region 1, the current Region 1 exam focuses on broad acre prairie cropping systems and does not cover the diverse horticultural and specialty cropping systems of the BC interior and lower mainland.

You may find that concepts and ideas are repeated or restated under different competency areas and performance objectives. This is in part a result of the way the Performance Objectives are laid out and in part a deliberate pedagogic strategy. As much as possible, we have tried to make each Proficiency Area self-contained, so it can be understood without referring to other parts of the guides. We have, however, cross-referenced material where a more complete explanation of a concept has been provided in another section. Also, repetition may not be the soul of wit but it definitely helps get the point across.

NOTES ON THE EXAM

The 4R exam is open to qualified CCAs, those who have already passed the International and Prairie Region exams. Since the 4R exam is a specialty exam, it will contain questions that are more in depth and complex than the questions used in the International and Prairie Region CCA qualifying exams.

The exam is based on the Region 1 Performance Objectives. Information in this guide follows the same PO structure. Every question on the exam will align with one or more of the Performance Objectives. Potential examinees should look at the verbs associated with each PO to determine the type of information that may be asked about each topic area. For example, the verb “list” would be considered a much less complex idea than a verb such as “interpret”. The format of the exam will be 70 to 80 multiple choice questions each with 4 choices and one right answer. Expect 10 to 15 questions to cover more general themes and the balance of the questions to be organized around 6 or 7 scenarios. In the scenarios, the examinee will be asked to interpret a situation and answer a number of questions relating to 4R concepts, principles, and practices in the context of the scenario. Each scenario may have data tables, figures, maps and other resources associated with it as well as written descriptions. There will be calculations required in some of the questions. During preparation potential examinees would be wise to work through sample calculations. The 4R exam will place more emphasis on interpretation and application of knowledge than on memorization and recall of specific facts. That is not to say that knowing the facts is not important but that knowing how to apply those facts will be a key to successful challenge of the exam.

Examinees should be able to convert between SI (metric) and Imperial units and vice versa. In this study guide, examples have been provided in both SI and Imperial Units. We have deliberately not standardized material to a single system so that users are exposed to both systems. Our approach when using figures and tables drawn from external sources is to leave them in the original units used in the source documents.

SUGGESTIONS FOR A STUDY PLAN

1. **Start Early and Study Often –** Be prepared to spend considerable time preparing for the exam. The exam is based on a broad and deep body of knowledge. For many experienced CCAs, exam preparation will largely be review of things known or previously learned. None-the-less give yourself sufficient time to recall, reorganize and review your existing knowledge within the 4R framework as well as learn the unique aspects of 4R.

2. **Review the Basics** – A good place to start is a review of basic 4R concepts. Working through one or more of the Fertilizer Canada eLearning courses listed in the additional resources section or reading the 4R Plant Nutrition Manual from IPNI will provide a solid review of 4R concepts and principles. For example, working through the three-part 4R Nutrient Stewardship Training course on the Fertilizer Canada eLearning website will not only give you a good background in 4R; it will let you earn 5.5 CEUs and qualify as a 4R Designated Agronomist. (See PA 1 for details on the 4R Designation Program and role of a 4R Designated Agronomist).

3. **Assess Your Strengths and Weaknesses** – There is a strong temptation when approaching a task to start at the beginning and just get at it. While this can be a successful approach if you have ample time for study, it may not work as well if your time is more constrained. A better approach is to review the Region 1 Performance Objectives and make note of where you are strong and where you are weak. You can then focus more of your efforts on the areas that need improvement.

4. **Develop Your Own Questions** – As you go through the competency areas think up scenarios and questions that might test the concepts in the performance objectives. Also think about what additional information (soil tests, yield goals, response curves etc.) might be provided with the scenario that would allow you to correctly answer the question. **NOTE:** Since the Prairie 4R exam is new there is not a body of questions that can be recycled for study purposes.

5. **Form or Join a Study Group** – there may be opportunity to join an existing group or if several colleagues in your organization or community are also writing the exam to form your own. Getting together once a week or so either face to face or virtually to share information and ask and answer questions can be a very effective way to prepare.

TIPS FOR WRITING THE EXAM

1. **Arrive Early** – Make sure you have time to organize yourself and settle in before the exam is opened.

2. **Read Through the Exam** – Scoping out the exam before you start madly answering questions will help you set a pace. The exam is set at 3 hours. If you know the material, there will be plenty of time to complete the exam. Spending 2 or 3 minutes to look things over before you start will give you an idea of what you face and let you allocate your time appropriately.

3. **Read the Scenarios Fully Before Answering –** It's always tempting to read the questions and then scan the scenario and support material to try and find a significant phrase or piece of data that you think holds the key to the answer. A much better approach is to read the scenario and make sure you understand it and any additional information sources like a soil test report or graph. Then read through all the questions for the scenario. Then start to work through the questions and choose the best alternatives.

4. **Read the Questions and Alternatives Carefully –** All questions are multiple choice with one right answer and three distractors. Nuances in wording may mean a question is actually asking something different than what you think at first glance. The same applies to the possible answers. Take extra care on questions that require calculations. A favorite trick of examiners is to move the decimal place on one of the distractors, so it contains the same digits as the right answer but is off by an order of magnitude. A second trick is to provide an alternative based on a common mistake such as a missed final step.

5. **Keep Moving** –If you are stuck on a question move on and come back to it. Before you move on mark what you think might be the right answer or any of the alternatives you have eliminated. That way when you come back you can pick up where you left off.

6. **Look for Consistency** – There will be several questions attached to each scenario. The answers for one question should not be inconsistent with answers to other questions unless the questions change the parameters of the scenarios.

7. **Answer All the Questions** – There is no penalty for wrong answers so if you are truly stuck guess. Even if you are not entirely confident in the right alternative, you can often eliminate one or two of the distractors based on what you do know increasing the odds of guessing correctly. When you hand in your paper every question should be answered.

8. **Check Your Work** – If you know the material you will likely finish well within the allotted time. Before you hand in your paper take the extra time to go back through the exam and double check your answers. That's not to say you should second guess yourself but spending an extra few minutes at the end might pick up a few mistakes that weren't obvious the first time through. You've spent hours preparing as well as hundreds of dollars on study resources and travel to the exam site. Wouldn't it be a shame if you

missed the pass/fail cutoff by a couple of percentage points because you had mis-answered questions you actually know.the pass/fail cutoff by a couple of percentage points because you had mis-answered questions you actually know.

USEFUL RESOURCES

There are a number of 4R resources available that can help extend the information found in this guide. The ones listed below are broad based and cover numerous aspects of 4R Nutrient Stewardship. Further links for specific performance objectives are provided throughout the guide.

1. **CCA 4R Nutrient Management Specialist Exam** – *Region 1 Performance Objectives* – The Prairie study guide is built around the Region 1 performance objectives but it's useful to have a copy of the actual document.

   Digital version available from CCA Home https://www.certifiedcropadviser.org/4rnms

2. **Fertilizer Canada eLearning Resources –** Fertilizer Canada has a number of 4R courses available on-line. The most relevant ones are listed below. There are CCA CEUs attached to the courses so you can earn a few CEUs while you study for the 4R specialty. They are all free to access but several charge for the quiz. The CEUs are logged when you write the quizzes. Keep that in mind if you are working through them near the end of your compliance cycle.

   4R eLearning training courses https://elearning.fertilizercanada.ca/en/4r-nutrient-stewardship-training/

Suggested Courses:

4R Essentials - A Short Course in 4R Nutrient Stewardship – Short course if you want a quick review of the overall concepts of 4R Nutrient Stewardship.

4R Nutrient Stewardship Training Parts 1, 2, 3 – This is a general course in 4R for those who are not fully familiar with 4R or want a refresher.

4R Nutrient Stewardship in Saskatchewan – Parts 1 and 2 of this course are generally applicable to Prairie crop production although the examples may be specific to Saskatchewan. Part 3 covers nutrient management regulations in Saskatchewan but many of the regulatory concepts are similar across the prairies.

4R Manitoba – Explores 4R concepts and practices in the context of Manitoba's cropping systems and regulatory environment. Strong on environmental aspects particularly P movement to surface waters.

3. **Fertilizer Canada 4R Resource Page -** Worth exploring the 4R section of the Fertilizer Canada site as it contains a considerable resource library.
   https://fertilizercanada.ca/nutrient-stewardship/

4. **4R Plant Nutrition Manual –** This manual from IPNI is a solid reference for 4R principles and concepts. Available in hard copy or as a Kindle eBook. The eBook renders well on a tablet and has the added advantage of being searchable, immediately available, and considerably less expensive than the printed version. Get the North American version.

   Printed copies available through The Fertilizer Institute store https://store.tfi.org/

   Kindle version from Amazon https://www.amazon.ca/dp/B00IECNA4

5. **4R CCA Nutrient Management Specialist Study Guide** – This guide developed by IPNI covers much of the same material included in the Prairie Guide. Aimed more for a US Midwest audience than the Canadian Prairies. Only available in a printed version from The Fertilizer Institute store.

   Printed copies available through The Fertilizer Institute store https://store.tfi.org/

6. **Ontario 4R Nutrient Management Stewardship Guide** – Developed by the Ontario CCA Board as a reference for 4R in Ontario and a study guide for the Ontario 4R Nutrient Management Specialist Exam. Much of the general information is relevant to the Prairies and the guide contains many useful illustrations and examples. Nutrient management in Ontario is more heavily regulated than in the Prairie Provinces, so filter out the regulatory portions. Useful but use with caution as climate, soils, and cropping systems in Ontario are quite different from the Prairies and some practices which are generally considered as not 4R consistent in Ontario (for example, fall N application) are perfectly acceptable on the prairies. Available in printed version for a fee but the online version is free.

On-line version http://ccaontario.com/4r-nm-specialist

4R printed materials are no longer available through IPNI which ceased operations on April 1, 2019; but can be ordered from The Fertilizer Institute store.

PROFICIENCY AREA 1
4R NUTRIENT STEWARDSHIP DESIGNATION PROGRAM

Canadian agri-retailers and their accredited professional staff play an integral role in supporting grower productivity goals. The emphasis on sustainable crop production is increasing in Canada and crop producers are turning to their agri-retailers for ways to reduce off-farm environmental impacts and meet consumers' sustainability demands while maintaining yields and profitability. To help retailers and growers meet these challenges, Fertilizer Canada has developed the 4R Nutrient Stewardship Designation Program. 4R Designation is a voluntary program facilitated by Fertilizer Canada that allows agri-retailers and their grower customers to solidify their commitment to sustainable crop production through the 4Rs (Right Source @ Right Rate, Right Time, Right Place®). The program provides a measure of performance to address economic, environmental and social considerations. Further, food companies and sustainable supply chain initiatives recognize the value of the 4R Nutrient Stewardship framework and program participation can assist growers in maintaining existing and accessing new markets for their products and realize the vision of moving Canada from the world's fifth to its second largest agriculture exporter. Agri-retailers who become 4R Designated are also helping to quantify the spread of sustainable agriculture in Canada, as the acres they manage are counted and contribute to Fertilizer Canada's goal of capturing 20 million acres under 4R Nutrient Stewardship by 2020. This goal when achieved will signify that nutrients on one-quarter of Canadian farmland is being managed using a demonstrably sustainable system – securing Canada's position as a leader in on-farm environmental stewardship.

The 4R program uses key scientific principles to guide the development of best management practices (BMPs) for nutrient application. These principles are universal and can be applied to any cropping system. The BMPs are site-specific and are therefore unique for a specific crop plan. They are, however, guided by appropriate scientific evidence. Consequently, what may be considered a BMP for a cropping system in one region may not be appropriate for another.

Key Scientific Principles Guiding the Development of 4R BMPS for Nutrient Application	
Right Source 1. Consider Rate, Time and Place 2. Ensure Balanced Supply 3. Suit Soil Chemical and Physical Properties 4. Supply Nutrients in Plant Available Form 5. Recognize Synergisms Among Nutrients 6. Recognize Blend Compatibility 7. Recognize Effects of Associated Elements 8. Recognize Effects of Non-Nutrient Elements	**Right Rate** 1. Consider Source, Time and Place 2. Assess Plant Nutrient Demand 3. Assess Soil Nutrient Supply 4. Assess All Available Nutrient Sources 5. Predict Fertilizer Use Efficiency 6. Consider Soil Resource Impacts 7. Consider Rate Specific Economics
Right Time 1. Consider Source, Rate and Place 2. Assess Timing of Plant Uptake 3. Assess Dynamics of Soil Nutrient Supply 4. Recognize Dynamics of Soil Nutrient Loss 5. Evaluate Logistics of Field Operations	**Right** Place 1. Consider Source, Rate and Time 2. Consider Where Plant Roots are Growing 3. Consider Soil Chemical Reactions 4. Suit the Goals of the Tillage System 5. Manage Spatial Variability

Fertilizer Canada has developed a 4R Designation toolkit to streamline the process for agri-retailers entering the program. The toolkit includes all required resources and information for becoming a 4R Designated agri-retailer.

Additional information for this competency area can be found on Fertilizer Canada's website (www.fertilizercanada.ca), under the tab Nutrient Stewardship, followed by the heading 4R Designation. The CCA should be able to identify the objectives and describe the purpose of the program. The CCA is encouraged to review various resources on the Fertilizer Canada page, including videos and publications, for context. Alternatively, you can also download the 4R Designation Toolkit and review the material it contains.

COMPETENCY AREA 1: UNDERSTAND THE MAIN OBJECTIVES AND ORGANIZATION OF THE 4R STEWARDSHIP DESIGNATION PROGRAM

Performance Objective 1. Understand the main objectives of the 4R Stewardship Designation Program.

A) Demonstrate on farm stewardship in nutrient management.

The 4R Nutrient Stewardship program recognizes that Canadian farmers are already at the forefront in adopting Best Management Practices for fertilizer use – but as a sector, we need to demonstrate that leadership to the world. Growers need help in completing and implementing a 4R Nutrient Stewardship management plan for their farm. Once a grower has completed a plan, the 4R Designation program allows us to count their acres and demonstrate the tangible commitment being made by the Canadian agricultural industry to sustainable food, fibre, and biofuel production. It's not enough to just do the right thing, we also need to be seen as doing the right thing. By getting acres counted, we are able to provide hard data that represents the good work that is being done on farms across Canada. Growers are looking for a program like this and grower associations are endorsing it because more and more end-use customers are demanding evidence of good stewardship practices.

Counting acres under 4R management is the best way that we can demonstrate to customers and stakeholders what our industry is doing to responsibly manage nutrients. When you help your growers get 4R Designated, you are helping them make better nutrient management decisions; you are helping the Canadian agriculture industry demonstrate its commitment to sustainable crop production; and you are helping yourself gain a deeper understanding of your customers' fertility requirements.

B) Provide a framework to improve sustainability.

The 4Rs provide a universally applicable yet regionally specific standard when it comes to sustainable nutrient management on-farm.

Growers are at many different starting points when they first enter into a 4R program. The use of performance levels to group practices provides guidance to growers and their crop advisors on the relative Rightness of practices for the crops and growing 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, developing suites of Right practices 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. A fourth category Not Yet 4R is used to classify growers that are using practices that are considered non-sustainable in a region. Growers who are Not Yet 4R can still develop a 4R Plan and participate in a 4R Designation Program. Their acres are not counted until their practices meet at least the basic 4R threshold. The general progression through the levels is based on the following concepts:

Not Yet 4R – One or more practices are considered as ill-advised for a region as they tend to lead to reduced fertilizer use efficiency, yield loss, and/or significant off-farm environmental impacts.

Basic – Practices are generally consistent with 4R principles. A significant proportion of growers 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 of up to 20% of cropped area in a region.

Advanced – Practices are fully consistent with 4R principles and may be considered aspirational and/or best in class. Adoption of a full suite of advanced level practices may occur over a longer time frame (3-6 years) particularly when they involve investment in new technology. Current adoption rates are generally less than 5% of cropped area in a region.

Determining what practices are included in a given performance level needs to consider 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 cropping system 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 all levels in cold dry winter climates (e.g. the Canadian Prairies) but not in warmer wetter winter regions (e.g. Southern Ontario). An example of 4R consistent practices for N in a common Prairie cropping system is presented in tabular form in the next competency area (PA1, CA2, PO1).

C) Quantify adoption of 4R planning tools.

One of the key messages to agri-retailers and growers participating in the 4R Designation Program is to ***Get your Acres Counted.*** Fertilizer Canada has a goal of capturing 20 million acres under 4R Designation by 2020. Registering 4R acres under the program, allows the industry to quantify the use of BMPs and implementation of 4R planning tools. To register acres a 4R Designated Certified Crop Advisor compiles and submits a list of 4R consistent acres to Fertilizer Canada on an annual basis. Guidance tables (such as the one shown in PA1, CA2, PO1) and other resources have been developed to help CCAs develop 4R crop plans. However, it is up to the CCA to decide if a given field meets 4R criteria using their professional judgement. Fertilizer Canada never sees the plans developed with your customers as that stays between you and your customer – all Fertilizer Canada looks for are the acres, crop and eco-district. Fertilizer Canada will use this information to communicate the number of 4R acres in Canada which demonstrates the industry's commitment to sustainable nutrient management. Acres can be submitted without grower information attached; however, there is an optional section on the form for producer information and this is intended to provide specific recognition to producers.

D) Provide recognition for farmers and their crop advisors.

An important component of the 4R Designation Program is recognition of participating farmers and their crop advisors. Canadian farmers have long been at the forefront of 4R Nutrient Stewardship. For CCAs, getting acres counted by adopting, completing, and implementing the 4R Designation Program in partnership with your farmers helps prove the point. On behalf of the growers, Fertilizer Canada will aggregate and report data to stakeholders over time. Not only will growers become 4R Designated, they'll be making a difference to the environment and improving their bottom line. Fertilizer Canada is also developing more specific recognition programs for participating CCAs, agri-retailers, and crop producers. This component of the program is summed up in the Fertilizer Canada tagline "Get your acres counted, we'll get the word out".

E) Create useful information for policy planning and supply chain requirements.

The principles of 4R are based upon the most up to date, relevant science which puts the crop production industry at the forefront of innovation. The industry, which includes a diverse group of stakeholders, has collaborated to provide useful information for policy discussion and planning. The crop production industry recognizes the importance of nutrient stewardship and the role of regulation in ensuring the proper use of nutrients. At the moment, nutrient management regulations on the Prairies are largely confined to land application of manure and nutrient containing waste materials. Current regulations are for the most part aimed at environmental protection of water resources. Voluntary adoption of 4R Nutrient Stewardship by the industry and willingness to participate in programs like the 4R Designation Program provides useful information for development of an effective and less intrusive regulatory framework.

Additionally, end-use customers are starting to demand that steps be taken to prove the agricultural industry is committed to sustainable practices. Food companies and sustainable supply chain initiatives recognize the value of the 4R Nutrient Stewardship framework. Adoption of 4R can assist growers in addressing compliance questions and assist in accessing new markets for their products. In the coming decade, it will be critical for members of Canada's value chain to respond in a proactive and cohesive manner to the challenges and opportunities presented by the growing global demand for sustainably grown ingredients.

Performance Objective 2: Understand the roles of various stakeholders in the 4R Stewardship Designation Program.

A) Grower

B) 4R Designated Agronomist

C) Agri-retailer

D) Registry Organization (Fertilizer Canada)

E) Other Parties (Government, NGOs, Supply Chain)

The 4R Designation Brochure in the 4R Designation Toolkit provides information on the roles of the first four stakeholder listed above (A-D). The role of Other Parties (E) was explained in part in the previous section. Governments, NGOs, and supply chains are secondary beneficiaries of the 4R Designation Program. The program will provide them with information and quantified data that they can use to guide policy and track progress on Canadian farms.

4R Designation

Step	Grower	Agronomist	Agri-Retailer	Fertilizer Canada
1. Education	Learn about 4R Nutrient Stewardship (e.g. via web, print, workshop, conference) and see if it makes sense	Ensure credentials are in good standing: › CCA › 4R eLearning (4R Nutrient Stewardship Training - Parts 1-3 minimum, and other region-specific courses) › Other required provincial accreditations such as P.Ag/Nutrient management planner where applicable	Corporate decision to buy-in Internal & external marketing 4R Training (overarching and region-specific courses)	Fertilizer Canada maintains and communicates recent, updated programs to retailer
2. Planning	Meet with the agri-retailer to develop 4R consistent plan along with fertilizer recommendations	Develop retailer procedures for 4R programming: › Training › Manuals › Other items of relevance Independents may have flexibility while larger companies may need ISO-type procedures	Work with 4R Agronomist to provide 4R training to staff update credentials as required, build 4Rs into agronomy software Meet grower to make NPK 4Rconsistent plan with CCA or equivalent advisor	Provide online system for agri-retailer to register 4R acres as they are approved by 4R Agronomist
3. Reporting	Consent to have 4R acres reported	Review and sign-off of 4R grower plan Report acres to Fertilizer Canada	-	Keep directory of 4R Agronomists
4. Implementation	Implement the 4R consistent plan	Follow up with agri-retail CCAs and growers to check on progress	-	Register information on acres, eco district, and crops under 4R Protect confidentiality of grower/ agri-retailer and keep data simple
5. Recognition	Receive 4R signage and recognition	Build relationship with customer	Support grower 4R implementation and provide recognition	Promote 4R Designated agri-retail sites through communications pieces: press releases, industry partners, internal newsletters, etc.
6. Review	Review progress with agri-retailer	End of season tune-up with with 4R consistent plan and actual implementation	Review progress with grower	Publish annual report on aggrigated crop, eco district acres, level of attainment (not reated on how well it was done but that the farmer did it), etc

Performance Objective 3: Understand the steps in the 4R Stewardship Designation process.

A) Education

B) Planning

C) Reporting

D) Implementation

E) Recognition

F) Review Progress

Refer to the table in the previous section that describes the roles and responsibilities of the different stakeholders during each step of the process. Further information can be found on Fertilizer Canada's website, under the tab Nutrient Stewardship, followed by *4R Designation*, as well as in the [4R Designation Brochure.]() The CCA does not need to describe the details for each stakeholder step by step but rather should be able to describe in a few sentences the key components of each step. Looking through the associated publications posted by Fertilizer Canada on their website and reviewing the documents contained in the 4R Designation Toolkit (see CA2, PO1B below) will provide further context.

COMPETENCY AREA 2: DEMONSTRATE COMPETENCIES REQUIRED TO SIGN OFF AS A 4R DESIGNATED AGRONOMIST

The information for this competency area can be found on Fertilizer Canada's website, under the tab Nutrient Stewardship, followed by 4R Designation. To create a local copy download the 4R Designation Toolkit from the Fertilizer Canada site. The CCA should review the material and be able to provide a general description of these tools and their purpose. The discussion below may help with understanding.

Under the 4R Designation Program, a 4R Designated Agronomists helps farmers complete 4R Nutrient Stewardship Management Plans, provides 4R consistent agronomic advice, and signs-off on 4R consistency allowing acres to be counted. The role of the 4R Agronomist is pivotal role in delivering the program along with agri-retailers. CCAs must meet the following education, training and experience requirements to qualify as a 4R Designated Agronomist in the Prairie Region:

A. CCA under the Prairie Board having passed both the International and Prairie certification exams and met the experience criteria.

B. Completion of the full 5.5 CEU 4R Nutrient Stewardship Training course on Fertilizer Canada's eLearning site including exams or attended an equivalent face to face workshop.

C. Completion of the 4R Designated Agronomist Attestation document confirming their credentials and competency to prepare and sign-off on 4R Nutrient Stewardship Plans:

These competencies should be reassessed every 3 years. Additional training may be required as courses are revised, or new courses are introduced.[1]

In support of 4R Designated Agronomists, agri-retailers must have processes in place to ensure all staff participating in Designation Program activities have the appropriate training, knowledge, skills and expertise related to their program duties and for the specific geographic areas where they work. Agri-retailers must have documented processes in place to initially evaluate competencies of personnel and on-going monitoring of competencies and performance of all personnel related to 4R Nutrient Stewardship Designation

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1 *A 4R Designated Agronomist is a CCA who meets the nutrient management experience and 4R training requirements outlined in the 4R Designation Toolkit and registered their participation in the 4R Designation Program with Fertilizer Canada. At present, all CCAs are eligible to become a 4R Designated Agronomists and participate in the 4R Designation Program. A 4R Designated Agronomist is not to be confused with a 4R NMS certified CCA who has challenged and passed the Prairie 4R NMS exam. A CCA with the 4R NMS certification must still take the training and register with Fertilizer Canada as a 4R Designated Agronomist to participate in the Designation Program.*

assessments. Agri-retailers must also maintain up to date records, including education, qualifications, experience, training, professional status, competence of personnel working on 4R Nutrient Stewardship Designation assessments.and improvement of 4R practices.

Performance Objective 1: Demonstrate knowledge of the available tools for implementing 4R.

A) 4R BMP Guidance Tables

Guidance Tables (also called practices suites) have been developed for N and P management in major cropping systems across Canada. The tables have been reviewed by a group of senior industry agronomists, researchers, and crop production specialists. They organize source, rate, time and place practices into four levels: not yet 4R, basic, intermediate, and advanced. A sample guidance table for N is shown below:

4R Nitrogen Practices for Spring Cereal, Oilseed, and Pulse Rotations in the Canadian Prairies without Manure or Compost				
Level	Right Source	Right Rate	Right Time	Right Place
Suites of 4R N Management Practices				
Not Yet 4R	X Applies UAN in fall. X Never inoculates pulse/legume crops. Exception: Not required for dry beans which are typically fertilized.	Sets same N rate for all fields.	X Applies N on frozen soil or snow-covered ground. X Applies unprotected N before the soil cools.	X Broadcasts unprotected N in fall. Exceptions: Fall broadcast MAP, DAP with incorporation is acceptable at the basic and intermediate levels.
Basic	Uses ammonium-based formulations for fall. Uses any N fertilizer with guaranteed analysis in spring. Inoculates pulse/legume crops in fields that have not grown the crop previously.	Sets field specific N rates. Considers field specific yield history and soil types and probabilities for weather variations when setting rates.	Applies N after soil cools below 10 ˚C in fall or if using a protected N source within two weeks of expected date for soil reaching 10 ˚C.	Spring Broadcast with incorporation. Fall broadcast of protected N following manufacturers recommendations on incorporation.

4R Nitrogen Practices for Spring Cereal, Oilseed, and Pulse Rotations in the Canadian Prairies without Manure or Compost				
Level	Right Source	Right Rate	Right Time	Right Place
Suites of 4R N Management Practices				
Intermediate	Uses enhanced efficiency fertilizers in high risk situations. Inoculates pulse/legume crops in fields that have not grown the crop in the past 3 years.	Applies N based on annual soil test using surface and subsurface sampling and/or other estimate of residual nitrogen in combination with estimates of other soil supply sources (mineralization and previous legume crop) and/or crop response curves.	Applies N in spring before or at seeding.	Applies in subsurface bands/injection. Uses enhanced efficiency ammonium-based fertilizers or nitrate-based fertilizers for broadcast surface applications in spring or in season.
Advanced	Uses enhanced efficiency fertilizers except in low risk situations. Inoculates pulse/legume crops each time they are seeded.	Intermediate Plus Applies N according to quantified field variability using digitized prescriptions (advanced variable rate). Monitor in-season and/or post season using one or more technologies such as ground based crop sensors, satellite or aerial imagery, field scouting, tissue testing, post-harvest soil sampling.	Applies all N in-season or split applies.	Applies in subsurface bands combined with subsurface or surface bands in-crop.

The purpose of a guidance table is to provide crop advisors with information on what are considered 4R consistent practices (BMPs) on the Canadian Prairies. The tables are not meant to replace the professional judgement and experience of the CCA in advising a farmer on what are reasonable practices given the unique circumstances of the farm. The tables should also be useful in helping CCAs direct their farm clients toward practice changes that will be most effective in reducing both environmental and economic risk. For example, early fall broadcast of urea is a source, time, place combination that carries significant risk of N loss prior to crop uptake. Losses that contribute to greenhouse gas emissions and surface and groundwater contamination as well as reduced yields. Consequently, it is a practice set that is considered inconsistent with 4r principles and not yet 4R.

The guidance tables are living documents that will be expanded to cover more Prairie cropping systems and modified as new information becomes available. For the purpose of the exam, the CCA should understand the purpose and structure of the tables and given a table and a field scenario be able to place to determine if the grower’s practices are 4R or Not Yet 4R.

B) Designation Program Toolkit

The Designation Program Toolkit is a downloadable package of information documents found on the Fertilizer Canada website. The toolkit provides all the necessary information for an agri-retailer (fertilizer dealer or independent agronomist) to register their organization's participation in the Designation Program. Portions of the toolkit are covered under the varies performance objectives in this and other proficiency areas. For exam preparation, the CCA is advised to download and review the toolkit information.

C) 4R Scorecard

The 4R Scorecard for Prairie cropping systems is still under development and won't be released in final form until after the exam. A conceptual description is provided below. The CCA should understand the concepts and uses of the scorecard. In particular, understand that when it becomes available it will be a tool to aid the conversation around implementation and improvement of 4R practices. 4R Scorecards are also being developed internationally.

Reasons for a Scorecard: The 4R BMP Guidance Tables at the basic, intermediate, and advanced levels provide a useful framework for determining if a grower's practices meet the basic threshold of 4R. They also allow for a qualitative assessment of where grower practices are more or less advanced. Targeting practice improvements at lower ranked practices will likely provide more benefits than fine tuning more advanced practices. Growers are often at different levels across the different Rs and while a minimum threshold can be set to qualify a 4R acre, the three levels do not lend themselves to measuring continuous improvement. Consequently, the 4R Metrics and Adoption Working Group brought together by Fertilizer Canada was interested in creating a 4R Scorecard. Such a tool would be useful in tracking not just acres enrolled in the program but also progress at the local and aggregate level. The conceptual structure behind 4R Scorecard is outlined below. Its purpose is to illustrate the score carding concept and generate discussion about the pros and cons of such an approach.

Characteristics of Good Scorecard: The purpose of the proposed scorecard is to provide a tool with the following attributes:

1. Easily understood and applied without requiring extensive on-farm data or time-consuming interactions by the agronomist or retailer.
2. Easily aggregated from field to farm to region (ecodistrict or watershed), to province to national levels to provide estimates of 4R BMP adoption.
3. Aggregates without requiring the transfer of farm identifiable data.
4. Provides sufficient insight into the individual R's to identify potential areas to target for improvement at the farm (individual action), watershed, province, or national levels (collective program action).

Level	Source	Rate	Time	Place
Not yet 4R	Source is if unknown nutrient content or unproven efficacy.	Rates do not consider differences among crops and fields.	Timing is high risk in terms of nutrient loss.	Placement significantly reduces efficiency or increases risk of loss.
Basic	Measured or estimated nutrient content. Known mode of action.	Field specific – the rate is set considering the unique factors in each field.	Reduce high risk timings.	Exclude high risk placement, low efficiency placements.
Intermediate	Enhanced efficiency sources (if available for the nutrient) in high risk situations.	Rate adjusted for subfield variation in soil supply and risk of off-site movement.	Move application timing closer to period of highest crop demand.	Concentrate placement in subsurface bands.
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 in subsurface bands in optimal configuration with rooting zone.

The scorecard approach assigns a score of 1, 2, or 3 for each practice on source, rate, time, and place based on a BMP Guidance Table.

Simple Scoring Regime for 4R Practices[1]				
Level	Right Source	Right Rate	Right Time	Right Place
Not Yet 4R	0	0	0	0
Basic	1	1	1	1
Intermediate	2	2	2	2
Advanced	3	3	3	3
Minimum of 4 (1 in each R) to qualify as a 4R acre.				
Level	Not Yet 4R[2]	Basic	Internediate	Advanced
N or P	< 4	4-6	7-9	10+
N and P	< 8	8-13	14-18	18+
When both N and P are applied 1 in each R for the individual nutrients minimum of 8 required.				
1 Note this has not been finalized and is used here to illustrate the scorecard concept only. 2 At the field level, a 1 or greater is required for each R to qualify the field as 4R consistent. A zero score for any source, rate, time, or place practice used for N and P disqualifies the field. Note that on some farms some crops may qualify while others may not.				

In using the scorecard, a grower would refer to the guidance tables (see earlier example CA2, PO1A) for a cropping system and rank a grower's N and P management practices based on where they fit in on the table. The score would be tallied as outlined above and the grower would have an aggregate score that placed them in the Not Yet 4R, Basic, Intermediate or Advanced Category for each crop that they grow.

Currently the 4R Designation Program uses a simple in or out approach to determine if a grower's acres can be included. The Designated Agronomist reviews the grower's N and P practices and if the practices for a particular crop type meet the basic threshold for source, rate, time, and place the acres are included.

PROFICIENCY AREA 2
NUTRIENT MANAGEMENT PLANNING

Provinces within the Prairie Region (Region 1 NMS) differ in their legal frameworks and regulations when it comes to Nutrient Management Planning. A CCA should be familiar with the regulatory framework in the province where they practice as well as any local regulations or guidelines. For the exam, aim to have a general understanding of the legal framework with regard to Nutrient Management Planning within the Prairie Region. Information on the legal framework to be considered within the context of the exam scenarios will be provided in the exam.

Performance Area 2 overlaps with PA7 Management of Manure, Compost, Biosolids, and Wastewater. Detailed information in the right source, rate, time, and place for the different nutrients is covered in PAs 3, 4, and 5.

A high-level view of the 4R planning cycle is illustrated below. Once the initial 4R Plan is put in place the plan is reviewed annually and adjustments made as necessary. A 4R Plan has an element of continuous improvement with the goal of optimizing nutrient management on the farm over time.

COMPETENCY AREA 1. ROLES AND RESPONSIBILITIES OF PROVINCIAL, LOCAL PUBLIC AND PRIVATE ENTITIES IN NUTRIENT MANAGEMENT PLANNING

The efficient utilization of nutrients is part of sustainable crop production. The sites referred to in this section provide science-based information for stakeholders regarding education, advocacy, and implementation of crop nutrient stewardship. Several guiding bodies endorse and support the 4R principles including: the International Plant Nutrition Institute (IPNI), Fertilizer Canada, The Fertilizer Institute (TFI), and the International Fertilizer Industry Association (IFA).

Performance Objective 1. Interpret a CCA's roles and responsibilities in nutrient management planning as described in the following references:

For Performance Objective 1 review the following sources with a view of understanding the key elements of the 4R planning process and how as a CCA you fit into that process. A good source of information on roles and responsibilities is 4R Nutrient Stewardship

Training Parts 1 available at the Fertilizer Canada eLearning site. Also review the Designated Agronomist's roles and responsibilities as outlined in Proficiency Area 1 (PA1, CA1, PO2)

A) International Plant Nutrition Institute (IPNI) 4R Stewardship [1]

i. The IPNI initiated the 4R concept through cooperation between the fertilizer industry and the scientific community. The 4R framework is global in nature and facilitates the development of site and crop specific fertilizer BMPs based on sound science. These principles and their implementation need be adapted in context to the local region. Interesting side note, 4R is being implemented globally but the conceptual framework originated on the Prairies.

http://www.ipni.net/4r

Chapter 9 of the 4R Plant Nutrition Manual provides a good review of the general roles, responsibilities, and concepts required to integrate 4R planning principles with regional regulatory requirements.

B) Fertilizer Canada 4R Nutrient Stewardship

i. Fertilizer Canada is an association that represents manufacturers, wholesale and retail distributors of fertilizers. The Nutrient Stewardship webpage houses Fertilizer Canada's 4R Nutrient Stewardship provincial programs. Each program shares a common goal of applying the 4Rs to increase production/profitability for growers, while enhancing environmental protection and improving regional sustainability.

http://fertilizercanada.ca/nutrient-stewardship/

ii. Review documents on 4R planning such as the 4R Nutrient Stewardship Planning Guide in the Manitoba section of the website.

https://fertilizercanada.ca/nutrient-stewardship/4r-designation/

The 4R Designation Program and the CCAs role in the Designation Program is covered in detail in PA1.

C) The Fertilizer Institute 4R Nutrient Stewardship

i. TFI is the US equivalent of Fertilizer Canada representing fertilizer industry interests and supporting 4R research and adoption.

http://www.nutrientstewardship.com/

D) Agriculture and Agri-Food Canada – Nutrient Management Planning:

i. The website below contains general information on nutrient management planning and best management practices for soil conservation and plant nutrients.

http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-nutrients/nutrient-management-planning/?id=1187355760327

1 The agronomic programs of IPNI ceased operations on April 1, 2019. This website will remain online until the end of 2019, but no further updates will be made. Questions about past IPNI operations and projects can be forwarded to the International Fertilizer Association, The Fertilizer Institute, or Fertilizer Canada.

E) Agriculture and Agri-Food Canada – Agricultural Practices

i. This website provides general information on a range of related topics: agroforestry, climate, soil and land protection and management, water issues related to livestock watering, ponds and dugouts, watershed protection, wells and groundwater.

http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/?id=1360876327795

F) Alberta Nutrient Management Planning Guide

i. This guide contains information designed for extension agents, agri-business service providers and producers who want to learn more about effective nutrient application and management. Contains detailed methodology on numerous aspects of nutrient management planning including the following: assessing field characteristics, manure and soil sampling, determining crop nutrient requirements and developing an application plan to optimize yield. Contains lots of practical tips on how to do things like manure sample as well as the background information needed in nutrient management planning. Keep in mind that some of the examples make reference to the Alberta regulatory framework and the Alberta Agricultural Operations Practices Act (AOPA).

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11920

G) Tri Provincial Manure Management Guide

i. The Tri-Provincial partnership is a collaborative and cooperative working relationship between Alberta Agriculture and Rural Development, Manitoba Agriculture, Food and Rural Initiatives and Saskatchewan Ministry of Agriculture. The partnership focuses on topics and issues related to sustainable livestock manure management.

The Tri-Provincial Manure Management Website linked below contains information on manure management and treatment technologies. The target audience includes producers, farm managers, consultants, specialists, agronomists and engineers servicing the animal production sector. The goal is to provide information to assist in making decisions that will optimize economic benefits and reduce the environmental impact of managing manure. This tool provides users a single portal for manure management information.

http://www.manuremanagement.ca/Info-Publications/tri-provincial.html

Performance Objective 2. Interpret roles and responsibilities of provincial, local public and private entities in nutrient management planning.

Provincial Government:

Provincial governments regulate nutrient applications to agricultural land. The focus is largely on nutrients in manure produced by confined feeding operations (CFOs) rather than fertilizer application. The legal framework generally tries to balance among right to farm, avoidance or reductions of nuisance conflicts, and environmental protection of air, soil, and water. Each province has an act or acts and an attendant set of regulations that define CFOs in terms of type of operation and animal numbers; creates a permitting or licensing process; set general standards for CFO locations; prescribes acceptable practices for storage and handling of manure; and describes which type of operations are required to create and file a formal nutrient management plan. Some aspects of fertilizer application may also be regulated. There is particular emphasis on protection of water resources and nutrient management regulations are closely tied to water use and quality regulations in each province.

While all three provinces have regulations governing nutrient use, there is considerable variance among provinces. A CCA needs to understand the regulatory framework in which their clients operate. However, as stated at the beginning of this PA, the exam will focus on the general premise for nutrient regulation and how it fits into nutrient management planning. Any required regulatory details will be provided with the scenario.

Overall roles and responsibilities of Provincial Governments in nutrient management planning are as follows:

- Provide background information on the governing acts, definitions, regulations and protocols.
- Provide training and resources for people subject to the regulation.
- Provide certification and training for third parties (consultants/applicators).
- Ensure a timely application approval process.
- Provide inspections and enforcement tools to ensure regulatory compliance.
- Assess regulatory effectiveness and communicate with stakeholders to ensure the regulation is having the intended impact.
- Integrate nutrient management principles into environmental protection planning as it relates to other provincial acts and regulation governing pollution and air, soil, water, and biodiversity.

If you are unfamiliar with nutrient management regulations for your province, it's a good idea to familiarize yourself with them before the exam. The links below will take you to information on the legislative and regulatory frameworks for the three Prairie Provinces. CCAs in the BC Peace Region may want to review BC's acts and regulations.

Manitoba

Nutrient Management Regulations fall under the Water Protection Act.

https://www.gov.mb.ca/waterstewardship/wqmz/

The Livestock Manure and Mortalities Management Regulation under the Environment Act also contains sections that are relevant to nutrient management planning.

https://web2.gov.mb.ca/laws/regs/current/_pdf-regs.php?reg=42/98

Nutrient management regulations are reviewed in Part 3 of the 4R Manitoba course on Fertilizer Canada's eLearning site.

Saskatchewan

Nutrient Management fall under the The Agricultural Operations Act and is administered by the Livestock Branch of Saskatchewan Ministry of Agriculture.

http://www.publications.gov.sk.ca/freelaw/documents/English/Statutes/Statutes/A12-1.pdf

Nutrient management regulations are reviewed in Part 3 of the 4R Nutrient Stewardship in Saskatchewan course on Fertilizer Canada's eLearning site.

Alberta

Nutrient management falls under the Agricultural Operations Practices Act (AOPA) and is administered by the Natural Resources Conservation Board (NRCB).

http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw12498

For a quick comparison of nutrient management regulations across the Prairie Provinces (as well as other Canadian provinces), read the Jurisdictional Scan of Nutrient Management Regulations by the BC Ministry of Agriculture.

https://www2.gov.bc.ca/assets/gov/environment/air-land-water/site-permitting-and-compliance/hullcar/review-docs/631700-3_bc_agri_2017b_jurisdictional_scan_of_nutrient_management_regulations.pdf

Local Public (municipal):

Municipal governments typically have responsibility for land use bylaws and zoning. Municipalities (including rural municipalities such as counties or municipal districts) may create land use zones that exclude certain agricultural activities such as CFOs and/or prevent manure application. Municipal bylaws may conflict with Provincial Regulations in some cases. Although not part of the exam material, CCAs have a responsibility to be aware of and understand the implications of local land use bylaws that may affect source, rate, time and place decisions.

The second role of municipalities that may touch indirectly on nutrient management planning is the issuing of building permits and enforcement of building codes following permitting of new or expanding CFOs. Municipalities may also prevent or prohibit certain types of development such as rural residential within a certain distance (minimum distance separation or MDS) of existing CFOs.

Private (landowner/consultant):

The roles and responsibilities of the CCA and the farmer when engaged in nutrient management planning will change somewhat depending on whether the NMP is prepared to meet a regulatory burden or is solely to meet a grower's enterprise goals to improve sustainability. The roles and responsibilities include:

Landowner (Grower/Operator)

i) be willing to define enterprise goals and commit to collecting and sharing key performance measures.

ii) should provide all necessary documentation and information.

iii) be willing to undertake reasonable costs in support of planning such as the cost of soil tests.

iv) be willing to follow the NMP to the extent possible.

CCA (Consultant)

i) know and be willing to assist grower in understanding applicable regulations governing nutrient planning and application.

ii) provide unbiased advice and suggest appropriate source, rate, time and place practices to fit the farm enterprise's unique circumstances.

iii) assist in the development of alternative practices when the NMP cannot be followed due to uncontrollable circumstances.
A 4R NMP should be thought of as Plan A. In some circumstances a Plan B may be required due to unsuitable weather conditions, equipment breakdowns, changing market conditions etc. The CCA should work with the grower to find the best alternatives for nutrient management under the specific circumstances.

Performance Objective 3. Discuss national, province-specific, and local-specific policies that relate to nutrient management planning.

National:

The Canadian Food Inspection Agency (CFIA) regulates fertilizer materials and soil amendments including biologicals that may be based on living organisms. This controls the nutrient products that are available in the marketplace and the type and accuracy of information the manufacturers, distributors, and retailers must supply to buyers.

The federal government regulates pollution under the Canadian Environmental Protection Act (CEPA). This is a catch-all piece of legislation that regulates potentially toxic substances. It's impact on nutrient management planning is largely indirect. At one time, ammonia was being considered for inclusion on the toxic substances list under CEPA.

Under the Fisheries Act, the federal government regulates water pollution and prohibits any discharge of a "deleterious substance" into water frequented by fish, and any works or undertakings that result in the "harmful alteration, disruption or destruction" of fish habitat.

Provincial:

Each province has their own acts and regulations regarding nutrient management and environmental protection for the areas under provincial jurisdiction. Some of the topics that effect nutrient management that are addressed by provincial policies or regulations include:

Setting minimum distance separation (MDS) for new construction projects. Impacts where a CFO is sited based on end use (livestock, odour, manure storage) and the distance separation from other residences, wells, sensitive features, lot lines, etc.

Setting guidelines or rules for timing of nutrient applications. For example, Manitoba sets specific dates that regulate when nutrient application must cease in the fall and when it can recommence in the spring.

Defining nutrient application setbacks or buffer zones from water features such as lakes, rivers, and wells. These setbacks may limit source, rate, time and place decisions for manure and/or fertilizer.

Setting limits that restrict fertilizer or manure application rates. These are usually based on soil test N or P levels. But may also take into account soil texture, soil salinity, and soil zone/climate considerations. Each province takes a slightly different approach. Manitoba's limits are based on soil test P and N. Alberta uses N limits.

The provincial environment or related ministry identifies potential threats to municipal water supplies and set provincial standards for safeguarding those water sources. Note that each province is a little different.

See Proficiency Area 7 of this guide for more details and examples of setbacks, buffer zones, soil test limits etc.

Local-specific:

Municipal governments may have specific sections of their land use or other bylaws that exclude CFOs and manure application from certain zones. For example, bylaws excluding CFOs from certain parts of watersheds that municipalities draw their drinking water from are fairly common in Alberta. Provincial Source Water Acts protecting surface and groundwater sources of drinking water may be used by municipalities to restrict manure and/or fertilizer application.

Performance Objective 4. Interpret and understand the certification process under the various Provincial Nutrient Management Regulations, if any.

Each province has its own permitting/licensing process for CFOs, and all require that CFOs develop a manure/nutrient management plan.

The requirement for certification for professional nutrient management planners varies by province. All provinces require engineering sign off on major manure storage facilities such as lagoons. With respect to nutrient application to agricultural land:

Alberta has no regulatory requirement for sign-off on nutrient/manure management plans by certified nutrient management planners. Certain aspects of nutrient/manure planning, such as size and suitability of the land base for application of manure by CFOs, are reviewed and approved by the Natural Resources Conservation Board (NRCB) as part of the permitting process. Typically, regulated livestock operations would follow a written NMP approved by the NRCB and keep records of where, when and how much manure is applied but are not required to submit information annually to NRCB or seek annual approvals prior to application.

Saskatchewan has no requirement for sign-off on nutrient/manure management plans by certified management planners. Regulated CFOs must produce a Waste Management Plan that is approved by the Ministry of Agriculture in order to land apply manure. Producers must keep records and the plan must be updated periodically or when there is a significant change in manure volumes, targeted land base, or application practices.

Manitoba requires regulated livestock operations to submit an annual Manure Management Plan (MMP) to Manitoba Sustainable Development. Livestock producers can prepare a Manure Management Plan themselves or with the assistance of a qualified Manure Management Planner. Manure Management Planners that prepare plans required by Manitoba Sustainable Development must have successfully completed the Manure Management Planner Course and be members in good standing of the Manitoba Institute of Agrologists (MIA) or Certified Crop Advisors.

Nutrient management planning is considered the practice of agrology in all three Prairie provinces. All three provinces treat agrology as a regulated profession. In Alberta and Saskatchewan, the respective acts are considered mandatory which in the simplest interpretation means that if you are practicing agrology you must be a member of the AIA or SIA. The Manitoba act is not considered mandatory, but you must be a Certified Manure Management Planner (and a CCA or PAg) to sign off on an MMP when one is required under Manitoba regulations.

Performance Objective 5. Identify responsible parties and their roles in implementing each component of a nutrient management plan following the nutrient management regulations and the logistics needed to apply the right source of nutrients at the right rate, at the right time, and in the right place.

Refer to Performance Objectives 2 and 3 and individual provincial rules, regulations and documentation/certificates.

See Proficiency Area 1 for roles and responsibilities under the Fertilizer Canada 4R Designated Acres Program. Responsibilities will vary depending on whether the NMP is required by regulation or is developed and implemented as part of a voluntary nutrient stewardship program. A general summary of roles and responsibilities is provided below.

Role	Responsibilities
Farmer	Provide information, keep records, insure documentation is filed to meet regulatory requirements, implement NMP, note deviations or contingencies that were implemented, provide feedback to CCA for further adjustment of plan. Manage logistics of NMP implementation including calibration of application and other equipment required to meet NMP goals and measures.
CCA	Provide advice on Right Source, Rate, Time, and Place. Use appropriate tools to access risks. Interpret technical information such as soil test results and manure analysis. Keep records of NMP as developed. Understand regulations that are applicable to NMPs in local area.
Applicator	Follow NMP including adhering to prescribed rates and ensuring setbacks are met. Keep records and provide to grower and/or CCA. Ensure equipment is calibrated.
Regulator	Review and approve NMPs when required by regulation. Enforce regulatory breeches. Work with nutrient management community to increase understanding of regulatory framework.

COMPETENCY AREA 2. CCA'S RESPONSIBILITY IN INTEGRATING 4RS WITH A NUTRIENT MANAGEMENT PLAN

Performance Objective 1. Differentiate between regulated and unregulated nutrient management planning and how 4R nutrient management principles and strategies fit into each.

A) Know the **major** regulatory framework agencies and rules within each Province.

See CA1,PO2 this section for links to the provincial regulations.

B) Know any reporting requirements and approval processes.

These vary by province. Common elements include:

I. Identifying operations and/or materials that are regulated.

II. Permitting or licensing of facilities such as confined feeding operations (CFO) that produce and apply manure and/or other regulated materials.

III. Filing of an NMP where required with appropriate regulatory agency generally as part of the approval process.

IV. Seeking approval for deviations from the regulations. For example, emergency manure applications on frozen ground.

CCAs should know what the approval and reporting requirements are in the province where they work.

Comparison of Regulated and 4R Nutrient Management Planning[1]		
	Regulated Nutrient Management Planning	**4R Nutrient Management Planning**
Goal	Goal is to meet the regulatory burden in order for the operation to stay within the legal boundaries governing the type of operation. The underlying goal of the regulations is typically to ensure beneficial use of nutrient products in such a way as to minimize environmental impacts and reduce rural land use conflicts	Goal is to develop BMPs using 4R principles and meet balanced economic, social and environmental goals set by the farm enterprise.
Right Source	Regulations are aimed at management of particular sources, typically waste materials from agriculture and non-agriculture operations that can, if appropriately applied, provide crop production benefits. These source materials include manure, biosolids and other organic material.	Select right sources to match crop requirements and ensure sources selected are compatible with rate, time and place practices. Use source selection to mitigate economic and environmental risk. 4R is aimed at selecting the right source(s) to match crop requirements; integration of source materials including manure into the nutrient plan; and ensuring sources selected are compatible with rate, time, and place practices which may be fixed by equipment and operational logistics.
Right Rate	Rate considerations in regulated nutrient management are aimed at balancing between crop demands and allowable limits on product application. These limits may be based on soil test values for N, P, salts, or metals depending on the material. Rate limiting factors are in place to prevent environmental damage rather than optimize crop response. Since regulated materials are often bulky and not all nutrients are immediately crop available, rates that exceed crop demand for a single year are often used.	Rates are generally set to meet crop demands in the year of application with exceptions when manure or some other organic source is used, or higher rates are used to build soil reserves. Additional rate setting principles are used such as assessing all nutrient sources in the cropping system; predicting the nutrient efficiency in the context of source, time, and place practices; and considering the economics of the rate chosen.
Right Time	Application time may be regulated within certain windows such that the first consideration of the time decision is to fall within the prescribed time period. Timing options may also be restricted by the nature of the regulated source and requirements for placement. For example, incorporation of solid manure can greatly increase efficiency and reduce nutrient loss but is not feasible in a growing crop.	Selection of time practices seeks to balance among principles including matching nutrient availability to crop uptake curve; assessing the dynamics of soil supply; and recognizing and avoiding or mitigating against loss during high risk periods. Time decisions are further modified by the logistics of field operations as dictated by climate/ weather and equipment.
Right Place	Placement in the regulatory framework is generally driven by reduction of environmental harm and may require setbacks from water bodies, wells etc. This may result in nutrient limitations for crops in the excluded areas. Other placement requirements such as incorporation are dual purpose. Reducing nuisance odors and improving nutrient use efficiency.	Placement decisions based on principles that aim to improve nutrient use efficiency and reduce loss as well as fit with efficient tillage system such as direct seeding. One of the features of 4R management is attention to spatial differences treating each field or zones within a field as a unique cropping system and is fully compatible with variable rate approaches.
[1] Note 4R can and should be used within a regulatory framework.		

Performance Objective 2. Be able to advise on the right source(s), at the right rate(s), at the right time(s), and the right place(s) to fit the client's cropping system, climate, soils, and farming situation.

The 4R Nutrient Stewardship approach is principle based and universal in application in that it can be adapted to any cropping system. The key to providing 4R based advice is best management practices that have been locally adapted and broadly accepted as meeting 4R principles. Not all practices used by farmers or recommended by agronomists in the past meet the threshold for a 4R BMP. Application of N or P fertilizer or manure on snow covered or frozen ground is an obvious example of a practice that has occasionally been used and even recommended that is not considered 4R due to the high risk of nutrient loss. The 4R principles are given below and expanded further in the proficiency areas dealing with particular nutrients.

Key Scientific Principles Used to Develop 4R Consistent BMPs	
Right Source	*Right Rate*
Consider Rate, Time and Place	*Consider Source, Time and Place*
Ensure Balanced Supply	*Assess Plant Nutrient Demand*
Suit Soil Chemical and Physical Properties	*Assess Soil Nutrient Supply*
Supply Nutrients in Plant Available Form	*Assess All Available Nutrient Sources*
Recognize Synergisms Among Nutrients	*Predict Fertilizer Use Efficiency*
Recognize Blend Compatibility	*Consider Soil Resource Impacts*
Recognize Effects of Associated Elements	*Consider Rate Specific Economics*
Recognize Effects of Non-Nutrient Elements	
Right Time	*Right Place*
Consider Source, Rate and Place	*Consider Source, Rate and Time*
Assess Timing of Plant Uptake	*Consider Where Plant Roots are Growing*
Assess Dynamics of Soil Nutrient Supply	*Consider Soil Chemical Reactions*
Recognize Dynamics of Soil Nutrient Loss	*Suit the Goals of the Tillage System*
Evaluate Logistics of Field Operations	*Manage Spatial Variability*

Right Source:

Supply nutrients in plant available forms, or in a form that will be in plant available form at time of crop requirement. For N sources, consider loss potential in relation to method and timing of application when selecting products. Consider potential and mechanism for loss (e.g. N or S leaching, denitrification conditions, or volatile loss potential of surface applied un-incorporated urea or manure) of all applied nutrients. Be aware of potential nutrient interactions such as high soil P level or high P application rates restricting Zn availability and plant uptake.

Know that some fertilizer materials are hygroscopic, and products can take-on moisture from the atmosphere. As well, understand that fertilizer granules vary in size and density and certain combinations of products may segregate when used in bulk blends. Differences in size and density can also affect uniformity of application. For example, a spin spreader will not throw a less dense granule as far as a more dense granule even if they are of similar diameter

Right Rate:

Set application rates to match crop species and potential yield. Recognize that soil properties, field variability, economic and environmental interactions all affect rate recommendations. Assess crop nutrient requirements and soil supply through appropriate tools such as: soil sampling, plant tissue analysis, field response experiments, control plots and local calibration and correlation research data. Account for all available nutrient sources being applied or that have been applied (e.g. past manure applications and/or previous legume crops) and potential mineralization of nutrients from these sources when setting rates.

When setting rates understand that applied nutrients are not 100% efficient. Adjust rates to compensate for expected nutrient use efficiency. Selecting BMPs that minimize loss potential and improve efficiency allows for lower rates and may improve economic and environmental outcomes. Use nutrient balance where appropriate to track nutrient removals by crops against inputs. Consider the differences in practices required for nutrients that may be held-over in the soil (e.g. P and K) as opposed to those nutrients (e.g. N and S) that may only have "annual residence" and may be lost from the soil if not taken up in the year of application.

A defining right rate BMP of a 4R consistent nutrient management plan is that each field is treated as a unique cropping system. In applying 4R rates are adjusted for differences in nutrient supply and yield potential among fields. This requires that the CCA develop some criteria and judgement as to what type and magnitude of differences are agronomically significant and when the benefits of changing rates from one field to the next would outweigh logistical drawbacks.

Right Time:

The timing of plant nutrient uptake varies with crop type as well as nutrient type. Soil properties and environmental conditions, planting date and method (e.g. seeding rate, row spacing, depth of planting), and plant growth stage all interact to control the balance between supply and demand. Sensitivity to nutrient deficiencies may occur at a particular growth stage and/or in response to particular environmental conditions.

The CCA needs to consider that the timing of processes such as mineralization of soil organic matter and decomposition of crop residues are additional factors that may affect the application timing decision. Synchrony between uptake and availability improve use efficiency. Lack of synchrony reduces use efficiency and can also result in nutrient losses depending on local environmental conditions and time of year. Consideration also needs be given to other field operations that may take precedence over nutrient application timing.

Right Place:

Nutrients need to be placed where they will be accessible by the plant when needed. Consider close placements (e.g. seed row, side band, concentrated bands) for immobile nutrients. When placing blends (e.g. N and P or P and S) consider how the concentration of two or more sources may affect availability. For example, dual banding N and P can improve P availability up to a point (approx.70 lb N/acre). Above that threshold P may be trapped within the band and availability may be delayed. Understand that placement options will be affected by the producer's tillage practices and that placement can directly impact availability as well as loss potential.Performance Objective 3. Consider in the available equipment, labor, and nutrient sources when implementing a 4R nutrient management plan for a given operation.

Performance Objective 3. Consider the available equipment, labor, and nutrient sources when implementing a 4R nutrient management plan for a given operation.

A 4R nutrient management plan must consider the interactive and iterative factors in the farm operation and the practicality of implementation. Land type and management, land tenure, cropping sequence, typical seeding dates, schedule of general field operations, equipment and labour availability, input costs and timing of purchase, storage facilities, etc. will impact how the plan will be developed, adjusted and implemented.

Performance Objective 4. Discuss the concept of using established and regionally calibrated soil tests for making nutrient recommendations.

Soil test calibration is the process through which a soil test method is correlated with crop response in a region. The most commonly accepted process is to perform calibration trials. This involves performing the soil test on samples from a field plot and then usually adding increments of the tested nutrient and measuring final yield against a control or zero rate treatment. The results from the check plots can be aggregated across a range of soils, crops, and years and statistically analyzed to determine a critical limit. The inflection point on a yield response curve separating high probability of response from low probability. During soil test calibration, factors such as sampling depth and sampling time are held as constant as possible. A calibrated soil test comes with depth and time criteria attached. Changes in sampling depth and/or time may significantly alter the interpretation of results. For example, P tests are generally calibrated for a 0-6-inch sampling depth. Since available P tends to be more concentrated near the soil surface, interpreting P levels in a 0-12 inch sample using the guidelines for 0-6 inch will typically underestimate the available P and result in high P fertilizer recommendations.

For some analyses like soil test P, there are a number of different methods available. Not all of these methods have been calibrated against crop response under Prairie soils and environmental conditions. When interpreting soil test results and/or using recommendations provided by labs, CCAs need to be aware if the recommendations are based on local response, calibration and correlation data specific to the crops they grow on their specific soil types. Consistency, reliability, and applicability (e.g. suitable extractant for the growing region and nutrient determination) are primary considerations in laboratory selection and use.

Soil testing on the Prairies is provided by a number of private sector labs in the region. With modern courier and digital communication, it is also feasible to send samples to and receive timely results from labs located outside the Prairies. While provincial governments no longer maintain soil testing facilities nor oversee a soil testing laboratory accreditation program, modern commercial labs have well-developed quality assurance systems and participate in third party proficiency testing and accreditation programs. Accreditation programs are aimed at accrediting particular methods performed by the laboratory rather than the overall laboratory operation. The CCA should understand if the laboratory providing the test is participating in industry accreditation and/or proficiency testing programs and what methods they are using for the various tests. Labs using methods that have not been calibrated for Prairie cropping systems should be avoided.

Critical limits and response probabilities of N and P are discussed further in PA3 and PA4. Note that a number of the micronutrient soil tests have not been fully calibrated in Prairie soils largely due to the low frequency of micronutrient deficiency. The critical limits provided with these tests may be based on data obtained outside the Prairie region and may not be relevant to Prairie soils and crops.

Performance Objective 5. Identify the best management actions that could be considered if nutrients need to be applied outside the optimum 4R nutrient management plan.

A 4R nutrient management plan must be interactive and adaptable, not only with each “other R”, but with all farm operations, economics, logistics, regulatory change and prevailing environments. Considerable deviation from the plan may be required when unforeseen factors come into play. The ability to adapt as conditions change and consideration to adopting the “next best R” would be a prudent part of the management plan at the outset and help manage risk.

Alternate practices for nutrient source, rate, time and application method should be considered in relation to the most likely contingencies. Changes in weather, crop development, equipment failures and changes in economic climate can all impact successful implementation.

At the outset of nutrient management planning, consider identifying alternate nutrient sources and placement methods, along with any required rate alterations and equipment logistics should the original plan need be changed. Nutrients applied using practices other than those in the plan should still be considered within the 4R framework (right source @ the right rate, time, and place) and application aimed at achieving best management under the changed circumstances.

Performance Objective 6. Discuss the rationale (agronomic and environmental advantages and consequences) of increasing soil nutrient levels above the crop nutrient response level.

Liebig’s Law of the Minimum states that crop response to an added nutrient occurs when the added nutrient is limiting crop growth. If the nutrient is already available in the soil in adequate amounts, crops do not respond to additions. Certain nutrients (e.g. P and K) lend themselves to a maintain and/or build strategy in which nutrient levels are raised and kept slightly above the response threshold or critical soil test limit, while others (e.g. N and S) do not. The decision to build soil test levels must consider environmental liability as well as economic benefit. Building soil test levels up to or slightly above the critical limit may result in a yield increase (to a certain point and under certain conditions such as cold dry springs when P becomes temporarily limiting), and perhaps an operational benefit where rates to meet sufficiency requirements cannot be met with the available time and place practices. Seed row safety, for example, can be an issue for sensitive crops such as canola and pulses. Building P levels through higher than required applications on the less sensitive crops in the rotation and/or placements away from the seed at rates higher than crop removal may over time alleviate the issues associated with low soil test P. There may be economic benefits from applying higher rates when prices are low for storage of a nutrient for later use (in the situation of rising fertilizer nutrient cost). But failure to recognize loss potential will negate the economic benefit and may increase the environmental liability.

The decision to apply a nutrient in excess of crop demand is predicated on farm management operations, economic risk, and characteristics of the particular nutrient. While soil "banking" P and K may have immediate and longer-term attractiveness on land owned by the operator, it is far less attractive on leased land where the tenure is not secure. Fertilizer N cannot be reliably banked, and excess N applications can lead to undesirable results such as lodging, delayed maturity, increased disease potential, as well as the high risk of loss. Excessive and poorly balanced fertility programs can lead to poor crop quality, yield reductions and reduced nutrient use efficiencies.

Performance Objective 7. Discuss the components of a 4R nutrient management plan that should be monitored and tracked over time and the impacts of any changes.

Aside from the initial plan development and the next best potential options to deal with contingencies, a 4R nutrient management plan should include a set of performance measures and indicators to evaluate the BMPs selected and identify further needs or adjustments. A 4R Plan contains an element of continuous improvement and should be evaluated and renewed on an annual basis as part of the cropping cycle. It's important to decide on performance indicators prior to implementation and ensure that the necessary information and data to allow assessment is collected during implementation.

Good record keeping in addition to nutrient source, rate, time and place information should include crops and varieties/hybrids planted, cropping sequence/rotation, planting date, seeding rate, nutrient application date, rate and group of herbicide applied as well as field weed spectrum, insecticide applications, harvest date, yield and particular environmental conditions around application timing and the growing season.

Additionally, note tillage practice(s) employed and any change(s) implemented (and why), harvest management practice, soil and tissue test data collected, information/analyses on manure application, equipment issues/concerns around any input placement (e.g. wearing openers, hoses, nozzles, etc.), soil property/quality information related to changes (e.g. erosional events, pH change, compaction, etc.), animal production records (e.g. number of animals, manure production, changes in manure use/storage, etc.), water information related to events such as drainage, run-off, dug-out and well water levels and quality, if any environmental farm plan initiatives have been undertaken and their impact on the farm operation and nutrient management planning process.

Examples of Performance Indicators and Measures that could be used in a 4R Plan	
Measure or Indicator	**Description**
Yield	Amount of crop harvested per unit of cropland per unit of time.
Quality	Sugar, protein, minerals, vitamins or other attributes that add value to the harvested product.
Nutrient Use Efficiency	Yield produced or nutrient removed per unit of nutrient applied.
Water Use Efficiency	Yield per unit of water applied or available.
Labor Use Efficiency	Labor productivity, linked to number and timing of field operations.
Energy Use Efficiency	Crop yield per unit of energy input.
Net Profit	Volume and value of crop produced relative to all costs of production.
Return on Investment	Profit in relation to capital investment.
Adoption	Proportion of producers using or acres receiving particular BMPs.
Soil Productivity	Soil fertility levels, and other soil quality indicators.
Soil Organic Carbon	Influences soil structure and quality as well as greenhouse gas balance.
Yield Stability	Resilience of crop yields to variations in weather and pests.
Farm Income	Improvements in livelihood.
Working conditions	Quality of life issues, worker satisfaction, employee turnover.
Water & Air Quality	Nutrient concentration and loading in watersheds or airsheds.
Ecosystem Services	Countryside aesthetics, natural predators and pollinators, outdoor recreation, hunting, fishing, etc.
Biodiversity	Difficult to quantify-can be descriptive.
Soil Erosion	Degree of soil coverage by actively growing crops and crop residues, and/or reductions in mass of soil loss per unit land area.
Off-field Nutrient Losses	The combined total of nutrient losses from the agricultural management zone-edge of field, bottom of root zone, and top of crop canopy.
Nutrient Balance	A total account of nutrient inputs and outputs at the soil surface, field gate or farm gate.
The above performance indicators vary considerably in terms of required data and difficulty of implementation. Since yield is the basis of most economic and agronomic efficiency measures, collecting good yield data at the individual field level is generally the best place to start.	
Source: 4R Plant Nutrition Manual.	

Performance Objective 8. Analyze various changes in the farm operation that will require updates or adjustments to a 4R nutrient management plan such as:

A 4R Plan is based on incremental improvement and should be designed to fit in with other aspects of an overall farm management plan which includes other agronomic aspects of crop management as well as financial and human resource. Some of the more frequently occurring changes in farm operations that may require changes in a 4R Plan are discussed below.

A) Cropping System or Rotation

Any unplanned change in the crop to be grown in the current cropping season will require an adjustment of the 4R nutrient management plan. Consideration must be given to the nutrient balance/source(s), application rate, method and time of crop nutrient uptake (in respect to application time, source and availability) for the crop change. When making a crop change, consider nutrients already applied (e.g. a N rate predicated on a canola crop selection, that will now change to a crop requiring less N or no N). In a change to wheat scenario - lodging, disease, delayed maturity, or higher yield and protein are some possible considerations. In a change to pea scenario – similar considerations exist as for the wheat selection, but also potential for “left-over” N and effect that will have on the N rate to be applied for the subsequent crop.

Adding new crops to the rotation can require plan adjustment, particularly if the new crops require equipment change and/or significant changes in time 4R practices.

B) Soil Test Results

Soil testing aids in decision making regarding nutrient source and application rate for the crop. Soil testing can also provide information related to any nutrient build-up or draw-down, as well as any changes in soil pH and salinity. Soil testing can help identify changes in soil properties related to cropping practice and be used to in diagnosis problem areas within a field. Soil testing can be used as a tracking tool to help evaluate the 4R nutrient management plan. For example, high soil test N following a season where yield goals were met can be an indicator of too high an N rate. A downward trend in soil test P over time may indicate the P inputs are not keeping pace with removals. This may be desirable if soil test P is well above critical P limits but detrimental if soil test P is falling into the low or very low range.

C) Livestock Housing or Animal Numbers

Manage manure application based on nutrient content and expected availability. Be aware that manure applications based on crop N needs will over-apply P and K. Changes in animal production practices such as new housing facilities or a change in manure storage may impact manure nutritive content. Following major changes, consider taking manure samples annually for three years, followed with samples every three to five years, (unless animal management practices change), to arrive at baseline manure management information. Recognize how nutrients may be concentrated in solid versus liquid manures, residence time in storage and impact on nutrient value, as well as the need for/impact of agitation.

Change in animal numbers may require additional land base for manure spreading in the case of an increase or supplementation with fertilizer if the numbers are reduced.

D) Application Rate

Nutrient application rate affects current crop as well as potentially impacting subsequent cropping options and nutrient requirement. Change of crop sequence in the rotation and/or adverse growing conditions may impact soil test levels and/or nutrient availability for the current and subsequent crop.

Manure application may over-supply crop P requirements. In situations where soil test P levels have reached regulatory limits and/or risk of P loss to surface waters is unacceptable, consider high P using crops in the rotation and reducing or eliminating fertilizer P. Additionally, N applied with manure application may be excessive for some cropping goals (e.g. keeping protein level in malt barley below the thresholds established by maltsters).

A subsequent crop selection choice would consider the potential to draw down or take advantage of increased soil nutrient levels.

E) Yields

Nutrient recommendations should be based on reasonable yield goals. When previous crop yields were lower than expected, the need to calculate a carry over or soil test for residuals is sometimes necessary. If applied nutrients were not removed, then soil test values may be higher, reflecting the need for lower rates of application in the subsequent crop year. This is more applicable when considering residual N. Fertilizer P rates for most crops tend to be in a range that a single year's application is unlikely to make a noticeable difference in the soil test P.

Consideration need be given as to why the applied nutrients may not have been taken up, or if they were taken up, when they may be re-released by the crop residue retained on the field. For example, when yield is limited by drought, the crop has left nutrients in the soil; when yield is reduced by a late season hail storm, the crop has taken up the nutrient and they must be released from the crop residue before they are available.

F) Equipment

A grower's equipment selection places limitations on 4R BMP selection. Ability to handle liquid, gas, or granular will set boundaries on source selection. Total product handling capacity will influence source and rate selection as will other elements such as opener type and configuration.

A change in tillage, fertilizer application, seeding, spraying, and harvest equipment can all require significant adjustments to a 4R Plan and open up new possibilities in source, rate, time and place practices. For example, acquisition of high clearance sprayers by farms on the Prairies has enabled efficient in-season N application using stream bars and UAN.

Implementing specific BMPs may require equipment changes and need to be worked into the farm enterprise's capital equipment planning cycle.

G) Technology tools

Technology tools can influence planning, implementation, and analysis phases of the 4R Planning Cycle. Adoption of new technology can both be a driver for changing the 4R Plan or be driven by 4R Plan development. Use of remote sensing in combination with geographic information systems (GIS) can help identify and map spatial differences in yield potential among or within fields. Global positioning systems (GPS) and flow control systems enable changing rates at the subfield level and are prerequisite to implementing variable rate application. Harvest monitors linked to GPS enable yield mapping and allow more detailed assessment of performance at the field or subfield level. These are just a few examples of technologies that may influence development of a 4R Plan.

One of the key areas to emerge in recent years is digital record keeping based on passive data collection. In these new generation information management systems, data is collected and increasingly analyzed automatically through decision support systems providing CCAs and crop managers with the information required for data driven decisions. Aggregated data across the farm or pooled over multiple farms can be used to establish performance baselines. These baselines can be used to quantify the performance of specific practices or compare fields using some of the performance indicators discussed earlier.

Record keeping is becoming a necessary element of sustainability programs in various supply chains. Adoption of new information management technology can help meet the record keeping burden imposed by regulation or buyer specifications.

Performance Objective 9. Discuss the record keeping requirements and responsibilities and the follow-up process with the operator/client and any or all parties involved with components of the plan both annually and over multiple years.

There are no dictated or required elements to a 4R Plan and it can take various forms. In order for a 4R Plan to be effective as a vehicle for practice change, a certain amount of record keeping is both necessary and desirable. CCAs working with farms to develop and maintain a 4R Plan should keep records that include details of the farm enterprise, of the fields included in the plan including crops seeded, and details of the source, rate, time, and place practices. Examples are provided on the Fertilizer Canada website. (Refer also to PA1 for record keeping requirements within the 4R Designation Program.)

https://fertilizercanada-ksiu6qbsd.netdna-ssl.com/wp-content/uploads/2015/07/4R-Nutrient-Stewardship-Planning-Guide-for-Manitoba-English.pdf

The CCA should keep a copy of the 4R plan and provide the grower with a copy or electronic access to the plan for their records. After initial plan development and implementation, a CCA should ideally work with the grower to assess how well the plan worked; where deviations from the plan were required; assist the grower in assessing the performance indicators; and discuss modification for the coming crop cycle. Ongoing records should include notes on deviations, changes, and tracking of performance indicators.

As previously mentioned, a 4R nutrient management plan uses adaptive management and incremental change as a driver in the adoption of practices that improve nutrient management. A 4R Plan is adaptable in the face of changing farm practice and influence(s) as well as can serve as a tool for affecting practice change. It should be revised and refined as circumstance dictates.

The 4R nutrient management planning process is annual and the annual assessment and update should begin well before the cropping season and the plan should be reviewed and revised as the cropping season approaches. Consideration should be given during the review and actual implementation process for any adaptations required in the face of changing farm operation factors and influences. Revisions in the plan should be noted and reasons for change(s) recorded.

During the annual review, a focus on understanding actions taken and ensuing results against "reasons why" will help define plan adjustments in advance of the following cropping season.

Some review items might be:

- crop yields and response to nutrient application, method and timing;
- pre and post season soil test results;
- manure sample analysis and change;
- change in/access to technology that may influence application rate or timing;
- market dynamics as it affects crop selection and sequence;
- new learnings from the current crop season;
- change in land ownership, rental agreements, divestiture, etc.;
- management and personnel change(s);
- changes in the community development bylaws, municipal, provincial or federal regulatory change.

Performance Objective 10. Discuss the need for maintaining up to date field map boundaries, records, and field identification systems with government agencies, the client, and the consultant.

Up-to-date field boundaries, consistent field names and/or numbering allows field operations, yields and input practices to be compared year over year. Consistency in field identification becomes increasingly important for both the grower/client and the consultant as record keeping migrates from paper to digital formats. Rigorous data records and field information provides a common reference for growers, their employees, service providers, and government agencies such as crop insurers. Records that allow traceability of practices are also becoming an important element of both regulatory compliance when using regulated source materials like manure and market access. In addition to nutrient management, records of which products have been used and what crops have been grown can be useful in determination of mis-application of herbicide products, insight into residual herbicide concerns and product/field traceability of/for crop end users.

Performance Objective 11. Understand and describe a CCA's professional risks, responsibilities and mitigating practices related to nutrient management planning.

Providing agronomic advice related to nutrient management planning carries the same professional ethics requirements and legal responsibilities as other types of business advice. CCAs must avoid and discourage sensational, exaggerated, or unwarranted claims or recommendations that might encourage growers to participate in unsound practices. CCAs should not give a professional opinion or make a recommendation without being as thoroughly informed as possible regarding the products, practices and services being recommended and the individual client's/customer's farming operation. CCAs also have an ethical obligation to inform their clients if they discover a material error in their recommendations.

Regardless of the particular service rendered or the capacity in which a CCA functions, advisors should protect the integrity of their work; maintain objectivity; and disclose any material conflicts of interest (i.e. recommending products or services from which the CCA or their employer may receive financial gain and where the relationship between the advisor and the product supplier is not apparent). Certified Crop Advisors should also recognize the limitations of their individual knowledge and when consultation with other professionals is appropriate or referral to other professionals necessary.

The best interest of the client/customer is protected by recommending only products and services that are beneficial to the client while taking into account and complying with legislation and regulation. Public good may also be a key factor in terms of environmental stewardship.

A key element in mitigating professional risk is continuing education. Staying current not only helps the CCA avoid bad decisions and recommendations; it helps validate their professional competence when trouble (legal or otherwise) arises. Whether in private practice or working within a corporate structure, CCAs should be knowledgeable of their financial exposure if legal action results in relation to their recommendations. Independent CCAs working as crop consultants are well advised to have errors and omissions insurance.

COMPETENCY AREA 3: ECONOMICS OF NUTRIENT MANAGEMENT PLANNING/BUDGET FOR OPERATION CHANGES DUE TO 4R

CCAs need to consider and may be asked for the economic rationale behind their recommendations. They should have a reasonable working knowledge of the economics of crop production.

Performance Objective 1. Construct a base financial budget for each crop/field.

Cost of production budgets consider costs associated with production and expected revenue from the crop produced. To develop an accurate budget actual per unit costs and prices received are required. Required items will include:

- Revenue — gross from crop by field for specific field budgets or by farm by crop for enterprise level budgets.
- Direct Variable Cost — expenses for commodity production (will change with production type and input cost, e.g., seed, fertilizer, pesticides, etc.)
- Indirect Variable Costs — all expenses related to production, e.g. crop insurance, fuel, labour and utilities.
- Fixed Costs — constant expense irrespective of commodity produced, e.g., equipment depreciation, property taxes, fire insurance and depreciation.
- Net Profit (loss) — revenue minus all variable and fixed costs.

While current or expected prices for the current year are generally preferred, cost of production information should be reviewed for the past three to five years. Information from previous years can help verify assumptions particularly with regard to quantities if not prices. Breakeven points may be used to set sell and buy points for the commodities produced. The following can be used in determination of breakeven points:

Breakeven price to cover variable costs:

Total variable costs ÷ Expected yield = $ / unit produced.

Breakeven price to cover total costs:

Total costs ÷ Expected yield = $ / unit produced.

Breakeven yield:

Total costs ÷ Expected price = unit # required to cover all costs associated with production of that unit.

Provincial Agriculture Departments and other entities provide information on cost of production. Apps for automating the calculations are available from a number of private and public sources. The links below provide additional crop and livestock production and budgetary information for the Prairie Provinces. In addition to looking at the sample budgets provided through the links, you may want to download and familiarize yourself with one of the crop budget apps.

https://www.gov.mb.ca/agriculture/farm-management/production-economics/cost-of-production.html

https://www.gov.mb.ca/agriculture/farm-management/financial-management/pubs/cop-crop-production.pdf

http://publications.gov.sk.ca/documents/20/105239-Crop%20Planning%20Guide%202018%20FINAL%20(Dark%20Brown%20Soil%20Zone).pdf

https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/farm-business-management

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ16572

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/econ10219

Performance Objective 2. Evaluate short and long-term changes in benefits, costs and risks of implementing 4R practices including:

A) Changing Fertilizer or manure placement methods:

A change in application method may be required to better match timing of nutrient availability to crop uptake and reduction in loss potential. Specific equipment type and application technology may be better suited or adaptable to nutrient management needs and result in improved nutrient use efficiency. Changing fertilizer placement can vary from changing openers, reconfiguring spacings on the tool bar, to changing the drill. Economic benefits such as better return on fertilizer dollars will occur if the change results in higher yields or allow lower fertilizer rates without yield loss. Costs depend on the magnitude of the change and economic pay back periods will be longer for higher cost changes such as changing drills.

B) Changing sources of nutrients, including manure:

Subsequent sections of this guide discuss particulars related to nutrient sources; risk of nutrient loss can be reduced or increased through source selection. As well, source interacts with environment, timing and method of application. Understand that manure sources vary in their nutrient balance, content and timing of availability of contained nutrient(s).

The 4R nutrient management plan will take into account a holistic approach to farm nutrient management, by accounting for all nutrients available in the cropping and soil system.

Changing a more efficient source such as an enhance efficiency nitrogen product may increase cost per unit of N applied. This will only be offset by higher yields if N was limiting at the previously used rates. In cases where rates were not limiting, they may need to be reduced to take advantage of the higher efficiency source.

C) Freight (logistics of handling fertilizer products or manure):

Storage availability, fertilizer material interactions, pricing, transport/hauling and equipment availability must be included in the decision of which products and forms are selected.

Distance ads costs to manure hauling but can also increase benefits if applied to more distant fields where it has a greater impact on yields. Applying manure to fields that have been previously manured to the point where there is no yield response, incurs costs but produces no benefit.

D) Use of Stabilizers and Additives:

The subsequent section on N (PA 3) discusses the use of stabilizers and additives in detail. Stabilizers and additives can be used to reduce risk and costs of losses of N and to improve use efficiency. For enhanced efficiency N sources, the additional costs need to be weighed against benefits of increased yields (not always realized) or reduced rates.

E) Choice of Timing Changes:

Nutrients applied closest to time of crop uptake demand will potentially reduce losses and increase nutrient use efficiency. However, farm operations often dictate nutrient applications occur well in advance of major uptake demand. For example, fall applied N may be less efficient than spring applied N or split N application, but this trade-off may result in more timely seeding operations. As well, moving to split application may mediate against N loss potential and may reduce the economic risk of over applying N in years when moisture might be limiting at seeding but will accrue added application cost.

F) Yield changes:

Establishing yield potential and setting reasonable target yields enable the determination of a cost effective fertilizer recommendation. Changes in yield potential for any reason may require changes to the fertility program, and that will have an impact upon not only rate, but potentially source, timing and application method for the cropping system. Yield also relates to nutrient removals and can affect long-term nutrient management planning (e.g. P and K soil levels and management). Achieving higher yields increases gross revenue but may require higher nutrient inputs increasing costs and increasing production risk and potential economic losses if the targeted yields are not achieved.

G) Alternate cropping options:

Diversifying into new crops, as well as crop selection within a rotation can provide nutritive benefits (e.g. cereal after legume), a break in a disease or weed cycle, improve water use efficiency (e.g. shallow versus deep rooted crop species), improved soil structure etc. Diversification can spread risk/benefits over more crops and increase economic as well as agronomic resilience of the cropping system. Alternate cropping systems may require different equipment. Growers must learn how to manage a new crop and introducing new crops that extend the rotation creates more management complexity. Risk tends to be highest in the first several seasons while growers become familiar with the production practices required for a new crop.

CCAs need to be aware of new cropping possibilities and educate themselves on the nutrient and other production practices that may need to be adjusted to manage a new crop in their region. New crops need not be special crops but simply new to a region. The spread of corn-soybean cropping systems on the Prairies is an example of a mainstream crop with an expanded range. Quinoa is an example of a specialty crop that has increased acreage on the Prairies over the past decade.

H) Crop Insurance (regulations and premiums):

Crop insurance provides farm operators with a production guarantee on crop loss(es) that are caused by natural perils. This may include: drought, flooding, frost, hail, excess moisture, insect infestations, lightning (fire), hail, wind damage, plant disease out breaks, and wildlife damage. Coverage is typically available at varying levels. Crop insurance allows growers to mitigate risk at a cost. Uptake varies across the Prairies and tends to be lower in Alberta than Manitoba or Saskatchewan. All three provincial governments backstop crop insurance on the Prairies which is available through government agencies. Private crop insurance products are starting to appear as well. Growers must supply production information when applying for crop insurance and are subject to on-farm audits of their records.

I) Optimal rate to produce maximum economic return:

Crops need a supply of available nutrient that meets their requirements during the growing season. However, yield response to added nutrients is a diminishing return function. Each additional increment of nutrient produces less response than the previous. A point is reached where additional nutrient produces no yield response. This is often referred to as the agronomic optimum nutrient rate and more precisely defined as the lowest rate that produces maximum yield. Maximum economic returns to nutrient application are always reached at a lower rate than that required for maximum yield. Fertilizing to guarantee maximum yield requires rates that are higher and less profitable than the rate required for maximum economic yield.

Applying nutrient at rates greater than those required to maximize profit also increases agronomic and environmental risk. For example, N in excess of crop demand increases the risk of loss from the cropping system and may also result in lodging, delayed maturity, and potentially higher susceptibility to disease. This concept is discussed in detail in PA3, CA2, PO2 and PO3.

Performance Objective 3. Estimate the costs for nutrient management plans including: plan preparation, record keeping, soil tests, manure tests, and labor.

A 4R nutrient management plan will lead to greater nutrient use efficiency. The CCA and their grower client will likely find synergies in the operation and un-accounted for nutrient value. Efficiency of use within a farming operation will allow growers to reduce both operational cost and environmental pressure. In many situations, improving practices generates both economic and environmental benefits. Typically, a new 4R practice that is well adapted to the region and fits within a grower's operation does not result in a cost increase when considering the long-term income stream.

Better understanding of the costs and benefits of fertilizer and manure nutrients and optimization of application practices will typically improve return on nutrient dollars as well as maintain soil productivity and reduce environmental liability.

Costs of planning vary depending on who is doing the plan, the intensity and frequency of soil testing or manure testing, and the level of record keeping required. Annual costs in the range of $2 to $10/acre are to be expected.

Performance Objective 4. Estimate the financial risk or exposure of not following a 4R nutrient management plan.

A 4R nutrient management plan aids in matching the nutrient needs of the crop and nutrient availability. The focus is on economic, environmental, and agronomic optimization of the nutrient program. Financial risk or exposure can occur when non 4R practices such as un-necessary or "insurance" application of nutrients are used, unrealistic yield goals are set, or source, time, and place practices followed significantly lower the agronomic efficiency and return on investment of applied nutrients.

COMPETENCY AREA 4. ENVIRONMENTAL AND SOCIAL RISK ANALYSIS

Performance Objective 1. Justify why nutrient management is important to the environment and public health.

The world's population requires access to adequate, healthy and sustainable food. If not managed appropriately, agriculture negatively impacts the environment including impacts that reduce the sustainability and resilience of the agricultural systems themselves.

Nutrients that escape the cropping system (not retained or harvested) cause harm with no attendant benefits. The negative impacts of N and P losses on surface and ground water as well as the role played by N and manure in greenhouse gas emissions is covered in detail in subsequent Proficiency Areas (PA3, PA4, and PA7). 4R based nutrient management recognizes that nutrients leaving farmland can cause harm to human, wild and domestic animal, and aquatic life. Lost nutrients can add additional costs and on occasion cause failures in processes necessary to maintain human health such as drinking water treatment. The impact of lost nutrients, for example blue green algae blooms, can diminish the enjoyment of recreational space and waters, and in some cases create significant health risks.

Implementation of a 4R nutrient management plan, adoption of appropriate BMPs, and using performance indicators to measure outcomes, can improve economic performance of the farm; reduce environmental risk; and demonstrate to the wider society that crop based agriculture is carried out responsibly.

Performance Objective 2. Discuss why environmental risk analysis is an important component of nutrient management planning.

Societal interest, awareness and access to information regarding water quality, soil degradation, and GHG emissions and how nutrient pollution can affect the environment has increased. Consumers are demanding a higher level of care in food production systems. Nutrient management planning helps reduce losses and mitigates against these concerns increasing.

As part of 4R nutrient management planning, an environmental risk assessment helps to address specific risks that exist within a farming operation. The potential for offsite nutrient movement and environment/groundwater contamination varies from farm to farm and field to field. Determining site specific characteristics for potential risk is a first step in the assessment.

Tools such as the Environmental Farm Plan have formalized procedures for assessing risks.

Performance Objective 3. Discuss the importance of broader social and local community concerns in nutrient management planning.

Concerns about the sustainability and environmental impacts in food production fall under the concept of social license or the ongoing acceptance of farming practices by stakeholders and the general public. In the best sense, social license creates a dialog between producers and consumers as well as other stakeholders on what is expected and what people are willing to pay for through food prices or through public money. In recent years, advocacy groups have corrupted the social license process by making demands on agriculture that are either unrealistic, unreasonable, and in many cases not supported by science. The continuing resistance by radical environmentalists to the use of GMO crops despite near universal acceptance by the scientific community is a case in point.

The nutrient management planning process addresses the storage, handling and application of farm nutrients such as manure and fertilizer in a way that is demonstrable and shows due diligence. The aim is to protect rural soil and water and give farm operators clear instruction on what they need to do to manage nutrients responsibly and in some situations such as manure application meet legislative requirements.

Farmers and their non-farming neighbours have a vested interest in local soil and water quality. Both want their community to thrive economically. Both prefer a rural way of life. And like people everywhere, they value harmonious relations with their neighbours.

Nevertheless, conflicts do arise. These days many farms need to expand, specialize and adopt new technologies if they are to succeed.

Increasingly farms are surrounded by relative newcomers that have migrated from urban areas in search of a pastoral lifestyle in the countryside. The rise of rural residential and other concurrent trends seems tailor-made to generate misunderstandings. Farmers should be proactive in establishing communication channels with their neighbours. The best approach is an informal one that brings farmers, neighbours and the greater community together to talk, listen and build mutual respect and trust — long before conflicts take on a life of their own.

Making demonstrable efforts to adopt environment friendly practices on cropland, along water bodies, and in and around farm buildings is a farmer's best defence. While adopting best management practices is important, they do little to pacify neighbours who do not understand or appreciate the efforts and investment farmers are making in environmental quality or agriculture's contribution to the economy in general. Simple one-on-one conversations can do much to prevent problems.

It is important to reinforce these conversations with comprehensive planning. These planning efforts demonstrate proactive environmental stewardship and reflect well on the CCA, the farmer and the agriculture sector. Producing high quality products in an environmentally responsible manner generates consumer confidence. Closer to home engaging with the local community can prevent issues and reduce conflicts.

The most common source of neighbor complaints in rural settings is the nuisance odour associated with manure application. There are a number of strategies that farmers can use and their CCAs can help them develop and refine to deal with this issue. Farmers who have conflict-avoidance strategies receive fewer complaints. These may include informing neighbors of when manure will be spread; how long the process will take; and what practices (for example, incorporation as soon as possible) will be employed to reduce impacts.

Certain aspects that touch on nutrient management such as the permitting of CFOs require that affected parties be notified and allowed to comment. While identifying potential concerns in the community this process also allows agreed upon solutions to be reached before a problem occurs.

Performance Objective 4. Discuss how regulatory requirements may supersede the results of a risk assessment.

Provincial regulations requiring a nutrient management plan are focussed on land spreading of manure. Certain aspects of the regulations or in certain situations the regulations may also apply to fertilizer application. For example, Manitoba regulates the timing of nutrient application (fertilizer or manure) with a stop date in the fall and a start date in the spring. Regulations may have been based on traditionally accepted common or standard management practices. Regulations are often designed to meet the worst-case scenario or for ease of enforcement a one size fits all approach. Site specific risk assessment when developing a 4R based plan may determine that a risk is low, and the practice imposed by the regulatory standard is excessive. In these cases, a 4R plan should be based on the regulatory standard. In cases where the regulatory standard is insufficient to mitigate the risk, a 4R Plan should consider imposing a more rigorous standard. Case in point are the various soil test N and P limits imposed by regulation. In landscapes where there is high risk of movement to surface waters, the allowable limits may be overly generous.

Performance Objective 5. Recognize the value and limitations of using standard soil test results in environmental risk analysis.

Soil testing is a starting point for nutrient management planning. Determination of existing nutrients in the context of crop requirements, and matching all input sources with crop need, helps to develop the nutrient application plan.

Soil testing allows the CCA/farm operation to monitor soil nutrient status in the context of crop use efficiency, economic considerations (e.g. soil build of P and K) and to manage nutrient level excess (e.g. soil build P and K).

The limitation of soil testing may well not be the test itself, but how it is interpreted and integrated with the over-all farm nutrient plan and incorporated into the environmental risk assessment. On the Prairies, research has established that the modified Kelowna phosphorus test is correlated with risk of P loss (other tests like Olsen P correlate less well). This should be interpreted in the sense that the higher the soil test P, the more mobile P is in the system and a greater quantity of P is likely to be lost should runoff occur. Soil tests for N and P are reasonable indicators of potential mobility but the risk of actual loss also needs to consider transport processes and the role of landscape, climate, soil types that play important roles in the determining site-specific risk.

Performance Objective 6. Be aware of required anhydrous ammonia safety protocols and training.

The Transportation of Dangerous Goods Act is in place to protect the public and environment from hazards associated with shipping dangerous goods. Anhydrous ammonia is listed under the act. Persons handling, offering for transport, or transporting anhydrous ammonia must be properly trained and hold a valid training certificate – this is a legal requirement and it also includes farmer's handling of the product. CCAs need to be aware of ammonia handling and application protocols and be able to make growers aware of the hazards and safe handling requirements. This is particularly important when CCAs are developing recommendations based on anhydrous ammonia with growers that are unfamiliar with the product.

Anhydrous ammonia information and training is available at the sites listed below.

https://fertilizercanada.ca/wp-content/uploads/2017/02/Anhydrous-Ammonia-Safety-and-the-Farmer-2017.pdf

https://caar.org/training/anhydrous-ammonia-tdg

https://caar.org/ag-retail-news/596-caar-updates-anhydrous-ammonia-training-modules

Performance Objective 7. Understand manure handling health and safety risks e.g., H2S, timing of incorporation after application.

There are a number of health and safety risks associated with manure handling and application. The hazard varies with the manure source, handling system, and application method. Hydrogen sulphide (H2S) is produced in liquid manure storage lagoons and may gas off at hazardous level when the lagoon is stirred prior to application. Presence of low levels of H2S is indicated by the tell-tale rotten egg smell; however, humans cannot smell H2S once it reaches toxic levels. Ammonia (NH3) is another toxic gas that can be released during manure handling and application.

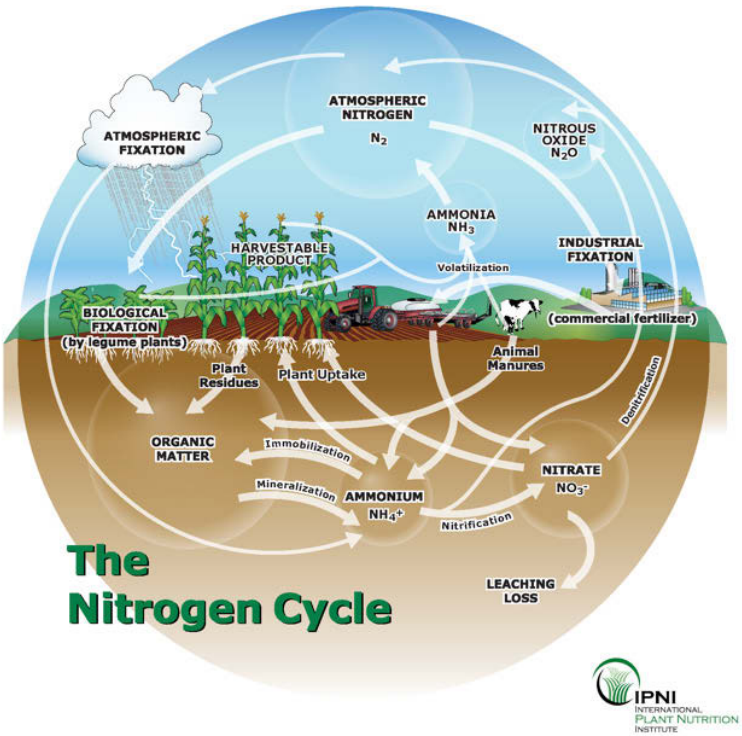
For further discussion see Proficiency Area 7, Competency Areas 1 and 2.

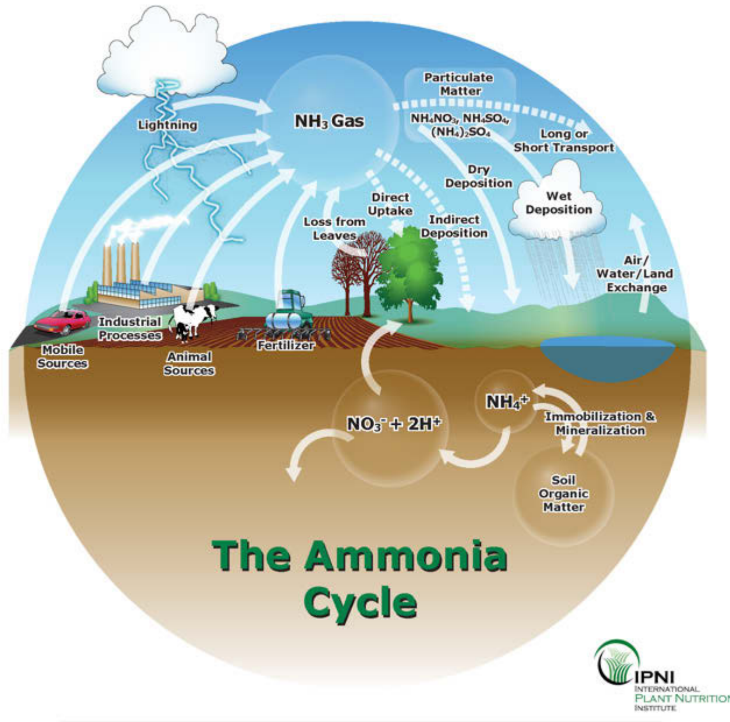
Performance Objective 8. Understand the implications of applying fertilizer or manure to saturated, frozen and/or snow-covered ground.

Application of fertilizer or manure to frozen soils greatly increases the risk of N and/or P loss. Water cannot infiltrate frozen soil. Snowmelt in many parts of the Prairies results in melt water running off over frozen soil. Snowmelt is the major runoff event on the Prairies in most years. During spring thaw, a shallow saturated soil layer may form over the frost front, denitrification can occur in this saturated layer even at low temperatures.

These issues are discussed in more detail in PA 3, CA 3, PO2 and PA4, CA3, PO1 – PO3.

PROFICIENCY AREA 3
NITROGEN





Nitrogen (N) is the most common limiting nutrient in non-leguminous cropping systems on the Canadian Prairies. It is also the nutrient applied in the largest amounts as fertilizer. Limits on the N supply reduces yield and crop quality while excess N can cause issues such as lodging in cereals and delayed maturity. The processes transforming and/or transporting N in cropping systems is complex. In addition to cycling internally through soil organic matter, crop residues and the soil biomass; N can be gained or lost from the atmosphere; leached through the soil profile to ground water; and transported off field with surface runoff. Losses from the system can have significant environmental and economic consequences. Nitrous oxide release from cropping systems are a major part of the greenhouse gas (GHG) emissions attributable to Canadian agriculture while losses to surface and ground water can seriously compromise water quality. Under certain conditions N losses can reach levels that appreciably reduce profit margins. On the other hand, the higher yields achieved with N additions help build soil organic matter and result in sequestration of atmospheric carbon dioxide. Under certain conditions N losses can reach levels that appreciably reduce profit margins.

Nitrogen is arguably the most difficult nutrient to manage. A key to managing N using 4R concepts, principles and practices is to first have a thorough understanding of the Nitrogen Cycle. As you go through the Performance Objectives for N, refer back to the N cycle often and think through how the application of 4R concepts, principles and practices affect the different processes. A quick review of major N cycle processes and forms is given below.

Nitrate

Nitrate (NO_3^-) is extremely soluble and one of two forms of plant available N. It does not bind with the negatively charged surfaces of clay minerals nor does it form low solubility compounds with other elements. It moves with soil water, so delivery to the root surface is through mass flow and tied to transpiration demand. Nitrate can be carried by downward percolating water below the soil root zone; can move laterally with subsurface flow, and overland with surface runoff.

Nitrite

Nitrite (NO_2^-) is an intermediate product in the bacterial mediated conversion of ammonium into nitrate. It seldom accumulates in the soil, since the conversion from nitrite to nitrate is generally much faster than the conversion from ammonium to nitrite. Nitrite moves much like nitrate in the soil and groundwater zones.

Ammonia/Ammonium

Ammonium (NH_4^+) the ion and ammonia (NH_3) the gas exist in equilibrium in soil. The equilibrium moves towards ammonia as pH becomes more alkaline or basic and towards ammonium as the pH becomes more acidic. Increasing temperature shifts the equilibrium towards ammonia as well. The table below shows the distribution as a percentage of the combined forms. Ammonia can escape to the atmosphere but it also highly water soluble and can be held in the soil solution.

Percent Ammonia + Ammonium in Ammonia Form.						
Temp	pH					
°C	6.0	6.5	7.0	7.5	8.0	8.5
10	0.018	0.058	0.186	0.586	1.83	5.56
20	0.039	0.125	0.396	1.24	3.82	11.2
30	0.080	0.254	0.799	2.48	7.46	20.3
Emerson et al. 1975						

Ammonium attaches to negatively charged surfaces of clay and negative charged sites on organic matter. Plants can take up ammonium directly but because it is held on the cation exchange complex, transport to the root surface is through diffusion or contact exchange. Ammonium levels in prairie cropping systems tend to be low because it is quickly converted to nitrate under conditions that are favorable for nitrification. The exception is where high rates of an ammonium fertilizer (anhydrous ammonia, urea or ammonium sulphate) or high rates of manure are applied to soil bands. High ammonia levels in the band disrupt the conversion to nitrate and ammonium can persist.

Organic-N

Most of the organic-N in soil is associated with the soil organic matter (SOM). There are many different chemical structures that incorporate N in soil organic matter and wide variation in stability and turnover rates. What they all have in common is attachment to a carbon (C) in some form of organic molecule. Stability and turnover of organic-N is in part controlled by the structural chemistry of the N containing molecules and in part by physical access of mineralizing microbes to SOM. A portion of the SOM and the associated N are protected from breakdown due to its position in soil aggregates.

Mineralization/Immobilization

Mineralization and immobilization are the processes that add and remove N from the organic-N pool. Both processes are biological involving the soil biota (living organisms). *Immobilization* involves uptake of nitrate or ammonium by the soil biota to meet their internal nitrogen needs. Subsequent chemical and physical transformations can result in stabilized N forms in the soil organic matter. *Mineralization* occurs when the soil biota breaks down organic-N sources to meet their energy, structural carbon, and nitrogen needs any excess N is released into the ammonium pool. Mineralization sources can include dead soil organisms, crop residues, and the soil organic matter. The carbon: nitrogen ratio of the substrate generally controls the balance between immobilization and mineralization with 25:1 used as an approximate cross-over point. In SOM rich prairie soils, mineralization is a significant source of crop available N during the growing season.

Nitrification

Nitrification is the process converting ammonia to nitrite and then nitrate. Two groups of specialized chemoautotrophic bacteria carry out the conversion. Ammonium oxidizers (*Nitrosomonas sp., Nitrosospira sp.)* oxidize ammonium to nitrite and Nitrite Oxidizers *(Nitrobacter sp.)* complete the conversion to nitrate. Nitrification proceeds most rapidly in warm, moist and well aerated soils in the neutral pH range. During nitrification nitrous oxide (N_2O) a greenhouse gas (GHG) with a global warming potential (GWP) approximately 300 times greater than carbon dioxide (CO_2) can be produced as a byproduct. Nitrification also produces H^+ as a byproduct. Nitrification of all ammonium forms of fertilizer are acidifying and lower soil pH over time. This includes urea, anhydrous ammonia, and Urea Ammonium Nitrate (UAN). Even though the initial reaction of these products in soil releases OH^- and raises pH, their net effect is to acidify soil. The rate of acidification is largely controlled by the amounts of ammonium added and the buffering capacity of the soil. Soils high in SOM and clay tend to be well buffered and resist changes in pH. Coarse textured soils low in SOM would be most susceptible to acidification by added ammonium. Calcareous soils, those with free calcium carbonate in the surface horizon, are highly buffered. The pH will not drop until all the lime has been neutralized.

Chemoautotrophs **are an interesting group of soil organisms. Like plants they can manufacture all of the components they need for growth and completion of their lifecycle from essential elements. Unlike plants they obtain the energy they require to reduce carbon from oxidation of chemical forms rather than sunlight. Chemoautotrophs are involved in nitrification of ammonium fertilizers; oxidation of elemental sulphur fertilizers, as well as conversions of iron and manganese in soils.**

Denitrification

Denitrification is a biological process that reduces nitrate to dinitrogen (N_2) gas or other intermediate reduced nitrogen compounds. Under conditions of low oxygen, soil microbes use nitrate as a replacement for oxygen as the terminal electron acceptor in an anaerobic respiration process. Many different families of bacteria in soil can denitrify. Denitrification occurs when soils are saturated resulting in oxygen depletion. Denitrifying organisms require a carbon source of energy . Like most biological processes, denitrification is temperature dependent but it can result in agronomically significant losses in cold saturated soils during the spring melt. Complete denitrification in fully anaerobic soil results in the release of dinitrogen. Under less than fully anaerobic conditions some of the lost N will be emitted as the green house gas nitrous oxide.

Leaching

Downward and lateral movement of water through the rooting zone and possibly towards agricultural tile drainage systems driven by water infiltrating from rainfall or a snow melt can carry soluble N below the rooting zone. Leaching occurs at times of the year or at points in a field where the amount of rainfall or snow melt i) exceeds evapotranspiration and ii) exceeds the soils water holding capacity. Under such conditions, soil water moving downwards recharges groundwater and/or contributes to tile drain flow, while carrying soluble N with it. Nitrate is the primary form of N leached in Prairie soils.

Volatilization

Volatilization occurs when ammonia is lost to the air. Warm, dry, windy conditions enhance volatilization. Volatilization potential increases with soil pH as the ammonia-ammonium equilibrium shifts towards ammonia at higher pH. Ammonia lost through volatilization can be redeposited on soil or water, convert back to ammonium, nitrify, denitrify, or leach into ground water. A small fraction will end up as nitrous oxide. Atmospheric ammonia is implicated in the formation of human health respiratory risks through the formation of damaging particulate matter.

Nitrogen Fixation

Nitrogen fixation is the conversion of dinitrogen to ammonia/ammonium by microbes. While there are a number of different nitrogen fixing systems in nature, symbiotic fixation by *Rhizobium* bacteria in legumes is the only one of significance in Prairie cropping systems.

Study Tip – Know the details of the N cycle including names of processes, chemical forms involved in each process, and conditions that control each process.

COMPETENCY AREA 1. DETERMINING THE RIGHT SOURCE OF NITROGEN

Selecting the Right Nitrogen Source should take into account soil properties, crop requirements, and potential losses to water and the atmosphere. Since N fertilizer is a major variable cost in cereal and oilseed production (as well as most other non-legume crops) economics must also be considered when choosing an N source.

Performance Objective 1. Discuss the most common sources of nitrogen used in the Prairie Provinces.

Two aspects to consider here. The first is which are the most commonly used N sources in terms of tonnage sold or applied. The second is which sources are commonly available to farmers. There are several enhanced efficiency nitrogen fertilizers that don't make up a large percentage of the total applied but are generally available to producers. Other products that may be available in other geographies (for example, ammonium nitrate and calcium nitrate) are not available except as minor use specialty products on the prairies.

Study Tip – Know the chemical formula and the grade of all the common N containing fertilizers. Know the chemical formula, phase and associated charge if ionic of the common N forms found in cropping systems.

*

Source	Formula/Grade	Notes
Anhydrous Ammonia (20-25%)*	NH_3 82-0-0 applied as gas Note: Under pressure in tanks ammonia is liquid allowing for more efficient storage, transportation and handling.	Anhydrous ammonia (AA) is the highest N concentration fertilizer available. Requires injection below the soil surface or can be bubbled into irrigation water. Initial reaction with water yields ammonium hydroxide (NH_4OH) raising the pH around the injection site. The ammonium (NH_4^+) enters into cation exchange reactions with the clay and organic matter. Ammonia is manufactured under conditions of high temperature and pressure using the Haber-Bosch process using dinitrogen (N_2) from the air and hydrogen gas (H_2) from natural gas. The resulting ammonia is the feedstock for most other N fertilizer sources.
Urea (50-55%)	$(NH_2)_2CO$ 46-0-0 granular	Urea is the most widely used N fertilizer on the Prairies. It is manufactured by reacting NH_3 with carbon dioxide (CO_2) to form ammonium carbonate ($(NH_2)_2CO_2$). The subsequent removal of an oxygen results in urea. The initial hydrolysis reaction in soil to form NH_3 is catalyzed by the enzyme urease which is widely distributed in crops, crop residues and soils. The initial reactions of urea raise the pH and the ammonia produced is subject to volatilization losses.
Ammonium Sulphate (6-8%)	$(NH_4)_2SO_4$ 21-0-0-24 granular	Ammonium sulphate (AS) is used primarily as a sulphur source in W. Canada. It is less susceptible to volatilization than urea and anhydrous ammonia because its initial reactions do not raise the soil pH.
Urea Ammonium Nitrate (12-15%)	28-0-0 Liquid	Urea ammonium nitrate (UAN) is produced by mixing urea, nitric acid and ammonia together. The final grade can be adjusted from 28 to 32% N. The 28% formulation is typically used in cold regions like the Prairies.
		* Typical proportion of total N applied on the Canadian Prairies. Shifts among N sources vary by year and by province depending on prices, product availability, and application conditions. For example, wet fall conditions that preclude fall applications may reduce use of anhydrous ammonia.

Enhanced Efficiency Nitrogen Fertilizers

The main modes of action of enhanced efficiency nitrogen fertilizers are i) formulations and or coating that slow or control release from a granule; and ii) formulation or additives that inhibit the biological or chemical conversion processes. These are sometimes referred to as "stabilized N" products. These products prevent a specific loss pathway. If the environmental conditions that favour that specific pathway are not present, then enhanced efficiency products tend to perform similarly to regular forms of N. Since these products improve nitrogen use efficiency, they should produce similar yields at lower rates.

Enhanced Efficiency Nitrogen Fertilizers[1]	
Product/Mode of Action	**Examples[2]**
Urease inhibitors are additives used with granular urea and UAN. They delay the hydrolysis of urea by disrupting the action of the urease enzyme. Urease enzymes are widely distributed in soil and crop residues, and urease catalyzes the hydrolysis of urea into carbon dioxide and ammonia. $(NH_2)_2CO + H_2O + urease \rightarrow CO_2 + 2NH_3 + urease$ It is used primarily to reduce volatile losses of ammonia (NH3) from surface or shallowly incorporated urea.	The most common urease inhibitor is N-(n-Butyl) thiophosphoric triamide (NBTPT or NBPT) Agrotain® is an example of a commercial formulation available in Canada.
Nitrification inhibitors are additives used with ammonium-based fertilizers (e.g., anhydrous ammonia, urea, etc.) that block the conversion of ammonium to nitrite by ammonium oxidizing bacteria (*Nitrosomonas sp*.) This blockage of nitrification also re-duces denitrification losses of oxidized N forms under saturated, or low oxygen, soil conditions. Both nitrite and nitrate can be denitrified (primarily to N_2 gas). A small proportion of the nitrogen is emitted as nitrous oxide, a potent greenhouse gas during nitrification and denitrification. Nitrification inhibitors are often used in fall-application situations to reduce over winter loss.	Nitrapyrin is an example of a nitrification inhibitor. It has recently been registered for use in Canada in the products N-Serve™ and eNtrench™. Dicyandiamide (DCD) is a second example, it is combined with NBPT in SuperU®.
Controlled-release nitrogen products are granular products that have a semi-permeable polymer coating. Under warm and moist soil conditions the coating becomes more permeable allowing N to pass through the polymer coating into the soil solution. The purpose of these products is to delay release of soluble N so that availability is more closely synchronized with the period of high crop demand. Because they release N slowly, they can be used at higher rates in the seed row than conventional urea-N sources.	ESN® is an example of a polymer coated urea available in Western Canada.
Slow-release nitrogen fertilizers come in two general forms. One is a non-soluble coating applied to the surface of soluble N fertilizer (e.g., sulfur-coated urea). The other is a N fertilizer reacted with another compound to form a low solubility complex that will be released over time due to chemical and biological breakdown (e.g., urea-formaldehyde reacted fertilizer, isobutylidene diurea, or an inorganic salt such as struvite). These products are widely used for forestry horticultural, greenhouse, and turf crops to provide a prolonged supply of N in the root zone and minimize environmental losses. Their use for agronomic crops is less common.	CrystalGreen® is an example of a struvite product manufactured in W. Canada from N and P recovered from municipal waste water.
Enhanced Efficiency Nitrogen Fertilizers[1]	
Product/Mode of Action	**Examples[2]**
root zone and minimize environmental losses. Their use for agronomic crops is less common.	

[1] The content of this table was adapted from material provided by IPNI.

[2] Products listed are used as examples only and does not constitute endorsement.

Performance Objective 3. Determine the Right Source of Nitrogen Based on:

Choosing the Right N Source for the cropping system needs to take into account crop and soil characteristics, the growing environment, and management as well as the interactions among these factors. Using 4R principles to make N source decisions allows flexibility in choosing an N source. There is no one right answer rather a list of considerations that should be worked through when making the source decision. The factors discussed below are also relevant (perhaps more relevant) to the rate, time and place decisions. We will revisit them from the Right Rate, Time and Place perspectives in subsequent competency areas. The first 4R principle under Right Source is Consider Rate, Time, and Place. Strive to develop an integrated view as you work through each of the source, rate, time and place competency areas.

A) Crop Type and Cropping System (including drainage and irrigation)

Factors include the seasonal demand for N by the crop and preferences for ammonium or nitrate. Generally, uptake as ammonium is more energetically efficient in the crop but nitrate tends to be more available and more mobile in agricultural soils. The major field crops tend to prefer nitrate while some horticultural crops prefer ammonium. Crops vary in the time of highest N demand, using an enhanced efficiency source can delay conversion and prevent loss in the period between application and maximum uptake by the crop. Nitrogen application to legume crops is generally restricted to the N contained in phosphorus fertilizers such as MAP and APP. Dry beans is an exceptionin that they are poor nitrogen fixers and generally required N fertilization. Nitrogen source is usually selected based on decisions around placement equipment, application timing, rate considerations, and other logistic factors rather than the specific crop type.

B) Climate (temperature, precipitation)

The microbial and chemical processes in the nitrogen cycle tend to speed up when soils are warmer and slow down when soils are cooler. There can be seasonal difference, for example nitrification may proceed faster in the fall than spring at the same soil temperature due to the presence of a larger nitrifying community at the end compared to the start of the growing season. Using anhydrous ammonia as a source slows nitrification due to a source placement interaction. The high concentration of ammonia in the band inhibits the activity of nitrifying bacteria as well as other microbes.

Rainfall can carry surface applied N into the rooting zone; however, too much precipitation results in runoff and/or leaching through the profile. Excess rainfall that results in soil saturation also leads to denitrification. Sources that contain nitrate or rapidly convert to nitrate are subject to these loss mechanisms. Keep in mind that ammonium will not convert to nitrate in wet soils.

Warm temperatures encourage ammonia volatilization. Surface applied sources that contain urea will volatilize to a greater extent than sources that contain ammonium. Nitrate sources are not subject to volatilization, but (with the exception of UAN) nitrate containing sources are not readily available on the prairies. Using urease inhibited sources can slow conversion and reduce volatilization.

High Volatilization Potential	Low Volatilization Potential
Climate	
Less than one half inch of rainfall	Greater than one half inch of rainfall
High soil temperature	Low soil temperature
Moist soil surface	Dry soil surface
High wind speed	Low wind speed
Soil Properties	
Coarse soil texture	Fine textured soil
Low organic matter	High organic matter content
High lime content (calcium carbonate)	Low lime content
Source: Sherritt Fertilizers	

C) Soil and Landscape Characteristics (leaching, runoff potential)

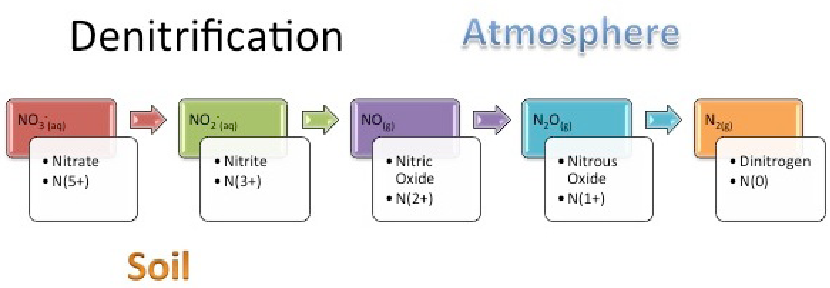
Soil texture impacts N dynamics in a number of ways. Coarse textured soils typically have low water holding capacity and tend to drain rapidly. Since, they tend to be better aerated than fine textured soil, nitrification may proceed more quickly. Nitrate is more likely to be leached through a coarse than a fine textured soil. Sandier soils tend to have lower CEC and consequently a lower capacity to retain positively charged ammonium. The higher CEC in fine textured soils increases ammonium retention. Fine-textured soils have lower infiltration rates, drain slower, and retain more water compared to coarse textured soils.Keep in mind that a well-structured fine textured soil may have infiltration rates similar to coarse textured soils. Nitrate leaching would likely be lower in a fine-textured compared to a coarse textured soil under conditions of equal water inputs. However, fine textured soils have a greater denitrification potential as they are more likely to be saturated and anaerobic for extended periods compared to coarser textured soils. They also have a higher runoff potential.

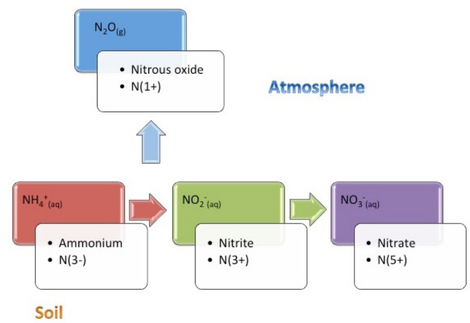
Denitrification and leaching tend to occur where water accumulates in the landscape typically in lower slope positions.

Soil pH has an influence on N transformations. Nitrifying bacteria are very sensitive to pH. *Nitrosomonas sp.*, the main ammonium oxidizing bacteria, have an optimal pH between 7.0 and 8.0. The optimum pH range for *Nitrobacter sp.*, the main nitrite oxidizing bacteria, is approximately 7.5 to 8.0. Conversion of ammonium to nitrate is slowed (and nitrite may even accumulate) in acid compared to neutral or slightly alkaline soils.

Soil pH also effects ammonia volatilization. Ammonia is in equilibrium with ammonium in soil solution. The equilibrium shifts strongly towards ammonia as pH increases from 7 to 8. Volatilization losses increase with higher soil pH, more crop residues and with higher temperatures. Urea hydrolysis creates alkaline conditions around the fertilizer granule. So significant volatilization can occur in soils with pH below 7. Avoid urea applications when the fertilizer will remain on the soil surface for prolonged periods of time. Clay soils with their higher CEC and greater buffer capacity, tend to retain ammonium better and experience less ammonia volatilization than coarser-textured soils. Consider using enhanced efficiency N sources on fields where a considerable portion of the landscape may be subject to high losses.

D) Potential for Environmental Loss and/or Impact (e.g., surface and groundwater, GHG emissions).





Nitrogen losses to surface water can lead to more rapid eutrophication, algae blooms, and oxygen depletion resulting in lower water quality for human and animal consumption as well as industrial and recreational use. Runoff is the main pathway from the cropping systems to surface water. Groundwater flow into surface water can also carry nitrate that has been leached below the rooting zone. Elevated nitrate in groundwater can result in health issues when consumed by humans or livestock. Volatilized ammonia will in part be redeposited in surface water or on soils and subsequently moved into surface waters. Both ammonia/ammonium and nitrate forms can negatively impact aquatic ecosystem function.

Nitrous oxide (N_2O) is a greenhouse gas (GHG) with a global warming potential approximately 300 times greater than carbon dioxide (CO_2). It is also the main GHG emitted from cropping systems with a significant portion of the emissions attributable to fertilizer and manure application. The two main processes that result in nitrous oxide emissions are nitrification and denitrification. During the conversion of ammonium to nitrite, nitrous oxide is generated as a by-product. Higher concentration of ammonium resulting in more rapid transformation tend to drive proportionally more N into the nitrous oxide form. Slowing conversion of ammonium to nitrite reduces production of nitrous oxide. N sources treated with nitrification inhibitors directly slow this conversion. Other EEFs (for example, urease inhibitors, polymer coated urea) that slow upstream processes can also reduce the conversion rate and reduce nitrous oxide production during nitrification. Using nitrate containing sources (if available) is an obvious way to avoid the emissions associated with nitrification. However, nitrate is the starting point for denitrification and nitrous oxide is one of the products formed as nitrate is reduced to dinitrogen (N_2). Under strongly reducing conditions (think saturated fully anaerobic soils) little nitrous oxide is produced. Under partial reducing conditions, nitrous oxide can accumulate and escape to the atmosphere before it can be further reduced to dinitrogen. Recent research at U of M has shown that spring applied nitrate sources under conditions with low risk of denitrification has the potential to significantly reduce nitrous oxide emissions. The Right Source decision combined with Right Rate, Time and Place practices can reduce nitrous oxide emissions by 30 to 40%.

E) Crop Stage

Source decisions for in-season application need to consider the crop's N demand at different stages. Use of sources that delay N availability are suitable for application early in the crop growth cycle when crop demand is low. For example, consider top dressing urease inhibited or polymer coated urea on a cereal crop post seeding up to the two-three leaf stage. Using an EEF source will help protect against early season N loss and help synchronize peak availability with peak crop demand during the stem elongation through kernel development stages. Applying the same products at stem elongation may delay availability beyond the window when a yield response is possible. An example of a better choice at later crop stages would be UAN with half the N in immediately available forms and the remaining half in urea which is quickly converted to available forms.

Ammonium sulphate is used as an adjuvant with some post-emergent herbicides. Rates are generally low (< 1 lb N/acre) and generally inconsequential in the overall N requirements of the crop.

Keep in mind that N is predominantly taken up through the rooting zone and that whatever source is used needs to be available in the rooting zone during crop stages when demand is highest.

Additional Resources Right Source of Nitrogen

1. Chapter 3, 4R Plant Nutrition Manual, IPNI

2. Part 2, 4R Nutrient Stewardship Training, Fertilizer Canada eLearning https://elearning.fertilizercanada.ca

3. Module 2, 4R Nutrient Stewardship in Saskatchewan, Fertilizer Canada eLearning https://elearning.fertilizercanada.ca

4. IPNI has an excellent series of fact sheets on N fertilizer sources. Go to http://www.ipni.net and find the Nutrient Source Specifics folder on their publications tab.

COMPETENCY AREA 2. DETERMINING THE RIGHT RATE OF NITROGEN

Crops require more N than any other nutrient and N is the most commonly deficient nutrient on the Prairies. Consequently, there is a yield response to added N in most fields in most years. Principles for Right Rate include assessing crop demand and soil supply as well as the contributions from other sources such as previous manure applications or pulse crop residues. For non-legume crops, N fertilizer typically commands the larger percentage of the fertilizer budget making economics and return on investment important considerations.

Nitrogen is only partially conserved in the cropping system. Excess applications that result in a large available N pool increase the risk of loss through leaching or denitrification as well as delaying maturity and triggering lodging in cereals. High residual nitrate levels in the soil profile following harvest may be the result of over application or less than expected uptake by the crop due to factors such as drought, hail, pest damage, or poor stand establishment. Overwinter environmental conditions will largely control if residual nitrate is lost or recovered by next season's crop. Under application can result in low yields, poor quality, and lost profitability. Nitrogen use efficiency is typically between 40 and 60% on the Canadian Prairies and strongly influenced by source, time, and place practices. Determining the Right Rate for N is one of the more difficult tasks in nutrient management, made even more so by the significant impacts of weather on both crop demand, soil supply, and system losses.

Performance Objective 1. Interpret soil test nitrogen levels in relation to crop yield response, crop quality, and potential environmental impacts.

A) The Nitrogen Soil Test

Although crops can take up both ammonium and nitrate, the standard N soil test used on the Prairies measures and reports nitrate-N (the quantity of N in the nitrate form) in units of pounds per acre. Nitrate is mobile in the soil and sampling to a depth of 24 inches is considered a best management practice for most crops. Sampling by depth increment (eg. 0-6. 6-24) assesses the distribution of soil test N (STN) in the profile as well as providing an appropriate depth increment (0-6 in) for other soil tests such as P and K. The nitrogen soil test is a direct measure of available N in soil and STN is generally considered equivalent in availability to fertilizer N. Keep this point in mind when you get to the sections on P and K. Soil tests for P and K are an index of the soils supplying power or capacity rather than a direct measure of the crop available form of the nutrient.

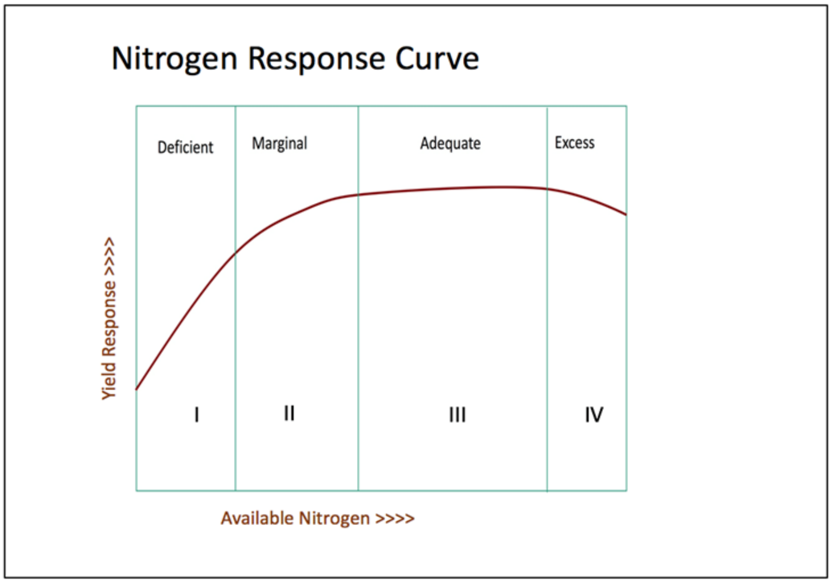
B) Interpreting Soil Test N, Probability of Yield Response

The STN is usually reported as a value with a class descriptor for the range the value falls in as shown below.

Generalized interpretation of soil test nitrogen in the 0 to 24 inch (0 - 60 cm) depth of soil.		
Soil test nitrate-N in lb/ac		**Rating**
Dryland	**Irrigated**	
0-30	0-60	**Deficient**
31-60	61-120	**Marginal**
61- 80	121-160	**Adequate**
80+	160+	**Excess**
Compiled from Alberta Agriculture Agdex 541-1 & Agdex 100/541-1. https://www1.agric.gov.ab.ca		

Laboratories and other sources vary in how they describe the different classes and where they draw the boundaries. The general interpretation is that as STN increases the likelihood of a response and the magnitude of the response decreases following the law of diminishing returns as outlined below.

Response to N in deficient soils follows a response curve that can be thought of having four regions: i) an initial region of relatively large incremental yield response per unit of N applied; ii) a region of diminishing response where the yield increment is still positive



but is becoming less with each additional increment of N; iii) a maximum or plateau where yield no longer increases; and iv) a region of decline where additional increments of N actually lead to yield reductions.

Nitrogen response curves or response functions can be used to assign N fertilizer rates. These response curves are developed by growing crops on soils with different STN levels and then adding increments of fertilizer N. The experiments are conducted over a number of years to capture year to year variability. This resulting crop response function is typically regional climate and crop specific. They can be further refined by soil type (organic matter and/or soil texture) and probability of moisture. Response curves can be incorporated into fertilizer management software such as the AFFIRM program developed by Alberta Agriculture. The underlying response function can also be used to create recommendation tables as shown in the HRS wheat example shown below. Note that the table is for response on black soils under high moisture conditions. This is an example of one of a series of tables. that would cover a range of moisture conditions and soil types for different crops.

Response of Hard Red Spring Wheat in Thin Black and Black Soils Under Conditions of High Moisture																
	Rate of Nitrogen Fertilizer Applied (lb/ac)															
	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
Soil Test Nitrogen (lb/ac/2ft Depth)	Expected Yield (bu/ac)															
10	12.3	22.2	30.2	36.8	42.5	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2
20	22.2	30.2	36.8	42.5	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6
30	30.2	36.8	42.5	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0
40	36.8	42.5	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2
50	42.5	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3
60	47.3	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4
70	51.4	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4
80	55.1	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4
90	58.3	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4
100	61.1	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4
110	63.7	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4	79.4
120	65.9	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4	79.4	79.4
130	68.0	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4
140	69.9	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4
150	69.9	71.6	73.2	74.6	76.0	77.2	78.3	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4	79.4
Source: Wheat Nutrition and Fertilizer Requirements: Nitrogen, Alberta Agriculture																

Performance Objective 2. Discuss the agronomic and environmental risks of applying nitrogen above economic optimums.

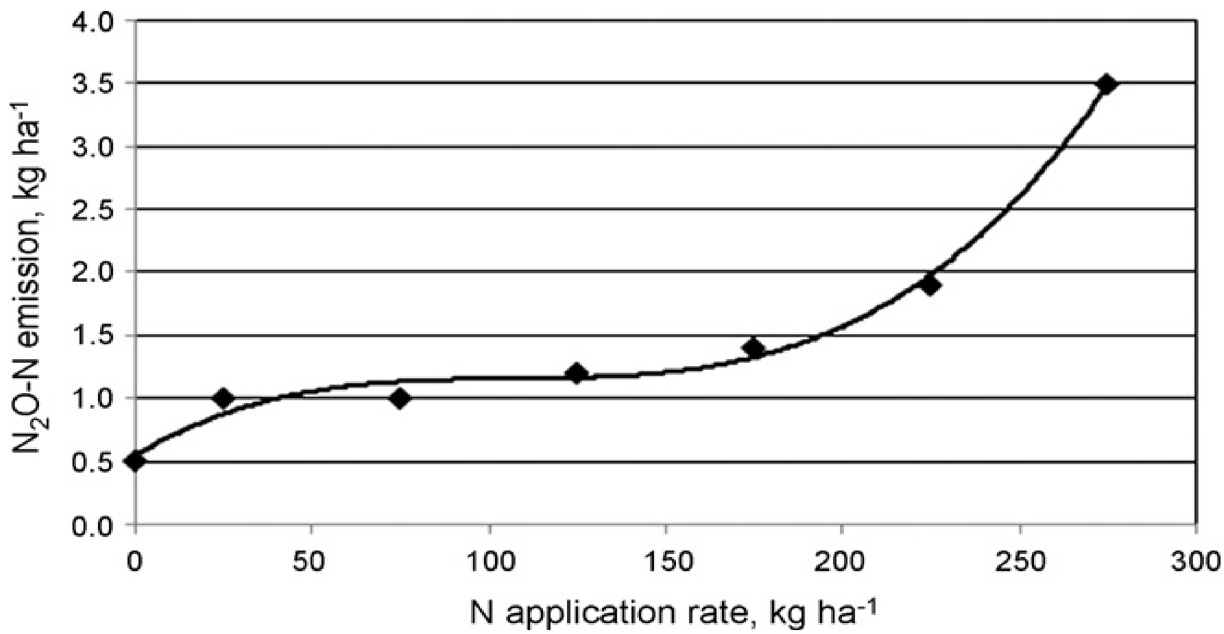
Study Tip: Review the material on maximum economic yield (MEY) and economic optimum nutrient rates (EONR) under the next Performance Objective (PO3) below before working through the discussion of agronomic and environmental risk.

Crops need a supply of available N that meets their requirements during the growing season. Nitrogen in excess of crop demand increases the risk of loss from the cropping system and may also impact the crop agronomically. Agronomic risks from applying too high an N rate include lodging in cereals, delayed maturity, and potentially higher susceptibility to disease.

The main loss pathways of applied N from cropping systems are volatilization, denitrification, leaching and runoff. Applying N using an EONR approach is economically justified as it maximizes profit and also provides a hedge against environmentally damaging N loss since MEY is always less than maximum achievable yield.

The generalized diagram below illustrates the concept. Nitrous oxide emissions increase slowly in response to N rate and then rise exponentially once crop demands are exceeded. Keep in mind that emissions do not occur uniformly during the growing season but tend to spike when environmental conditions are favorable and the ammonium or nitrate concentrations are relatively high. High rates of ammonium based N combined with warm, moist and well aerated soils favours rapid nitrification. High levels of nitrate in wet soils favours denitrification.

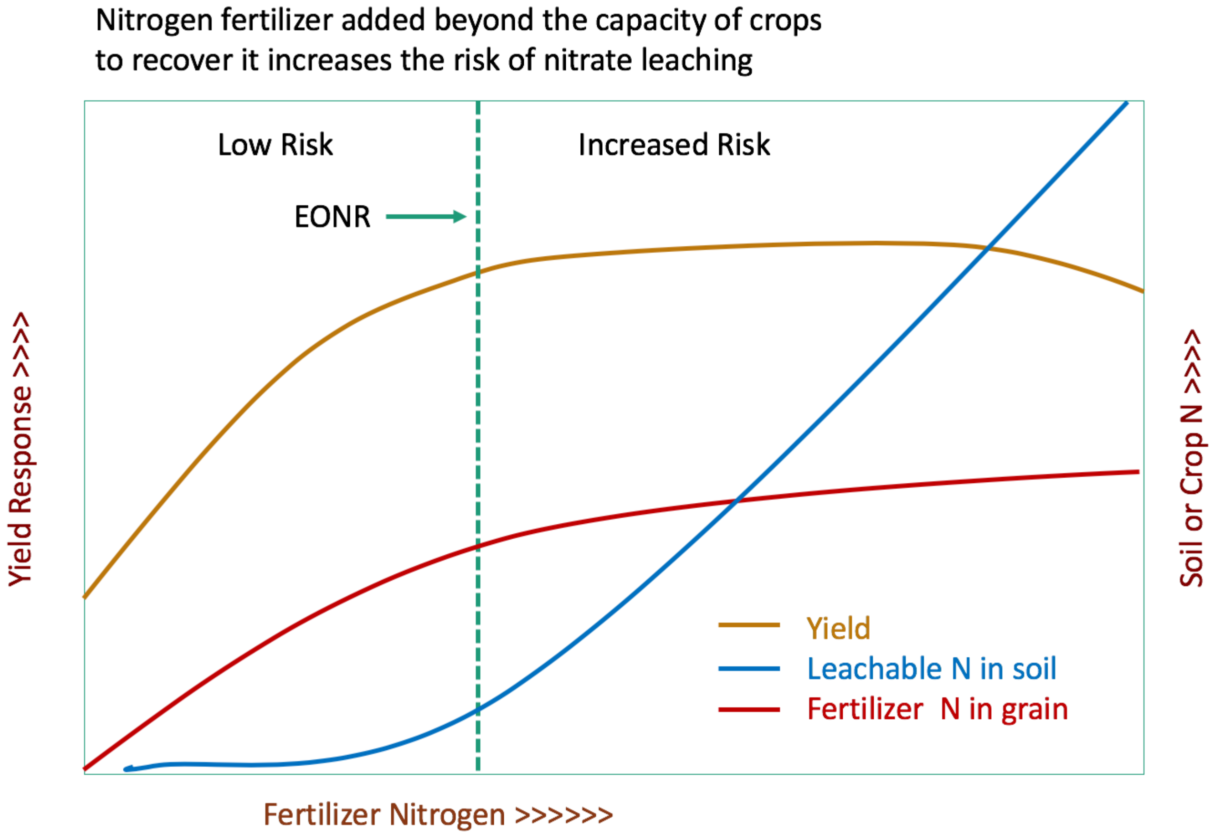
General Relationship between N rates and Nitrous Oxide Emissions.



Adapted from Bouwman et al., 2002. See also Snyder et al., 2009

The risk of leaching loss increases when N rates exceed the capacity of crops to recover the N. On the semi-arid prairies, it's important to distinguish between risk of N loss and actual N loss. Nitrate can be moved down the profile but if it is still within the rooting zone may be recovered by the next crop. Denitrification requires specific conditions of wet soil, available nitrate, and an available carbon supply to occur. Nitrous oxide emissions tend to peak when soils are wet but not fully anerobic. Under more complete conditions of saturation and oxygen depletion, the denitrification pathway favours production of dinitrogen (N_2) and less nitrous oxide (N_2O) is produced.

Risk of denitrification and leaching is not evenly distributed across the landscape. Areas where water accumulates are more likely to develop the conditions for denitrification and leaching. Low spots where water temporarily ponds during snow-melt or following heavy rains are likely to experience higher N losses than up slope positions.

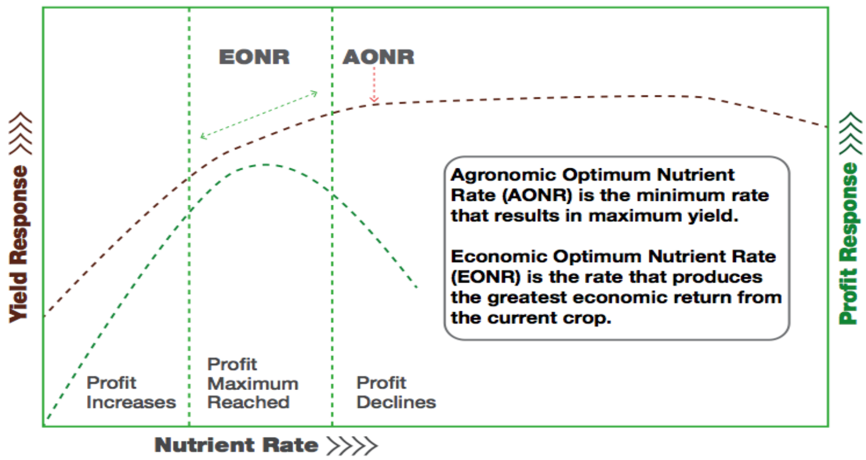


Adapted from http://www.ipni.net/NitrogenNotes

Performance Objective 3. Explain the Considerations for Nitrogen Application Rate Based on:

A) Economics

When setting N rates, the emphasis should be on Maximum Economic Yield (MEY), the yield where the highest net return from N fertilizer investment is achieved, rather than on maximizing yield. The agronomic optimum nutrient rate (AONR) and the economic optimum nutrient rate (EONR) are two useful concepts in discussing MEY and economics of N rates. While the EONR concept applies to other nutrients, it is particularly relevant, given that N is only partially conserved in cropping systems, to the discussion of N rates. It is less relevant to nutrients like P and K that are retained in the soil and can be recovered over several years.



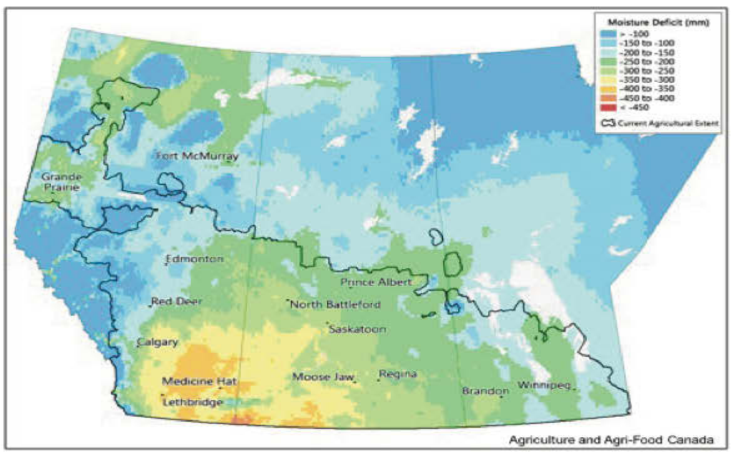
For N, AONR will vary by crop type and variety, seasonal growing conditions, and management factors such as irrigation. It does not change with crop or fertilizer prices. The EONR will change depending on the ratio of per unit crop prices to per unit N prices. If crop prices go up and/or N prices go down then the EONR will be higher and if crop prices drop and/or N prices rise the EONR will be lower.

An economist would tell you that with respect to N rate MEY occurs and return is maximized when the last increment of N applied results in just enough additional yield to pay for that last increment. In other words, the benefit:cost ratio is 1:1. In practice, many agronomists would recommend a slightly lower rate setting the benefit:cost at 1.5:1 or 2:1 as a hedge against risk.

The EONR is always less than the AONR. Setting N rates to maximize yield results in reduced profitability.

B) Weather and Climate, including temperature;precipitation amount; rainfall intensity; precipitation patterns.

The Canadian Prairies are located near the northern limit for agricultural production. The length of the growing season, the time between the last killing frost in the spring and the first killing frost in the fall or frost-free period, is a limiting factor for the types of crops that can be grown. Unusually late spring frosts or early fall frosts can have serious consequences reducing both crop yield and quality. Temperatures during the growing season can also be a limitation. Cooler than normal summers can slow crop development, delay maturity and increase the risk of frost damage in the fall. Excess temperature can also be an issue. Yields of crops like canola and field peas can be reduced by extended high temperatures during flowering. Hot weather increases the crop demand for water which leads into the second major limitation on crop production available moisture. All the major crop growing areas on the Prairies have a moisture deficit during the growing season. That means the cumulative evaporative demands of the atmosphere and the transpiration demands of the crop or evapotranspiration on average exceeds the growing season precipitation.



Moisture Deficit Impact on Spring Seeded Small Grains

(mm)	Limitations
-150	Minimal
-300	Slight
-400	Moderate
-500	Severe

Since available water tends to be a yield limiting factor in dryland Prairie agriculture, yield goals and N rates need to consider expected growing season precipitation. The moisture deficit map reflects the general trends of growing season precipitation and temperature across the Prairies with higher moisture deficits occurring in hotter drier regions. Lower moisture deficits tend to occur in the wetter cooler fringe areas. Southern Manitoba is somewhat of an exception with more of a warm wet growing season relative to the rest of the Prairies.

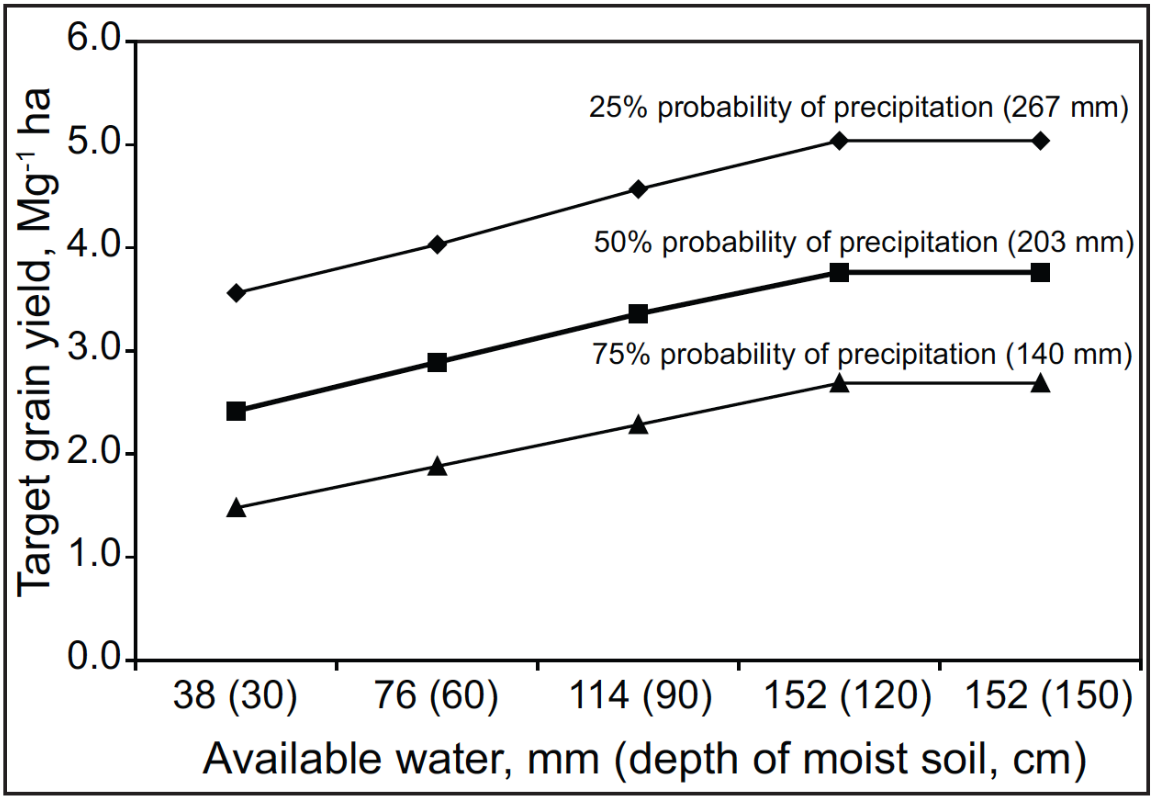
C) Stored Soil Moisture;

Stored soil moisture at time of seedings is an important N rate consideration on the Prairies. Growing season precipitation is always unknown prior to seeding and can only be treated as a probability based on averages or normal. Stored soil moisture can be known or estimated with reasonable accuracy through measurement and/or modelling. The graph below shows the potential effects of stored soil moisture both in terms of quantity of water in millimeters and depth of moist soil in centimetres, on yield of CWRS wheat. The different probabilities of precipitation (POP) refers to growing season precipitation based on long-term normals. The 25% POP, for example, should be interpreted as likely to get at least that much precipitation (267 mm) 1 year in 4.

The relationships shown suggest that in the Black soil zone a soil moist to 120 cm (fully recharged) would support an additional 1 to 1.5 tonnes/ha of wheat above what would be supported in a poorly recharged soil (30 cm). That extra 1 to 1.5 tonnes will take up in the range of 30 to 40 kg N/ha.

Study Tip: Convert the above yield increase to bushels per acre and multiply by the current wheat price to get an idea of what a moist soil profile is worth in terms of gross revenue. Calculate the additional N uptake in lb N/acre.

Effect of stored soil moisture on expected CWRS grain yields in a loam textured Black soil.



Source: Karamanos and Henry, 2007.

Relationships derived from various sources of research data.

Depth of moist soil can be estimated with simple tools like a Brown probe; measured directly using soil moisture probes or core soil samples; or calculated using various equations (models).

Water storage capacity varies with soil type. Soil texture is the main controlling characteristic. Soil organic matter tends to increase water holding capacity but its influence is generally confined to surface horizon. Keep in mind that although heavy clay soils may store the most water in absolute terms, it's the medium fine textured soils silty clay loams that contain the most plant available water at field capacity.

Plant-available water holding capacity for soil textural classes	
Soil textural class	**Soil moisture holding capacity in a 120 cm root zone (mm)**
Sand, Loamy Sand	100 - 120
Sandy Loam	150
Loam, Silt Loam, Silt	200
Clay Loam, Sandy Clay Loam, Silty Clay Loam	220
Sandy Clay, Silty Clay, Clay	200
Source: Alberta Agriculture. Adapted from: Brown and Carlson, 1990. Grain Yields Related to Stored Soil Water and Growing Season Rainfall.	

D) Irrigation

Irrigation has the potential to reduce and/or eliminate the moisture deficit on the Canadian Prairies supporting higher yields and higher demand for N. Irrigation also has the potential to increase leaching and denitrification particularly methods such as flood irrigation that tend to saturate the soil profile under the furrow. With higher target yields, higher N rates under irrigation can be justified but need to be balanced against increased environmental risk. When developing N rates for irrigation keep in mind that Fertilizer Nitrogen Use Efficiency (FNUE) tends to be higher under irrigation than dryland.

E) Crop Type, Cultivar, and Growth Stage

Nitrogen requirement varies by crop type and within a crop type, wheat for example, uptake requirement can vary by class. Classes with similar protein, like Canadian Western Red Spring (CWRS) and Canadian Western Amber Durum (CWAD), will have similar N uptakes per bushel. Lower protein classes like soft wheats or winter wheat will have lower N uptake requirements per bushel but higher yield potential per acre. Nitrogen uptake and removals for various crop types are shown below.

Crop Nutrient Requirements

			Nutrient (lbs nutrient/bushel crop)			
Crop	Protein	Factor	N	P_2O_5	K_2O	S
Wheat, CWRS	13.5	Uptake[1]	1.82	0.75	1.86	0.20
		Removal[2]	1.42	0.55	0.45	0.10
Wheat, Durum	13.5	Uptake	1.82	0.75	1.86	0.20
		Removal	1.42	0.55	0.45	0.10
Barley, Feed	11.7	Uptake	1.14	0.53	1.25	0.19
		Removal	0.90	0.40	0.30	0.10
Barley, Malt	11.0	Uptake	1.08	0.53	1.25	0.19
		Removal	0.84	0.40	0.30	0.10
Canola		Uptake	2.80	1.27	2.25	0.52
		Removal	1.90	0.90	0.50	0.30
Lentils		Uptake	3.00	0.82	2.55	0.30
		Removal	2.00	0.61	1.08	0.15
Peas		Uptake	3.00	0.85	2.75	0.25
		Removal	2.25	0.70	0.70	0.13

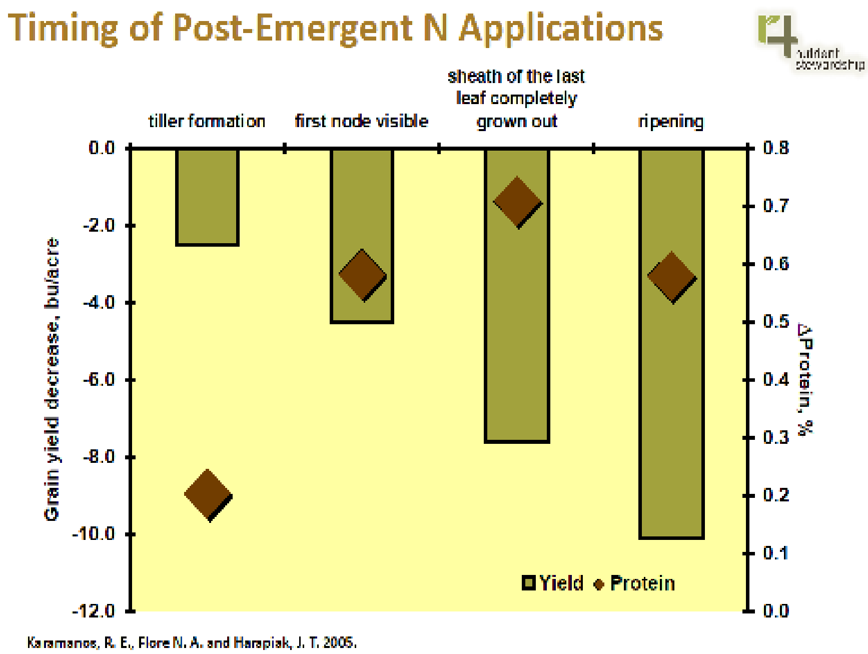
[1]Uptake is the total nutrient taken up by the crop (grain, straw, etc.).
[2]Removal is the total nutrient removed with the grain.

Source: Derived from Fertilizer Canada Nutrient Uptake and Removal by Field Crops Western Canada

Cultivars/varieties can vary in their N use efficiency. The switch from open pollinated to hybrid canola varieties achieved higher yields without the need to proportionally increase N rates. A second example is in potatoes where the nitrogen use efficiency of shorter season potatoes tends to be lower than longer season varieties.

Adjusting N rates based on cultivar selection is often not feasible as there is insufficient data available to differentiate. More commonly varieties are selected for local suitability across a range of traits including yield based on variety trials where N rates are held constant.

When applying some or all fertilizer N in season, agronomist need to be cognizant of crop stages. Application at too late a stage may not boost yield, although it may boost protein in cereals. The key to split application on the Prairies appears to be adding sufficient N (at least 50% of total rate) at or before seeding so that the crop is not N stressed prior to the in-season application. The graph below illustrates what happens when N application is delayed and insufficient N was available to meet early season crop needs.



F) Yield Potential and Targeted Use of the Crop;

Nitrogen rates should be adjusted with crop type and expected yields as well as crop end use. For example, N rate would typically be reduced on malt barley compared to feed barley since high protein in malt barley is a discounting factor. Yield Potential is influenced by many factors including:

- Genetics – crop type and adaption of the cultivar selected to the region.
- Growing Environment – climate and soil type.
- Management – in addition to nutrient management disease and pest management will influence yield potential. Rotation is another aspect with yield potential of each crop in the rotation generally increasing with longer rotations.

Yield potential varies among fields as well as within fields. One of the fundamental requirements of 4R is that differences in yield potential among fields is evaluated and taken into account when setting N rates. Higher yield potential generally justifies higher N rates but other factors such as higher levels of soil organic matter and potential for N mineralization also need to be accounted for in determining the final N rate.

G) General Equipment Capabilities and Limitations with Respect to Application Rate.

On the Prairies the air drill is commonly used for seeding and concurrent fertilizer application. An important consideration when setting N rates is the total amount of product that the fan can move effectively. This total product load needs to take into account all products that need to be handled during the seeding operation including seed and, other nutrient sources, as well as the N source.Equipment for applying anhydrous ammonia may have a lower operating threshold below which the applicator does not function properly.

Performance Objective 4. Explain the impacts of hail, frost and other environmental stressors on crop growth and forage quality and application of nitrogen.

Hail and frost can slow growth, reduce above ground biomass and generally reduce N demand by the crop. Environmental stress can also interrupt assimilation of N into amino acids and proteins through disruption of enzymes like nitrate reductase that converts nitrate to nitrite in plant shoots. High nitrate levels in forage crops or damaged annual crops being harvested for forages can lead to nitrate poisoning. Ruminants are particularly susceptible. Nitrate is not very toxic but conversion to nitrite by rumen bacteria can result in nitrite uptake into the bloodstream where it interferes with oxygen transport. Harvesting immediately after hail or frost (1 day) reduces the risk as nitrate has not had opportunity to accumulate. Otherwise the crop needs to be left until it has recovered sufficiently to process whatever nitrate has accumulated. Recovery is usually complete after about two weeks provided the stress has not recurred. Nitrate accumulation does not occur after a killing frost and is not a significant issue with legume forages like alfalfa. Risk of nitrate accumulation is increased by high N rates from fertilizer or manure.

Following an environmental stress that reduces N uptake by a crop there may be more than usual amounts of residual N in the nitrate pool at the end of the season. This residual N should be accounted for in setting N rates for the subsequent crop. A fall soil test provides a measure of residual N. Since N can be lost over the winter, considerations of the likely effects of environmental conditions fall to spring on N losses should be part of the evaluation of residual N availability to the subsequent crop.

Performance Objective 5. Discuss the considerations for nitrogen application rate based on potential losses associated with leaching, denitrification, immobilization, volatilization:

Setting N Rates Considering Site Conditions				
	Leaching	**Denitrification**	**Immobilization**	**Volatilization**
How would you adjust N rate (up/down)? What source, time, place practices would reduce loss at a given rate?	Is minimized when nitrate levels in the rooting zone are low during periods when water is likely to infiltrate beyond the crop recovery depth.	Is minimized when nitrate levels in the rooting zone are low during periods when soil is likely to be saturated.	Is minimized when ammonium and nitrate are physically separated from high C:N ratio residues.	Is minimized under acidic conditions, urea hydrolysis is slowed, contact of ammonia/ ammonium from fertilizer or manure with the atmosphere is reduced or disrupted through incorporation.
a) Soil Characteristics	Higher in coarse textured soils. Lower in fine textured soils.	Higher in fine textured, high organic matter soils. Lower in coarse textured, low organic matter soils.	Soil moisture imposes significant controls on immobilization. Coarse textured soils tend to immobilize less than fine textured under water limited conditions.	Risk reduced as soil pH drops below 7. Fine textured soils have greater capacity to hold ammonium and reduce atmospheric contact.
b) Crop Residue Conditions	High residue levels reduce erosion and runoff and increase infiltration.	May change soil water dynamics and provide carbon source for denitrifying bacteria.	Incorporated high C:N ratio residues tend to increase immobilization in the soil. Immobilization by microbes breaking down surface residues can occur when N is surface applied. Straw and chaff management can reduce losses.	Crop residues are a source of urease. Can lead to rapid conversion of surface applied urea.

Setting N Rates Considering Site Conditions				
	Leaching	**Denitrification**	**Immobilization**	**Volatilization**
c) Topography and Runoff	Slope steepness and length effect runoff and erosion. Slope position effects soil moisture. Runoff can accumulate in lower slopes and depressions and move through rooting zone. w	Slope and slope position effect runoff and soil moisture. Runoff can accumulate in lower slopes and depressions and saturate soil for longer periods.	Immobilization tends to increase downslope with better moisture conditions and higher residue levels.	Differences in moisture, residue, temperature may result in different volatilization loss rates in lower compared to higher slope positions.
d) Crop Type and Growth Stage	Matching N rate to the needs of the specific crop will reduce nitrate residuals in soil.			
e) Seasonal Moisture Conditions	Leaching potential is high when snowmelt accumulates in depressions and moves through profile. Reduced by actively growing crop.	Denitrification potential is high when snowmelt saturates surface soil above frozen soil layer and or snowmelt accumulates in depressions. Reduced by actively growing crop.	Tends to be higher during periods of the year when soils are at or near field capacity. Lower soil moisture slows immobilization.	Application during periods of higher rainfall will generally result in lower losses. For shallow banded N, losses will be lower and higher rates can be applied when soil is moist. For surface applied N, higher rates on drier soil will result in higher losses.
f) Time of Applications	Reduced by matching application more closely to time of rapid crop uptake (spring and/or in-crop).	Reduced by matching application more closely to time of rapid crop uptake (spring and/or in-crop).	Application during cooler drier periods may slow immobilization.	Rainfall can wash urea into the soil where ammonium following hydrolysis is held by the cation exchange. Application ahead of rain or during cool weather reduces losses.

Performance Objective 6. Estimate nitrogen credits from:

A) Previous Nitrogen Application;

It is important to take into account any residual N that may be remaining from fertilizer applications to a previous crop or added to the field after harvest. If sufficient N was applied for an expected high yield but growing conditions were less favorable (e.g. drier than normal), then significant residual N might be expected and could be measured with soil testing. However, if the N was applied after harvest (for example a late fall application of anhydrous ammonia), it can be difficult to assess. Some of the N may have been lost through leaching or denitrification or immobilization prior to spring seeding and/or some of the applied N may not show up in a soil nitrate test because it is still present in the ammonium form but will be converted to nitrate at a later date. Confirming fall-banded N levels with a soil test is made more difficult because of sampling error and requires specialized sampling techniques. In most cases, it is assumed that the majority of the fall-applied N is still in the soil in the spring if the soil was sufficiently cold to halt nitrification. It is generally advisable, to discount fall-applied N by 10-15% to account for overwinter losses. Also consider, overwintering losses of residual nitrate from the soil. A dry growing season may result in high residual soil test N levels when sampled in fall, but a wet winter and spring may significantly reduce those residuals by seeding time. One strategy when unsure of overwinter losses of residual N is to resample a subset of fields in spring.

B) Soil Organic Matter;

Mineralization from SOM needs to be accounted for when setting N rates. There are various rules of thumb for estimating mineralization based on soil organic matter percentage. For example, 10 lbs N per %SOM or is it 8 lbs or perhaps 10 in the lower slopes and 5 on the drier hilltops. The actual amount of N mineralized depends on the weather, soil moisture, and temperature. Regional estimates for the different soil zones under conventional and minimal tillage are shown below. Note that the values for minimum tillage are for mature systems.

Nitrogen Mineralization

General Mineralization Rates During the Growing Season

Soil Zone	Organic Matter	Conventional Tillage	Minimum Tillage
	%	lbs N/acre	
Brown	2.0	27	31
Dark Brown	3.5	44	51
Thin Black	4.0	50	58
Thick Black	5.5	62	71
Dark Gray	4.5	54	62
Gray	3.5	44	51

Derived from Karamanos and Henry. 2006. A water based system for deriving nitrogen recommendations in the Canadian Prairies. http://phosphorus.ipni.net

Source: Derived from Fertilizer Canada Nutrient Uptake and Removal by Field Crops Western Canada

Depending on the way the recommendation has been developed the amount of N mineralized from soil organic matter may have already been taken into account in determining the N rate. Be sure to understand whether that is the case with your recommendation source. Regional response curves, for example, are a recommendation approach that accounts implicitly for the mineralization contribution.

D) Manure;

The properties and chemical composition of the manure being applied to a field as well as the quantity determine the actual N rate. There are large differences among manures from various livestock species. Even for manures from the same species there can be differences based on diet and other farm specific factors. Storage can also affect the total N concentration in manure and the distribution between organic and inorganic (primarily ammonium) forms. When developing 4R N recommendations, knowing the nutrient content of the specific manure source by having it analyzed is preferred to average nutrient contents gathered from extension materials. Not all the N (or P) is immediately plant available. A general guideline is that 25% of the organic N plus whatever ammonium-N and nitrate-N (generally small in raw manure) is retained will be crop available in the year of application. Available N in composted manure can be estimated at 13% of the organic N plus whatever ammonium-N and nitrate-N is retained. Nitrate-N levels in compost can be significant and should be tested for when testing composted manure. Release of N from the organic-N fraction after Year 1 is usually estimated at half of whatever fraction was used in year 1. For example, if 25% was release in Year 1, then 13% would be released in Year 2, and 7% in Year 3.

Manure Type		Total Nitrogen	Ammonium Nitrogen	Organic Nitrogen	Total Phosphorus	Dry Matter
		-------------- lb/1000 gal --------------				%
Liquid Pig[2] n=70	Ave	36	22	14	12	4.3
	Max	68	52	37	32	8.0
	Min	6.0	4.4	1.6	1.0	2.0
Liquid Dairy n=208	Ave	31	15	16	8.2	7.1
	Max	76	72	56	85	15
	Min	7.0	0.7	0.5	1.0	1.0
Liquid Chicken n=65	Ave	79	58	21	25	8.3
	Max	115	99	92	51	14
	Min	30	1.1	1.3	6.0	2.6

Source: MAFRD, 2013

Available P_{yr1} = Total P x 0.70

Available N_{yr1} = [(Total N – Ammonium N) x 0.25] + Ammonium N

How the manure is handled and applied will affect the amount of N delivered to the crop. Surface application without incorporation can result in high volatilization losses as ammonium coverts to ammonia. Weather during application also plays a significant role.

Study Tip: To more fully understand manure rate calculations work through the rate setting examples found in Section 4 of the Nutrient Management Planning Guide available on-line from Alberta Agriculture. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11920

Ammonium Nitrogen Loss with Application Method, Timing, and Weather					
Application and Incorporation Strategy	Weather Conditions During Application				
	Average	Cool-Wet	Cool-Dry	Warm-Wet	Warm-Dry
Surface applied, incorporated within 1 day	25%	10%	15%	25%	50%
Surface applied, incorporated within 2 day	30%	13%	19%	31%	57%
Surface applied, incorporated within 3 day	35%	15%	22%	38%	65%
Surface applied, incorporated within 4 day	40%	17%	26%	44%	72%
Surface applied, incorporated within 5 day	45%	20%	30%	50%	80%
Not incorporated	66%	40%	50%	75%	100%
Injected	0%	0%	0%	0%	0%
Cover Crop	35%	25%	25%	40%	50%
Source: Nutrient Management Planning Guide					

E) Biosolids and Other Organic Amendments;

A common source of biosolids available for land application is sewage sludge from municipal waste treatment plants. It is usually a thick liquid material that is most often injected into the soil. Biosolids originating from a municipal source may have higher concentrations of heavy metals compared to livestock manures. Land application rates are generally regulated on the Prairies in terms of individual applications, frequency of application, and lifetime applications in order to limit heavy metal build up. The regulatory guidelines tend to be conservative and limit application well below levels that would be considered environmentally damaging. Credits for nutrients supplied from application of biosolids should be included in a Nutrient Management Plan. The treatment plant providing the biosolids or the regulating agency will usually provide information related to the N concentration and the expected N release rate.

F) Irrigation applications (groundwater, surface water, and wastewater);

The nitrate concentration of the irrigation water should be tested and monitored, whether it is coming from surface or groundwater. The groundwater may have higher concentrations of nutrients than surface water, especially N, S, and Cl. The majority of irrigated land on the Prairies is located in Southern Alberta (86% of irrigated acres on the Prairies, 67% of the Canadian total). Surface water is the major source of irrigation water on the prairies.

G) Previous Crops and Cropping Practices (e.g., cover crops, legumes, fallow).

Usually an N credit is given for growing a non-legume crop after a legume crop. This credit may be based on the yield of the previous crop. For example, following a 60-bushel pea crop, a credit of 30 lbs N/acre may be used in the rate calculation for the subsequent crop. At the N cycle process level, the "N credit" is not N mineralized from the legume residue, but rather reduced immobilization of N from the available N pool. The C:N ratio of the legume residue is sufficiently low to meet the N needs of the microbes decomposing the residue without taking up ammonium and nitrate from the soil.

Typical N Credits Following a Pulse Crop

Crop	lb N/bu
Faba bean	0.40-0.60
Peas	0.40-0.60
Lentils	0.30-0.50
Soybean	0.30-0.50
Chickpea	0.15-0.25

Multiply pulse yield by crediting factor to estimate credit applicable to following crop.

Overwinter cover crops (sown post-harvest and sprayed or cultivated out prior to spring seeding) are not widely used on the prairies. When they are, N uptake by the cover crop results in a reduction of the available N pool. Residues from cover crops can depending on their C:N ratio result in additional immobilization and reduce the available N pool in the soil for the subsequent crop.

Following a fallow year, nitrate-N levels tend to be elevated due to mineralization. Without a crop to take up N, and providing weed are largely controlled, the mineralized N accumulates as nitrate. The accumulated nitrate is exposed to loss from leaching and denitrification and whether or not it is available for the following crop depends largely on moisture conditions during the fallow period. Nitrate levels following fallow are best assessed by a soil test.

Cropping systems that regularly included fallow such as crop-fallow and crop-crop-fallow systems have largely been replaced by continuous cropping on the Prairies. In some drier parts of the brown soil zone, chemical fallow is still included in some rotations. This may include use in flex-crop systems where crops are not seeded when spring soil moisture is low. Over the long-term regular summer fallow reduces soil organic matter particularly repeated tillage is used for weed control.

Performance Objective 7. Discuss the use of technologies to make ongoing adjustments to the nutrient rates that may have been identified during the 4R nutrient management planning process such as:

A) Crop Canopy Sensors;

This technology measures the reflectance of specific portions of the electromagnetic radiation spectrum, basically light, both visible and out of the range of visibility usually in the near infrared (NIR). Sensors can be passive measuring the reflectance of ambient light (sunlight when used in the field). Active sensors emit their own light and have the ability to measure the intensity of the light reflected off the crop foliage compared to the light emitted. The sensors may be handheld or mounted on a tractor (sometimes referred to as proximal sensors). Sensors mounted on a UAV (drone), an airplane, or a satellite are generally referred to as remote sensors. The choice of platform depends on the intended application, required frequency of observation, and required resolution. These tools generally give an estimate of the amount of crop biomass and greenness (chlorophyll content) of the crop foliage. Using algorithms developed from field research specific to the crop and region, they provide a useful estimate of the N status of the crop, and whether or not an additional N application would be beneficial.

B) Normalized Difference Vegetative Index (NDVI);

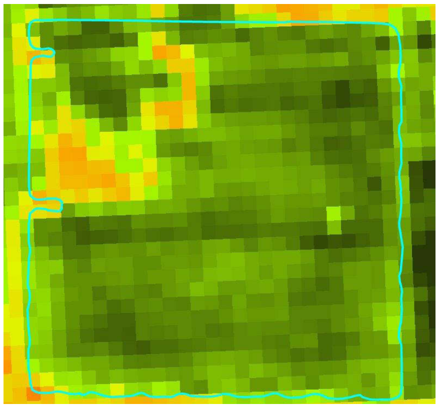
The NDVI is a ratio of the intensity of different bands or parts of the light spectrum measured during crop sensing. Red and near infrared bands (NIR) are typically used. There may be variants based on use of a red edge band.

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})}$$

NDVI distinguishes between active and less active plant biomass and provides a relative indicator of crop health and has been correlated to leaf area index, nitrogen status, and final yield. Note that NDVI is used with both proximal and remote sensing systems as described above.

NDVI is commonly used to map management zones in fields in variable rate systems. It is also used for in-season assessment of crop health and making rate decisions for in-season N application. When using NDVI, it is important to remember it is a measure of the density and activity of biomass and a general indicator of crop health. It is not a direct measure of the N status of the crop. Crops in areas of the field where NDVI indicates poor growth may be limited by non-nutrient factors such as soil salinity, soil acidity, pests etc. Ground truthing through directed soil sampling (grid or zone) and field scouting can help determine if the yield limiting factor is N or some other factor.

In the NDVI shown below the deep green is healthy crop and the orange areas are stressed crop. Keep in mind that NDVI images are false colored and you need to know how the color gradient was applied to understand the image. NDVI values tend to increase in magnitude as the crop develops and then drop off once the crop is mature. In some crops, canola for example, NDVI drops off rapidly when the crop flowers due to interference from the yellow bands.



Many indexes (literally hundreds) have been developed for use with cropping systems based on spectral data from remote and proximal sensors. NDVI is only one example of a spectral index. Different sensors are sensitive to different parts of the EMR spectrum. The range of wavelengths sensed and the width of the bands within that range vary depending on sensor. Visible and near infrared bands are often correlated with various aspects of plant health, while bands in the microwave or radar region correlate with factors such as soil moisture.

D) Soil Nitrate Test;

The soil nitrate test was covered in detail under PO1 of the Right Rate Proficiency Area. In the context of 4R planning and adjustment of plans including decisions about in-season applications, the nitrate test can provide information on the current state of the available N pool. Nitrate is highly dynamic in soil and a nitrate test value has a limited shelf-life. Annual post-harvest or pre-seeding sampling for nitrate analysis is useful for setting N rates as is in-season sampling for determining if sufficient N is available to meet crop demands. Nitrate tests are of no value beyond the cropping cycle in which they were obtained.

E) Plant Analysis Including Post Season Stalk Nitrate Test in Corn and Petiole Testing in Potatoes;

Plant tissue analysis is a diagnostic technique based on the concentration of total mineral nutrient elements in the plant. The recommendations for specific plant parts, the plant stage, and handling procedures need to be closely followed in order to get meaningful results. For N, the specific plant part for the crop type and growth stage is sampled at a number (15-20) random field locations, stored in a paper sample bag, and sent to a plant analysis laboratory to measure the total N concentration. The N concentration of the sample is compared to an accepted N concentration range that is deemed sufficient or non-limiting. If the N concentration is suboptimal, additional fertilizer may be needed to improve the N status of the crop. Tissue testing can be used in many crops to determine if supplemental N would be beneficial. It can also be used in a differential diagnostic where areas of poor growth are sampled as well as adjacent areas of good or better growth. Results from the two sampled can be compared to determine if N or some other nutrient is the cause of the poor growth.

For potatoes, the nitrate concentration in the petioles is analyzed as an indicator of the N-supplying capacity of the soil at the time the samples were taken. Petiole testing is usually done periodically, often weekly, during the growing season and the results interpreted against norms for the specific crop stage. In irrigated potato production, petiole testing is often used to set fertigation N rates.

The Post Season Stalk Nitrate Test is used to gauge the success of N fertilization in corn. Nitrogen taken up by the corn plant tends to accumulate as the nitrate form in the lower stalk. During grain-fill, plants running low in N, mobilize more of this N out of the stalk. Conversely if the plant has ample N, it draws sparingly on this N. If N is available in surplus amounts, then nitrate levels can be quite high in the lower stalk. The amount of nitrate-N remaining in the stalk at maturity can be compared to benchmark values to indicate whether the crop was inadequately, excessively or appropriately fertilized with N. The thresholds for inadequately, excessively or appropriately fertilized need to be calibrated regionally. Some work in Manitoba has been done on calibration in the corn growing areas of Manitoba.

Many of the soil test labs currently offer this test. An 8” section of the corn stalk is cut from the 6-14” height above the soil. In Manitoba testing of this technique has found it to be useful as long as sampling occurred within a couple weeks after reaching maturity (kernel black layer). If sampling is delayed too long after harvest and rainfall continues, it is possible that nitrate may leach from the stalk, producing low stalk levels.[1]

F) Grain Protein;

Wheat protein can be used as a post-season indicator of whether sufficient N was supplied for the crop to meet full yield potential. If hard red spring wheat is less than 13.5% protein1 or hard red winter wheat is less than 11.0-11.5% protein2, then insufficient N was supplied to meet that crop’s yield potential. One shouldn’t consider these values as actual final targets for protein. Farmers may want to target higher proteins and apply more N to capitalize on protein premiums.

For planning purposes, it is important to identify the possible causes of low protein in what was otherwise an appropriately fertilized crop. Possible reasons for wheat protein falling below these benchmark values may be:

- Growing conditions that permitted higher yield potentials than expected.
- Losses of N through higher risk application methods such as fall applications, broadcast rather than banded or surface applications.
- Insufficient N supply, especially for newer, very high yield potential varieties.

Nitrogen tends to increase yield until some other factor becomes limiting and then any surplus N goes to protein. Additional N may be required to meet protein goals in years with good to excellent growing conditions due to the reasons outlined.

1 Explanation of Post Season Stalk Nitrate Test in Corn and Grain Protein adapted from Manitoba Agriculture Website. https://www.gov.mb.ca/agriculture/crops/soil-fertility/post-harvest-assessment-tools-of-soil-fertility-practices.html

G) Variable Rate Technology (VRT).

Variable Rate Technology is a group of interacting technologies within the emerging field of Precision Agriculture. In the field of nutrient management, the core technologies are Global Positioning Systems (GPS), Geographic Information Systems (GIS), and variable rate controllers on the fertilizer equipment. Secondary technologies include various sensors (see CA2, PO7A) which may be used pre-application or during application and Decision Support Systems (DSS) that can be used to calculate rates. The underlying premise of Variable Rate Application (VRA or VR) is that there is considerable variation in yield potential at the subfield level. The goal of VR in nutrient management is to more closely match fertilizer or manure application rates to this intra-field variability. This is very well aligned with the principles of 4R which strives to match fertilizer rates with crop demand in space as well as time.

Variable Rate Application can be, Map Based or Sensor Based.

Map Based VRA is pre-planned, and applications are based on prescription maps that an agronomist or advisor prepares based on georeferenced data sources. Data sources can include satellite imagery, UAV imagery, ground-based sensors (example EM-38 electrical conductivity mapping), yield maps from previous years, gridded soil sampling etc. These data sources may be used individually or layered. A common procedure is to divide the field into subfields or management zones. The zones need not be continuous but distributed in a number of polygons. A fertilizer prescription is developed for each zone and the resulting prescription map loaded into the rate controller on the fertilizer application equipment. During application GPS is used to determine where the application equipment is in the field, the controller then sets the rate according to the information embedded in the prescription map.

Conductivity mapping is a proximal sensing technique for measuring electrical conductivity in the field. In saline soils, the readings are related to the level of salts in the soil. In non-saline soils, conductivity is related to the proportion of clay in the soil. Conductivity mapping can be used to map saline areas in a field and/or differences in soil texture. Two types of instruments are commonly used. Electromagnetic induction-based soil sensing, for example EM38, measures the electric field at the soil surface without soil contact. Machines like the Veris measure the voltage drop when an electric current is passed through the soil. Soil contact is required so two electrodes need to be introduced into the soil. With the Veris system coulters are used as electrodes and the system resembles a small tillage implement. An EM38 can be mounted on a sled or cart and dragged across the field.

Sensor Based VRA is calculated real-time, based on sensors that are local to the variable rate applicator. The sensor based approach relies on sensing and interpreting spectral data from the soil surface or crop canopy and adjusting the N rate on the fly. So far practical applications of this technique have been limited to in-crop applications. A number of sensor approaches have been tried including soil sensors that attempt to measure soil nitrate levels or soil organic matter on the fly. These soil based technology has not been widely commercialized or adopted.

There are a number of limitations on variable rate that must be understood in order to get good results. First is that intra-field variations in yield potential are not all due to differences in nutrient levels. Differences in salinity, texture, pH, and compaction to name but a few of many factors can result in yield differences across the field. These non-nutrient factors need to be addressed when developing the prescription map. This may involve soil sampling or other forms of ground truthing.

A second limitation is equipment. The width of the equipment and the distance required for the controller to make the change in rate limits the resolution actually achieved in most map based VRA. Drills with section control can increase the resolution. Similar equipment restrictions apply for sensor based systems; but systems are now becoming available that have a sensor for every row or nozzle. In row crops such as corn, where row spacing and plants spacing within the row are relatively wide this starts to approach varying the N rate at the individual plant level.

COMPETENCY AREA 3. DETERMINING THE RIGHT TIMING OF NITROGEN APPLICATION

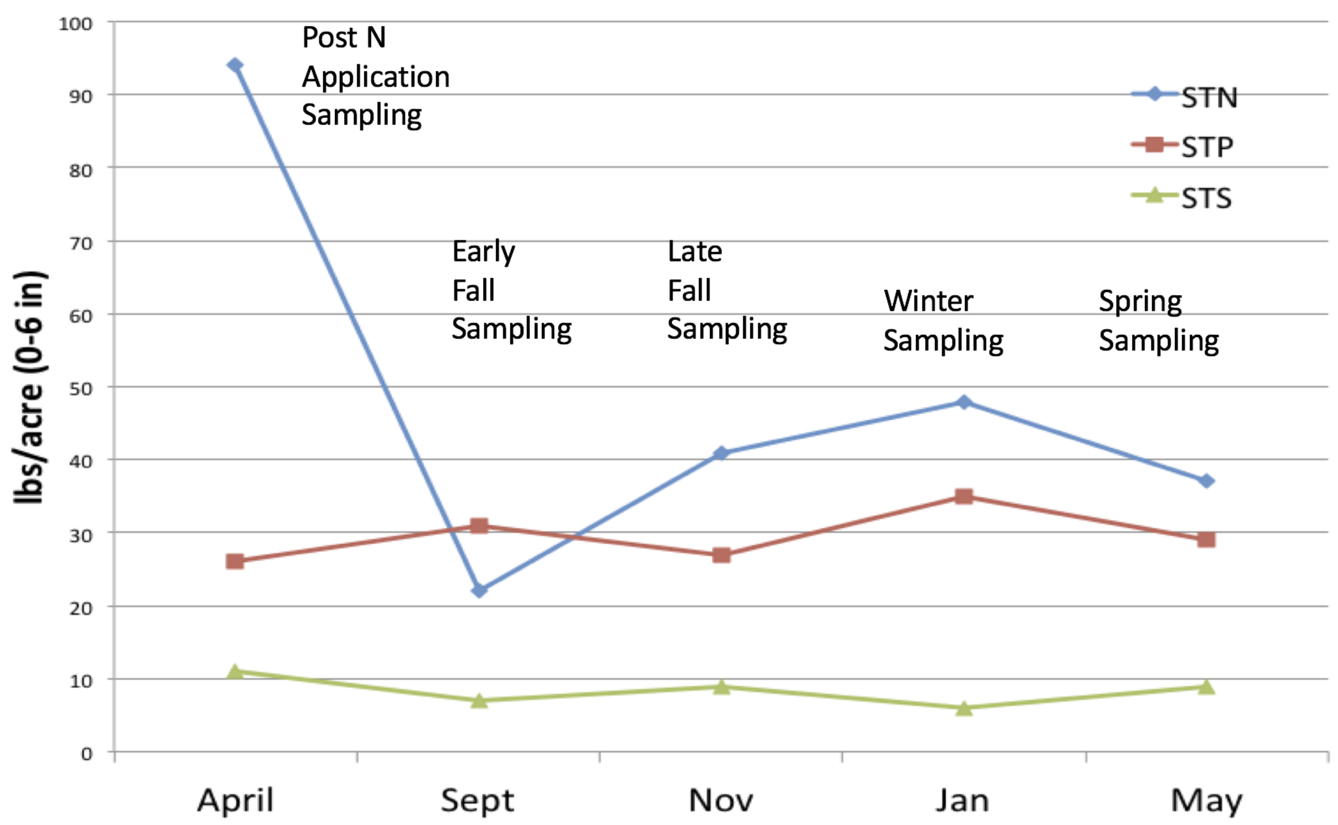
Performance Objective 1: Discuss how the timing of soil nitrogen tests can impact test levels.

Soil test nitrogen (STN) can vary considerably through the cropping cycle. As a general rule, sampling that is closer to the time of application gives a more accurate portrayal of the soil nitrate pool. Soil testing after the soil has thawed and before planting provides the most accurate assessment of the nitrate-N pool for spring-seeded and fertilized crops. The regional soil calibration and crop response research used to build nitrogen response curves has for the most part been based on spring sampling. Recommendations based on an N balance approach using target yields will generally improve when spring sampled nitrate-N values are used.

When it comes to time of sampling what is best in terms of accuracy and what is achievable logistically are not well matched. The short growing season and need to seed early allow only a very limited window for spring sampling. Sampling capacity (trucks and samplers) is finite and turn-around-time from when the sample is taken to when the results are returned to the farmer or agronomist may range from several days to a week or more. Furthermore, farmers and retailers need lead time once they have a fertilizer recommendation for purchase and delivery of the required products particularly when custom blends are being used.

Fortunately, on the Prairies with typically dry cold winters there is a reasonably strong correlation between post-harvest fall sampling and pre-seeding spring sampling. This does not necessarily mean that nitrate-N levels don't change through the winter but rather that additions and losses tend to balance out as shown in the graph below. Fall sampling after the soil has started to cool is a reasonable tradeoff between accuracy of soil test results and the logistic restraints on sampling. For farmers who fall apply, fall soil testing allows them to gauge residual N levels before setting rates. Furthermore, sampling after an N application can cause considerable distortion of the results particularly if the N has been banded. Fertilizer N is often less expensive in the fall than in the spring. Fall-sampling can help growers estimate their total N needs prior to purchase, take advantage of discounted prices, and ensure timely delivery.

Changes in Soil Test Levels Fall to Spring in a Black Chernozemic Soils in Central Alberta.



Source: D. Heaney unpublished data.

Performance Objective 2: Estimate the Environmental Risks in the Timing of Applying Nitrogen:

When the chance or probability of an outcome is known in advance this is called risk. When the chance of an outcome is not known in advance this is called uncertainty.

In the context of N application timing, risk as defined above would be based on factors that are known about the cropping system. For example, we know that given a certain amount of rainfall water will move further down the profile in a sandy soil than in a clay soil. If the water moves below the rooting zone, nitrate-N in that water has been lost through leaching. We may know that such an event occurs with a certain average frequency, for example one year in five. We may even know in what part of the annual cropping cycle, events are likely to occur. For example, the risk of N losses through runoff are highest during the spring thaw when snowmelt runs over frozen soil. What we usually don't know in advance is how much rain will fall or snow will accumulate; whether rain will fall in fewer intense storms or be spread out over less intense events; or if snow melt will occur quickly or more gradually. While we can characterize risk, we are less adept at predicting whether a risk will be realized in a particular year.

The two main environmental risks associated with N loss on the Prairies are nitrous oxide emissions and losses to surface and ground waters. Timing N applications closer to the period of high crop demand tends to reduce the risk of N loss and lowers environmental risks. When logistics require use of less than ideal timing, risk can be reduced by selection of appropriate source, rate, and place practices.

Eutrophication or nutrient enrichment of surface waters leads to algal blooms, nuisance aquatic plant growth, low oxygen levels in water (anoxia), and death of aquatic organisms. Freshwater aquatic ecosystems tend to be phosphorus limited and degradation of water quality is typically driven by phosphorus loading including additions from fertilizer and manure. Once phosphorus limitations are removed, nitrogen lost from fertilizer and manure can make the problem worse.

Nitrification and denitrification are the two main processes that result in direct nitrous oxide emissions. Since nitrification is aerobic and denitrification anaerobic, the conditions that suppress one enhance the other. Losses through volatilization and leaching contribute to indirect emissions as the lost N can be subsequently converted to nitrous oxide once it has escaped the cropping system.

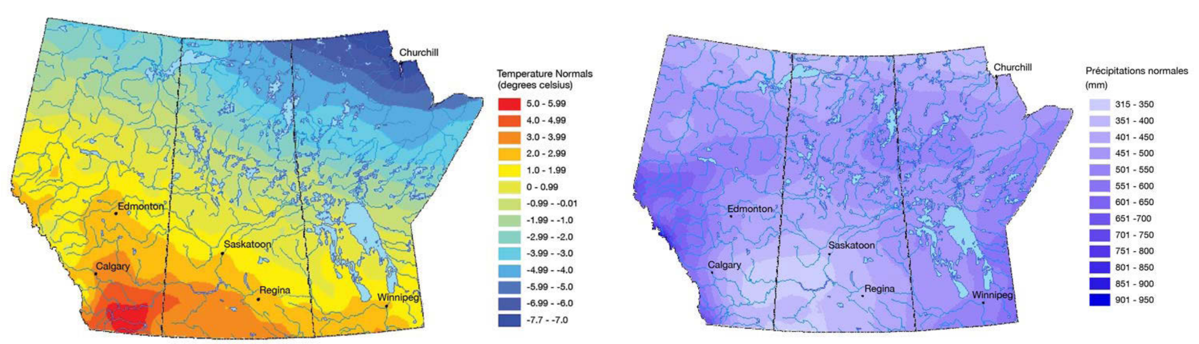
High ammonia concentrations in surface water can also be toxic to aquatic organisms and impair water for livestock or human consumption. Excessive nitrate-N in surface and drinking water also reduces water quality. While we typically view nitrogen contamination of water to be a groundwater issue, tile drains divert leaching nitrates to surface water bodies and surface applied ammonium N sources can be lost with surface runoff if runoff occurs shortly after N application.

The various factors that affect risk and need to be considered in assessing risk are discussed below.

A) Climate

The main climate factors that influence environmental risks are precipitation, temperature, and evaporation. Losses and environmental risk tend to be higher in wetter parts of the Prairies. Runoff from snowmelt is a major transport mechanism. Areas with higher snowfall levels and where low temperatures allow snow to accumulate through the winter have a higher risk of loss during spring runoff. Comparatively areas like SW Alberta, where snow tends to be sublimated by Chinook winds, have a lower risk. In areas where snow accumulates, spring runoff tends to be the most significant runoff event in most years. Melt waters are prevented from infiltrating while the soil is frozen and consequently move laterally.

Temperature and Precipitation Normals on the Canadian Prairies



Source: Environment Canada

B) Season

Risk of N loss on the Prairies is higher for fall-applied compared to spring-applied. Overwinter N loss is very dependent on soil characteristics and soil moisture.

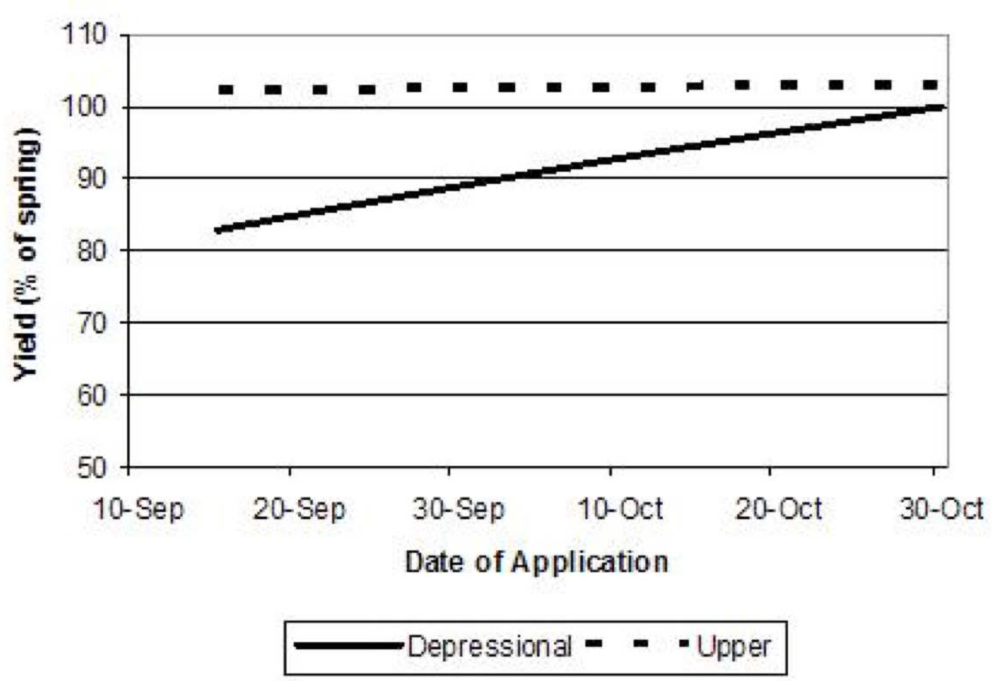
Crop Yields with Fall-applied N as a per cent of spring broadcast and incorporated				
	Soil climate categories			
Application method	Dry	Medium	Wet	Irrigated
Spring broadcast and incorporation	100	100	100	100
Spring banded	120	110	105	110
Fall broadcast and incorporation	90	75	65	95
Fall banded	120	110	85	110

Dry = Well drained soils that are seldom saturated during spring thaw.
Medium = Well to moderately drained soils that are occasionally saturated during spring thaw for short periods.
Wet = Poorly to moderately drained soils that are saturated for extended periods during spring thaw.
Irrigated = Well drained soils in southern Alberta that are seldom saturated during spring thaw.

Alberta Agriculture – Fall-applied Nitrogen: Risks and Benefits. Agdex 542-11 (2013)

Late fall application reduces risk compared to early fall. However, there is a strong landscape component to the risk of loss. There can be wet areas (lower slopes) and drier areas (upper slopes) and a range of risk in the same field. The figure below based on research from Manitoba illustrates this idea.

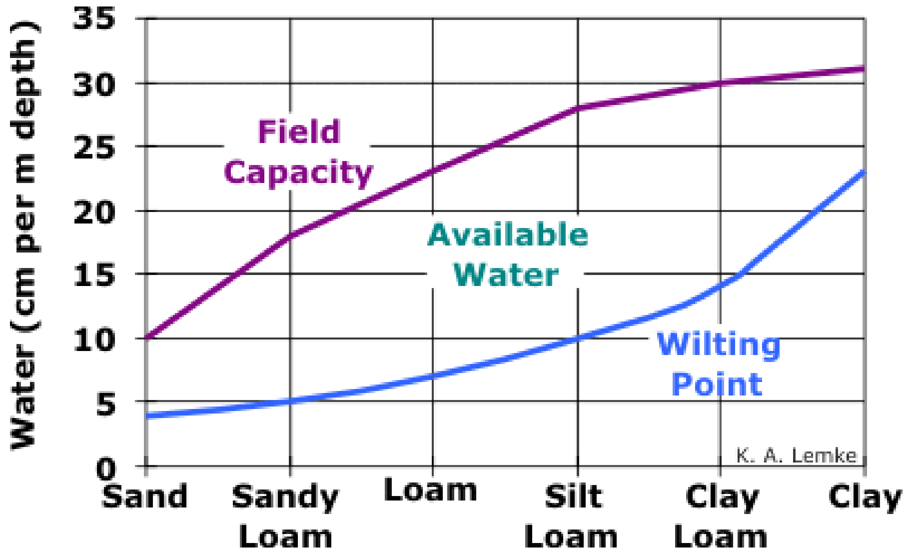
Effect of application on spring wheat grain yields from fall-banded urea relative to spring-banded urea at three sites near Winnipeg and one site near Brandon (2001-2002).



Tiessen et al. (2003) http://www.umanitoba.ca/faculties/afs/MAC_proceedings/2003/pdf/flaten_fall_banded_N.pdf

D) Soil characteristics;

Texture is the main soil characteristic that influences risk of loss. Coarse-textured soils have a lower water holding capacity and, therefore, a greater potential to lose nitrate through leaching when compared with fine-textured soils. Nitrate-N can be leached from any soil if rainfall or irrigation moves water through the root zone. Once field capacity is exceeded water is free to move through the profile under the force of gravity. Preferential flow through macropores can move soluble N on the surface below the rooting zone. Finer textured soils or soils that are poorly drained result in a greater risk of denitrification and the production of greenhouse gases.

Field Capacity, Wilting Point, and Crop Available Water in Relation to Soil Texture.


Another way to illustrate differences in water holding capacity is by looking at the depth of a wetting front following rainfall. In a clay loam soil, an inch of rain will only penetrate about a third as deep as in a sand.

Soil Texture	Penetration (inch soil/inch rain)
Clay Loam	3
Sandy Loam	5
Sand	10

While leaching of N can occur in any soil when field capacity is exceeded, how fast water moves through the soil also plays a role. This is usually expressed in terms of hydraulic conductivity.

Soil Properties in Relation to Soil Texture.

Textural Class	Bulk Density (Mg/m^3)	Porosity (%)	Hydraulic Conductivity (cm/s)
Sand	1.55	42	1.2×10^{-1} to 2.0×10^{-3}
Loam	1.20	55	1.7×10^{-4} to 1.7×10^{-7}
Clay	1.05	60	2.5×10^{-9} to 1.0×10^{-9}

Saturated Hydraulic Conductivity

After Hanks and Ashcroft, 1980

The actual rate of water movement depends on the hydraulic head; the height of the water column above a fixed point like the bottom of the rooting zone. Well-developed structure can significantly modify the functional hydraulic conductivity in undisturbed soil. Imagine a scenario where water is ponded over a saturated soil. Movement below the rooting zone would potentially occur in hours in a sandy soil, might take days in a loam soil, and likely weeks in a clay soil.

E) Runoff;

Infiltration rates tend to be lower on clays particularly on poorly structured clay soils, than on sands. Water that doesn't run in will run off carrying soluble N forms at or near the soil surface. When runoff results in erosion, ammonium can also be carried with the runoff water attached to clays and organic matter as part of the sediment load. Nitrogen in runoff may be redeposited downslope or carried off field in surface flow. Runoff collecting in depressions may percolate downward and move N through to groundwater or the N may be denitrified.

F) Irrigation;

Nitrogen leaching during irrigation is directly related to the drainage volume (amount of water that passes through the profile and out of the rooting zone). By increasing irrigation efficiencies, both the drainage volume and amount of N leaching are reduced. Both water management and N management are important in controlling N leaching. A balance needs to be maintained between the depth of irrigation water penetration and the prevention of leaching of N. On irrigated soil, net movement of water through the profile is required to prevent build-up of salts in the rooting zone. By using improved water management practices that control the amount of water applied and using the proper time to apply water (when the crop most needs and can utilize it), the irrigation efficiency is increased and N leaching is reduced. Applying only enough N fertilizer to meet crop requirements for a realistic yield goal, time of application, and use of EEF N sources are N management practices that will reduce N leaching under irrigation. The type of irrigation system utilized is also a factor. Low pressure sprinklers are generally the norm in Prairie irrigation. These allow more even distribution of water and lower leaching compared to older furrow irrigation methods. Drip and sub-surface drip irrigation systems target water more effectively to where plant roots are growing. They reduce surface ponding which helps minimizes nitrate leaching loss. However, these systems are generally not practical for broadacre annual crops.

G) Leaching Potential.

Leaching potential can be considered as the integration of the factors discussed above. The ability of a soil to retain water depends upon the inherent water holding capacity of the soil and the current proportion of the water holding capacity that is already filled with water. Finer textured soils typically hold more water at field capacity than coarser textured soils and thus have a lower leaching potential. Wetter soils have more of the water holding capacity already filled and thus it takes less additional water to drive water through the profile. Soils in the same field, may vary in water holding capacity due to differences in clay or organic matter. They may also be relatively wetter or drier based on their slope position.

On an annual basis, leaching potential on the Prairies is typically greatest in the spring when soils can be saturated following snowmelt. While nitrate-N leaching does occur on the Prairies, the leaching potential is generally low compared to more humid climates like the American Midwest or Southern Ontario. The semi-arid climate, cold dry winters, frozen soil, predominance of medium and fine textured soils formed on till or lacustrine parent material are some of the reasons that N leaching losses on the Prairies are relatively low.

A final note, process based computer based models are now being used to estimate environmental risk associated with N application including timing of application. These models require extensive data sets on soil characteristics, local weather, and crop types. These models allow estimation of N cycle processed including denitrification, leaching, mineralization, immobilization, and crop uptake at a field or subfield level.

Performance Objective 2: Estimate the Risks of Applying Nitrogen on Saturated, Frozen, or Snow Covered Soils.

Nitrogen Applied to frozen ground is at higher risk for loss through runoff. Water cannot infiltrate frozen soil. In spring, the soil surface may melt creating a shallow saturated layer but until the frost front has retreated down the profile sufficiently to allow infiltration and redistribution, snow melt water runs off. Spring runoff is in most years the major runoff event in Prairie landscapes. Applications of products like urea on snow result in partial or complete dissolution of the fertilizer granule. Urea is highly soluble and will move with runoff before it can be converted to ammonium and enter exchange reactions.

Application of N to saturated soils is less of an issue in Western Canada than in areas where nitrate-based products, such as ammonium nitrate, are available. Application of ammonium-based products like ammonium sulphate or urea on saturated soils require nitrification, an aerobic process, before they can be leached or denitrified. Saturated soils are generally not trafficable but one can envision situations in certain landscapes where saturated depressions or drainage channels may be broadcast with urea from equipment passing upslope. Subsequent rainfall resulting in runoff could result in N transport as urea off field.

The results below from North Dakota illustrate the yield loss associated with applying urea on snow covered and/or frozen soil. Risks inherent to this practice are economic as well as environmental and it is considered a non 4R practice as it violates a number of 4R time and place principles.

Application of urea to frozen soils preceding spring wheat, winter of 1995-1996.		
	Yield (bu/acre)	Protein (%)
Fall applied, incorporated	45.4	14.5
Soil frosted, not deeply frozen, November	45.8	13.8
Soil deeply frozen, December	27.6	12.7
Soil deeply frozen, March	33.3	13
Applied prior to seeding, April incorporated	49.6	14.6
LSD 5%	5.0	0.5
Source: Carrington, Endres, Schatz and Franzen, North Dakota State		

Performance Objective 3: Discuss How the Timing of Nitrogen Application is Dependent Upon the Nutrient Source.

The right time differs depending on the N source selected. Source can restrict or allow greater flexibility in application timing depending on the properties of the source and the risks of loss or detrimental effects inherent to the time of application. This may be illustrated with a series of examples. Keep in mind that rate and placement also play a significant role.

Early fall before soil has cooled below 10 °C – Unprotected N sources (UAN, AA, AS, Urea) have opportunity to nitrify with subsequent overwinter loss of nitrate-N. Protected N sources (treated with urease inhibitors (UI), nitrification inhibitors NI, UI/NI, or polymer coated urea (PCU)) may allow application up to two weeks before expected soil cooling date.

Late fall after the soil has cooled below 10 °C – AA, AS, Urea and the protected sources would be acceptable, if banded. Sources such as MAP would be acceptable based on broadcast and incorporated as the associate N rates are relatively low. Data suggests that PCUs such as ESN perform about equally when broadcast and incorporated or not incorporated but banding would be the preferred practice.

Spring prior to Seeding – All sources are acceptable.

Spring at Seeding – All sources are acceptable subject to rate restrictions for seed-placed N. See discussion in CA4, PO4,5.

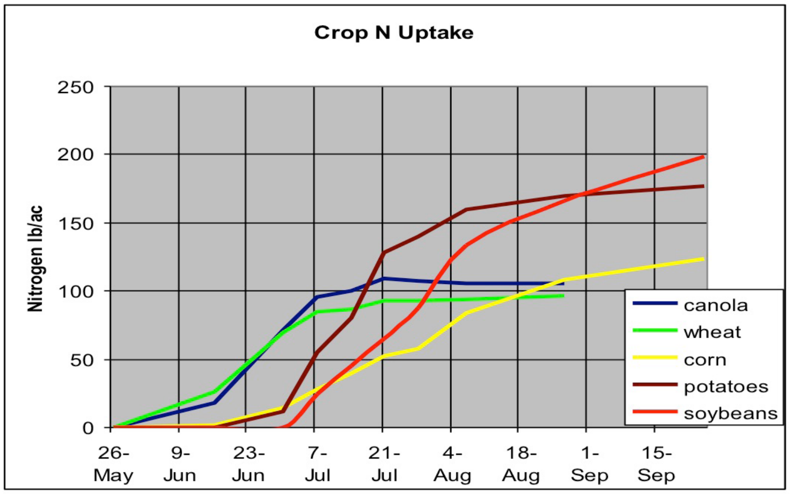
In-Season – All sources are acceptable. Consideration should be given to conversion times required to convert to plant available forms if protected sources are used. Discussion of crop stage and timing see next PO.

Performance Objective 5: Discuss the Opportunities and Risks that Split Application Offers for 4R Nitrogen Management by Crop Type.

Dividing total N application into two or more treatments can more specifically match supply with a plant’s demand. Split application can help reduce losses and enhance fertilizer nitrogen use efficiency by the crop. When the N rate is supplied with a single pre-plant or at-planting application, the N is at risk of loss until the crop reaches the rapid uptake stages.

Split application offers efficacy benefits on a wide range of crops and forages but its management must be considered on a crop-by-crop basis. The timing of in-season N applications is especially critical on the Prairies with our short growing season. To be effective in soils with low soil test N, there must be sufficient N applied at or before seeding to carry the crop through early growth stages and the in-season application must be timed to enhance the available N pool as the rapid uptake phase commences. If the crop is N deficient for any significant period between emergence and physiological maturity, yield and/or quality will be reduced. While N uptake in crops can be generalized as an S curve, there is enough variation among crops to preclude use of a general guideline.

Nitrogen Uptake (S) Curves of Various Crops



Source: IPNI

In the case of corn, for instance, all of the N should be delivered to the plant before ears are set. This occurs later in the growing season than the critical window for wheat. In wheat, the second application of N generally is best made 10 days to two weeks prior to the jointing stage when a stem is formed, and the plant's N requirement increases as it begins its reproductive phase. Nitrogen applied after stem elongation may increase protein but will have minimal impact on yield. Canola seeded at the same time as wheat initiates rapid N uptake at a similar crop stage (bolting) but yield responses can be obtained up to early flowering, reflecting the indeterminate flowering habit of canola and the crops plasticity.

Forages especially benefit from split-applying N when more than one cut is taken during a single season. Application following each cut recharges the available N pool prior to regrowth.

Irrigated potato is another crop that benefits from split application where one or more applications are made following tuber initiation.

Regardless of the crop type, application timing must be sufficiently ahead of the high demand period to allow the N to convert to available form and enter the root zone.

Split-applying N can enhance efficiency. Although it does not change what the plant needs, the higher efficiency should allow total rates to be reduced. The downside for split applications is that wet conditions may prevent timely treatment. Also, dry conditions can prevent fertilizer from reaching crop roots and extra fuel costs from additional trip through the field must be considered.

Research on the Prairies shows that as a general rule, at least 50% of the total N rate should be applied at or before seeding. The research also shows that in most years on crops like wheat and canola, there is no yield advantage to splitting the application. In addition to improved efficiency, reasons to split apply may include:

- Top up of N rates due to change in conditions that improve yield potential or economics such as a significant increase in crop prices or protein premiums.
- Conditions that prevented application of full rate at or before seeding. For example, N could not be applied in fall and equipment cannot handle the full N rate at seeding.

Performance Objective 6: Discuss How Cover Crops Can Affect Nitrogen Availability in Follow-up Crops and Supplemental Nitrogen Application Timing.

Cover crops are not widely used on the Prairies but when used can have an impact on N availability. Low adoption rates are in part due to the predominance of reduced and zero tillage and reduced erosion risk.

The shortness of the season is another factor that reduces their practicality. In situations where they are used; fall-seeded crops such as fall rye can scavenge residual N and prevent loss. Spring seeded legumes or mixtures including legumes can be grown as green manure (or plough down) and provide N to cash crops that follow. Green manuring plays an important role in organic farming systems.

The effect of cover crops on available N will vary on the crop type, when it is terminated, and the environmental conditions that control residue breakdown and the release of N into the available pool. Keep in mind that legumes will only contribute positively to the N balance, if they were actively fixing N prior to termination. Cover crops are generally terminated before maturity and have a lower C:N ratio than cereal and oilseed residue following harvest; it may still be sufficiently high (>25:1) to trigger immobilization. Non-legume crops seeded into a recently terminated cover crops will likely need supplemental N at seeding. In situations where the cover crop was terminated earlier, for example early the previous fall, there may be sufficient available N to carry the crop through early stages and supplemental fertilizer N may be more effective in-season.

Performance Objective 7: Evaluate the Principles, Appropriate Use and Impact to Timing of Nitrogen Applications for Protected N Sources.

The sources discussed below are referred to as protected, enhanced efficiency, or stabilized N. For a more complete discussion of the modes of action and examples of products see PO1 at the beginning of this Proficiency Area. The discussion in this section will focus on timing considerations. Keep in mind that these enhanced efficiency sources may depending on the mode of action reduce N availability in the near term and the delay in availability needs to be factored into the timing decision.

A) Urease Inhibitors;

Chemical additives that slows the hydrolysis of urea by interfering with urease activity. Reduces ammonia volatilization by preventing accumulation of ammonia/ammonium and allowing time for nitrification to convert ammonium to non-volatile nitrate. Most effective under conditions when volatilization is expected such as spring broadcast or shallow spring banding. Less effective as a single product for fall-applied N when risk of volatilization is lower. Can be an effective product for in-season top dressing if there is sufficient precipitation to move N into the soil and sufficient time for conversion.

B) Nitrification Inhibitors;

Chemical additives that block the conversion of ammonium to nitrate by disrupting the bacteria responsible for the conversion. Can be used with urea, anhydrous ammonia, UAN, and liquid manure. The effective period varies with product and environmental conditions (less under warm moist) but is in the range of 15-30 days. Nitrification inhibitors are useful when N is fall-applied as they helps keep N in the ammonium form and reduce losses through leaching and denitrification. Also useful in preventing nitrous oxide emissions. Keep in mind that preventing nitrification of products like urea keeps N in the ammonium form where is it subject to volatilization loss if surface applied or shallow banded.

Several products (for example, SuperU) combine UI and NI chemistry. These are effective when applied in fall as the combination slows conversion to nitrate more than an NI alone. Spring application generally does not require the NI component as the danger of nitrate loss is reduced. Inclusion of NI component will reduce nitrous oxide emissions associated with nitrification. Use in-season as a top dress product needs to account for conversion time and requires precipitation to move N into the soil. Keep in mind that N is mobile as urea or nitrate but not as ammonium.

C) Controlled and/or Slow Release Nitrogen Products.

Polymer coated urea (ESN for example) is the most widely used of these products in broadacre crop production. Slow release sources are common in horticulture and turf grass applications. The polymer coating slows release of the urea into the soil under cool conditions and becomes leaky under warmer conditions. These products are effective spring and fall at slowing conversion to ammonium and nitrate. Problems can arise when surface applied to dry soil, as the product needs to be in contact with moisture to release. Not generally recommended as an in-season product for spring seeded crop as N release may be delayed past peak demand.

COMPETENCY AREA 4. DETERMINING THE RIGHT PLACEMENT/METHOD OF APPLICATION FOR NITROGEN

Performance Objective 1: Discuss how the source of the nitrogen will determine the best placement or method of application.

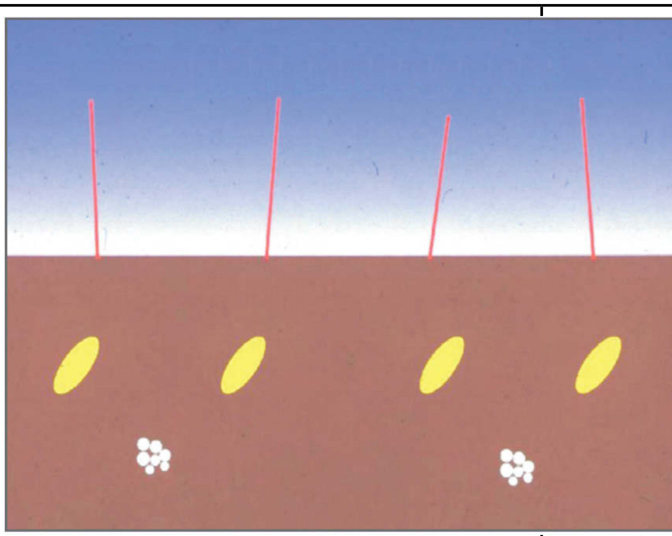
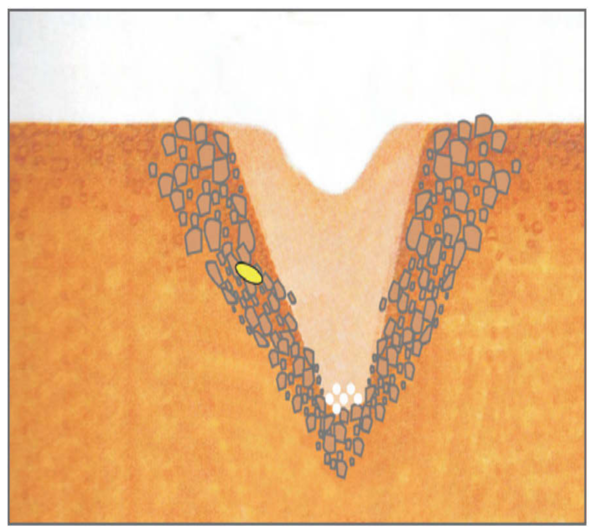
Urea (46-0-0)

Granular or prilled urea rapidly hydrolyzes to NH_4^+. Losses increase with higher soil pH, more crop residues and with higher temperatures. Urea can be used broadcast, banded or placed in the seed row and is typically the major N source in fertilizer blends (dry or liquid). Choice of appropriate placement practices is under most circumstances the single biggest factor in improving the efficiency of unprotected urea N.

Urea hydrolysis is rapid under warmer temperatures. Light rain or heavy dew is sufficient to drive dissolution of the granules and allow hydrolysis. Under conditions favorable to dissolution and hydrolysis about two-thirds of urea-N converts to ammonia/ammonium-N within one day and hydrolysis is complete within one week.

Broadcast with/without incorporation: If urea is surface applied and not incorporated (either by rain or tillage), N losses through volatilization can approach 40% when the potential for volatile loss is high. Approximately 0.5 inch (12-13 mm) of rainfall is required to move urea into the soil. Given the potentially rapid hydrolysis of urea, incorporation should occur as soon as possible after broadcasting to prevent losses.

Banding: Below the soil surface in a band is the preferred placement for granular urea. Banding can be effective in fall after the soil has cooled, in spring before seeding, or at seeding in a mid-row or side band. Deeper bands, narrower openers and wider row spacing all tend to slow conversion to nitrate. Shallow band with narrow openers and wider row spacing may lead to some volatilization losses depending on soil texture, pH, temperature and moisture. Side-banding without sufficient separation of seed from the urea can under conditions that favour rapid production of ammonia result in seedling toxicity. Poor separation can be a result of the opener(s) design, misalignment or may come about as openers wear down.

	
Mid-row Banding	Side-Banding
Not drawn to scale.	

Seed Row Placement: Crops vary in the rates that can be tolerated when urea is placed in the seed row. Ammonia toxicity rather than the salt effect tends to be the primary damaging mechanisms when seed row tolerance is exceeded. Increasing seedbed utilization, the ratio of the width of the seed row to the row spacing, reduces the risk of seedling damage. Tolerance also tends to increase in finer textured soils and under better moisture conditions. Suggested safe seed row rates for Saskatchewan are given below by way of example. Suggested safe rates of seed row urea tend to be lower for Manitoba due to the preponderance of calcareous soils. The pH of the surface horizon needs to be considered when setting seed row urea rates regardless of location.

Saskatchewan Agriculture Safe Limits for Seed Row Urea with Canola and Flax. Limits for Cereal Grains Approximately Double Rate Shown.

Soil Texture	1 inch spread[1]			2 inch spread[1]			3 inch spread[1]		
	(disk or knife)[2]			(spoon or hoe)			(sweep)		
	Row spacing			Row spacing			Row spacing		
	6"	9"	12"	6"	9"	12"	6"	9"	12"
	SBU[3]			SBU[3]			SBU[3]		
	17%	11%	8%	33%	22%	17%	50%	33%	25%
Light (sandy loam)	10	5	0	20	15	10	30	20	15
Medium (loam to clay loam)	15	10	5	30	20	15	40	30	20
Heavy (clay to heavy clay)	30	15	10	40	30	20	50	40	30

1. Width of spread varies with air flow, soil type, moisture level, amount of residue and other soil conditions, so it must be checked under field conditions.
2. Some openers give less than 1" spread.
3. Seedbed Utilization (SBU) is the amount of the seedbed over which the fertilizer has been spread. Thus, it is a reflection of the relative concentration of fertilizer. SBU (%) is the width of spread divided by the row spacing multiplied by 100. For example, if the seeding implement has six-inch spacing and spreads the seed and fertilizer over two inches, the SBU would be 2 ÷ 6 x 100 = 33 per cent. The higher SBU, the more fertilizer that can safely be applied with the seed. Although some openers will also spread the seed and fertilizer vertically, SBU does not take this into account since it is generally recommended that all seed be placed at an even depth for even germination and emergence.

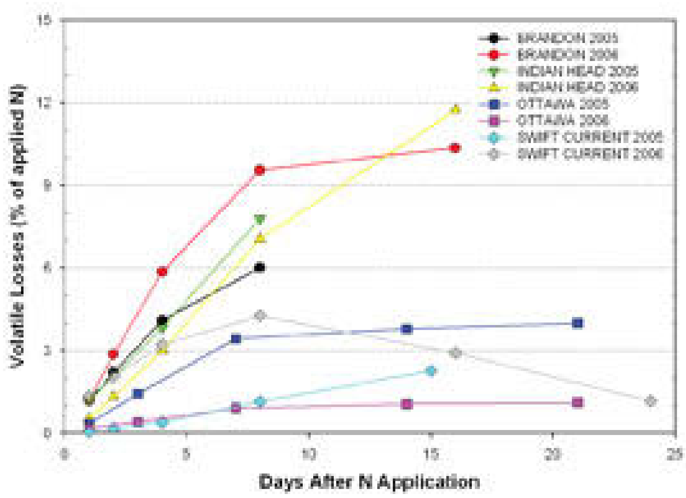
Source: Saskatchewan Agriculture

Urea-Ammonium Nitrate Solution (UAN) (28-0-0 to 32-0-0)

The nitrogen in UAN solution is 50% urea-N, 25% ammonium-N, and 25% nitrate-N. Once applied, urea is hydrolyzed to ammonia/ammonium followed by nitrification. Ammonium from the ammonium nitrate component nitrifies. The nitrate-N portion provides an immediately available mobile N source. UAN can be subsurface banded, dribble banded, or sprayed onto the soil surface.

Sprayed on Soil Surface (Foliar): This essentially broadcast placement would typically be done in-crop. UAN is compatible with some herbicides. Volatilization losses when compared to broadcast urea would tend to be lower at similar N rates as only half the N is in urea form. In practice, in crop spray applications of UAN using a flat fan nozzle can result in significant crop damage. Rate and weather conditions will determine the extent of damage but 20 lbs N/acre is often used as an upper limit.

Volatilization losses from dribble banded UAN.



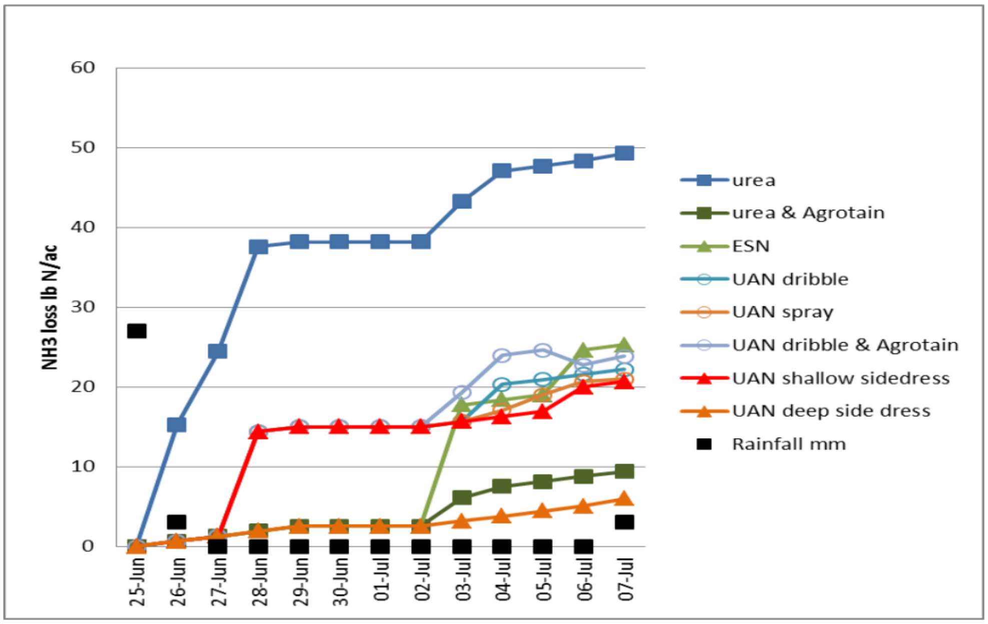
Source: IHARF

Dribble Banded: There are various techniques for dribble or surface banding UAN depending on crop type and stage. Adoption of high clearance sprayers has made in-season dribble banding more common. In row crops like corn, Y-drops can be used to dribble band UAN beside the corn row. Since foliar contact is minimized, crop burning is avoided. In cereals and other solid seeded crops, streamer nozzles are the more common approach. Crops can tolerate higher UAN rates with streamer nozzles than with a flat fan application. Streams that hit leaves tend to run off and less of the total leaf area is exposed to damage.

Study Tip – Y-drops are fairly new on the Prairies. "Google Y-drop images" if they haven't appeared in your area.

The figure above illustrates volatilization losses from surface banded UAN. Notice that it varies considerably by site and year, but in the worst case losses approach 12% of applied N. The data represented in the graph below shows the interaction between source and placement. While this is based on only one year's data, it clearly illustrates that volatilization from broadcast urea can be considerable and there are a number of source-place options that can reduce losses.

Volatilization losses with different sources and placements.



John Heard – unpublished data, single site year- Carman

Subsurface Banded: UAN can be applied at any of the band configurations and timings of granular N products provided of course that application equipment can handle liquid fertilizer. One of the advantages of UAN is it can be blended with other fluid forms to create a uniform product that is not subject to segregation.

Seed Row Placement: UAN can be seed placed but there is a significant risk of seedling damage due to rapid conversion of urea to ammonia/ammonium.

Anhydrous Ammonia (82-0-0)

Since anhydrous ammonia is a high-pressure liquid that turns into a gas; placement options are limited. Ammonia reacts quickly with water to form ammonium, which can then enter exchange reactions and be stabilized on cation exchange sites. Ammonia is highly soluble in water so not only does good soil moisture allow for rapid hydrolysis and cation exchange, it helps hold the gas form in the soil as well.

Banding: The only feasible placement method for anhydrous ammonia. Anhydrous ammonia is the preferred source for fall-banding. The concentration of ammonia in the band creates a sterile zone eliminating or suppressing the soil biota including soil nitrifying bacteria. Banding at depth reduces contact with nitrifying and immobilizing microbes, and a portion of the nitrogen is maintained in the ammonium form over the winter reducing nitrate accumulation and the risk of denitrification or leaching. Shallow banding and/or poor closure of the furrow can allow ammonia to escape from the soil. Deep banding 4-6 inches is the preferred placement when feasible.

Good moisture and finer texture reduce volatilization losses. Losses will tend to be higher when soils are drier or in coarse textured soils.

placement when feasible. Good moisture and finer texture reduce volatilization losses. Losses will tend to be higher when soils are drier or in coarse textured soils.

Anhydrous can be applied at seeding taking advantage of its high N content and creating additional room in the fertilizer cart for dry products. Placement configurations with the seed drill must ensure sufficient separation between the anhydrous band and the seed row to avoid ammonia toxicity. Banding directly below the seed is not recommenced. Ammonia creates a pear-shaped fertilizer reaction zone above the band. Separation distances of 2-4 inches between band and seed row depending on soil texture, moisture and rate are recommended to minimize or eliminate seedling damage.

Ammonium Sulphate (21-0-0)

A dry granular material with all N in the ammonium form. It is used for direct application and in blends. Commonly used as a sulphur source for canola and forage legumes.

Broadcast with/without incorporation: Using ammonium sulphate by itself or in blends lowers the risk of volatilization compared to use of urea when surface applied. Ammonium sulphate is subject to volatilization when left on the surface of soils with alkaline pH.

Banding: Ammonium sulphate can be banded in any of the common configurations. Banding of ammonium sulphate commonly occurs in blends where it is added to provide sulphur.

Seed Row Placement: Ammonium sulphate has a salt index of 69.0 and a partial salt index 3.253. It has the highest partial salt index of any of the common N fertilizer meaning that per unit of N applied it will be more osmotically damaging in the seed row than urea or monoammonium phosphate. Developing safe seed row rates of ammonium sulphate needs to take into account crop type, seed bed utilization, texture, and moisture as well as the cumulative effects when combined with other products in a starter blend.

utilization, texture, and moisture as well as the cumulative effects when combined with other products in a starter blend.

Salt Index and Partial Salt Index of Common N Sources Used on the Prairies.		
Source	**Salt Index**	**Partial Salt Index per Unit of N**
Anhydrous Ammonia[1]	47.1	0.572
Ammonium Nitrate[2]	104.7	2.990
Ammonium Sulphate	69.0	3.253
Monoammonium Phosphate	34.2	2.453
Urea[1]	75.4	1.618
UAN[2]	95.0	2.304
Products with a higher salt index are more likely to cause osmotic damage to seedlings per unit of total product applied when placed with seed or too close to seed. Products with a higher partial salt index are likely to cause osmatic damage per unit of N applied.		
1 Ammonia toxicity can damage seedlings in addition to salt effects. 2 Ammonium nitrate not widely available in W. Canada except as component of UAN.		

Using enhanced efficiency sources of N can significantly modify the risk to benefit equation when making placement decisions. This topic is covered in Performance Objective 5 in this proficiency area.

Performance Objective 2: Discuss how the time of the year, climate, tillage practices, and residue management will impact the proper placement or method of application.

Time of Year

As a general rule, timing N application closer to the period of high crop demand will result in fewer losses and greater fertilizer nitrogen use efficiency. Placement must work with source, rate, and time to ensure that N is positioned in the rooting zone in crop available form and sufficient quantity when the crop needs it.

Spring banding at or before seeding tends to be more efficient than fall-banding. Fall-banding can result in similar efficiencies in drier parts of the prairies. Deep fall banding after the soil has cooled can perform better than spring banding in situations where reducing spring disturbance and conserving seed bed moisture is a priority. Fall-broadcasting is generally the lowest efficiency time-place combination and should be avoided. Spring broadcasting is typically less efficient than spring banding.

Keep in mind that place-time combinations that result in higher losses do not necessarily result in lower yields. Consider a scenario where banding and broadcasting are compared using the same rates and similar yields are achieved even though condition suggest that losses from broadcasting were considerably higher. If net available N after losses from broadcasting are still sufficient to meet crop needs, then there will be no yield reduction. The implication in the above scenario is not that broadcasting and banding are equally efficient but rather that the N rates are too high for both placements.

Climate

Climate is the long-term pattern of weather in a particular area. Some scientists define climate as the average weather for a particular region and time period such as 30-years.

Choosing the right place requires the right equipment and is consequently harder to change in relation to short term variations in weather. Over a period of years, differences among placements will tend to be more pronounced in parts of the Prairies where risk of loss is higher. The climate risk is primarily related to moisture. Higher rainfall, greater snowfall, more spring runoff, longer saturated periods in spring or during the growing season; these are conditions associated with the wetter parts of the Prairies.

Tillage Practices

Tillage systems on the Prairies should be viewed as a continuum. On the zero till or no till end are one pass systems using minimum disturbance openers and wider row spacings. At the opposite conventional or full tillage end are systems that completely invert and/or pulverize the soil. Surface and subsurface applications are possible all along the continuum but economic and environmental risks will vary widely. Systems that minimize surface disturbance will tend to be the least effective in incorporating broadcast N and preventing volatilization and immobilization.

Tillage System	*Description*	*N Placements*
No Till	Characterized by the use of low disturbance openers and wider row spacings with the aim of reducing soil disturbance and retaining residue on the surface. Benefits include improved moisture storage, increased soil organic matter levels, and reduced erosion risk. Examples Anhydrous ammonia application in fall on 15 in spacing using narrow knives followed by a single pass at seeding. Single pass direct seeding using mid-row or side band placement.	Banding is the preferred N placement with No Till systems. Broadcasting of unprotected N sources increases risk of volatilization, immobilization and runoff losses. Liquid manure can be injected but solid manure is surface applied with high risk of volatilization and runoff losses.
Reduced Till	One or more passes between harvest and seeding using higher disturbance equipment. Significant residue is still retained on the soil surface. Example heavy duty cultivator in fall, spring harrowing followed by mid-row, side band or seed placement of fertilizer at seeding. Seed placement typically done with high SBU openers.	Tillage implements that minimize surface disturbance will tend to be the least effective in incorporating broadcast N and preventing volatilization and immobilization. Banding in reduced tillage systems will be most effective if the band is left undisturbed. Liquid manure can be injected. Level of incorporation of solid manure or surface applied liquid will depend on disturbance level of equipment.
	Multiple passes for weed control, residue management, fertilizer application, seed bed preparation with high disturbance equipment with little or no residue remaining on the surface prior to seeding. Example Fall disk and spring harrowing after broadcasting N.	Most effective for incorporation of broadcast N. Banding in conventional tillage systems will be most effective if the band is left undisturbed. Liquid manure can be injected. Surface applied liquid or solid manure can be fully incorporated.
Strip Till/ Vertical Tillage	There is little consensus on where these tillage systems fit on the Zero-Reduced-Conventional continuum of disturbance. The level of disturbance is very equipment specific. In general, these tillage systems result in more vertical mixing than implements that slide horizontally under the soil surface like sweeps but do not invert soil like a disk. Benefits can include faster warming in spring, redistribution of surface nutrients in the profile, improved water infiltration, improved water infiltration, and break up of surface and near surface compacted layers. Widely used with corn in the US and becoming more popular in Canada as corn acreage increases. Promoted for moisture management during wet years.	Effective for incorporating dribble banded N or N can be banded into the disturbed strip. Side-banding with the drill or seeder is also compatible with these systems.

Residue Management

Placing N in contact with high C:N ratio crop residues tends to increase immobilization. Some of the immobilized N will be released through mineralization once the immobilizing organisms start to die off. Whether that occurs in the current or subsequent crop seasons depends on the quantity and quality of residue and environmental conditions. Warm and moist favours rapid turnover while cool and dry slows release of immobilized N.

Surface applying N in zero-till systems will result in significantly more immobilization than placing N in a band. Banding places the N below the residue layer, reduces soil contact by concentrating the placement, and inhibits microbial activity in the nearby soil. Incorporating residue prior to broadcasting N may reduce immobilization but can potentially increase volatilization. For in-season applications, dribble banding concentrates the N and likely reduces immobilization compared to broadcasting.

Residue management begins with the combine. Poor spreading behind the combine or windrowing straw for baling can result in areas of concentrated straw and chaff and increased immobilization. Heavy residue strips can interfere with accurate placement and incorporate straw and chaff in the fertilizer band. Immobilization caused by poor residue management can induce N deficiency. This tends to show up as lighter green strip of crops aligned with the previous year's swaths or combine tracks.

Performance Objective 3: Discuss how crop stage and crop type will determine the placement or method of application. Crop type dictates row spacing, planting time, N uptake by stage, and N rate. The efficacy and efficiency of the different placements and source, rate, and time interactions have been discussed in early sections of this proficiency area. A brief recap with a focus on the feasibility of different placements based on crop and stage is given below:

- Placements prior to seeding is generally unrestricted by crop type. Seedlings of more sensitive crops may be affected where the seed row crosses a recently applied shallow urea or anhydrous ammonia band.
- Placements at time of seeding needs to consider crop type. Crops vary in their sensitivity to seed placed nitrogen. Cereals are significantly less sensitive than canola and pulses. Higher SBU placements reduce risk. Side banding reduces or eliminates seedling damage provided the separation is sufficient to prevent salt and/or ammonia migration into the seed row. Mid-row banding essentially eliminates issues with seed safety for all crops. However, it may reduce early season N availability depending on band configuration (every row or every other row), row spacing, N rate, available soil N, and the rooting pattern of the crop.
- Placement after seeding needs to consider both crop type and crop stage. Granular N can be broadcast at any time from preemergence through to the time when crop uptake ceases. Crop stage and crop demand determines whether the added N will increase yield. Constraints are crop damage from equipment (clearance, compaction, crushing etc.) and sufficient precipitation or irrigation to move N into the rooting zone. Liquid N sources can be sprayed, or dribble banded after seeding. In addition to equipment constraints, crop tolerance for tissue damage varies by crop type and stage and needs to be factored in when placement involves foliar contact. Sub-surface banding after the crop has emerged is restricted to row crops such as corn and potato and requires specialized equipment.

Performance Objective 4: Discuss how planting pattern (narrow or wide row/solid seeded or row crop) will determine the placement or method of application.

Following along from the discussion above:

- Wider row spacing increases the concentration of N per linear foot of band or seed row. Wider row spacing at the same rate with the same opener reduce the safe level of seed row N and could theoretically at least increase the required separation for side band configurations. Wider spacings also increase the distance from seed row to a midrow band which may slow seedling access to the N.
- In-season placements on the soil surface while avoiding foliar contact are more feasible in row crops than solid seeded crops. Subsurface placements such as side-dressing using coulters are feasible with row crops like corn or potato.

Performance Objective 5: Discuss the role of nitrogen technology products and the considerations for nitrogen placement or method of application for:

Enhanced efficiency nitrogen sources have been discussed at length in various other sections of this proficiency area. A quick recap with a focus on placement is provided below:

A) Urease inhibitors;

Improve efficiency of surface applied urea or UAN by reducing volatilization and allowing time for rainfall to move urea into the soil. Can reduce ammonia toxicity and improve seedling safety when used in the seed row or banding below the seed. However, when using in this application results are dependent on environmental conditions. If there is insufficient moisture to disperse the accumulating ammonia and allow nitrification as the UI declines in efficacy, seedling damage can occur.

B) Nitrification inhibitors;

Prevent nitrification when used with granular, liquid or gas forms of ammonium N. Used with subsurface placements. Surface placement with urea or UAN can result in increased volatilization unless combined with a UI. Useful alone or in combination with a UI in early fall banding applications. Nitrapyrin can be added to liquid manure and injected.

C) Controlled and/or slow release nitrogen products.

Polymer coated urea can be used to increase safe rates of seed placed urea. PCUs can also be used in broadcast application to reduce volatilizations losses, for example, spring applications on winter wheat or forage stands. PCUs generally reduce overwinter N loss compared to standard urea when fall broadcast with or without incorporation. They can be used in fall banding to reduce overwinter N loss and in spring banding to delay N availability to more closely match crop demand. Delayed release under dry surface conditions can be a problem when surface applied in-crop including winter wheat, forages and spring seeded crops.

An expert sums up...
In-soil banding is still the gold standard for nutrient use efficiency in Manitoba. While enhanced efficiency products do not close the gap between in-soil banding and surface applications, they can narrow the gap if used correctly. Surface applications will not normally be as good as in-soil bands from the perspective of nutrient use efficiency, but they may provide advantages in other areas of the farming operation, including more rapid seeding, reduced soil disturbance, less draft requirement, lower equipment and fuel costs and increased field trafficability. Delaying nitrogen applications until after seeding may also allow assessment of yield potential before the nitrogen is purchased, potentially reducing the inputs into a low-yielding crops or allowing greater N applications on a better than expected crop. In-crop applications may also play a role in protein management in high-quality wheat production. Since the decision to use surface application rather than in-soil banding requires consideration of the potential costs and benefits of each method of application. This includes determination of how much nitrogen will likely be lost from the various pathways and how effective use of enhanced efficiency products will be in reducing those losses. It also requires an assessment of how important savings in time, soil disturbance, draft requirements, fuel and equipment costs, or increased flexibility of timing of application are in contributing to crop yield potential or economics of production. While in-soil banding is still the gold standard for nutrient use efficiency, there may be situations where surface applications with the use of enhanced efficiency fertilizers may contribute to whole farm efficiency. A sound understanding of agronomic and nutrient management principles will help to ensure that the best decisions are made for the overall farming operation. -Dr. Cindy Grant (2014)
Extracted from Surface versus banded nitrogen: Do new products close the gap?

Performance Objective 6: Evaluate the role of in-crop application, including fertigation, in 4R nutrient management planning.

In-crop application provides flexibility in 4R nutrient management planning. Some of the benefits include:

- Ability to adjust to improving crop growth conditions. For example, reducing yield goals and N rates in a dry spring and then using in-crop application to provide additional N if moisture conditions improve.
- Control economic risk and respond to changes in market conditions. If crop prices are volatile during planning and seeding, conservative N rates can be applied and in-crop application used in response to improved or stabilized market conditions. This

may include rising crop prices and/or changes in quality premiums like protein in wheat.

- Increase protein levels in wheat. In-season N application between stem elongation and the start of heading tends to build protein levels rather than increasing yield.
- Manage fertilizer logistics. For direct seeders, moving a portion of the N from at seeding to in-season can help create room in the fertilizer cart for other nutrients or speed up seeding by reducing the number of cart fills required. Also, an option when fall application was not completed due to any reason (late harvest, early freeze up, soil too wet or too dry).
- Reduce environmental risk. In-season application reduces the time between application and the period of maximum uptake (think of the S curve) and reduces the exposure of N to loss.

Fertigation is a particularly useful tool for high value irrigated crops where N availability needs to be closely monitored and controlled to balance yield and quality requirements. Application of N through irrigation water also allows for dilution of the N source and higher rates can be applied with no risk of crop damage. A good example of this approach is with irrigated processing potatoes in S. Alberta. Once tuber initiation starts, growers will monitor nitrogen levels weekly using petiole testing. If N levels start to fall below a predetermined threshold, N is added to the irrigation water.

Additional Resources

Dr. Cindy Grant did a nice review of source by place interactions in Surface versus Banded Nitrogen: Do new products close the gap? Available from the University of Manitoba website:

https://umanitoba.ca/faculties/afs/agronomists_conf/media/Grant_-_Surface_versus_Banded_Nitrogen_-_paper.pdf

COMPETENCY AREA 5. ENVIRONMENTAL RISK ANALYSIS FOR NITROGEN

Performance Objective 1: Explain nitrogen management decisions as they affect water quality (groundwater and surface water).

A) Eutrophication;

Eutrophication is the process of nutrient enrichment in aquatic ecosystems. Surface waters on much of the Prairies tend to be naturally eutrophic or nutrient rich supporting abundant plant growth. They are generally phosphorus limited meaning that available P levels set the upper limit of plant biomass production. Removing that limit through P loading from crop lands can increase the primary plant biomass production through algae blooms and aquatic weed growth. Most prairie lakes, rivers, streams and wetlands supported algae blooms prior to agricultural intensification. Usually in mid-summer when P is released from bottom sediments. Nutrient loading has resulted in increased frequency and duration of these blooms. Often when the P limitation is removed, N is the next limiting nutrient. Nitrogen loading can consequently act synergistically with P loading to increase algae growth beyond what it would be with P loading alone. Photosynthesis produces oxygen and respiration consumes oxygen. As plant biomass peaks and then declines and decays oxygen is depleted and the system can become anoxic. Greater production of algae in a boom and bust cycle can increase the frequency and duration of hypoxic events where oxygen levels fall below the concentration required to sustain animal life.

Nitrogen management practices that increase losses from the cropping system to surface waters can lead to eutrophication. This includes leaching into tile drains or groundwater that feeds surface water bodies as well as edge of field losses through runoff. While it is a fairly minor component, a portion of volatilized N will also be redeposited on water bodies or on soil where it can convert to nitrate and find its way into surface waters. Source, rate, time, and place practices that reduce cropping system losses particularly losses through tile drains and surface runoff will help reduce eutrophication.

B) Aquatic Life;

As explained above, nutrient loading can lead to algae blooms. These blooms can reduce sunlight penetration to the point where rooted aquatic plants die resulting in loss of fish and invertebrate habitat. Hypoxic events triggered by decay of rotted plants and algae as a bloom collapses can result in fish kills. Fish vary in their tolerance to low oxygen levels with members of the trout family including lake whitefish succumbing before other species.

Blue-green algae or cyanobacteria are a common form of algae in Prairie waters. They produce toxins that can kill aquatic animals. Mammals including humans drinking from waters with high levels of cyanobacteria can develop serious gastric problems and can die. Humans swimming or bathing in water with high levels of cyanobacteria can develop skin rashes, eye irritations, and allergic reactions.

Fish and aquatic invertebrates have a low tolerance for ammonia. Nitrogen loading from agricultural lands can contribute to aquatic ammonia levels. Volatilization of N from fertilizer or manure followed by re-deposition in water is one pathway. Ammonia is a highly soluble gas and can also move with runoff waters. Ammonia release to the atmosphere from industrial sources is high on the Prairies with N fertilizer plants being a major contributor. Addition of N to waters in any form will over time increase ammonia concentrations through nitrogen cycle processes. The guideline for ammonia for the protection of aquatic life, NH_3 (g) often referred to as un-ionized ammonia, in freshwater is 0.019 mg/L or 19 parts per billion.

C) Drinking water quality relative to the standards.

The Prairie Provinces subscribe to the Canada Health Standards for nitrate and nitrite in drinking water. The maximum acceptable concentration (MAC) for nitrate in drinking water is 45 mg/L. This is equivalent to 10 mg/L measured as nitrate-nitrogen. The MAC for nitrite in drinking water is 3 mg/L. This is equivalent to 1 mg/L measured as nitrite-nitrogen. The conversion from nitrate the anion (NO_3^-) to nitrate-N (NO_3-N) and nitrite to nitrite-N is shown below.

$$\frac{MWNO_3}{MWN} = \frac{14+3\times16}{14} = \frac{62}{14} = 4.43$$

$$\frac{MWNO_2}{MWN} = \frac{14+2\times16}{14} = \frac{46}{14} = 3.29$$

Nitrate in drinking water has been linked to a host of human health issues including blue-baby syndrome, thyroid issues, diabetes, and cancer. Recent research suggests that consistently high levels of nitrate in surface waters can harm some forms of aquatic life, particularly amphibians. Unlike nitrate and nitrite, ammonia is not a human health concern in drinking water at the levels typically observed in the environment.

Performance Objective 2: Evaluate management strategies that will reduce nitrogen loss impacts to air, including ammonia volatilization and nitrous oxide emissions, and surface water and groundwater.

The N cycle[3] illustrates the various forms and pathways that N can take as it is transformed and transported through an agricultural production system. Understanding the processes that make up the N cycle and their relative importance, which may change spatially and temporally, is key to any evaluation of N management strategies. Evaluating N losses can take many forms and no one method or tool is appropriate for all situations. Any evaluation should identify what the major risks of N loss are likely to be, provide some level of ranking of that risk, and apply economics where feasible to ensure that dollars are spent efficiently on risk reduction. In some cases, risk reduction practices may be dictated by regulation and the role of the 4R agronomist is to recommend practices that cost effectively meet the regulatory burden.

Implementing practices that reduce N loss from cropping systems will reduce fertilizer and manure N impacts on the environment. In reality, however, significant leakage is unavoidable. Even when applied N utilization by a crop is high, the N removed in harvested material is subject to escape into the environment along the food chain to the ultimate end user. In the modern world, N moves from a geographically dispersed production in a cropping system to geographically concentrated consumption (feedlots and cities, for example). Leakage into the environment occurs at every step along the way and while the ecosystem has some capacity to absorb and ameliorate that leakage, environmental harm results when that capacity is exceeded.

While N leakage is inevitable, the aim of 4R Nutrient Stewardship is to reduce leakage from the cropping system through application of Right Source @ the Right Rate, Time and Place principles and practices. Managing N to minimize environmental damage must be balanced against economic goals for the farm and social goals such as the demand for food. The principles and practices of 4R N management have been covered in the Competency Areas on Source (CA1), Rate (CA2), Time (CA3), and Place (CA4). What follows is a brief recap of N loss processes, their environmental impacts, and 4R strategies and practices that can reduce N losses.

Keep in mind that practices can be combined when they are synergistic or offsetting. For example, a poor timing can be improved by a right source or placement selection. In some circumstances there is no further advantage or additionality from combining practices. For example, deep banding of anhydrous ammonia after the soil has cooled in the fall using narrow knives with good closure in moist soil is not likely to be improved much by addition of a nitrification inhibitor.

Volatilization

Ammonia volatilization occurs when manure or an ammonium-based fertilizers (particularly urea) are applied without timely incorporation into the soil. Shallow banding, poor furrow closure, excessively wide band spacings in relation to rate can also result in ammonia release over the band. Over half of the ammonium N from surface applied manure can be lost to the air under warm, dry conditions, greatly reducing the fertilizer value of the manure. However, the concentrations of ammonia released are not high enough to cause direct environmental or human health harm outdoors, and most of the ammonia is re-deposited within a few hundred meters of where it was released. Volatilization does contribute in a minor way to the N loading of surface waters and a portion of the volatilized N is converted to nitrous oxide following re-deposition and subsequent nitrification and denitrification. Volatilization losses can significantly impact the economics of crop production.

Main strategies to reduce volatilization include:

- Use of protected N or less volatile N sources in surface application. This can include pre-treatment of manure to stabilize N.
- Reducing/matching rates to reasonable yield goals.
- Applying when weather conditions are cool and moist or moderate rain is expected. Apply once the canopy has established in forage crops.
- Incorporation with tillage and banding at sufficient depth is arguably the most effective strategy to trap ammonia when manure or unprotected fertilizer N sources are used.
-

3 See diagrams of the N cycle and ammonia cycle at the beginning of Proficiency Area 3: Nitrogen.

Denitrification

Denitrification occurs in cropping systems with slow internal drainage (fine-textured soils), an ample carbon supply and saturated soils from snowmelt, shallow groundwater or heavy rainfall. The other triggering factor is accumulation of nitrate. Practices that slow or reduce the accumulation of nitrate will tend to reduce denitrification losses. The environmental impact of denitrification occurs when denitrification is incomplete and a portion of the lost nitrate is emitted as nitrous oxide instead of dinitrogen. Denitrification can impact profitability substantially as losses can result in significant yield reductions.

Main strategies to reduce denitrification include:

- Selection of ammonium-based sources or protected N sources over nitrate containing sources.
- Ensuring that rates do not exceed crop demand by setting reasonable yield goals and accounting for soil N sources when setting rates. This ensures low residual nitrate at the end of the growing season.
- Applying in late fall after the soil has cooled or in spring or splitting N applications to match crop demand periods more closely.
- Banding of fertilizer or band injection of liquid manure.

Leaching

Leaching occurs in cropping systems with fast internal drainage (coarse texture) where saturation from snowmelt or heavy rainfall allows water to move below the rooting zone. The other triggering factor is accumulation of nitrate. Practices that slow or reduce the accumulation of nitrate will tend to reduce leaching losses. The environmental impact of leaching occurs when nitrate enters groundwater and reduces the water quality. Leached nitrate can also reach surface waters through drains or groundwater contribution to streams or rivers where it can drive eutrophication. A fraction of leached nitrate will undergo denitrification and contribute nitrous oxide to the atmosphere.

Main strategies to reduce leaching include:

- Selection of ammonium-based sources or protected N sources over nitrate containing sources.
- Ensuring that rates do not exceed crop demand by setting reasonable yield goals and accounting for soil N sources when setting rates. This ensures low residual nitrate at the end of the growing season.
- Applying in late fall after the soil has cooled or in spring or splitting N applications to match crop demand periods more closely.
- Banding of fertilizer or band injection of liquid manure helps slow conversion to nitrate

In some aquifers, denitrification can convert nitrate to dissolved N gas, which is not directly harmful to aquatic ecosystems or human health. However, denitrification cannot be counted on to eliminate all the nitrate-N leaching to groundwater or running off to surface water.

Runoff

Runoff occurs when water accumulates on the soil surface from precipitation or snowmelt faster than it can infiltrate. Infiltration is related to texture (coarse>medium>fine) but can be significantly modified by structure. Granular water stable aggregates in surface horizons in medium and fine textured soils can have infiltration rates approaching sandy soils. Soil compaction, crusting, and excessive tillage can all destroy structure and reduce infiltration. Snowmelt is the most significant runoff event in most years.

Meltwater running over frozen soil can carry soluble N forms in solution and less soluble exchangeable forms in sediment. Practices that slow or reduce runoff and/or avoid surface accumulation of mobile N forms will tend to reduce runoff losses. The environmental impact of runoff occurs when nitrate or other forms of N reduce surface water quality. Runoff can pond in a field and leach nitrate as the water moves through the profile during groundwater recharge. A fraction of runoff N will undergo denitrification and contribute nitrous oxide to the atmosphere.

Main strategies to reduce N loss in runoff include:

- Avoid surface application of urea and nitrate sources without incorporation in fall.
- Incorporate manure.
- Avoid surface applications of fertilizer N ahead of major precipitation events that are like to generate runoff. A rainfall of 3 to 5 tenths of an inch (8-12 mm) will move surface applied urea into the rooting zone. Greater amounts may result in runoff losses particularly if the soil is at or above field capacity.
- Avoid application of fertilizer or manure on frozen or snow-covered ground.

Secondary Practices and Strategies to Reduce N Losses

- Soil test annually for N to a depth of 24 inches. Nitrate-N is highly dynamic and a current soil test is one of the best ways to understand the current available N status in soil and associated environmental risks.
- When planning nitrogen applications, account for contributions from all sources, previous legume crops, manure or biosolid application. Most importantly factor in an estimate of N mineralization.
- Calculate an N balance, return on investment, production efficiency (yield per unit of N) and/or fertilizer use efficiency such as agronomic efficiency or recovery efficiency.
- Use buffer strips and erosion control structures to filter runoff before it enters surface water. Buffer strips in riparian zones have proven to reduce nutrient movement off the field into nearby surface water sources. Buffer strips consume excess nutrients before they flow into surface water and enhance opportunities for groundwater denitrification. Buffers include riparian buffers, filter strips, grassed waterways, shelterbelts, windbreaks, living snow fences, contour grass strips, cross-wind trap strips, shallow water areas for wildlife, field borders, alley cropping, herbaceous wind barriers, and vegetative barriers. On the Canadian Prairies, the effectiveness of buffer strips is reduced when snowmelt is moving across buffer strips where the soil is still frozen.

Performance Objective 3: Discuss the role of nitrogen management in greenhouse gas (GHG) emissions and particulate matter development.

GHG emissions from cropping systems can include carbon dioxide, methane, and nitrous oxide. Nitrous oxide and methane emissions are linked to fertilizer and manure applications. Carbon dioxide emissions are linked to loss of soil organic matter caused by excessive tillage and stubble burning.

Sources of Greenhouse gas emissions from Canadian agriculture excluding CO_2 emissions associated with energy use.

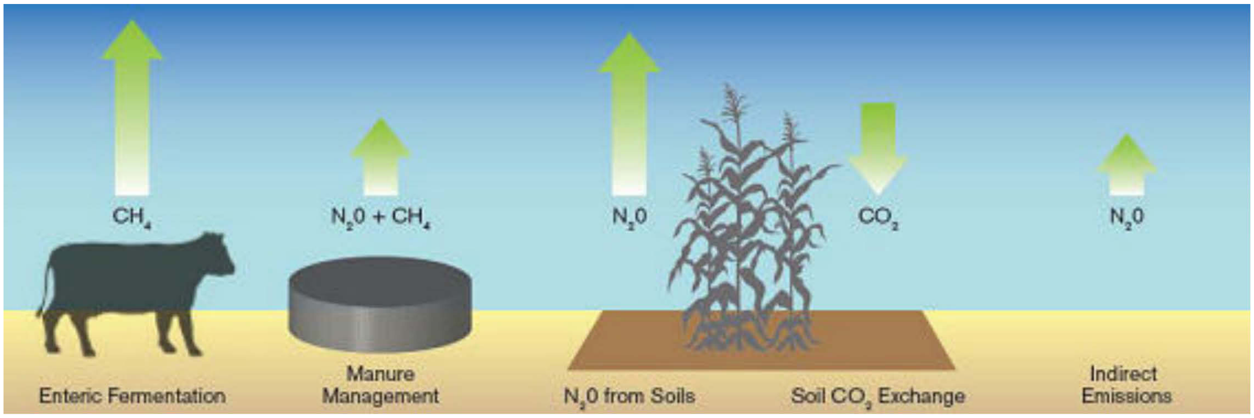


Figure shows the relative magnitudes of greenhouse gas emissions from four sources. From highest to lowest the emitters are CH4 from enteric fermentation, N20 from soils, N20 + CH4 from manure, and indirect emissions of N20. Cropping systems remove CO2 from the atmosphere during photosynthesis and a portion ends up in soil organic matter.

Source: Agriculture and Agri-Food Canada.

Nitrogen BMPs can significantly reduce nitrous oxide emissions from soil. Conservatively estimated improved N management is likely to reduce nitrous oxide emissions associated with N fertilizer application by 15-35% in Prairie cropping systems. Nitrous oxide emissions are generated primarily through nitrification and denitrification. Source, rate, time, and place practices that slow nitrification and prevent build-up of nitrate and subsequent denitrification will reduce direct nitrous oxide emissions. Reducing cropping system N losses through volatilization, leaching, and runoff also reduces indirect nitrous oxide emissions.

Nitrogen management also plays an important role in carbon dioxide emissions. The advent of reduced and zero tillage cropping systems on the Canadian Prairies has reversed the trend of soil organic matter (SOM) loss and carbon dioxide emissions. Prairie agricultural soils are now a net sink for atmospheric carbon dioxide. Capture of carbon dioxide by crops followed by the return of crop residues to the soil and stabilization of that carbon through formation of SOM (the carbon sequestration process) results in net removals of carbon dioxide from the atmosphere. [4]Higher yielding crops produce more residue and adequate nitrogen supply ensures a greater portion of that residue remains in the soil as SOM.

Performance Objective 4: Evaluate the influence of soil type, topography, and location of watersheds on the environmental impacts of nitrogen on surface and groundwater resources.

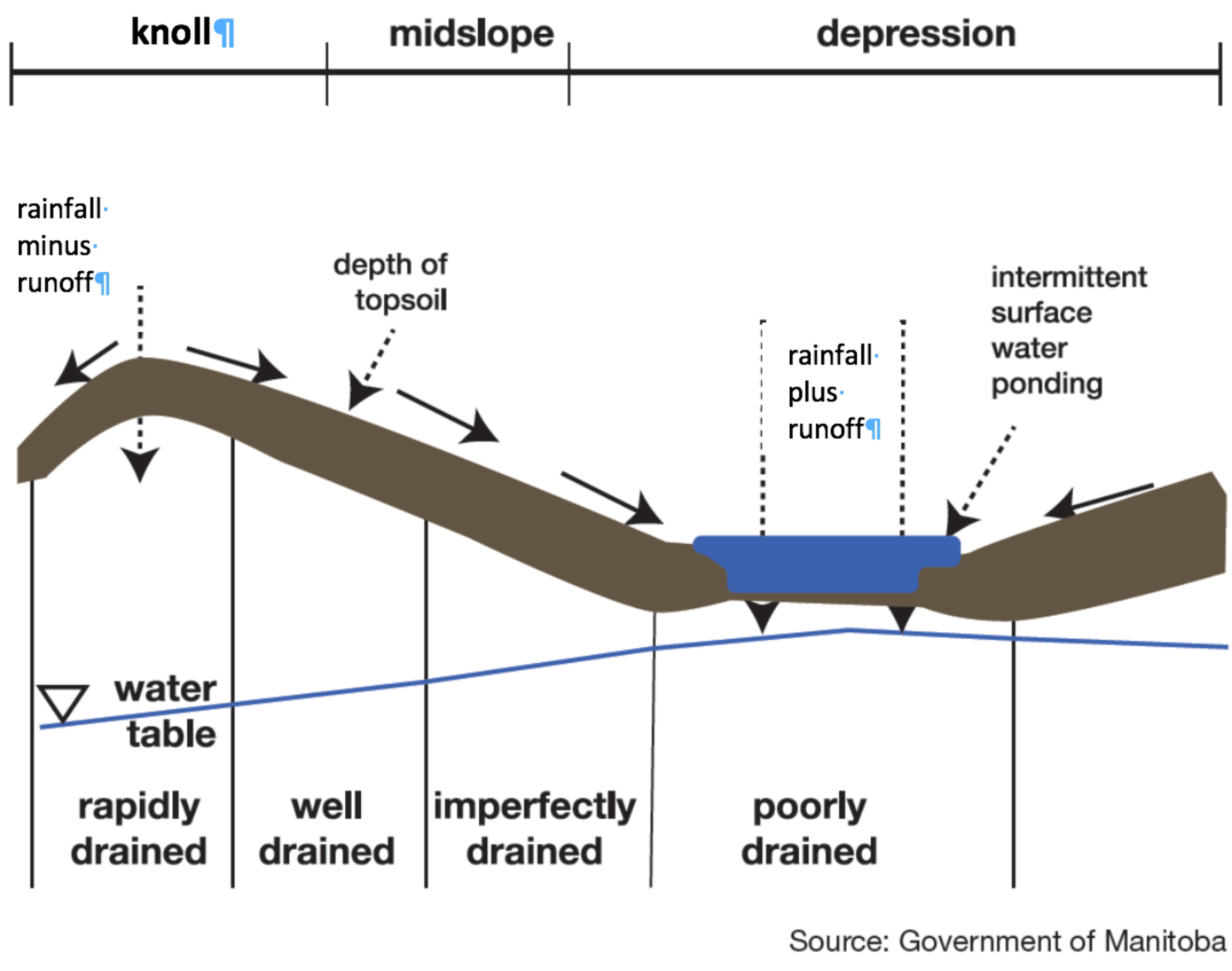
Every field has unique soil and topographic characteristics that control the movement of water in the landscape and must be considered during nutrient management planning.

Prairie landscapes are the result of relatively recent (10,000 years BP) glaciation and Prairie soils have developed on glacial drift material. The most common landform is morainal and the most common parent material is till. As a result, the majority of Prairie soils are developed on medium textured material with undulating to hummocky topography characterized by small closed basins and unconnected drainage. Water runs into the nearest depression, carrying nitrogen with it. If there is sufficient water, to move down and recharge the groundwater N can leach. If the soil is only temporally saturated or movement down the profile is slow, nitrate may denitrify before it is leached. N losses may not be of much concern environmentally in these situations. Even if the nitrate moves

4 In Alberta, the GHG capture by cropping systems has been monetized through the Alberta Carbon Offset Program. Zero-till farmers are paid for the carbon dioxide they capture.

through to groundwater, unless it enters into a domestic well there may be little or no risk. However, losses may be agronomically significant.

Water Movement and Leaching in Prairie Landscapes



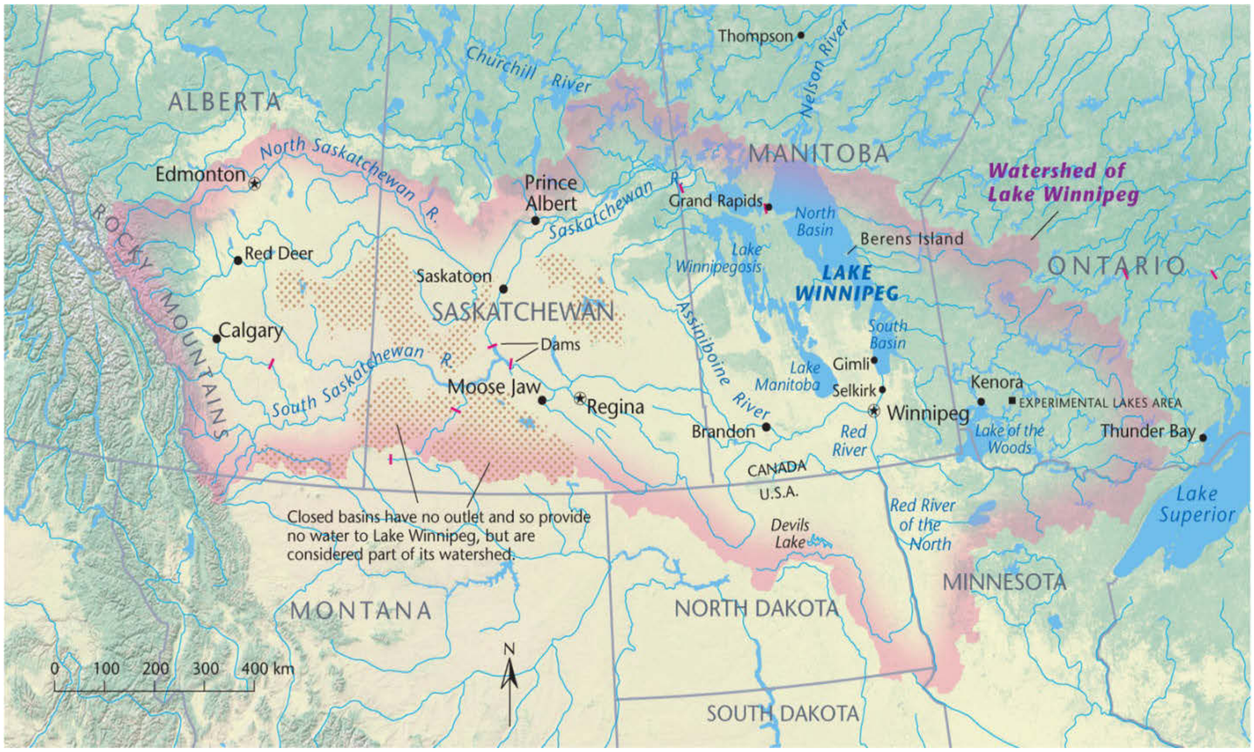
In landscapes with closed basins, water moves downslope with runoff and collects in depressions. Leaching potential is higher in depressions (precipitation plus runoff) than it is upslope (precipitation minus runoff). There is more water to move through the profile. In spring, snowmelt cannot penetrate frozen soils and collects in temporary meltwater ponds. Nitrogen surface applied on frozen or snow-covered soil moves with melt water and can move through to groundwater in depressions or can be lost through denitrification in the saturated soil.

In the flatter areas of the Prairies, (for example, the Red River Valley near Winnipeg, the Regina Plain, and the Lake Edmonton Basin) soils are developed on old glacial lake bottoms. These tend to be fine textured soils, water is likely to run-off or pond in shallow depressions (fields are never really flat) and denitrification losses will predominate. Movement of nitrate to groundwater is less likely as movement of percolating water through the profile is extremely slow in these fine textured soils.

In fields with connected surface drainage, water may actually leave the field resulting in edge of field N losses. Tile drainage can move water from closed basins into surface waters, connecting leached nitrogen to downstream surface waters. The semi-arid climate on the Prairies, significantly reduces runoff. However, it is important to assess the size of watersheds, how surface water runoff gathers, and where it eventually drains. Also, when runoff is likely to occur. For example, N losses in surface runoff during the spring melt may be low (a few percent of fall-applied N and have little effect agronomically), but if the watershed is large and drains into a stream or lake that is susceptible to nitrogen loading, the environmental impact may be much greater than the agronomic loss.

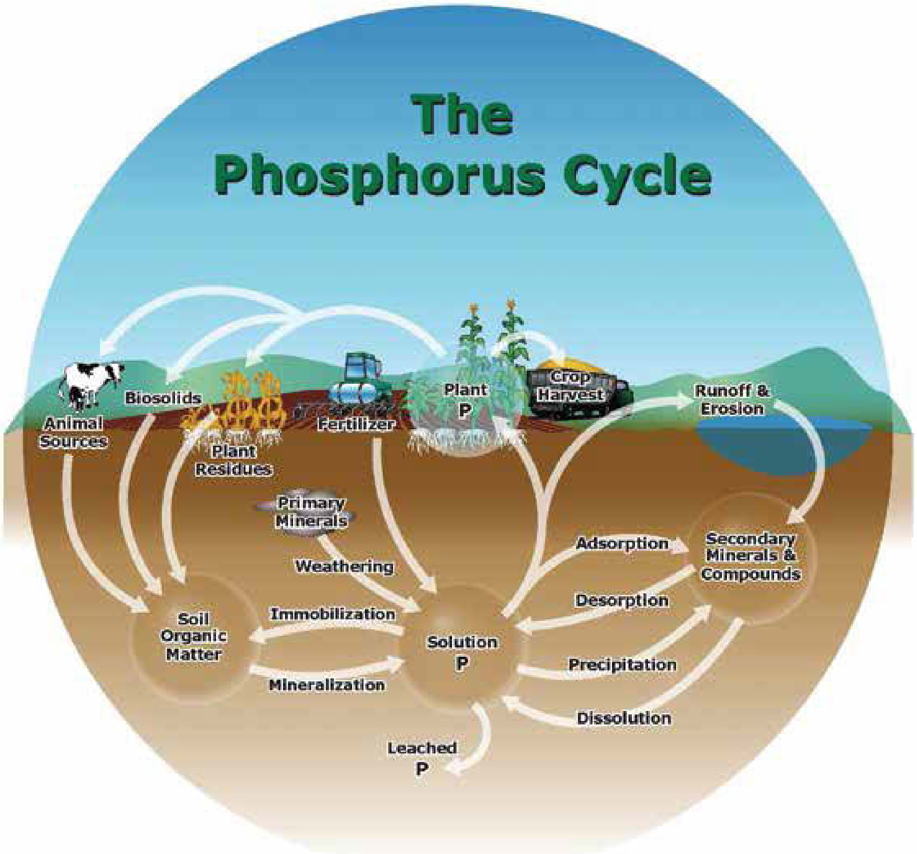
As shown below, Lake Winnipeg is the final destination for water leaving the field in most of the agricultural areas of the Prairies.

However, there are areas of Southern Alberta and Saskatchewan that connect to the Mississippi-Missouri drainage that ends in the Gulf of Mexico. There is a significant anoxic (dead) zone in the Gulf of Mexico caused by nutrient loading in the Mississippi-Missouri system. Unlike freshwater systems, marine systems tend to be more sensitive to increases in N rather than P.



There should be continued efforts to reduce losses of N in runoff wherever possible. Fields are likely to have areas that are unconnected and areas that are connected to surface drainage. Assessment of topography and soil type can identify contributing and non-contributing areas in a field and help focus reduction strategies where most appropriate.

PROFICIENCY AREA 4
PHOSPHORUS



Source IPNI

Phosphorus (P) is an essential plant nutrient. Reduced soil P availability can result in reduced emergence and reduced early season growth, delay in maturity and reduced crop yield. Phosphorus is immobile in soil but mobile in plants and will be translocated to the growing points when deficiency occurs.

Depending on crop type, P-deficient leaves turn dark green with stunted crop growth (which may also be subtle symptom expression). Phosphorus deficiency is also expressed as reddish/purple coloration on older leaves as anthocyanin pigments accumulate, or older leaf and leaf tip blunting with browning ends.

Note: The Competency Areas and Performance Objectives in this Proficiency Area tend to overlap quite a bit. As a result, there is a fair amount of repetition of important points.

Severe Phosphorus Deficiency in Canola

Source: D.L. Armstrong PPIC

Phosphorus is relatively immobile in soils and is generally retained by the soil and its component fractions. Added P can be precipitated out as sparingly soluble compounds of calcium, magnesium, iron, and aluminum. Added P can also be adsorbed onto soil surfaces. Plant available P is generally in greatest availability between soil pH of 6.0 and 7.0. Plants absorb most of their P as primary orthophosphate ($H_2 PO_4^-$) with lesser amounts being taken up as secondary orthophosphate (HPO_4^{2-}); this balance depends on pH and the ionic species HPO_4^{2-} can be dominant in soils with pH above 7.5.

Phosphorus losses from cropping systems are relatively small and are not generally agronomically or economically significant.

The small amounts of P loss from soils (particulate or dissolved) can impact water quality by stimulating algal blooms. Practices that prevent excess P build up in soil, control soil erosion and restrict off-field water movement will limit the losses of P bound to soil particles and dissolved P in soil water. Source, rate, time and placement of P are important considerations in limiting P movement and run-off. The principles of 4R Nutrient Stewardship provide a scientific basis for a farmer to make fertilizer decisions to achieve production goals in an environmentally acceptable manner that meet social objectives.

COMPETENCY AREA 1. DETERMINING THE RIGHT SOURCE OF PHOSPHORUS

Selecting the Right Phosphorus Source should take into account soil properties, crop requirements, and potential losses to water and the atmosphere. The most common manufactured P fertilizer sources on the prairies are monoammonium phosphate (MAP: 11-52-0) or ammonium polyphosphate (APP: 10:34-0)).)). Other P fertilizers readily available on the Prairies include Microessentials® S15 (13-33-0-15) granular P and sulphur fertilizer. It contains monoammonium phosphate as the P source.

Alpine makes a fluid starter fertilizer that is a mixture of potassium monophosphate (KH2PO4) and ammonium monophosphate (NH4H2PO4). Di-ammonium phosphate (DAP: 18-48-0) is not a common source used on the prairies.

Performance Objective 1. Discuss the most common sources of phosphorus used in the Prairie Provinces.

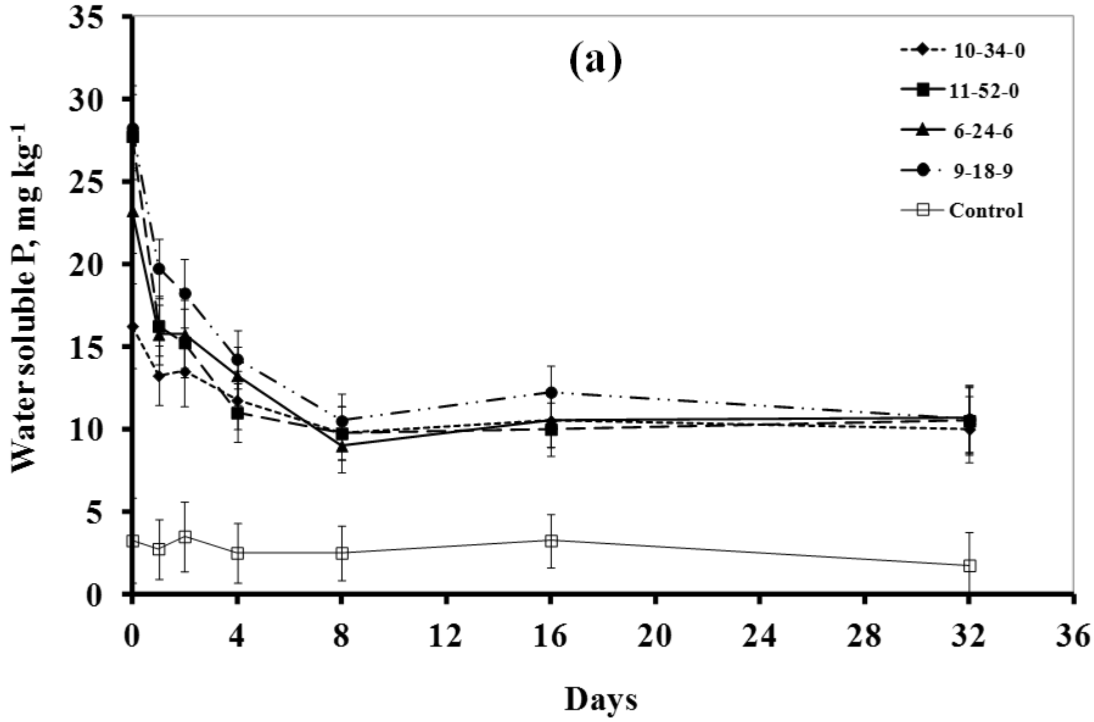
Monoammonium phosphate is a widely used source of P and N. It typically has a P_2O_5 content of 52% (variations of 48 to 55%) and a typical N content of 11% (variations of 10% to 12%). This product is water soluble and dissolves rapidly in soil with adequate moisture. The product dissociates into NH_4^+ and $H_2PO_4^-$. Upon dissolution, MAP forms an acidic solution that can aid in P availability in neutral to higher pH soils. Within seed placed safety limits, MAP is most commonly applied in-row or as a side-band; less commonly it is surface broadcast and incorporated.

The most common analysis for APP is 10-34-0. Typically, about 50% to 75% of the P in APP is in long chain P linkages ("poly – phosphate") with the remainder being in the orthophosphate form. Phosphatase enzymes in the soil convert polyphosphate chains to orthophosphates ($H_2 PO_4^-$ / HPO_4^{2-}) relatively quickly under spring prairie conditions (approximately 2 to 5 days).

Agronomically, there is no significant difference in P nutrition between dry and liquid P fertilizer forms.

When P fertilizer is added to Prairie soils, whether in granular or liquid form, it reacts quickly to form less soluble compounds that precipitate out of solution. In an experiment comparing granular MAP to three liquid P fertilizer, the amount of soluble P remaining in the soil solution was the same after 8 days.

Soil Solution P Concentrations of Granular Compared to Liquid Sources.



Graph courtesy of Dr. Tee Boon Goh

Performance Objective 2. Discuss considerations to determine the right source of phosphorus.

Since all the readily available fertilizer sources tend to be agronomically similar (with MAP and APP being the predominant commercially available P forms), the main considerations in source selection are cost and logistics related to rate, time, and place. Crop type, rooting pattern/distribution, cropping sequence/rotation, environment/climate, soil texture, pH, crop stage, and environmental concerns are secondary factors to consider in P source selection.

COMPETENCY AREA 2. DETERMINING THE RIGHT RATE OF PHOSPHORUS

Fertilizer P is expressed as P_2O_5; some analytical reports may express the content in the “P” form (e.g. manure analysis). Convert P to P_2O_5 by multiplying P x 2.29 (where, 1 lb P = 2.29 lb P_2O_5).

Apply P based on the soil nutrient supply and plant demand, along with consideration for P needs of the cropping sequence. Encouraging growers to establish a soil testing program is critical in determining the right rate and understanding which approach sufficiency, removal placement or build and maintain is appropriate for the cropping system. Crop uptake primarily concentrates P in the grain. The table below indicates general P requirements and removals for several prairie region crops. Certain crop species have higher P requirements per unit of production than others.

Soil test laboratories may use different extraction methods and recommendation philosophies vary across laboratories. Reported plant available P and critical P soil concentrations also vary with laboratory. Laboratory philosophy may be predicated on sufficiency, maintain, build and maintain or build soil test P level. The standard soil test P extractant methodologies used on the prairies are the Olsen and/or the modified Kelowna – P soil test.

A plant tissue test can be used to measure plant P concentration. These are compared to plant P sufficiency ranges to determine if P is sufficient (see also table below for examples).

Crop Phosphorus Requirements

Crop	Yield	P_2O_5 lbs/ac
Wheat	60 bu	44-53 (32-39)
Canola	45 bu	60-75 (50-60)
Barley	75 bu	35-40 (28-30)
Corn	150 bu	75-110 (55-66)
Oat	100 bu	36-45 (23-28)
Soybean	35 bu	32-35 (29-32)

(Value in brackets is P_2O_5 removed in grain)

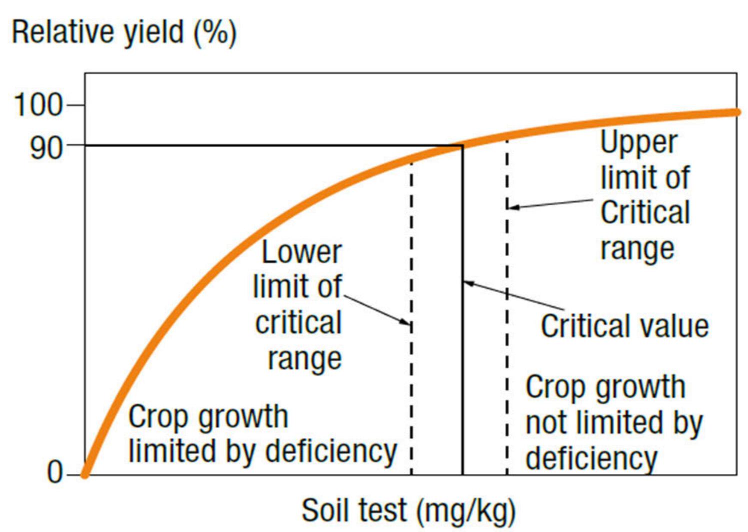
Fertilizers Canada

Performance Objective 1. Interpret how soil test phosphorus levels relate to crop yield response and potential environmental impacts.

Soil testing can be a useful predictor for the requirement of P fertilization and the likelihood of an economic response. Proper P management, through the use of soil testing parameters, can aid in evaluating risk of P loss to erosional events, surface runoff or field drainage water.

Phosphorus soil tests need to be calibrated for the crops and soils in a region through a series of field trials that correlate soil test phosphorus (STP) levels with yield. Trials are run for different crops at multiple locations over a number of years. Sites are selected for a range of soil test values. At each site a check is compared to a treatment that received P fertilizer at a rate that ensures maximum response. Data from these trials is analyzed by expressing the check yield relative to the maximum yield obtained. The data from multiple sites is pooled to determine the critical value; the STP value above which the response function flattens out . Typically, the critical value is defined as the point on the curve where 90% relative yield is reached.

Critical Values from Soil Test Calibration



Source:IPNI

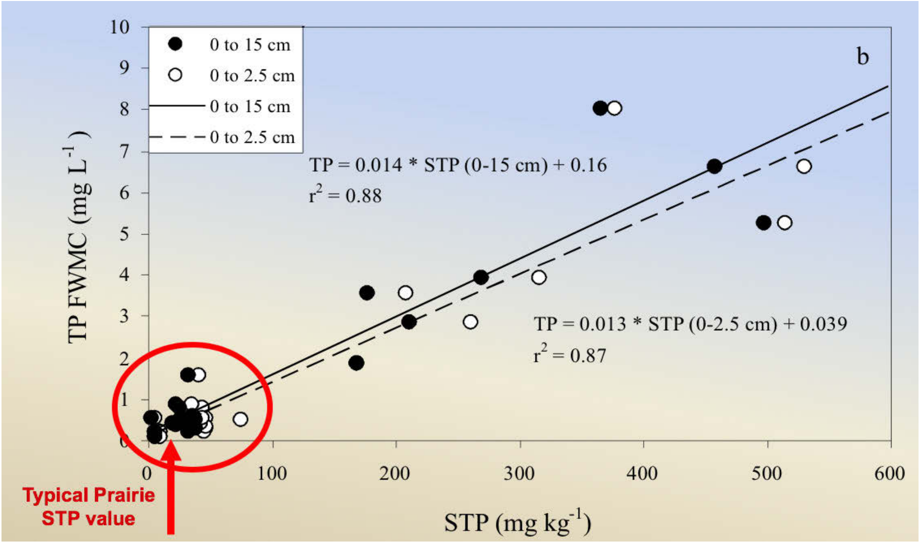
The critical value separates soils where crop growth is likely to be P limited from those where P is not likely to be limiting. In practice, the below and above sections are broken into subsections with each having a probability of response.

Soil Test as a Probability Function		
Soil Test Class	**Probability of Response**	**STP Range (mg/kg)1**
Very Deficient	Profitable response in all but rare cases	0-10
Deficient	Profitable response in most seasons	11-17
Marginal	Average response over years is profitable	18-25
Sufficient	Occasional profitable response	26-40
Excessive	Profitable response unlikely	41>
Critical Value	Point of 90% Relative Yield	20
[1] Based on the Modified Kelowna Soil Test Method and canola as the test crop.		
Source:McKenzie et al.		

The example shown is from calibrations performed for canola using the Modified Kelowna Method in Alberta. Keep in mind that critical limits and recommendations vary by crop and region and different labs may use different soil test methods with different critical limits. Recommended P rates are higher at lower STP levels. Recommended rates for each soil test level may be modified by soil texture, spring soil moisture, and soil zone.[1]

Adequate P application rates improve crop yield, but as shown below potential for loss increase as soil test P increases. Adding P beyond what is sufficient to achieve reasonable target yields, increases risk of negative environmental impacts with no economic benefits. Risk of P loss is not only dependent upon rate, but interactive with application timing and placement method.

At High Levels of STP, STP Is Strongly Related to Total P Concentrations in Runoff in Alberta

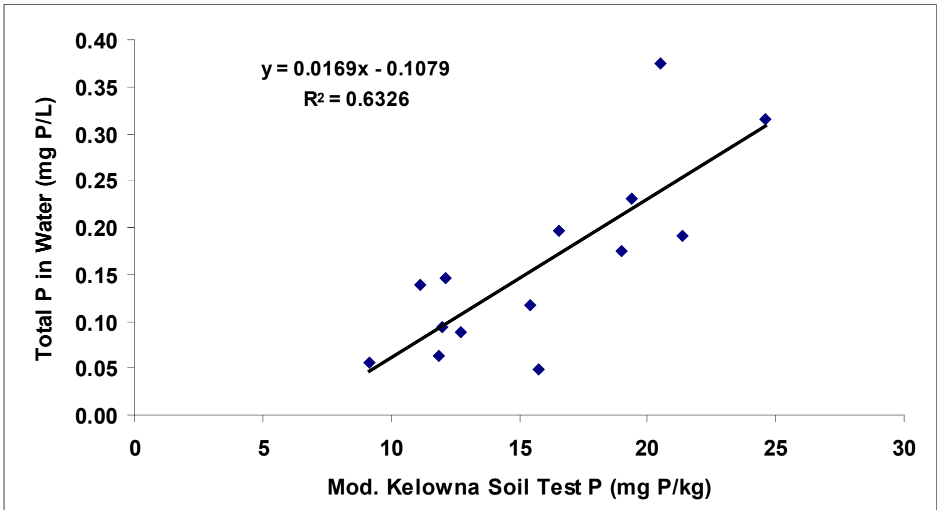


Little, J.L, Nolan, S.C, Casson, J.P. and Olson, B.M. 2007. Relationships between soil and runoff phosphorus in small Alberta watersheds. J. Envir. Qual. (2007). Snowmelt > 90% of runoff, DP = 55 % of TP, Modified Kelowna STP extraction method.

1 For a more detailed explanation and examples of P recs for various crops see https://open.alberta.ca/dataset/6065151

While the above shows that the higher the STP the greater the amount of total P carried in runoff water, the figure below shows that in areas with high STP surface waters tend to contain more P.

Soil Test P and P Concentrations in Manitoba Waterways Are Strongly Related



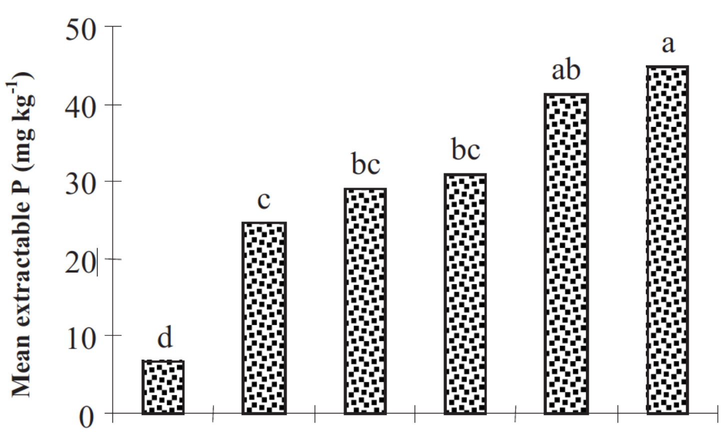
Adapted from Salvano and Flaten. 2006. Phosphorus risk indicators: Correlation with water quality in Manitoba.

Soils with STP levels at or slightly above the critical level provide resilience and flexibility. Growers can reduce P rates below replacement levels with generally little risk of yield loss if fertilizer prices are high or the right P source is unavailable. There is no agronomic or economic advantage in adding fertilizer P to build STP more than a few parts per million above the critical value. In cases such as heavily manured fields where STP is well above the critical limit, the strategy should be to draw down the STP levels and reduce environmental risk.

Performance Objective 2. Evaluate different soil test phosphorus extraction methods.

Soil test extractant varies with laboratory used. Preferably, one should use a laboratory that has calibrated and correlated their extraction methodology with local crops and soil. Olsen-P and the modified Kelowna extract (PK-2 or PK-3 in the figure below) are the most widely recommended and used soil tests on the Canadian Prairies. Other extractants such as Mehlich III, Weak Bray, and Strong Bray are sometimes used. These methods have not been researched and calibrated to Prairie soils to the same extend as the Olsen and Modified Kelowna tests. Regardless of test, interpretation must be made using critical limits specific to the test as described in the previous section (CA2, PO1). As shown below, soil test methods differ in the amount of P they extract.

Comparison of Soil Test P Using Different Extractants



Mean of P extracted by the different soil test P methods. (Means indicated with the different letters were significantly different ($P < 0.05$); PW = water extractable P; POls = Olsen extractable P; PM3 = Mehlich-3 extractable P; PK1 = Kelowna-1 extractable P, PK2 = Kelowna-2 extractable P and PK3 = Kelowna-3 extractable P; n = 115).

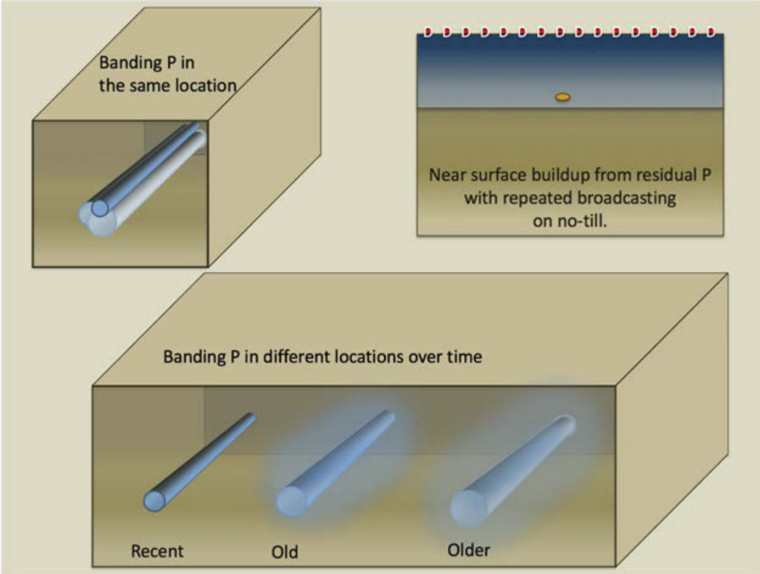
Source: Ige et al. 2007.

The plant root simulator probes (PRS) is also in use on the Prairies and offer insight to P, availability and supply power. The PRS method for P places moist soil in contact with an anion exchange resin. This can be down by inserting the membrane mounted on a probe in the field or by collecting a soil sample in the conventional way and placing the soil in contact with the membrane. In either case, the membrane and soil are left in contact for sufficient time to allow diffusion of P to the membrane surface where it exchanges with a replacing anion. Once equilibrium is reached the membrane can be removed; the P washed off it with an anionic solution; and the amount of P determined by standard analytical methods. The idea behind the PRS approach is that it behaves in a similar way in the soil to a plant root. Keep in mind that like all P soil tests, the results must be interpreted using calibration data specific to the method.

Performance Objective 3. Explain how nutrient stratification in no till or wide placed fertilizer bands for row crops may influence the soil sampling approach for phosphorus.

Banding results in P concentration in residual bands or stratification within specific zones. Reduced tillage results in less frequent mixing of surface and soil at depth, concentrating P at the banding depth over time. Similarly, when side-banded for widely spaced row crops, P may be concentrated in residual bands, as opposed to being more uniformly distributed in the bulk soil. Random point sampling may skew the results up if residual bands are sampled or down if residual bands are avoided. Several approaches have been developed to try and deal with this problem. If sampling in stubble, avoiding samples from the previous seed row or band placement is one approach. Sampling across the band is a second approach that has been tried. This requires special equipment and tends to be more labour intensive than sampling with a probe. Proportionally sampling, such as two cores away from the band for every core near the band, may be feasible when the location of the band is known. Increasing the number of cores is likely the only practical approach where the band location can't be determined.

Build-up of Residual P



Adapted from IPNI

Performance Objective 4. Discuss the pros and cons of applying phosphorus above crop response optimums.

Phosphorus application at rates in excess of crop requirement can lead to a build-up of soil test P. This may become both environmentally and economically penalizing, but at the same time, may also be economically beneficial. If soil and applied P are not at risk of loss, a soil P build program can allow for soil P banking – P which may be utilized in future years when fertilizer costs increase. This may also be a strategy employed to P load the soil for future crops, that cannot be adequately/safely P fertilized in the year of their planting. Applications and incorporation at a high rate prior to establishing perennial forage crops can be used to provide P for a number of years and ensure that the P is in the rooting zone. Typically with manure applications, the total P rate exceeds crop response optimums. Not all the P in manure is available immediately and will release over a period of years.

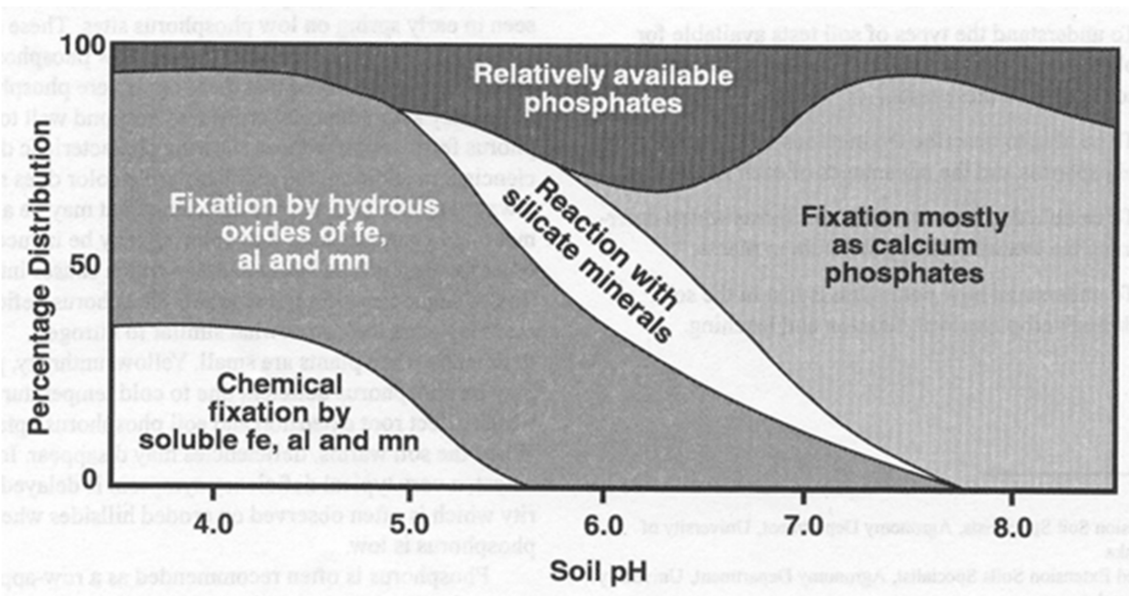
While P fertilizer use efficiency is quite low in the year of application (≈30%), utilization over multiple seasons is quite high. Up to 80% of P fertilizer is taken up by crops over a period of 5-8 years. The remainder ends up in very low solubility forms in the soil.

Performance Objective 5. Justify phosphorus application rate based on:

A) Soil characteristics including leaching

Soil clay and organic matter content, as well as pH greatly impact soil P availability and loss potential. A soil's ability to fix or absorb P increases with clay content. Precipitation as Ca-P increases as pH increases and Fe-P and Al-P precipitate as pH decreases. The optimal pH for P availability is 6.5. In calcareous soils, P rates need to be increased to compensate for increased tie up of P.

Phosphorus Reactions and Soil pH



Phosphorus does not generally leach from soils due to precipitation and adsorption reactions. Soils can hold only so much P, before P sorption capacity has been reached and downward movement of dissolved P begins. Movement below the root zone would occur once P sorption capacity has been reached in each successive depth increments. In soils with well-developed macropores, phosphorus can be potentially leached in particulate and dissolved forms through these preferential flow pathways. Most agricultural soils on the Canadian Prairies were developed on calcareous material and contain a calcium carbonate rich horizon at the bottom of the soil profile. This Cca or Ck horizon likely acts as a barrier to P movement by precipitating dissolved P as Ca-P. If P is deposited into tile drains, it can move into surface waters either in particulate form if the flow rates in the drain are sufficient to maintain the particles in suspension, or if sedimented out by recharging the drainage water with dissolved P. A coarse textured soil in a higher rainfall area or under irrigation with a history of heavy manure application might be a scenario where P could move below the rooting zone.

B) Topography and run-off

Runoff is strongly controlled by topography. Slope steepness, length, and connectivity to water courses will determine if P contained in runoff will be deposited within the field or result in edge of field losses. Manure as well as manufactured P fertilizer rates need to be optimized in situations where the risk of runoff leaving the field is high. For crops like corn where higher P rates are required, placement and timing should be optimized to reduce the risk of loss. Broadcast fertilizer or surface applied manure without incorporation is more likely to move with runoff. Stratification of P at the soil surface when broadcast is combined with no-till is another scenario that is likely to increase P losses when runoff occurs.

C) Crop conditions, crop type and growth stage

Phosphorus moves through the soil solution to the plant root by diffusion; diffusion rates increase at higher temperatures and soil moisture levels. As a result early season P availability can be limited in cold or dry soils. Since early season P requirements are relatively critical to plant growth, ensuring adequate P supply through appropriate rate and placement practices becomes more important in cold and/or dry seeding conditions. Such conditions may warrant starter P to ensure early season P availability even when soil test P levels are sufficient.

Application rates may need be predicated on crop yield potential and removal rate. For example, a 60 bu/acre canola crop will take up 30 lbs/acre more P2O5 than a 60 bu/acre spring wheat crop. (See PA3, CA2, PO3E for more details). Annual crops tend to be fertilized at or before planting, whereas perennial forage may be fertilized in spring, summer and/or in fall. Some vegetable crops (e.g. potato) may also be fertilized throughout the season. In-season application of P if required pose several challenges. Uptake through plant leaves is quite limited and because P is immobile in soil; surface applications without incorporation are not likely to get to the roots.

Performance Objective 6. Discuss the concepts of build and maintain philosophy, sufficiency and removal.

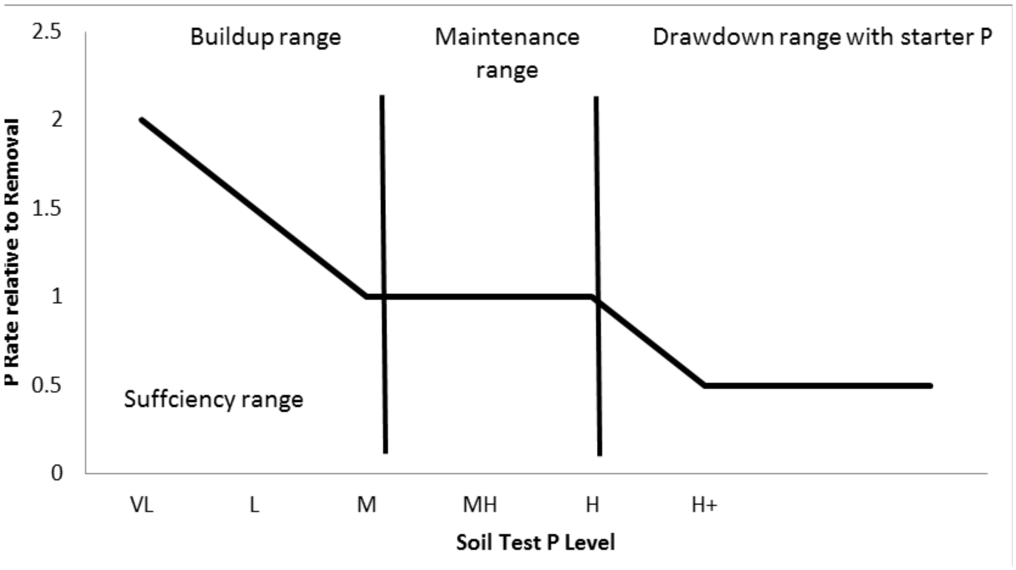
Applying P at "sufficiency" rates refers to the concept of P management that applies P to a level that maximizes net return on the P application in the year of application. It is used when soil test P levels are kept in the lower/responsive soil test range (below the critical value). Agronomically the rate is set at what is deemed sufficient to meet the needs of the current crop.

A build and maintain philosophy is based on the idea that crops are more resilient and perform better over a wider range of growing conditions when soil test P levels are at or slightly above the critical value or in the non-responsive range. Soil test P levels are increased to the non-responsive range generally over a period of years, by annual applications that exceed annual crop removal rates. Then the soil test level is maintained through annual P application rates that match crop removal rates.

Removal is a rate setting strategy based on replacing what was removed by the harvested portion of the previous crop. It is a reasonable approach when soil test levels are at or above the critical level. It is less viable when soil test levels are in the deficient range; replacement based on previous or expected crop removal may not be sufficient for crop needs.

Drawdown is a strategy used when P soil tests levels are well above the critical levels. Applications are stopped and no further P is applied, except perhaps for a seed row or starter application as warranted by the prevailing environmental conditions, until the soil test levels are drawn down to or below the maintenance range. A variant of the drawdown strategy is often used with manure applications where sufficient P to supply 3-5 years of crop demand is applied.

Phosphorus Fertilizer Strategy in Relation to STP levels



Adapted from Ontario Ministry of Agriculture, Food and Rural Affairs.

Performance Objective 7. Recognize phosphorus credits from:

Nutrient stewardship management must account for soil P supply. Past P applications, cropping sequence and environmental conditions affecting P accumulation or depletion need be considered in the context of P application program.

A) Previous crop

Phosphorus taken up by crops is concentrated in the grain and 70-80% leaves the field with harvest. The remainder is returned to the soil and is released as the straw and roots decompose. Phosphorus from crop residues is generally not directly credited when setting rates on the Prairies.

Residual soil test P levels may vary according to previous crop and the cropping sequence. As an example, although soybean has high P demand, it may rely more on soil P as opposed to the current P fertilizer application. Canola or wheat tend to take up more of the current season's applied P. High P removal in canola grain often means a draw down in soil test P levels relatively to cereal crops. Mycorrhizal fungi infect the roots of many crops and extend the root system delivering P to the plant. Canola does not form mycorrhizal association which may be one of the reasons it draws more heavily on recently applied P. Fields that have grown canola for several years in a row can be low in mycorrhizal inoculum which may limit a cereal or pulse crops access to soil P.

B) Previous phosphorus application

Phosphorus fertilizer efficiency is in the range of 20-30% in the year of application. The residual P remains available and over a period of years up to 80% of this year's application will be taken up by crops. Application rates exceeding crop P removal may be a strategy to build soil test P in the face of economics, agronomics (e.g. raising low P testing soils) or a strategy for future P supply, when application method options may be limited (e.g. fertilizing with higher than required P rate in a cereal phase of the cropping sequence, to supply adequate P for a following pulse or oilseed crop). It generally takes more P in clay soils and less P in lighter textured soils to raise the soil test level. The excess P required can be considerable, data from long-term research on the Prairies found 16 – 41 lb/A of excess applied P_2O_5 (i.e. above crop removal rate) were required to increase soil test P by 1 ppm.

C) Manure, biosolids and other organic amendments

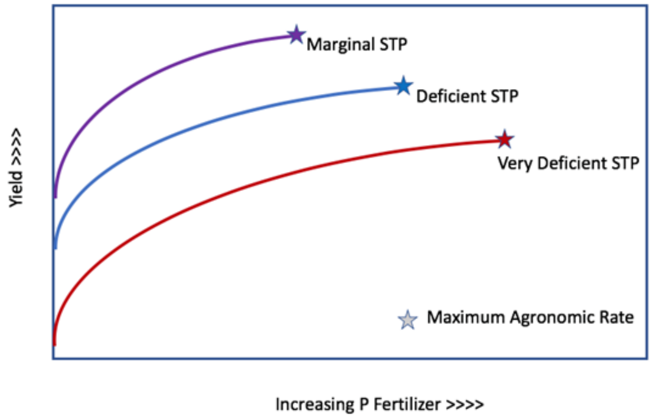
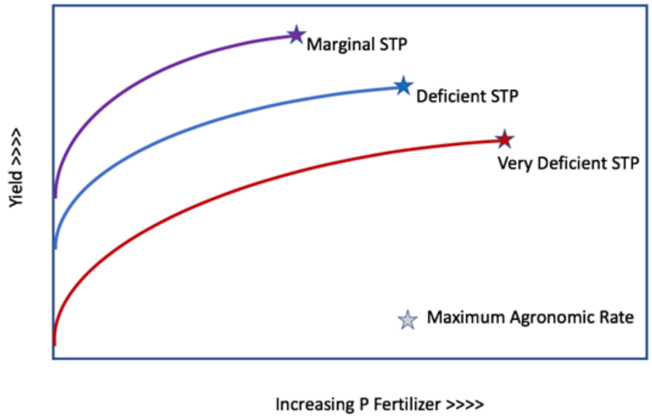
These materials can vary considerably in their P content and the availability of P. They tend to be applied at rates that will meet N crop demand, and due to an N:P ratio lower than the N:P required by crops, often provide enough P for several years of crop removal. Repeated manuring of a field at rates calculated to meet crop N requirements will lead to a build-up of soil test phosphorus. Soils testing more than 60 ppm of P likely have a history of manure application. The availability of P from manure and similar organic materials is covered in detail in PA 7.

D) Wastewater

Wastewater (on or off farm) contains varying amounts of P. Analysis of the material should be obtained to properly apply the required amount of P. It is also important to have some idea of the chemical forms of P is the material. More recently there are companies operating in the wastewater treatment space to remove and granulate/package the P as an "easier to handle" P source. Struvite (NH4MgPO4·6H2O), a sparingly soluble phosphate material, is one such material that is now being marketed on the Canadian Prairies. The CCA should consider that these lower solubility materials will behave somewhat differently in soil than conventional fertilizers such as MAP. Higher P rates may be required to achieve sufficiency. Manure, compost, biosolids, and waste water are discussed in detail in Proficiency Area 7.

Performance Objective 8. Justify the potential need to adjust the phosphorus application rate based on historic phosphorus use.

In fields where harvest removal exceeds replacement, P availability will gradually decline. This is what occurred on most Prairie soils once they were broken for annual crops. Prior to the widespread use of fertilizer, the natural phosphorus fertility was depleted. Currently something on the order of 80% of Prairie fields test below the critical P threshold. In fields with a history of underapplication and declining soils tests, P rates in excess of crop removal can be justified on the basis of building P levels or at the least stopping further drops in soil test levels. The diagram below illustrates the general issue with allowing available phosphorus to fall too far below the critical value. Yield cannot be restored with a single banded application. Very large broadcast and incorporated fertilizer application and heavy manure rates would be required to bring the very deficient to the same yield level as the marginal soil in the year of application. Roots have a limited capacity to absorb P per unit area of root surface. While they may proliferate around a P band, they still need to draw P from the remaining soil volume for adequate nutrition. When P very deficient, uptake from the band cannot meet crop demand and the deficit is not made up from depleted soil.

Generalized Response to Banded P at Different STP Levels



On the other hand, fields with a history of heavy manure applications or other P containing materials may contain high levels of available P. This "legacy" P can be measured with soil tests. In soils testing greater the 60 ppm STP, P rates can and should be reduced to zero or at most a minimal starter rate with the seed. Monitoring through soil test will provide an indication of when draw down has depleted the reserve to the point where P additions are again required. Mining legacy P has both economic benefit through cost saving and environmental benefit be reducing risk of P loss.

Performance Objective 9. Understand how phosphorus placement affects rate.

Phosphorus has limited mobility in soil and placement methods that improve positional availability for root uptake can result in a reduction in the relative application rate. Typically, to provide a similar yield increase, broadcast P must be applied at a rate that is 2X that of P applied in a band, side-band or seed-row (within safe seed placed guideline). Keep in mind that as outlined in the previous PO, there can be issues with banding in very deficient soils. Also, in soil that test at or above the critical level, placement becomes less critical and banding and broadcast incorporated are about equally effective. Banding near the seed will likely still be advantageous in cold or dry springs.

COMPETENCY AREA 3. DETERMINING THE RIGHT TIMING AND PLACEMENT OF PHOSPHORUS APPLICATION

Performance Objective 1. Discuss the mechanisms of phosphorus loss to surface water.

Phosphorus loss from agricultural land is a combination of dissolved and particulate P. In the context of algal growth and eutrophication in surface water, dissolved P is immediately available and particulate P is more slowly available.

A) Runoff

Surface run-off events transport P in both soluble and particulate form. Particulate P transport is tied to soil erosion and will only contribute directly to P loading if the sediment is deposited in surface water. Once deposited, particulate P can recharge the soluble P pool in the water body. Often sediment from water erosion is redeposited in the field or in physical barriers, buffer strips for example, between the field and surface waters. Sediments deposited beyond the field may subsequently contribute to soluble P movement into surface waters by recharging runoff that passes over or through it.

Soluble P moves with runoff water and will enter surface waters unless intercepted. Interception can include deposition in temporary runoff ponds in depressions or other mechanisms for infiltration into soil along the flow path. When runoff is carrying a sediment load the largest P fraction lost will likely be in the particulate form. Tillage, discussed under PO 2, is an important factor in the transport of dissolved P.

B) Leaching

Phosphorus is so reactive with the soil solid phase that leaching through the profile is generally inconsequential agronomically or environmentally. Conditions that may lead to enhanced downward movement of P generally involve significant loading of P on the soil surface such as very high manure application rates followed by infiltration through preferential flow that moves water below the rooting zone with minimal soil contact. Preferential flow occurs through cracks, old root channels, and animal burrows. As discussed earlier, preferential flow can transport particulate as well as dissolved P.

C) Tile drainage

Drainage water from tile systems typically ends up in surface waterways. Dissolved P in the drainage water can consequently contribute to surface water degradation. However, tile drainage also enhances infiltration and reduces the volume of water available for surface run-off events and consequently may reduce overall P losses. Keep in mind that snowmelt over frozen soil accounts for the majority of surface runoff in the Prairie region in most years and tile drains are ineffective when the soil above them are frozen.

Performance Objective 2. Discuss the relationship between tillage practices/system on phosphorus management.

Reduced and no-till practices are effective in reducing particulate P loss, but may lead to increased dissolved P loss from vegetative residues or from surface-applied fertilizer or manure. Incorporation or sub-surface placement of fertilizer or manure reduces P loss potential. In zero-till systems side-bands or seed-row are the preferred fertilizer placements for balancing between crop access and P loss with runoff. Macropores can be disrupted with tillage and reduce P movement through soil.In systems where P is surface applied without incorporation, for example forage stands, timing can reduce risk of loss. Avoid application on snow or frozen ground. Application in spring after runoff and the soil is thawed is likely the best time to balance between agronomic and environmental goals.

Performance Objective 3. Discuss the importance of the following in determining the optimal timing and placement or method of application of phosphorus management:

A) Precipitation (intensity, type, duration)

Phosphorus movement occurs when there is water movement. When rain falls infiltration can carry soluble forms of surface applied P into the soil where it is rapidly adsorbed or precipitated. If the rainfall intensity exceeds the infiltration rate, ponding or runoff occurs depending on slope. Once runoff is initiated it will continue as long as the rainfall intensity remains above the infiltration rate. Runoff water interacts with the surface and near surface soil. Since P concentrations in rainwater are generally lower than the soil solution, runoff can become charged with dissolved P and transported to other parts of the field or off field depending on the connectivity of the surface drainage.

Rainfall intensity and duration are controlling factors in particulate P movement. Water erosion is initiated when large high energy rain drops break down soil aggregates. Disaggregation reduces infiltration and once runoff is initiated soil particles and any P adsorbed to them can be transported downslope and potentially off the field depending on the duration of the event and the connectivity of the surface drainage system.

Performance Objective 4. Discuss the effects of timing and placement short- and long-term crop response.

A) Seed row, side band, mid row

Seed row, side band, and mid row placements are primarily used as annual P application methods. Seed row applied P is particularly effective in cold soils, but caution needs be used to ensure application rates are within seed tolerances for the crop type. Side band application places P where the developing roots will fairly quickly gain access and typically performs as well or when high rates are required better than seed placed. Mid row band placement may result in early season P deficiency until the roots grow to the band. High rates of N applied with P in the mid row band can also limit access. When this is a concern – a small rate of P may be seed row applied and the balance placed in the mid row band. Mid row band application is also a strategy employed to ensure adequate rates of P are applied when the safe seed row rate will be exceeded; as well, mid row applied P can be used in a soil P building program.

B) Broadcast

Broadcast P may in some circumstance be used as an annual application method, but more often is used as a soil P loading strategy for both annual and perennial crop types. Given its relative immobility, P is best placed in a position where early season developing plant roots may gain access. Furthermore, if P is broadcast, it should be incorporated to improve access and reduce the risk of runoff losses.

C) Foliar

For most annual crops (with the exception of some specialty crop types like potato) foliar application of P is reserved for in-season rescue attempts when a P deficiency is diagnosed. Foliar P solutions must be at quite low concentrations (1-2% P_2O_5) to avoid burning plants. At these low concentrations, the amount of P applied is generally not high enough to increase yield.

Performance Objective 5. Discuss the implications and interactions of co-banding phosphorus with other nutrients.

Dual band applied N + P fertilizer can aid in, or delay P availability and crop uptake. Ammonium N can aid in keeping fertilizer P soluble by acidifying the fertilizer reaction zone as it undergoes nitrification. Delays in P availability occur when the concentrated N band may temporarily discourage root proliferation and reduce root absorption of the P within the band. The immobile P in effect becomes trapped inside the fertilizer reaction zone of the more mobile N. This is more likely to happen when the N rate is higher than 70 lb/acre.

Performance Objective 6. Compare and contrast reduction strategies and management for particulate phosphorus loss due to soil erosion, and reduction strategies and management for dissolved phosphorus loss.

The component parts of soil P loss can be characterized as dissolved P and particulate P (bound to soil); dissolved P is also referred to as dissolved reactive P (DRP). No-till can reduce particulate loss but may increase loss of DRP. Incorporation of surface applied P and sub-surface banding of P will reduce P loss in runoff. On the Prairies, DRP levels in runoff tend to be correlated with soil test P in the top few centimeters of the soil profile. However, DRP is also strongly related to the amount of soluble P released by vegetation after freezing and thawing or drying and rewetting.

The higher the STP level, the higher the concentration of DRP in runoff waters is likely to be. The use of cover crops and rotational cropping practices that drawdown soil P levels will over time reduce the potential for DRP movement in runoff. Additionally, occasional tillage in no-till systems can aid in reducing P stratification and potentially reduce build-up of DRP near the soil surface.

Best practices for preventing P loss from manured fields include subsurface injection of liquids and incorporation of solids, keeping STP below reasonable thresholds and drawing down high STP levels, and insuring adequate setback from surface water features. Manure use is discussed in detail in PA 7.

Performance Objective 7. Discuss the considerations for phosphorus timing, placement and method of application based on the risk of phosphorus runoff.

Application as close to time of crop uptake and in sub-surface band or in-soil can reduce potential for P runoff. Phosphorus placed below the soil surface is at reduced risk of surface runoff. Avoid application on snow covered or frozen soil or saturated soil. Band or incorporate broadcast P in the fall. When broadcasting in forage stands, spring after runoff is likely lower risk in most cases than fall application.

For most spring and winter annuals, banding or seed placement at time of seeding is both good agronomic and environmental management. When developing time and place strategies keep in mind that depending on topography substantial portions of the landscape may be disconnected from surface water features. When broadcasting must be used because of operational constraints on time or equipment, broadcasting on fields that are unlikely to contribute runoff and using subsurface bands on the fields that do runoff is a valid approach to reducing risk.

Performance Objective 8. Plan the best timing, placement or application method for phosphorus to minimize the transport of phosphorus offsite.

Since most P loss in the Prairies is due to surface runoff and erosion, placing P below the soil surface reduces the risk of loss. For fertilizer P sources, banding would be preferable to broadcast and incorporation if it results in lower soil disturbance and reduces erosion. Best timing of fertilizer P balances application during periods when potential for runoff is lowest but also needs to consider when the crop needs P. Side banding and or seed row placement are the best time and place combination for fertilizer P in most annual crops. For forages, spring application after snowmelt is probably the best timing placement combination for reducing loss to exposing P to runoff.

For manure, spring application with incorporation for solids and banding for liquids would be considered the best management practice to reduce offsite transport. Surface application in forage stands will likely be more effective in reducing P losses if it is delayed until the stand is actively growing. What is “best” for preventing P loss and what is logistically feasible are not necessarily compatible.

When developing BMPs and incorporating them into a 4R Plan, consider the whole rotation. Also look to characterize the agronomic and environmental risk by field. The next CA deals more explicitly with environmental risk

COMPETENCY AREA 4. ENVIRONMENTAL RISK ANALYSIS FOR PHOSPHORUS

Phosphorus applied in fertilizer or manure becomes a problem when it escapes the cropping system and enters surface water. For this to occur, there must be a mobile source of P and a transport mechanism.

Performance Objective 1. Discuss how to use water quality vulnerability or risk assessment tools (e.g. Environmental Farm Plans) on a site specific basis for phosphorus nutrient planning.

A relevant (Provincial or Federal if applicable) water source protection plan, related to the prevailing jurisdiction, must be followed for any field falling within a nutrient risk management zone. Phosphorus may not be directly implicated, but indirectly, as regulations and planning relate to animal and manure management practice**.**

Each province has its own version of the Environmental Farm Plan. The EFP is a tool for assessing and managing environmental risk on the farm. The provincial governments provide support and technical assistance to growers who wish to complete or update a plan. Plans are typically updated (or at least should be updated) every 5 years. The assessment is comprehensive and covers risks ranging from pesticide use to farmstead waste management in addition to fertilizer and manure storage, handling, and application. The EFP provides specific tools to assess environmental risk associated with nutrient application on a field specific basis. Fertilizer Canada is working with the national EFP committee to imbed the concepts of 4R Nutrient Stewardship in the EFP.

Performance Objective 2. Be able to evaluate how changing a specific phosphorus management strategy will affect the outcome of a risk assessment.

Source, rate, time and place interact with tillage, crop choice in the cropping sequence, conservation practices, and edge of field management practices. Source, rate, time and place practices need to be combined to reduce P loading of runoff and/or intercept runoff water. Strategies for reducing edge of field P loss may well be situational, requiring assessment of site-specific risks. Some of the key attributes to consider when evaluating runoff potential are slope, soil texture, and connectivity to surface drainage. Soil test levels are a good indicator of whether phosphorus loading of runoff water will take place. Some general BMPs are shown below.

	Management Practices that will Reduce P losses	**Example of BMPs**
Soil Erosion	Any practice to reduce soil erosion.	Reduce slope length; tillage reduction to increase surface residue; plant cover crops; crop rotation, strip cropping, contour tillage.
Water Runoff Class	In some instances, tile drainage installation may change the effective soil hydrologic group rating.	Tile drains may reduce runoff water volumes and thus lower risk of P loss in surface runoff. They may increase risk of P loss through tile drains by increasing connectivity.
P Soil Test	The management of fertilizer and manure ap- plication methods/rates will control the rate at which the P concentration in the soil changes.	The P concentration of a field can be lowered on a long-term basis by reducing application rates of manure/fertilizer and/or by using crops with higher P removal capabilities.
Commercial Fertilizer Application Rate	Applying less fertilizer to a field will lower the risk of P loss accordingly.	An agronomically appropriate reduction in the commercial fertilizer application rate in conjunction with improved application methodology
Commercial Fertilizer Application Method	The use of an application method that incor- porates P fertilizer quickly and efficiently will result in a lower rating factor.	Changing the application method from broadcast unincorporated to seed placed, side-banded or mid row banded.
Manure/Biosolid Application Rate	Applying less manure to a field will lower the concentration of P accordingly.	A reduction in the manure/biosolid application rate.
Manure or Biosolid Application Method	The use of an application method that incor- porates the manure quickly and efficiently will increase P use/application efficiency.	Changing the application method from un-incorporated on bare soil to injected will reduce risk of P loss.

Performance Objective 3. Evaluate management strategies and BMP's, which reduce phosphorus loss to surface and groundwater.

A) Tile drainage

Tile drainage tends to redirect water movement from runoff to internal drainage. Drained soils are less likely to experience P run-off events but may transport P though internal drainage. Phosphorus moving with water towards drains may be adsorbed or precipitated by low P soil layers lower in the profile reducing overland losses. On the other hand, drained fields can transport more P to edge of field by increasing the connectivity of the landscape to surface drainage ways. Strategies to intercept/utilize this P need be considered.

B) Buffer strips

Buffer strips that incorporate permanent interceptive cover, can utilize edge of field P and provide stabilization to fields and waterways. Harvest of plants from buffer strips through haying or occasional intense grazing can help reduce P build up in the buffer strip. Grassed field borders and waterways can slow water and sediment movement and absorb P. However, the effectiveness of buffer strips in the Prairie region is not consistent or substantial, partly because the vegetation in buffers are dead or dormant and the underlying soil frozen during snowmelt, which is usually the dominant type of runoff in the Prairies.

C) Cover crops

Cover crops offer protective surface cover and P interception properties; particulate P may be reduced, but DRP could be increased. Cover crops may not result in reduced total P loss, if the cover crop undergoes freeze-thaw over the winter and releases P from damaged tissue.

D) Wetlands

Preserving and protecting wetlands can aid in trapping particulate P and sediment. Studies on the Prairies suggest that while the ability of intact wetlands to absorb DRP is limited, it is much higher than drained wetlands. Intact wetlands act as P sinks while draining wetlands turns them into sources that contribute P to surface waters.

Performance Objective 4. Discuss how to use drainage water management to reduce phosphorus nutrient losses to surface water.

Reducing water movement off fields reduces P loss in surface flow. In addition to the practices mentioned in PO 3, interception (grassed water ways, field buffers and borders) practices can limit P loss to surface water. Drainage water from tile drains, can be filtered through constructed or natural wetlands or collected in settling ponds where P precipitates. Diversion terraces well seldom used on the Prairies can effectively reroute water across slopes rather than down slope. This reduces erosion and runoff, allows greater infiltration, and lowers the amount of water leaving the field. Diverted water can be channeled into an appropriate collection or outlet.

Performance Objective 5. Discuss how tillage system (including no-till) affects environmental losses of phosphorus.

Conservation or reduced tillage can result in P stratification in surface soil. The table below gives an example of soil P stratification under no-till practice. Roughly half the P found in the top 12 inches of this profile is concentrated in the surface 2 inches. This concentration of P in surface layers can influence the loss of P in surface run-off water, and the movement of P through (macropores) tile drainage. Reduced or zero-till practice can reduce particulate P loss but can increase DRP loss.

Stratification of surface or near surface applied P in a no-till system.

No-Till P Stratification

Depth	P		
0-2"	30		
2-4"	16		
4-6"	6		
6-8"	3		
8-10"	4		
10-12"	2		

Courtesy Agvise Laboratories (Olsen soil test P – ppm)

The acreage of full tillage row crops (corn, soybean, potato) is increasing on the Prairies. Practices such as strip-tillage and contour tillage can reduce runoff, erosion, and both particulate and dissolved P losses.

Performance Objective 6. Compare the differences in soil, topography, and location of watersheds (e.g. local, regional, national) on environmental impacts of phosphorus on surface and groundwater resources.

Heavier (finer textured) soils are relatively more likely to generate surface P loss with run off as opposed to lighter (coarse textured) soils. Prairie crop production mainly occurs on medium to fine textured materials developed on till or lacustrine parent materials interspersed with generally lesser inclusions of coarser textured soils of eolian or fluvial origin.

Soils of fields with long and steep slopes are more likely to have erosional P losses as compared to soils of short – shallow sloped fields. Measures to control mechanisms of particulate P loss would be of greater relevance as opposed to those measures aimed at controlling and reducing DRP loss from the field. Much of the Prairie landscape consists of small close basins that don't connect directly to the regional surface drainage network. Water collecting on these Prairie potholes may act as recharge sites for groundwater.

Prairie climate is not uniform with annual precipitation in wetter regions approaching double that found in the drier regions. Snowmelt is a significant contributor to runoff and P loss. Snow accumulations vary widely across the Prairies. Areas like SW Alberta, where Chinook weather systems tend to sublimate snow before it melts, may generate very little spring runoff. On the other hand, this region may contribute some P to surface waters through wind erosion depositing dust on rivers, lakes and drainage ways. Other regions like the Prairie Parkland region will have considerable snow accumulation and generate spring runoff most years.

Understanding of historical climate patterns, temporal and spatial distribution within the geography of concern can help the practitioner to integrate and understanding 4R nutrient management stewardship with respect to P application method, timing and preventative or altered management practices that will retain more P on/within the field.

Performance Objective 7. Discuss the role of phosphorus, including legacy phosphorus, in the eutrophication process and the potential consequences of eutrophication.

Misplaced P can contribute to water quality concerns and speed up the eutrophication or nutrient enrichment of surface water bodies. Water body sensitivity to added P depends upon a myriad of interacting factors. One of the most important is whether P is a limiting nutrient in the aquatic ecosystem. Most Prairie water bodies were naturally eutrophic, or nutrient rich and algae and aquatic weed growth are part of these ecosystems. In Prairie lakes, algae blooms in mid-summer would historically have been fairly common in mid-summer when low oxygen levels would have increased the solubility of P held in bottom sediments. Although classed as nutrient rich historically, P was the limiting nutrient setting the upper limit on photosynthesis in surface water.

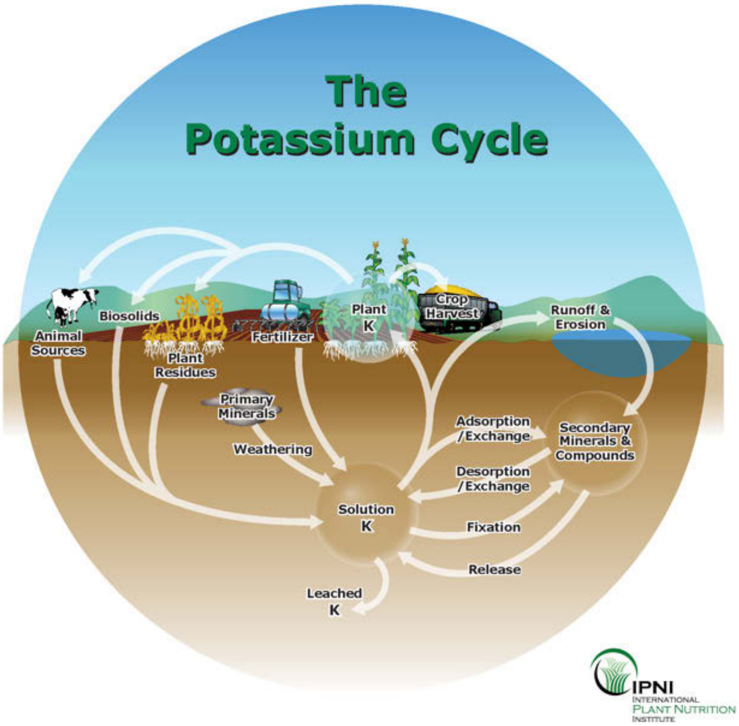
Algae bloom on a Prairie Lake showing the typical green water appearance.

Phosphorus application to farmland and discharge of urban sewage among other practices have increased the P loading of Prairie surface waters. Drainage of wetlands has removed the natural filtration and interception system that prevents P from entering major rivers and lakes. As a result, algae blooms on many Prairie lakes start earlier, last longer, and are more intense. Blue-green algae are of particular concern as they produce toxins that make water unsuitable for human and animal consumption and are hard to neutralize or remove during treatment.

Excessive growth of algae and plant material becomes self-limiting during the summer as nutrients become limiting and sunlight is blocked from penetrating the water column by the algal mass near the surface. As the bloom collapses, decomposition of the algal material requires oxygen, and the ensuing lack of oxygen can result in the death of aquatic species. The low oxygen can result in fish kills and less obvious deaths of aquatic organisms.

Accumulated ("legacy") P in land or aquatic systems is the result of past activities that have added P to the system. In lakes and rivers, the bulk of this legacy P resides in bottom sediments where it can be released back into the water system. Rehabilitation of P polluted water has a long time line. Once the flow of P into water is removed or reduced to acceptable levels, legacy P can contribute to loading and downstream transport of P.

PROFICIENCY AREA 5
POTASSIUM, SULPHUR, CALCIUM, MAGNESIUM AND MICRONUTRIENTS



Potassium (K) is an essential plant nutrient and is taken up primarily through diffusion as the cation K^+. Potassium deficiency can result in reduced yield, increased lodging, lowering of cereal grain protein and inefficient water use by plants. Potassium is involved in cell wall structure and strength, protein synthesis, water regulations within plant cells, translocation of sugars, starch production and N fixation in legumes.

Potassium deficiency symptoms often manifest as marginal chlorosis on older, lower leaves and also may present symptoms similar to drought stress. Although K is relatively immobile in soils, it remains mobile in plants. Harvest removal of K in grains and oilseeds as a percentage of total uptake is much lower than N or P with most of the K returned to the soil with plant residue. Forage harvesting does remove considerable K with the harvested portion of the crop.

Potassium Deficiency (L), Sulphur Deficiency (R) on Canola

Source: T.L Roberts, IPNI

Sulphur (S) is important in amino acid formation and linked to protein production. It is absorbed as the sulphate anion (SO_4^{2-}) and can also enter the plant leaf though the air as sulphur dioxide (SO_2). Sulphur aids in development of enzymes and vitamins, promotes nodulation in legumes, aids in seed production and is required for chlorophyll formation. The sulphur cycle is similar to the nitrogen cycle in many respects.

Sulphur, although mobile as SO_4^{2-} in the soil, is immobile in plant tissue and deficiency symptoms present themselves on newer leaf tissue. Deficient leaves exhibit light to pale green and yellow coloration, curling and cupping of canola leaves is a classic S deficiency symptom.

Calcium (Ca) is taken up by plants in the form of Ca^{2+} and functions in several roles: stimulating root and leaf development, as a structural compound in cell walls and enzyme activation. Calcium deficiency is rather rare on the Canadian Prairies where most soils were developed on Ca rich parent material and continue to have high base saturation. Deficiency symptoms would be related to poor root development, death of growing points and reduction of new plant tissue/plant stunting as Ca is not mobile within the plant.

Magnesium (Mg) is taken up as the Mg^{2+} cation. Magnesium is largely contained in the chlorophyll molecule and is essential to photosynthesis. Magnesium is mobile within the plant and deficiency symptoms appear on lower, older leaves first. Interveinal chlorosis on broad-leaf crops and strong striping on grass-type crops are common symptoms. Deficiency is more likely in acid soils with low CEC.

The micronutrients of interest on the Canadian Prairies are: copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), chloride (Cl) and boron (B). There has been some interest in molybdenum (Mo) on brassica type crops and under lower soil pH conditions. With exception of Mo (more available at higher soil pH) and Cl (not affected by pH), the remaining micronutrients of interest have increased availability at lower soil pH levels. With the expansion of soybean acres on the Prairies, iron deficiency chlorosis (IDF) is starting to appear particularly in wet years on calcareous soils.

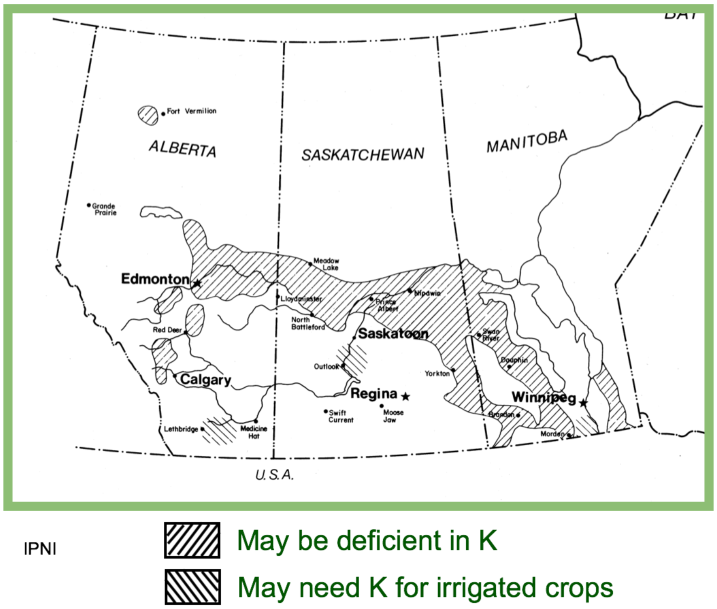
COMPETENCY AREA 1. DETERMINING THE RIGHT SOURCE OF POTASSIUM

Common K fertilizer sources on the Canadian Prairies are 0-0-60 (potassium chloride), 0-0-50-18 (potassium sulphate) and the liquid form ammonium potassium phosphate (3-10-10). Potassium magnesium-sulphate (KMag: 0-0-22-22- 11 Mg) is available as a combined K and S source. Potassium nitrate (12-0-46) are not typically used in prairie field cropping situations.

Performance Objective 1. Discuss the availability/potential deficiency of potassium in the Prairie Region.

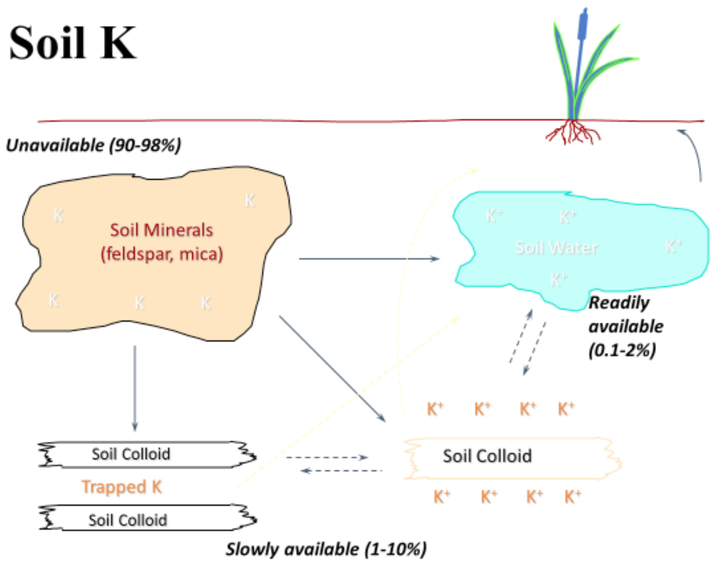
Saskatchewan is home to the world's largest known K reserves held as soluble potassium chloride (KCl) evaporite salts from ancient seas. The majority of what the soil holds is tied up in primary minerals and relatively plant unavailable. Plant available K is generally adequate to meet plant requirements. Soil test K (STK) levels in Prairie soils are typically in the 300 to 600 ppm range. Despite generally adequate levels in medium and coarse textured soils, supplemental K application is often required in coarse textured soils in the wetter parts of the Prairies or under irrigation.

Areas of Potential K Deficiency on the Canadian Prairies



Potassium resides in soil dissolved in soil solution, as exchangeable and non-exchangeable K and relatively unavailable mineral K. Potential for K deficiency exists when K availability/application rate does not meet plant uptake requirements and/or when environmental conditions impact soil K form and availability.

Soil K Forms in Soil



International Plant Nutrition Institute (IPNI)

Performance Objective 2. Discuss the most common sources of potassium used in the Prairie Region.

The most common source of K fertilizer is potassium chloride (0-0-60) which contains both K and Cl. Chloride has been found to be deficient in areas of the prairies where both spring and winter wheat are grown. Potassium sulphate (K_2SO_4, 0-0-50) has relatively minor use; mostly restricted to crops where Cl sensitivity or its effect on crop quality parameters (e.g. potato and specific gravity interactions) may be of concern. Monopotassium phosphate (KH_2PO_4) is used in some NPK fluid fertilizer formulations in combination with monoammonium phosphate. In addition, potassium magnesium sulphate ($K_2SO_4 \cdot 2MgSO_4$; 0-0-22) is starting to appear on the Prairies as a KS source.

Performance Objective 3. Discuss considerations that may be used to determine the right source of potassium, sulphur, calcium, magnesium, and micronutrients based on:

a) Crop type

Crop species vary in requirement and sensitivity to nutrient type. Potassium requirements in forage species, soybean and high yield cereals and corn can be quite high as compared to a crop like canola – which takes up about as much K as it does N to meet its growth requirement but does not respond as strongly to applied K as do other crops. Cereals may be more responsive to Cu, Zn and Mn, while edible beans, corn and flax may respond better to Zn application. Peas may be more sensitive to Mn deficiency, while alfalfa and canola may be more likely to have higher B needs. The need for Ca and Mg on the Canadian Prairies is limited to low CEC, low pH, coarser textured soils and addressed on a field by field basis. Often the application of agricultural lime (calcitic or dolomitic limestone) to adjust soil pH is more beneficial than the addition of either Ca or Mg as a fertilizer. While crop types differ in their response to secondary and micronutrients, no crop will respond to additions if the soil supply is already adequate to meet crop demands.

b) Tillage and cropping system:

Consideration of typical cropping sequence in conjunction with soil characteristics and historic/prevailing environment can aid in decision making regarding source, of nutrient application. Choosing the right source also needs to consider rate, time and place. Effectiveness of elemental-S, which requires time to oxidize to sulphate, may be increased by using a fall broadcast unincorporated method as opposed to a spring applied incorporated method. Elemental-S could also be applied at a point in the rotation prior to the year in which it is required. For example, application to a cereal crop with the intent to have available S for next year's canola crop with the intent to have conversion to available S before seeding for next year's canola crop. Copper may be applied in the canola crop year to supply Cu to the following cereal crop. Potassium can be fall broadcast incorporated at high application rates for the following year's seeding to perennial forage, to "front-load" the soil for these high K demanding crops. Where application equipment limits application rate or method of placement – K, secondary and micronutrients can generally be applied at a convenient point in the rotation following 4R Nutrient Stewardship Management principles and concepts. These include consideration of potential leaching losses for the mobile nutrients S, B, and Cl.

c) Crop growth stage:

The common K, S, Ca, Mg and micronutrient fertilizer sources tend to be soluble and immediately plant available (depending upon soil environment). Elemental and oxide or oxysulphate forms of some nutrients may require longer soil residence time to become plant available. With the exception of S, B. and Cl, secondary and micronutrients are relatively immobile once they contact soil. Micronutrients in soluble forms can be timed to coincide with crop uptake using foliar application. Since only trace amounts of the micronutrients need to get into the plant, foliar application and uptake can be effective. Research on the Prairies has shown that timing foliar application of Cu closer to the flag leaf stage tends to improve effectiveness compared to application at earlier stages. This is likely due to increased leaf area to intercept and absorb the foliar spray. Time of main uptake by each crop species will dictate when each nutrient must be applied/be plant available and the appropriate source to use.

d) Soil test or tissue test:

Soil testing may be used as a predictive index of nutrient sufficiency, deficiency or excess – but not necessarily an indicator of nutrient availability at a given time in the future. Soil tests offer a recommendation for the application of a nutrient but cannot account for what the prevailing environment will be when that nutrient is in plant demand. Soil tests can help with source decisions by indicating whether there is likely to be an immediate deficiency in which case a readily available source is required. For example, a soil testing low in S ahead of a canola crop would suggest that a sulphate containing source would be a prudent choice. The reliability of certain micronutrient tests as predictors of deficiency is questionable. For example, the DTPA test for Cu and Zn appears reasonably reliable for susceptible crops, but the common hot water B test may have little or no relevance for predicting deficiency. CCAs should use micronutrient soil tests with caution and examine all the evidence (yields, symptoms, soil properties, manure history, crop susceptibility etc.) before making an expensive and potentially unneeded fertilizer recommendation.

Plant tissue tests can be used to monitor a nutrient application program with respect to adequacy of a nutrient within the plant, or as a diagnostic tool to assess potential nutrient deficiencies within a plant and take corrective action(s). Tissue test interpretation uses sufficiency ranges that are based on particular plant parts at specific crop stages. Often differential diagnostics are useful where plants from the area of poor growth or suspected deficiency are compared with plants from areas of better growth. Since tissue tests are an assessment of a growing crop, when deficiency is detected and intervention is still possible, an immediately available source should be selected

E) Timing and placement of application:

Choosing the right source requires understanding timing of nutrient uptake as well as mobility and loss potential for applied nutrient(s). Potassium may be relatively immobile and environmentally benign, but soil reactions can occur that may reduce availability in the short-term. For example, broadcast K can enter into exchange reactions in the top few millimeters of soil and be stranded if the surface soil dries. As well, the potential exists for Cl^-, H_3BO_3 and SO_4^{2-} leaching in specific environmental conditions. Fall application of soluble Cl or S sources to depression where water collects in spring can result in leaching loss. Equipment limitations and on-farm logistics may limit best time and placement options – so proactive planning around time of application, uptake requirements and available labour need be considered. Soil application of nutrients addresses expected uptake requirements, but in-season application (dry broadcast, liquid surface band or liquid foliar) may be required to address unexpected deficiencies or increased demand due to weather change(s). With the immobile micronutrients broadcasting or banding granular sources at low rates can be an issue. The density of granules is low and plants near a granule have access, while those farther away do not. Compound fertilizers that contain small amounts of micronutrients combined in each granule with macronutrients applied at higher rates is one solution. Liquid blends are another approach that can make distribution more even.

Performance Objective 4. Discuss how managing the 4Rs for potassium, sulphur, calcium, magnesium, and micronutrients influences nitrogen and phosphorus losses to surface water and groundwater.

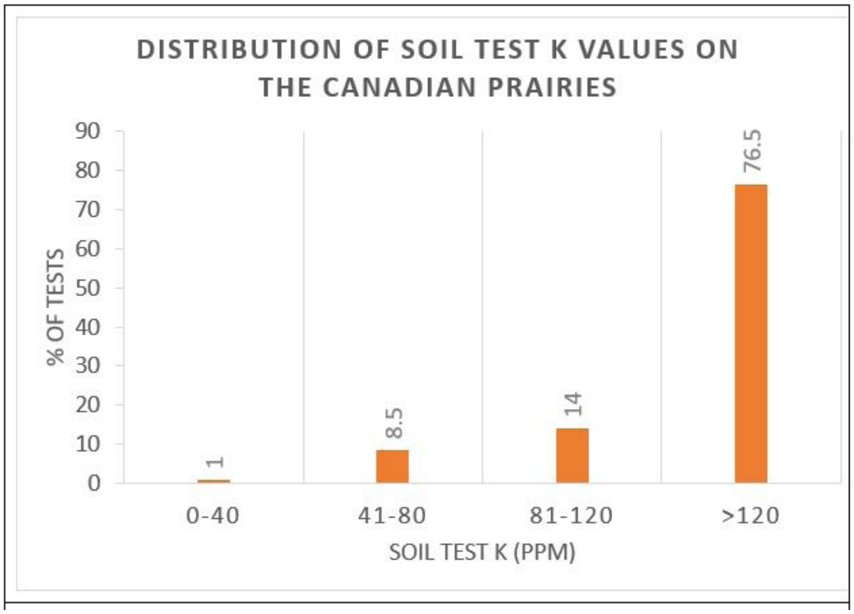
Liebig's Law states that growth is limited by the nutrient in shortest supply relative to plant demand. Poorly managed/unbalanced fertility can lead to "left-over" applied N or P that can find its way into water bodies and in the case of N lead to increased GHG emissions. Just like over addition of manure, applied N or P may be inefficiently used when there is a lack of K or S, Ca, Mg and/or micronutrients.

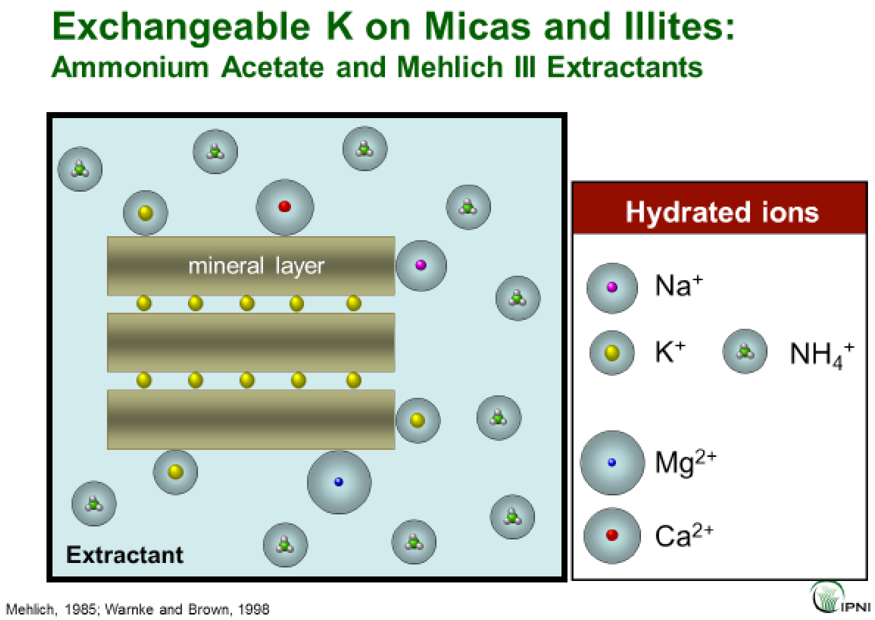
Each plant nutrient plays a specific role within the plant and its nutrition; each nutrient tends to behave distinctly in the soil environment. One plant nutrient cannot take the place of another, and there is a great deal of nutrient interactions that occur; many are synergistic but there are problematic antagonistic reactions as well.

Potassium aids in protein synthesis and S helps with amino acid production that leads to protein formations, P is involved in energy transport and storage and if deficient – all other growth processes are reduced. Antagonistic reactions between elevated soil P and Cu and Zn availability and uptake are well documented in the literature, as is the relationship/ratio between N:S for cereals and canola.

COMPETENCY AREA 2. DETERMINING THE RIGHT RATE OF POTASSIUM

Potassium is relatively immobile and is generally retained by the soil and its component fractions. Added K as manufactured fertilizer or animal manure is used to supplement the soil's natural supply, which may be inadequate or temporally unavailable to meet crop demand. Plants take up K from soil solution and the solution K concentration is realitively low. The K removed from solution is recharged in the short-term from the exchangeable K pool. The part of the K cycle that deals with solution K and the reactions that occur can be complex.





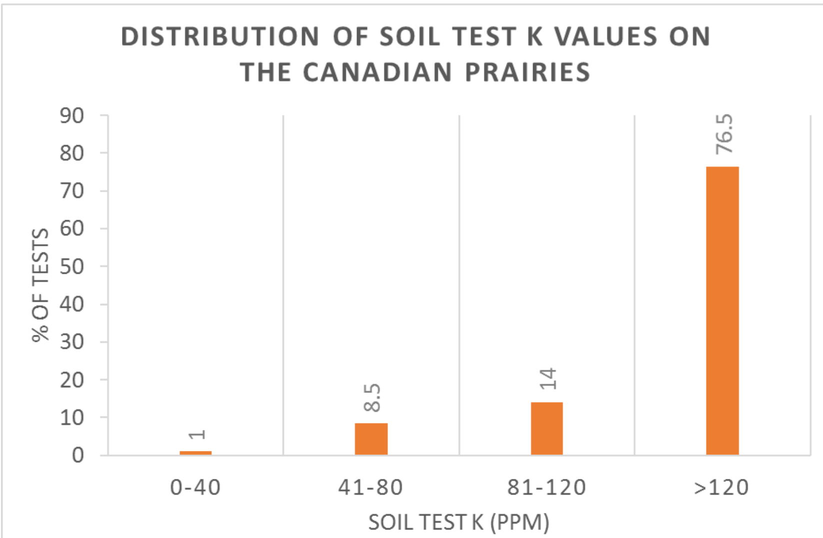
Although only a small amount of solution K is available for plant uptake, a large reserve is held in the various solid phase pools. Cation exchange capacity, mineral weathering, soil moisture conditions, and mineral type play a role in determining plant available K.

Crop removal rates and soil testing can be used to help determine application rate. Depending upon crop type and yield potential, large amounts of K can be removed from the field (e.g. potato, silage, perennial forage); keep in mind that a large percentage of crop K is retained in straw and as that is returned to the soil, K levels will be supplemented.

Performance Objective 1. Interpret how soil test potassium levels relate to crop yield response and potential environmental impacts.

The standard soil test for the Canadian Prairies uses the 1 M ammonium acetate extraction. This soil test measures soil solution and exchangeable K and depending on soil type may extract a small amount of fixed K. Soil test K levels are characterized as deficient, marginal, optimal, and excess (or alternatively low, medium and high), relative to a critical level based on local research data. Below the critical level a profitable response to added K is likely while soils testing above the critical level would be expected to result in limited or no response to added K.

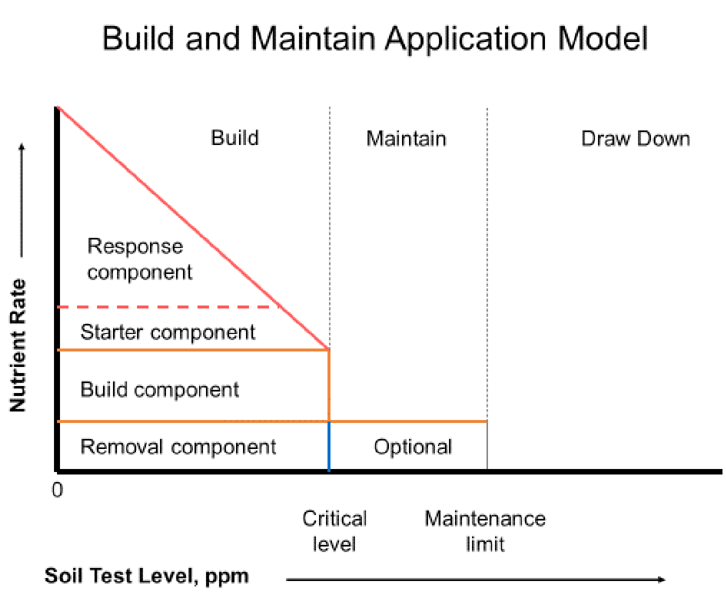
The critical level on the Canadian Prairies is generally set at 125 ppm (mg K/kg soil) or 250 lbs K/acre in the 0-6 in depth. Canola is a highly efficient K scavenger and seldom responds to K additions until soil test K drops below 75 ppm. Based on data compiled by the International Plant Nutrition Institute (IPNI) in 2015, about 23% of the soil tested on the Prairies fall below 120 ppm. The percentage is highest in Alberta (34%) and lowest in Saskatchewan (13%) with Manitoba falling in between at 21%. As shown below, three quarters of soils on the Prairies test above the critical limit. What is interesting is that soil test K values are gradually declining. Since 2001 the median value has fallen from 235 ppm to 195 ppm.



Source: IPNI 2015 Soil Test survey

The K soil test is a reasonably reliable predictor of K response. Based on soil test values, K rates can be set using a sufficiency approach to meet current crop needs or using a build and maintain approach. Since most K deficient soils on the Prairies are coarse textured, build and maintain must be approached with caution and is probably not suitable for soils with very low in CEC.

IPNI 2015 Soil Test survey



Source: Modified from Mengel, MB Agronomists Conference, 2011

As previously discussed, adequate K fertility relates to improved water use efficiency and aids in the mechanism that allows a plant to reduce its water loss and improve reaction to drought stress. Adequate K nutrition aids in the efficient use of other added plant nutrients; reducing the potential for carry-over and build-up of environmentally problematic N and P

Performance Objective 2. Describe how potassium rates may be affected by soil characteristics, which may include:

A) Cation exchange capacity:

Soils with high CEC tend to hold and maintain K in adequate levels to support plant growth. On the Prairies, high CEC soils are seldom K deficient. Low CEC soils have reduced capacity to maintain K for season long availability. Application rates for high CEC soils tend to be lower as opposed to those recommended for low CEC soils. Potassium can leach from low CEC soils in higher rainfall regions or under irrigation. CEC increases with clay and organic matter content.

B) Organic matter:

Potassium (unlike N, K and S) is not a structural components of soil organic matter. Organic matter contains negatively charged sites that retain exchangeable K^{+}. Increasing soil organic matter content increases CEC which in turn increases soil ability to hold K. Soils with high OM tend to hold more K (in reserve) that may be released for crop uptake.

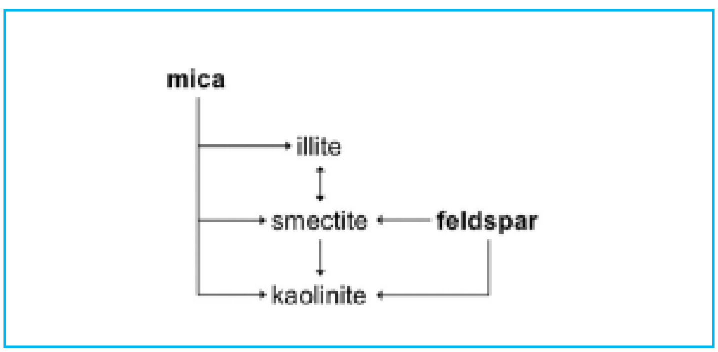
C) Texture:

Soil texture is an indicator of the relative distribution of soil particle size. Soils higher in clay, the smallest size fraction (< 2 μm), have higher CEC and tend to hold greater amounts of K in reserve for potential crop availability. Dependent upon mineral type, this "clay associated – K" may be held on the outside surface of the clay particle (exchangeable K) or may be held between clay mineral layers (called non-exchangeable or fixed K) and only slowly available as reserve K source.

D) Clay type:

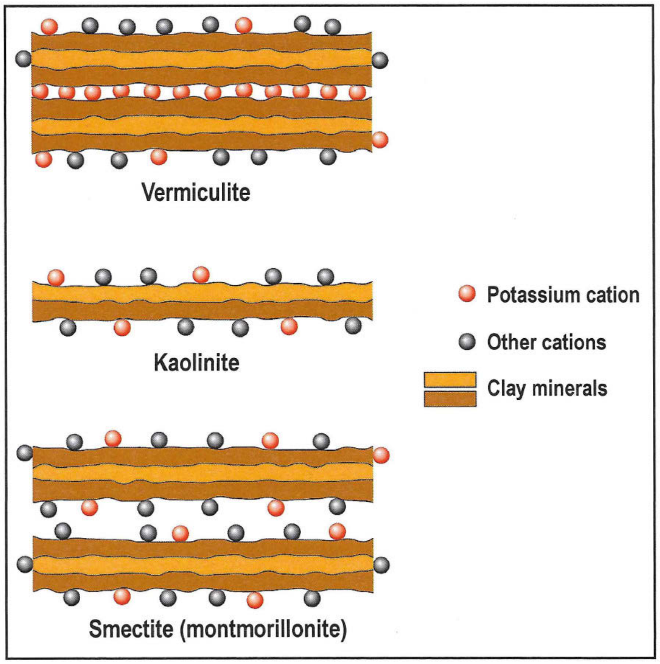
Clay mineralogy influences exchangeable K and fixed K. Feldspar and mica are common K containing primary minerals is soil. Feldspar weathers slowly to form clay minerals in the smectite or kaolinite groups. Mica weathers more quickly to form illites, smectites or kaolinites. Despite relative difference, weathering is an extremely slow process. In relatively young Prairie soils (<10,000 years old), clay content is largely a result of the clay contained in the parent material. Very little of the clay present has been formed through weathering in place.

Formation of Clays from K Containing Primary Minerals



Source: Franzen & Bu, 2018

Clay minerals differ in their ability to hold K. Prairie soils tend to be rich in 2:1 clay minerals that have a relatively high CEC compared to the 1:1 clays such as kaolinites. Smectites such as montmorillonite and bentonite are expanding clays which means that water and K can move in and out of the space between clay plates and is available to plants. Illite is also a 2:1 clay mineral derived from muscovite mica. The plates are held together very tightly because potassium fits perfectly between the plates of illite and is held there or fixed where it is not readily available to plants. Vermiculite is a smectite type mineral derived from biotite micas. It behaves somewhat like illite in that K can get fixed between adjacent clay platelets but it is more expandable than illite, so a portion of the fixed K can be released during wet-dry or freeze-thaw cycles. Conversely added K can be fixed under the same conditions.

Potassium and other nutrients (such as ammonium) can be trapped between the layers of some clay minerals. Fixation occurs when K is held on highly charged sites in the interlayer region of clay minerals (such as vermiculite and mica). This differs from exchangeable K which is held on charged sites at the surface and edges of clay minerals and on organic matter.

Source: IPNI

PERFORMANCE OBJECTIVE 3. DISCUSS THE CONTRIBUTION OF POTASSIUM FROM:

A) Previous potassium application:

Potassium removals are largely through the harvested portions of crops. Since K is largely held in the vegetative parts of plants, most K taken up by grain and oilseed crops is returned to the soil with crop residues. Forage crops have higher removal rates. Soil erosion and leaching on very coarse textured soils also remove K from cropping systems. Soil K application rates that exceeds crop removal build available K levels. As with P, soil test K levels may be deliberately built up as an agronomic or economic strategy. For example, a multiyear application ahead of seeding a perennial forage. Regular soil testing provides information that can be used to match application rates with crop removal; keeping in mind changes in environmental conditions such as pronounced wet-dry cycles may cause some variability in STK levels.

B) Manure:

Manure analysis should be conducted to verify the K content. Manure application rates are typically based on either N or P but understanding how much K is applied with manure is useful in managing K nutrition in subsequent years. Manure typically contain more K than N or P and the K tends to all be in plant available form. Supplemental K is seldom required when manure application rates are based on N or P; in fact, repeated manure application can result in a significant buildup of K in soil. When the buildup occurs on grazed forages it can result in magnesium deficiency (grass tetany) in cattle. The deficiency is in the cow not the plant and is more common in dairy cattle grazing stands where liquid manure has been over applied. The risk is particularly high in spring when grass is growing rapidly and may be taking up luxury amounts of K that interfere with Mg use in the rumen of cattle or sheep.

C) Biosolids:

Unlike manure K levels in biosolids tend to be low compared to N and P. Analysis of the K content and the application rate of the biosolid material can be used to assess whether or not additional K is warranted. Biosolid K is generally considered to be immediately plant available. Depending upon nature of the biosolid and application method – availability may be limited until the material and/or the K is moved into the rooting zone by infiltration or incorporation.

D) Previous crop residue:

As previously discussed, the greater percentage of K taken up by crops is contained in vegetative biomass. Crop residue returned to the field releases K rapidly and will supplement soil K for future crop requirements. Removal of straw following grain or oilseed harvest and silage or hay harvest significantly reduce K return to the soil. In zero till systems, K released from residues may build up near the soil surface. This K stranding is only a problem in soils that are already low in K. Attention should be paid to total crop K removal based on crop species and what level/amount of K is being returned to the field as crop K residue. A K balance can be used along with periodic soil testing to determine if removals in excess of additions is likely to cause deficiency in the near term.

E) Wastewater:

The K content of waste water is highly variable depending on the source and processing prior to application. For example, the typical range for potassium in most municipal wastewaters is 5 to 40 mg/L. If 30 cm (12 in) of wastewater were applied as irrigation, this would translate to a K loading of 15 to 120 kg K/ha/yr (13 to 107 lbs K/ac/yr). While these levels are are not considered to be of an environmental or health risk, analysis for K content is necessary in determine if the application rate is sufficient to meet crop needs. Regular analysis will ensure proper K rates are applied, as well as addressing potential concerns around undue salt loads and nutrient imbalances. Land application of many types of waste water is regulated in all three provinces.

Performance Objective 4. Discuss the impact of timing and placement on the rate of potassium applied.

Potassium uptake efficiency is increased when K is placed near or with the seed. Crops vary in their tolerance to seed placed K, (consult provincial guidelines for specific crop regarding safe seed placed rate). (See PO3 in CA3 below)

Concentrated bands are more efficient than broadcast applications in many situations. Low soil testing fields respond well to side-band and seed placed K to meet early season crop need – especially when early season soils are cool. Mid-row bands may delay access until seedling roots reach the band. Surface applied K (without incorporation) may become stranded and relatively plant unavailable, most notably when dry surface soil limits root activity. Typically, broadcast K recommendations on low K soils (with or without incorporation) call for 2X the rate of band or seed row applied recommendations. Application in fall or spring are both effective. While K is not subject to high overwinter loss, application on frozen or snow-covered ground should be avoided.

Performance Objective 5. Recognize how environmental conditions may modify the need for potassium, including soil moisture and temperature.

Potassium movement occurs through both mass flow and diffusion. Diffusion typically accounts for greater than 75% of transport to the root surface. Diffusion rates are mediated by soil moisture and temperature – movement and availability of K is greater with warm and moist soil. Crops grown on soils testing above the critical limit may still benefit from side band or seed placed K when spring conditions are not conducive to K movement and availability of K to the developing seedling and plant.

COMPETENCY AREA 3. DETERMINING THE RIGHT TIMING AND PLACEMENT/METHOD OF POTASSIUM APPLICATION.

Timing and placement practices need to consider the source and required rate. Understanding individual crop requirements and uptake timing coupled with soil characteristics will improve decision making with respect to K application timing and method.

Performance Objective 1. Discuss how the timing and method of potassium application can impact crop response.

Potassium can be broadcast, broadcast with incorporation, banded or seed placed. Band and seed row applied K tend to be more available and efficiently used than broadcast K. Potassium is relatively immobile and movement to the emerging plant occurs largely through diffusion, which is mediated by temperature and moisture. Cool, dry, and low K testing soils benefit from proximity of K placement and application at time of seeding. Preferred timing is at or before seeding as K availability early in the growing season is important in stand establishment and root growth. Repeated broadcast K without incorporation in no-till systems can lead to build-up at or near the soil surface. This near surface K will not be available if the surface layer dries.

Performance Objective 2. Recognize toxicity concerns with excess rates of seed row placed potassium.

Fertilizer K placed directly with the seed can cause injury. Granular fertilizer requires soil moisture to dissolve and draws moisture from the soil. Once dissolved the fertilizer solution creates a saline environment that can prevent seeds from imbibing moisture or seedling from taking up water. Liquid fertilizer is a saline solution when applied and if in direct contact with the seed at too high a rate can reduce germination and emergence. For certain chloride sensitive crops, placing potassium chloride in the seed row can lead to chloride toxicity in addition to the salinity effects. Most cereals and oilseeds are fairly chloride tolerant with the exception of sunflowers. Vegetable crops tend to be sensitive.

Crop species have varying tolerances for seed row K and the 4R agronomist should consult provincial guidelines for safe rate of K that can be applied in seed row. Alberta suggests the maximum for seed placement is 35 lbs K2O/ac for cereals and 15 for canola and pulses. Saskatchewan suggests using the guidelines for seed placed P2O5 which would translate to 50 lbs K2O for cereals under good moisture conditions in a medium textured soil. To stay safe, P2O5 and K2O added together should be no more than the safe rate. Like N and P, the potential negative impacts of seed row placement are reduced in finer textured and moister soils and openers with greater seed bed utilization. Keep in mind that effects are cumulative and if the seed row P guidelines are used, the P2O5 plus K2O combined rate should not exceed the maximum safe rate for P2O5. Some caution may be warranted when using maximum safe rates for P2O5 as the limits for K2O application. The salt index per mass of product is approximately 3X higher for KCl (114) compared to MAP (34). Salt index is an indicator of the relative effect of fertilizer material on the salinity of the soil solution. Sodium nitrate (NaNO3) is set as the standard at 100.

Soil texture, soil organic matter, soil moisture, and seed furrow openers all affect seed row tolerances. Low clay and organic matter, dry soil and narrow openers on wide spacing individually or in combination require reduced rates in the seed row . Higher clay and organic matter, better soil moisture, broader openers and/or narrow spacing all increase tolerance and allow for higher rates.

Performance Objective 3. Discuss considerations to determine the proper placement and method of application of potassium based on the:

A) Crop type:

Shallow rooted crops are able to utilize surface applied and incorporated K. Deeper rooted crops will benefit from deeper placed and/or band applied K and may more effectively access subsoil K. Cropping sequence can impact movement and uptake of soil K through the variations in rooting structures that explore different portions of the root zone. Potassium trapped at or near the surface as it dries can be stranded regardless of rooting system.

B) Cropping system:

Application rate, placement and application method can be based upon the sequence of crops to be grown, their uptake requirements and rooting structure as well as seed row tolerance. Rates may be applied to provide for a multi-crop/multi-year application. For example, high rates on corn allowing carryover to feed a subsequent soybean crop. Perennial forage may benefit from an initial one-time large application rate during stand establishment, followed by annual “maintenance rate” applications. Annual crops may benefit more from band or seed placed rates that match crop removal requirements.

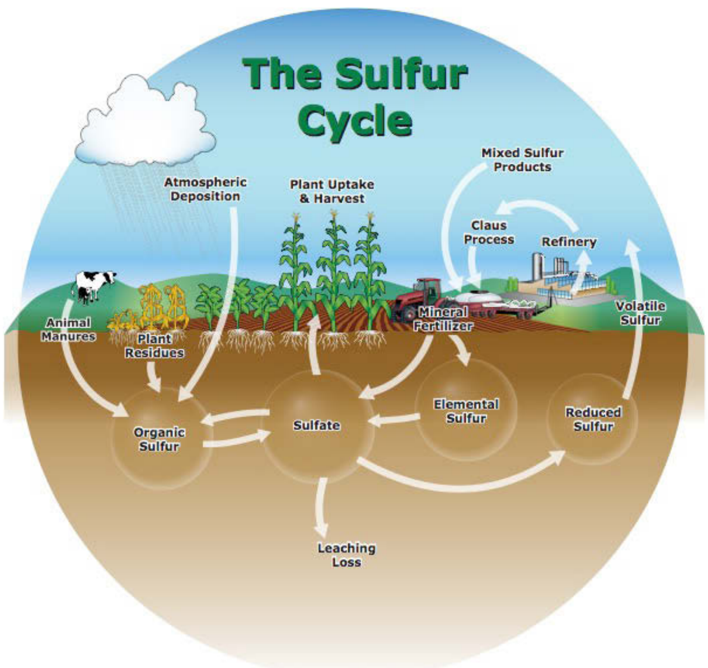
C) Method of tillage:

Tillage will aid in redistribution of K applied as fertilizer, returned as residue, or stranded in the surface soil layer. Conventional tillage mixes near surface K with deeper soil layers, disrupts residual bands, and generally distributes K through a larger soil volume. No-till practices can result in surface stratified K layers. Stratification of K can become problematic in dry years when root absorption occurs at soil levels deeper than the position of the stratified K. In such situations, starter placement of K with seed or as a side-band can help with early season K availability.

Performance Objective 4. Recognize the options for placement and method of application of potassium based on current potassium soil test levels and soil texture.

When soil test K levels are at or near adequate levels – placement of K becomes less critical. Adequate available K allows the plant to draw from a larger soil volume, as opposed to low soil test K levels, when there is less likely chance of K being in proximity to roots for uptake. The lower the soil test K level, the more critical becomes the K placement method. Concentrating K in a band on soils testing deficient and very deficient improves uptake efficiency.

Soils with finer textures have higher CEC and a higher reserve K potential. This reserve can aid in supplying additional exchangeable K throughout the growing season – provided it becomes available for plant uptake in a timely fashion. Exchangeable K availability should be thought of as largely a positional issue. Exchange reactions that release K+ into the soil solution are near instantaneous as solution K+ concentrations fall due to root uptake. Low moisture can reduce diffusion to the root as well as prevent roots from exploring and exploiting K near the soil surface. Surface placements on finer textured soils will tend to confine K closer to the surface than on a coarser textured soil. Seed row K is safer on soil with more clay.



COMPETENCY AREA 4. DETERMINING THE RIGHT SOURCE, RATE, TIMING AND PLACEMENT/METHOD OF SULPHUR.

Source, timing and placement interactions need be considered when setting S application rates. The risk of S loss is generally low but varies depending upon soil type/texture, application time and prevailing environmental conditions. Application of S can occur several months before crop demand materializes, providing the applied S is maintained in the soil, or the form of applied S is not subject to leaching loss. Although labour demands may require such application timing, applying S (as SO_4^{2-}) as close to time of major demand is still preferable. Understanding individual crop S requirement and uptake timing coupled with soil characteristics will improve decision making with respect to S source, rate, time and place

Performance Objective 1. Discuss the availability/potential deficiency of sulphur in the Prairie Region.

Sulphur deficiency is more prevalent on sandy, coarse textured soils, low in organic matter. High rainfall geographies are also likely predisposed to potential S deficiency as a result of sulphate leaching. Higher yields and increased frequency of S demanding crops such as canola in rotation have the potential to draw down soil S levels. In non-saline soils, S is largely supplied by the soil organic matter through mineralization. Prairie soils may have gypsum ($CaSO_4$•$2H_2O$) in the lower horizons which may be exposed at the surface on eroded hilltops. Gypsum is a sparingly soluble salt but supports a relatively high solution concentration of sulphate. It can act as an internal S source once the roots come in contact with a gypsum enriched horizon. Saline soils are typically high in available S as the common soluble salts in Prairie soils are sodium and magnesium sulphate. Sulphur is unevenly distributed in most landscapes. There can be areas that are highly enriched with sulphate-S and other areas that are very deficient in the same field.

Performance Objective 2. Discuss the most common sources of sulfur in the Prairie Region.

A) Sulphate based (recognizing solubility differences):

Granular S sources dominate the S marketplace in the Canadian Prairies. Ammonium sulphate (21-0-0-24 and 20.5-0-0-24) is the most common granular product. They supply sulphate-S that is immediately available to crops. Potassium sulphate or sulphate of potash (K2SO4, 0-0-50) is not widely available or used on the Prairies for field crops but does potentially have a place with Cl sensitive crops like potatoes. Gypsum is occasionally used as an amendment on sodic and solonetzic soils and can be considered a low solubility S source. Keep in mind that soils receiving gypsum are seldom deficient in S.

B) Elemental-Sulphur:

There are several elemental-S products marketed on the prairies, ranging in S content from 70 to 90%. These products typically contain a dispersing agent such as bentonite that imbibes water and swells causing the granule to readily disintegrate following application. Dispersion is required to increase surface area and expose the elemental-S to oxidizing soil microbes.

Elemental granular products tend to perform best when applied in the year before they are required. For example, in the cereal phase of a wheat-canola-pulse rotation. This allow for an appropriate oxidation period to convert elemental-S to sulphate-S. Typically these products are surface applied in fall, left to disperse on the soil surface over the fall and winter, and incorporated by some method the following spring.

The size of individual particles of elemental-S in the granule determines total surface area and is an important factor in determining the oxidation rate. Research suggests that for timely oxidation the individual particle size should be less than 90 µm, and preferably less than 60µm. Aside from particle size and dispersion related to surface area – oxidation is also mediated by soil water content, organic matter and soil pH – as they relate to creating a favorable microbial environment. Elemental-S application builds the population of sulphur oxidizing bacteria. Soils that have received recent applications of elemental-S tend to oxidize more quickly than soils that have never been exposed to the product. Elemental-S products have a high grade and usually a relatively low price. When applied using appropriate practices, they can form the basis for a successful S program on chronically deficient soils.

C) Liquid ammonium thiosulphate:

Ammonium thiosulphate (12-0-0-26) is a non-corrosive liquid S source suited for use in liquid fertilizer systems and fertigation. It supplies both colloidal elemental-S and sulphate-S. This product is toxic if placed in direct seed contact but is suitable for band application and as a foliar S source.

D) Combined sulphate and elemental-S products:

Combination granular S sources (for example, 13-33-0-15, MicroEssentials® S15™) containing elemental-S and sulphate -S are now widely available on the Prairies. Smaller particle size becomes more important with higher percentage of elemental-S in the granule. Larger particle size and high elemental percentage can lead to granule collapse that traps elemental-S inside - reducing oxidation potential.

E) Recognize interactions among sources, timing and placements:

Pure elemental-S products are best applied well in advance of crop demand using placement methods such as broadcasting that allow dispersion. Elemental-S rates in excess of what the crop actually requires can be used as a hedge against slower than expected oxidation rates. Elemental-S products may be used as a long-term S supplying source with growers taking advantage of a one- time large application rate.

Sulphate-S products provide immediately available S to the crop. Sulphate may be susceptible to leaching, so practitioners wishing to fall apply should be aware of leaching potential of the target fields. Areas where spring runoff collects and moves through the profile as the frost leaves the ground may be deficient even though fertilized the previous fall. Spring applications on sandy soil with higher leaching potential may result in S deficiency following large volume rainfall events rainfall events.

Combination products offer the benefit of short and longer-term S availability, good storability and potential for reduced seed row application injury. However, the process of oxidation still controls the overall availability of the elemental-S portion in the granules of these products. More even distribution of multiple nutrients is a related advantage of compound products.

Performance Objective 3. Discuss considerations that may be used to determine the right source of sulphur based on:

A) Crop Type:

Crops vary considerably in their S requirements. Canola is a high S user and will fail to produce oil if S is deficient. High N rates without S can actually depress yields in S deficient soils. Forage and grain legumes are high S users as the S containing amino acids are required by nitrogen fixing bacteria in the synthesis of the nitrogen fixing enzyme nitrogenase and the oxygen controlling compound leghaemoglobin. Sulphur deficiency in these crops can be more devastating than in crops with better tolerance for marginal soil S levels and/or lower overall demands such as cereals. None-the-less cereals are susceptible to S deficiency particularly on coarse textured or low organic matter soils in higher rainfall areas. Sulphur is often a limiting nutrient in the grey soils zone on the Prairies. Seeding high demand crops into known S deficient soils or alleviating deficiency in a growing crop requires the use of sulphate-S containing sources.

B) Tillage and cropping system:

Understanding individual crop demand within the longer-term cropping sequence can aid in product selection, rate and timing. Management may be undertaken to utilize products to provide S in the immediate and longer-term by taking advantage of product characteristics (for example, elemental-S vs sulphate-S), residence in soil and fertilizer economics and farm logistics and labour. Sulphate-S is mobile in soils. The requirement for incorporation into the rooting zone with tillage is less critical provided there is sufficient moisture between application and demand to move the sulfate into the rooting zone before crops demand increases. Elemental-S is largely insoluble; however, incorporation can slow oxidation by reducing dispersion of the granules. In essence, a granule surrounded by soil may imbibe water and collapse with little increase in total soil contact.

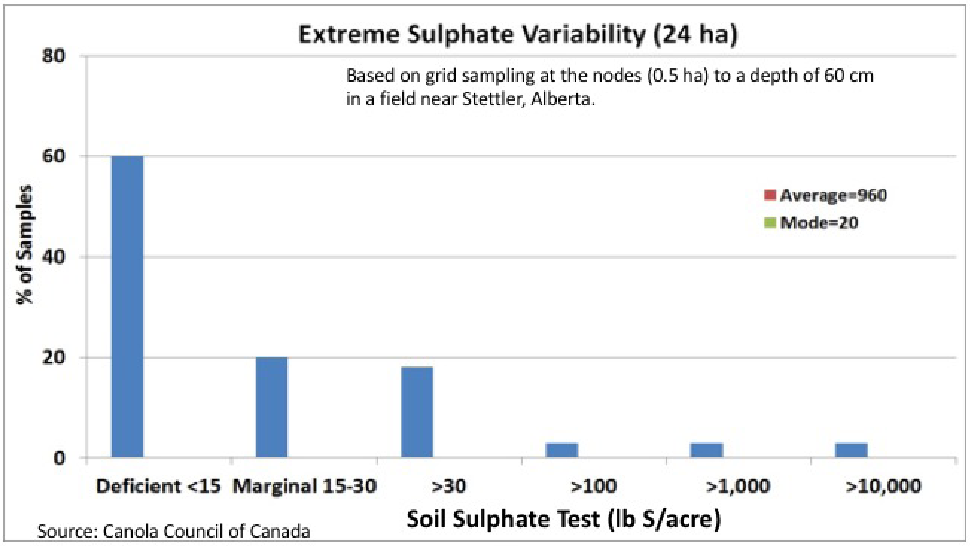
C) Crop growth stage:

For most crops, S is required throughout the season and season-long availability needs be considered. The idea behind combined sulphate and elemental products is that the sulphate supports early season growth and the elemental-s slowly oxidizes to support demand later in the season. Early season deficiency can be corrected with in-season application provided it contains sufficient sulphate. In canola, yield can be largely recovered if S is applied up to bolting and a yield response or partial recovery is still possible up to early flowering. Although S in required in considerably smaller amounts than NPK, it is still considered a macronutrient. Uptake of foliar applications will be largely through the roots rather than the leaves. Dribble banded thiosulphate can be effective in season as the thiosulphate rapidly converts to sulphate. In-season application can be limited to areas of the field that are showing or suspected of deficiency.

D) Soil test or tissue test:

Due to the spatial and temporal variability of S within fields – composite soil test values cannot be viewed using the same probability of response approach used with other nutrients. A field with a deficient or marginal soil test S (STS) value will in all likelihood respond to added S and would point to the use of an immediately available S source with the current crop. Composite STS values in the optimal or excess range may indicate adequate S or they may be skewed by the inclusion of cores from areas enriched with sulphate salts. In these cases, the soil test can be very misleading, suggesting sufficiency when significant portions of the field may in fact be deficient.

Most often S application is made based on crop removal/yield requirement and an understanding of soil characteristics and environment. For example, adequate S is more likely to be evenly distributed in medium to fine textured fields with uniformly high organic matter and low relief than in fields with large variations in those factors. In fields testing high in S, zone, grid, or landscape directed sampling is required to understand S distribution. Plant tissue testing can be used to confirm suspected S deficiency, and also to address areas of a field that may potentially become deficient in future cropping situations.



E) Timing and placement of application:

As sulphur is plant immobile, S needs to be available throughout the growing season. Select a source, application rate and method to ensure season long availability. Where leaching potential is significant, source and time can be adjusted to reduce loss. For example, fall application of an elemental-S or combined source will reduce losses compared to a pure sulphate-S source. If using a source that requires oxidation to become available for plant uptake – be aware that placement (surface) and timing (well ahead of demand) are important considerations in determining availability and use efficiency. Ammonium sulphate placed in the seed row can be quite toxic and is generally better placed in a side-band or mid-row band away from the seed or broadcast. Thiosulphate can be blended in liquid blends but is quite toxic if placed in contact with seed.

Performance Objective 4. Discuss how managing the 4Rs for sulphur influences nitrogen and phosphorus losses to surface and groundwater.

Sulphur and N are closely linked in plant growth through protein production and both nutrients are associated with chlorophyll production. Poorly managed/unbalanced fertility can lead to “left-over” applied N that can find its way into water bodies. Similarly, reduced crop production resulting from inadequate S application can lead to unused P which may also accumulate in water bodies. Surface application of S containing combination fertilizers that also contain N or P can increase the potential risk of N and P losses to runoff. Grey wooded or Luvisolic soils tend to be S deficient. Ensuring adequate S nutrition in these soils increases yields, reduces residual N, returns more residue, increases soil organic matter. All factors that help prevent or reduce N and P losses.

Performance Objective 5. Discuss considerations that may be used to determine the right rate of sulphur based on:

A) Source of sulphur:

All of the S in the fertilizer is considered immediately plant available if using a sulphate-S based source; application rate is reflective of crop requirement. If using an elemental-S source or a combined S product, the rate of application may need to be increased to ensure adequate available S in the year of application.

B) Crop type:

Crop S requirement varies with crop type. Similarly, the importance/need of S also varies with crop. Removal should be considered not only on a total production basis, but also on a lb/bu basis. Rates need to reflect yield goals as well as crop type.

Sulphur Uptake and Removal by Various Crops					
Crop	Factor	lbs S/bu	Crop	Factor	lbs S/bu
Wheat, CWRS	Uptake1	0.20	Triticale	Uptake	0.90
	Removal2	0.10		Removal	0.45
Wheat, CPS	Uptake	0.30	Corn	Uptake	0.16
	Removal	0.15		Removal	0.07
Wheat, Durum	Uptake	0.20	Canola	Uptake	0.52
	Removal	0.10		Removal	0.30
Wheat, ESRS	Uptake	0.20	Flax/Linola	Uptake	0.49
	Removal	0.10		Removal	0.20
Wheat, Winter	Uptake	0.30	Mustard	Uptake	0.52
	Removal	0.15		Removal	0.30
Wheat, Soft	Uptake	0.30	Sunflower3	Uptake	1.68
	Removal	0.15		Removal	0.89
Barley, Feed	Uptake	0.19	Edible Bean3	Uptake	0.50
	Removal	0.10		Removal	0.25
Barley, Malt	Uptake	0.19	Soybean	Uptake	0.12
	Removal	0.10		Removal	0.06
Oats	Uptake	0.14	Sugarbeet3	Uptake	1.6
	Removal	0.05		Removal	0.60
Rye, Spring and Fall	Uptake	0.26	Potatoes3	Uptake	1.0
	Removal	0.09		Removal	0.65

1Uptake is the total nutrient taken up by the crop (grain, straw, etc.).

2Removal is the total nutrient removed with the harvested portion of the crop (grain, tubers).

3Units are lbs S/ton crop.

C) Tillage and cropping system:

Understanding individual crop demand within the longer-term cropping sequence can aid in source selection, placement, and timing. Crop rotations with more frequent inclusion of high S demanding crops will require higher S rates over the rotation. Management may be undertaken to utilize products to provide S in the immediate and longer-term by taking advantage of product characteristics, residence in soil and fertilizer economics and farm logistics and labour. In such cases S may be front-loaded elemental-S to supply S for future crops. Sulphate-S is mobile in the soil and surface applied S can be moved into the rooting zone by rainfall or snowmelt.

D) Crop growth stage:

For most crops, S is required throughout the season and season-long availability needs be considered. In plastic crops such as canola, early season deficiency can be overcome with in-season applications. The data from Agriculture Canada shown below suggests that S application even up to flowering can to some extent overcome deficiency and raise yields but will not fully compensate for an inadequate rate applied at or before seeding. Product rate may be weighed against crop removal and also local environment if loss conditions are expected during the season.

Time and Place Interactions with Rate in Canola

Treatment	S rate (kg/ha)	Yield (kg/ha) Mean of 6 sites
No Fertilizer	0	406
S sidebanded at seeding	30	779
N + S incorporated at seeding	15	1074
	30	1228
N + S sidebanded at seeding	15	1064
	30	1208
N + S seedrow placed at seeding	15	1083
	30	1156
N + S topdressed at bolting	15	823
	30	937
N + S foliar applied at bolting	15	910
	30	1002
N + S topdressed at flowering	15	646
	30	766
N + S foliar applied at flowering	15	788
	30	813

Source: Canola Encyclopedia https://www.canolacouncil.org/canola-encyclopedia/

E) Soil test or tissue test:

As discussed earlier (CA4,PO3), due to the spatial and temporal variability of S within fields – soil testing for S is not necessarily considered valuable. Soil test sulphur levels below 8 lbs S/acre in the 0-24 in depth are considered severely deficient while the critical limit above which response is unlikely is typically taken as 30 lbs S/acre. For a S demanding crop like canola, soils testing low would require rates up to 30 lb S/ac to ensure sufficiency, while soils testing marginal would typically require 10-15 lb S/ac. Most often S application is made based on crop removal/yield requirement and an understanding of soil characteristics and environment. Plant tissue testing can be used to confirm suspected S deficiency, and also to address areas of a field that may become potential deficient in future cropping situations.

F) Timing and placement of application:

As sulphur is immobile in the plant, S needs to be available throughout the growing season. As shown above, applying too low a rate at or before seeding cannot be fully compensated for by in-season application. If using a source that requires oxidation to become available for plant uptake – it may be prudent to increase application rate if time and place and/or oxidizing conditions (cool, dry) are likely to result in insufficient conversion to meet crop demand. A less risky approach would be to use a sulphate or combined source when time, place and oxidative conditions are less than ideal.

G) Irrigation:

Irrigation water should be tested for S content and accounted for in setting S rates. Irrigation water on the prairies typically contains sulphate and this may range from little to as high as 25 lb S/acre-inch of applied irrigation water. Sulphur concentrations will vary with source (groundwater > surface water) and time of year, typically highest in June and then tapering off through the remainder of the growing season. In southern Alberta, a typical application of 12 inches of irrigation over the growing season would supply about 30 lb S/acre more than adequate for most crops.

H) Atmospheric deposition of sulphur:

More stringent regulation of sulphur dioxide (SO2) emissions and advances in technology for reducing emissions has resulted in less S being incidentally applied to farm fields. As such, S requirements are often higher than what they were in the past and more S deficient situations arise. Atmospheric deposition may still be a significant contribution to S nutrition in depositional areas downwind from refineries, coal fired power plants or other large industrial emitters.

COMPETENCY AREA 5. DETERMINING THE RIGHT SOURCE, RATE, TIMING AND PLACEMENT OF CALCIUM AND MAGNESIUM.

The soils of the Canadian Prairie region are relatively young, and the last glacial period deposited and mixed pre-glacial calcareous material containing a large component of limestone bedrock. Nearly all the agricultural soils have developed on calcareous till or lacustrine parent materials and still contain a lime layer in the lower profile. Additionally, the preponderance of medium and finer textured soils with relatively high CECs and the semi-arid climate has maintained Ca and Mg in the upper horizons of the profile. Finally, Prairie soils for the most part developed under grassland or parkland with grass as a major component. Grasses tend to draw Ca from the subsurface to the surface where it is deposited with residues. As a result, the vast majority of Prairie soils have high base saturation dominated by exchangeable Ca with Mg typically being the second most abundant cation held on the cation exchange complex.

Most CCAs working on the Prairies will never see an actual Ca or Mg deficiency during their careers and will likely never be in a situation where application of Ca and Mg is required to correct deficiency. Calcium and Mg interactions with K may require some consideration, as should particular geologic deposition and soil formation within specific geographies, e.g. Peace River Valley Region of NW Alberta where glacial till deposits were shallow, and overlaid pyrite deposits which weathered to produce acidic soils with low base saturation. The use of Ca and Mg products in amelioration of acid and sodic soils is discussed in detail in the amendments section (Proficiency Area 6) of this guide.

Performance Objective 1. Discuss the availability/potential deficiency of calcium and magnesium in the Prairie Region.

Calcium and Mg deficiencies are extremely rare on the Canadian Prairies. Special crops such as fruits and vegetables have a higher Ca and Mg requirement as opposed to general field crops.

Conditions that may lead to Ca and Mg deficiency include:

- Strongly acidic soils or soils that have been acidified by contaminants.
- Sodic soils that contain high exchangeable sodium levels and have a high pH. Canola responses to Ca have been reported in the Peace River Region and East Central Alberta and are associated with soils of high sodium (Na) content.
- Sandy soils with very low organic matter levels, low CEC and high oxide content.
- Soils from parent materials high in serpentine minerals and disproportionately high magnesium content may be prone to Ca deficiency.
- Temporary Ca deficiency can occur in saturated soils, but in this case Ca fertilizer will not help. Excess soil moisture can reduce Ca uptake and since Ca is required for cell extension deficiency symptoms can occur almost immediately and in some cases are quite pronounced on new growth.

With the exceptions noted above, the soils of the prairies typically have adequate Ca and Mg for crop production. Soil tests have not been calibrated with crop response in Prairie soils. In other regions, a soil test level of 50 ppm Mg and 200 ppm Ca in the surface 6 inches is generally considered adequate for field crops. In IPNI's 2015 summary of over one hundred thousand Prairie soil samples, Mg tested over 100 ppm in 98.8% of samples and no samples (zero) tested below 50 ppm. The median value for Mg was just under 2000 ppm. Although comparable values for Ca were not collected as part of the IPNI summary, Ca soil test results reported by the Canola Council are shown below.

Soil type	Mean values extractable Ca (mg kg^{-1})
Non-calcareous	3200 ± 1051
Calcareous	6560 ± 3235
All soils	4050 ± 5263

The vast majority of Prairie agronomists have never encountered and are not likely to encounter an actual Ca or Mg deficiency. That said, agronomist working in areas with coarse textured acid soils, sodic soils, and horticultural crops such as potatoes should be aware of the symptoms and remedies for Ca or Mg deficiency.

Consider the following worse-case scenario. An acidic sandy soil at pH 5 and a CEC of 6 me/100 g•soil, would still have a base saturation of approximately 50%. If, as is likely, the most common basic cation was Ca^{2+} and it occupied 40% of the cation exchange then the Ca concentration would be 480 ppm or roughly 1000 pounds of available Ca in the top 6 inches.

Performance Objective 2. Discuss the most common sources of calcium and magnesium used in the Prairie Region.

Calcitic or dolomitic limestone can be used to supply Ca or Mg + Ca, respectively. Gypsum is also used to supply Ca and magnesium sulphate can be used as a source of Mg. Wood ash can also be a significant source of Ca and K. Calcium and Mg application on the prairies is more typically due to pH adjustment in acid soils or use of products containing other nutrients. For example, potassium-magnesium sulphate may be applied as a KS source. Calcium may also be applied as gypsum in the amelioration of sodic soils, but even sodic soils contain more than adequate Ca for crop growth.

Calcitic lime (calcium carbonate)	$CaCO_3$
Magnesium carbonate	$MgCO_3$
Dolomitic lime (calcium magnesium carbonate)	$CaMg(CO_3)_2$
Calcium hydroxide	$Ca(OH)_2$
Calcium oxide	CaO
Magnesium hydroxide	$Mg(OH)_2$
Magnesium oxide	MgO
Potassium hydroxide	KOH
Gypsum (Calcium sulphate)	$CaSO_4 \cdot 2H_2O$
Wood Ashes	n/a

Performance Objective 3. Discuss considerations that may be used to determine the right source of calcium and magnesium based on:

A) Crop type:

Prairie soils mostly have large reserves of Ca and Mg and crop removal is not a significant concern. Vegetable and fruit crops would likely be more predisposed to Ca or Mg deficiency as opposed to general field crops. The source would depend upon whether Ca or Mg was required, and with or without a soil pH reaction adjustment.

B) Tillage and cropping system:

Depending upon the nutrient of interest and crop selection in the sequence, calcitic or dolomitic limestone may be applied at rates to provide several years' worth of either Ca and or Mg + Ca. In shorter – term cropping need situations, gypsum or magnesium sulphate products may be considered.

C) Crop and growth stage:

Gypsum and magnesium sulphate may be preferred sources if there is immediate need for Ca or Mg. Foliar spray preparations are available to supplement soil supply for crops with high Ca and/or Mg requirements, that cannot be met in a timely fashion through root uptake and distribution within the plant.

D) Soil test or tissue test:

Soil testing and plant tissue testing will advise of the need for Ca or Mg. Keep in mind that soil test Ca and Mg have never been correlated with yield response in field crops on the Prairies, so critical levels and soil test interpretation is based on data from elsewhere. More often additions of Ca and Mg are related to soil pH adjustment; then product considerations relate to effective neutralizing value, solubility, particle size, availability and cost are the relevant factors when making a source decision.

E) Timing and placement of application:

Prairie soils typically contain adequate Ca and Mg for crop growth. Short term need can be met with a fall or spring application of a readily soluble product type such as potassium magnesium sulphate. Longer term needs can be met with a large application of lime, gypsum or wood ash. Liming products are generally incorporated to aid in the movement and soil distribution of Ca and Mg. Given its greater solubility, incorporation of gypsum as a Ca supply is not as important.

Performance Objective 4. Discuss how managing the 4Rs for calcium and magnesium influences nitrogen and phosphorus losses to surface and groundwater.

Magnesium and N are closely linked in plant growth as constituents of the chlorophyll molecule. Magnesium aids in phosphate metabolism. Poorly managed/unbalanced fertility can lead to "left-over" applied N that can find its way into water bodies. Similarly, reduced crop production resultant from inadequate Ca and/or Mg application can lead to unused P which may also accumulate in water bodies. Given that Ca and Mg deficiency is extremely rare, the impact of managing these nutrients as fertilizer has negligible effects on N and P loss.

Performance Objective 5. Discuss considerations to determine the proper rate, timing and placement/ method of calcium based on the:

A) Crop type:

Crops such as alfalfa, soy bean and vegetables have higher Ca sufficiency requirements as opposed to other field crops. Vegetable and fruit crops are likely be more predisposed to Ca deficiency as opposed to general field crops. Potatoes have a high demand for Ca during tuber set and low Ca availability can affect tuber quality as well as storage. Calcium deficiency is reasonably common in other potato growing areas of North America and potatoes are often grown on slightly acidic soil to reduce scab. In those areas, potatoes tend to respond best to side dressed Ca timed to coincide with tuber initiation.

B) Cropping system:

Calcitic limestone may be applied at rates to provide several years' worth of Ca; for in season and shorter – term crop needs gypsum products may be considered. Low soil pH and high K application rates may exacerbate a Ca deficiency.

D) Crop and growth stage:

Gypsum and calcium chloride or calcium nitrate may be preferred sources if there is immediate need for Ca. Foliar spray preparations are available to supplement soil supply for crops with high Ca requirements, that cannot be met in a timely fashion through root uptake and distribution within the plant.

E) Soil test or tissue test:

Soil testing and plant tissue testing will provide information on the level of Ca relative to average or median values for the Prairies. Since soil tests for Ca have never been calibrated for crop response on the Prairies, the use of critical values from elsewhere needs to be approached cautiously. Given that correlation of soil and tissue test results with response is not backed by research findings under Prairie conditions, differential diagnosis (comparing soil or plant samples from affected with non-affected areas) would be the appropriate course of action when investigating suspected Ca deficiency .

Base Cation Saturation Ratios (BCSR) and Crop Response – BCSR sometimes referred to ideal ratios of Ca:Mg:K are widely used to make Ca and/or Mg and/or K recommendations in other parts of the world. A 2007 paper published in the Soil Science Society of America Journal found that there was no scientific basis for the ideal ratio concept. The abstract of the paper is provided below along with the complete reference for those who want to read the details.

The use of "balanced" Ca, Mg, and K ratios, as prescribed by the basic cation saturation ratio (BCSR) concept, is still used by some private soil-testing laboratories for the interpretation of soil analytical data. This review examines the suitability of the BCSR concept as a method for the interpretation of soil analytical data. According to the BCSR concept, maximum plant growth will be achieved only when the soil's exchangeable Ca, Mg, and K concentrations are approximately 65% Ca, 10% Mg, and 5% K (termed the ideal soil). This "ideal soil" was originally proposed by Firman Bear and coworkers in New Jersey during the 1940s as a method of reducing luxury K uptake by alfalfa (Medicago sativa L.). At about the same time, William Albrecht, working in Missouri, concluded through his own investigations that plants require a soil with a high Ca saturation for optimal growth. While it now appears that several of Albrecht's experiments were fundamentally flawed, the BCSR ("balanced soil") concept has been widely promoted, suggesting that the prescribed cationic ratios provide optimum chemical, physical, and biological soil properties. Our examination of data from numerous studies (particularly those of Albrecht and Bear themselves) would suggest that, within the ranges commonly found in soils, the chemical, physical, and biological fertility of a soil is generally not influenced by the ratios of Ca, Mg, and K. The data do not support the claims of the BCSR, and continued promotion of the BCSR will result in the inefficient use of resources in agriculture and horticulture.
-Kopittke and Menzies (2007) Soil Sci. Soc. Am. J. 71:259-265.

F) Timing and method of application:

Prairie soils typically contain adequate Ca for crop growth. Short term need can be met with a fall or spring application of a readily soluble product type such as calcium nitrate. Longer term needs can be met with a large application of lime, gypsum or wood ash. Liming products are generally incorporated to aid in the movement and soil distribution of Ca.

Performance Objective 6. Discuss considerations to determine the proper rate, timing and placement/ method of magnesium based on the:

A) Crop type:

Crops such as alfalfa, soybean, sugar beet, wheat, peas, rye and vegetables have higher Mg sufficiency requirements compared to other field crops and would theoretically require higher rates. Vegetable and fruit crops are likely to be more predisposed to Mg deficiency as opposed to general field crops. That said as a general rule that is seldom excepted, the right Mg rate for Prairie crops is zero.

B) Cropping system:

Depending upon the nutrient of interest and crop selection in the sequence, dolomitic limestone may be applied at rates sufficient to provide several years' worth of Mg and or Mg + Ca. In situations required more immediate availability, magnesium sulphate products may be considered. Low soil pH and high K application rates may exacerbate a Mg deficiency. Grass staggers or grass tetany in cattle can be caused by Mg deficiency in soils high in K. The deficiency is in the animal not the plant.

C) Crop and growth stage:

Magnesium sulphate may be the preferred source if there is immediate need for Mg. Foliar spray preparations are available to supplement soil supply for crops with high Mg requirements, that cannot be met in a timely fashion through root uptake and distribution within the plant.

D) Soil test or tissue test:

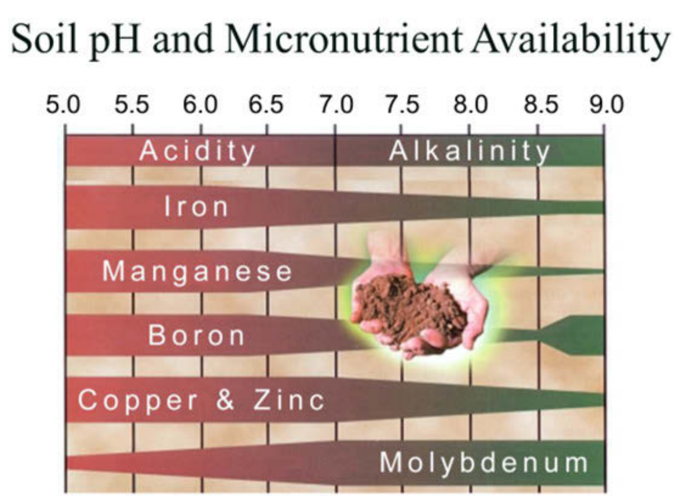
Soil testing and plant tissue testing will provide information on the level of Mg relative to average or median values for the Prairies. Since soil tests for Mg have never been calibrated for crop response on the Prairies, the use of critical values from elsewhere needs to be approached cautiously. Given that correlation of soil and tissue test results with response is not backed by research findings under Prairie conditions, differential diagnosis (comparing soil or plant samples from affected with non-affected areas) would be the appropriate course of action when investigating suspected Mg deficiency.

E) Timing and method of application:

Prairie soils typically contain adequate Mg for crop growth. Short term need can be met with a fall or spring application of a readily soluble product. Longer term needs can be met with a large application of dolomitic limestone or magnesium sulphate. Low solubility liming products are generally incorporated to aid in the movement and soil distribution of Mg.

COMPETENCY AREA 6. DETERMINING THE RIGHT SOURCE, RATE, TIMING AND PLACEMENT OF MICRONUTRIENTS.

Micronutrient deficiencies on the Prairie Region are not widespread. They typically occur under specific circumstances and within a relatively well-defined set of soil parameters. Extremes in weather condition, sensitive crop species, soil organic matter, pH and texture, as well as years in production, can all impact soil availability of micronutrients for crop production. Deficiency symptoms can be transitory and may not require intervention or in some cases such as deficiency induced by water logged soils, intervention may not solve the issue even if practicable. Application of micronutrients should be confined to situations where there is reasonable likelihood of a profitable response in terms of yield or quality. Micronutrients, like macronutrients, follow Liebig's Law of the Minimum and micronutrient fertilizer will only generate a positive response when the specific micronutrient applied is limiting. Micronutrient responses are generally not progressive like some of the macro nutrients, N for example. Increasing the rate does not necessarily increase the yield response. The right rate is a function of the source, time and place decisions rather than meeting a desired yield goal.



Source: IPNI

Micronutrient mobility in the soil varies. Boron and Cl are mobile: Fe, Cu, Mn, Zn, Mo, and Ni are not. All micronutrients are immobile or have low mobility in the plant, consequently deficiency symptoms show up on the growing tissue such as new leaves.

Performance Objective 1. Discuss the availability/potential deficiency of micronutrients in the Prairie Region.

Micronutrient levels are generally adequate to support crop growth. Deficiencies do occur and are more likely to increase in the future as higher yields draw down soil reserves. Furthermore, better technologies for mapping variation in yield potential are likely to identify areas of micronutrients at the subfield level that have previously been avoided or ignored.

A) Copper:

Copper deficiency in cereals is the most prevalent micronutrient deficiency on the Prairies. Copper deficiencies are most common (but not limited to) in the black soil zone occurring on sandy high organic matter soils, or sandy soils low in organic matter. Deficiency can occur although less commonly in medium and fine textured soils and are common in organic (peat) soils. High rates of manure can induce Cu deficiency under certain circumstances.

B) Manganese:

Manganese deficiency in oat, barley and peas may occurs under the same soil conditions described for Cu deficiency. In fine textured soils, Mn availability is affected by soil oxidation: reduction potential and soils that begin the season wet and then drain and dry may exhibit transient Mn deficiency symptoms. In oats, Mn deficiency is expressed as the physiological disease grey speck.

C) Zinc

Zinc deficiency has been noted on cereals, flax, edible beans and corn, and is associated with sandy, low organic matter soils and soils with high pH (e.g. > 7.5). Zinc deficiency in crops like corn can be induced by excessive manure application and high soil P levels.

D) Boron

Boron deficiency symptoms may occur on canola and alfalfa on low organic matter, lighter textured, well drained land and soils that are highly leached.

E) Iron

Iron deficiency chlorosis (IDC) can limit yield in soybeans and is correlated with free carbonates and soil salinity. Varieties differ in susceptibility.

F) Chloride

F) Chloride

Chloride deficiency is associated with down slope positions in coarser textured soils. Chloride is the most mobile of all nutrients in soil and can be readily leached down the profile. Not surprisingly, Cl deficiency tends to show up following one or more wet years. Chloride deficiency occurs more frequently or at least is more noticeable in cereals where it causes physiological leaf spotting. Varieties vary in their susceptibility to chloride deficiency. Chloride deficiency is easily remedied with potassium chloride. (Although nutrient management generally uses the term chloride, the essential element is actually chlorine and correctly speaking it's a chlorine deficiency. Chloride is the ionic form Cl^-.)

Copper, Zn, Mn, and Fe are immobile in soil, while B an Cl are subject to leaching. All of these micronutrients tend to be more available with lower soil pH and higher organic matter content (exception being peaty soils and soils with > 30% organic matter). Heavy manure applications may tie up metal micronutrients in chelates and induce a Cu or Zn deficiency. As well, high soil P levels can negatively affect uptake of Zn and Cu.

Performance Objective 2. Discuss the most common sources of micronutrients used in the Prairie Region.

Micronutrient fertilizers are available as chlorides, sulphates, oxysulphates, oxides, chelates, and complexes. Pure oxide forms are not commonly used due to low solubility and poor availability to the crop. Oxysulphate forms are manufactured by partially acidulated oxides with sulphuric acid. The degree of acidulation controls the proportion of sulphate forms and the water solubility of the micronutrient and its plant availability in the year of application. Finely ground oxysulphate powder forms (dry dispersible powders) can be added to granular fertilizer blends. Sulphates are usually 100% water soluble and plant available, as are chelated forms. Some granular sulphate forms (e.g. - copper sulphate) are corrosive and deliquescent (attract water) and not suitable for blending. Effective products should have a minimum of 35% water soluble available micronutrient, and preferably >50%.

Chelates (from the Greek for claw or talon) are complex organic molecules with two or more functional groups that hold metallic cationic ions. Chelated micronutrients are protected from soil reactions like precipitation as low solubility oxides that would render them less soluble and less plant available. The chelated micronutrient is in equilibrium with the soil solution and as plants take up the micronutrient the chelate releases to maintain the equilibrium. The more common chelation agents used on the prairies are EDDHA, EDTA and DTPA.

Performance Objective 3. Discuss considerations that may be used to determine the right source of micronutrients based on:

A) Crop type:

Even though micronutrients are required in small amounts, their presence is critical to crop growth and production.

Micronutrient removed by good yields of various crops.								
Crops harvested and portion used for analysis		Micronutrients removed (kg/ha)						
Yield level t/ha		Chlorine (Cl)	Boron (B)		Iron (Fe)		Zinc (Zn)	
Alfalfa	- hay	1.3	6	0.10	< 0.1		0.70	0.70
Barley	- grain	4.0	8	0.10	< 0.1		0.10	0.10
	- straw	-	1	0.02	< 0.1		0.70	0.10
Corn	- grain	9.5	2	0.70	< 0.1		0.10	0.20
	- stover	-	1	0.06	< 0.1	1.0	1.70	0.30
Oats	- grain	4.0	1	-	< 0.1		0.20	0.10
	- straw	-	1	-	< 0.1		0.20	0.40
Peas	- vines & pods	-	-	0.07	< 0.1		0.50	0.10
Potatoes	- white, tubers	40	27	0.07	< 0.1		0.20	0.10
Wheat	- grain	4.0	6	0.06	< 0.1		0.20	0.20
	- straw	-	2	0.02	< 0.1		0.30	0.10
Compiled by Alberta Agricultural from several sources.								

In addition to removing different amounts, specific crop types have varying sensitivity levels to the different micronutrients. In general, a crop with high sensitivity is more likely to be affected and more responsive `than a crop with low sensitivity when grown under similar conditions of micronutrient scarcity. For example, alfalfa may exhibit B deficiency when grown on a coarse textured low organic matter soil, but barley grown on the same site likely would not.

Sensitivity of Various Crops to Micronutrient Deficiency					
Crop	**Boron**	**Copper**	**Manganese**	**Molybdenum**	**Zinc**
Alfalfa	High	High	Medium	Medium	Low
Barley	Low	High	Medium	Low	Medium
Canola	High	High	Medium	Low	Medium
Clover	Medium	Medium	Medium	High	Medium
Corn	Low	Medium	Low	Low	High
Oats	Low	High	High	Medium	Low
Peas	Low	Low	High	Medium	Low
Rye	Low	Low	Low	Low	Low
Wheat	Low	High	High	Low	Low
Potatoes	Low	Low	High	Low	Medium

Source: Manitoba Agriculture

B) Tillage and cropping system:

Since crops vary in requirements, the crop rotation may contain a mix of sensitive and less sensitive crops. A common strategy is to apply micronutrients only to sensitive crops in the rotation and only in the year that crop is grown. A second is using a large one-time application (e.g. Cu) to front load for several subsequent sensitive crops such as cereals. Surface applied Cu, Zn, Mn, and Fe availability is improved with tillage. In no-till systems, foliar application of those nutrients may be a better alternative than broadcasting. Pre or in-season application of leachable B or Cl would be better 4R Nutrient Stewardship than attempting to apply a large one-time application. Within crops, varieties vary in their sensitivity to micronutrient deficiencies which can be a secondary management strategy in cases where less susceptible cultivars have been identified.

C) Crop growth stage:

Micronutrient needs tend be consistent through the growing season with peak demand timing for some crops, as well as a window of application time to be met for maximum crop benefit. Soil or foliar application can both be used as successful strategies but care needs to be taken to ensure the source selected is compatible with timing and placement.

D) Soil test or tissue test:

Not all micronutrient soil tests have been calibrated with crop response on the Prairies and interpretation may be based on use of critical limits imported from elsewhere rather than locally derived. Different laboratories may use different extractants giving very different results. The standard methods on the Prairies are DTPA for Cu, Mn, Fe, and Zn; Hot Water B; and Calcium Nitrate for Cl. Micronutrient levels can vary across a field and accurate soil testing levels may be difficult to obtain when composite sampling is used. A field representative sample may mask or elevate a deficiency reading. Understanding the variability within a field is essential and directed rather than random soil sampling can be a useful tool in delineating areas of deficiency.

Micronutrient Soil Test Interpretation

Micronutrient	Concentration (mg/kg)		
	Deficient	Marginal	Adequate
Copper			
• soil with less than 7% organic matter	0.0 - 0.4	0.5 - 0.6	> 0.6
• soil with more than 7% organic matter	0.0 - 0.6	0.7 - 1.0	> 1.0
Iron	0.0 - 2.0	2.0 - 4.5	> 4.5
Manganese	0.0 - 1.0	–	> 1.0
Zinc	0.0 - 0.5	0.6 - 1.0	> 1.0

Sources: McKenzie, Ross. 1992. *Micronutrient Requirements of Crops*. Agdex 531-1. Alberta Agriculture, Food and Rural Development; and Solberg, Elston et al. 1999. *Copper Deficiency: Diagnosis and Correction*. Agdex 532-3. Alberta Agriculture, Food and Rural Development.

Soil test values for pH, salinity, and free carbonates can help shape the decision among sources. In soils where micronutrients may be tied up, a source compatible with foliar application may be preferred. Plant tissue testing can be used to confirm symptoms of suspected micronutrient deficiency in season, or as additive information to what may have been a suspected (e.g. “marginal”) low soil test micronutrient level. In diagnosing and recommending micronutrients, information from soil and tissue tests needs to be supported by other sources of evidence such as soil type, field history, symptoms that point to deficiency.

E) Timing and placement of application:

Depending upon the cropping sequence, crop sensitivity, economic situation, land ownership situation etc., micronutrients (depending on source) may be seed placed (within safe rate guidelines), banded, broadcast and incorporated, or foliar applied. Some micronutrients are soil mobile (B, Cl, Mo) while others are not (Fe, Cu, Zn, Mn) or undergo soil reactions that render broadcast in-soil application less effective as compared to foliar (Fe, Cu, Zn, Mn). Relative to broadcast application, banding immobile granular products as part of macro nutrient blend can result in poor spatial distribution given the small quantities of the micronutrient product included in the blend. Compound fertilizer sources that include low levels of micronutrients in each granule can help with more even distribution. Fluid blends and/or inclusion with post emergent herbicide applications for products that are compatible with that application method are effective means to get more even distribution. Banded applications of micronutrients in conjunction with other acid or acid-forming fertilizers (e.g. ammonium sulphate) has been shown to be effective in maintaining the solubility of the immobile micronutrients.

Performance Objective 4. Discuss how managing the 4Rs for micronutrients inf uences nitrogen and phosphorus losses to surface and groundwater.

Micronutrients are closely linked to many plant enzyme systems, as well as chlorophyll formation, pollen grain development, protein synthesis and hormone (e.g. auxin) production and balance. Any micronutrient deficiency will result in loss yield and inefficient use applied N or P. Poorly managed/unbalanced fertility can lead to “left-over” applied N that can find its way into water bodies. Similarly reduced crop production resultant from inadequate micronutrient application and plant availability can lead to unused P which may also accumulate in water bodies.

Micronutrient deficiency in fields may be spatially controlled by difference in soil type and landscape position. For example, Cl deficiency tends to occur in lower slope positions where water accumulated and leaches it through the rooting zone. Applications of N to those areas at full field rates may not be utilized and may be leached. This is just one example of how micronutrient deficiency can influence N and P loss.

Performance Objective 5. Discuss considerations to determine the proper source, rate, timing and placement of copper based on the:

A variety of granular and liquid Cu products are available in Western Canada. Different sources require different rates, timing, and placement to be effective. The table below provides an overview of the Cu chemistries available. Different companies may offer similar chemistries in slightly different combinations or concentrations. This may include products that contain combinations of micronutrients rather than a single element.

Product	Chemical	Cu Content
Cu Lignosulfonate (granular)	Cu Lignin Sulfonate	5%
Cu Sulfate (granular)	CuSO4-5H2O	25%
Cu Oxysulphates (granular)	Cu Treated with H2SO4	15-20%
Cu Chelate-EDTA (liquid)	Cu-EDTA	93.5 g/L
Cu-Sequestered (liquid)	Cu Complexed with Lignin Sulfonate	61.1 g/L
Cu Sulfate/Chelate (soluble granules)	Copper Sulfate, citric acid, EDTA	20%
Cu-Sequestered (liquid)	Cu Oxychloride	500 g/L

A) Crop type and variety:

Sensitive crops should have readily available Cu applied at the recommended rate based on accurate soil testing, and with confirmation via plant tissue analysis. Recognize that cereals tend to be most responsive to Cu, and some varieties are potentially predisposed to Cu deficiency (i.e. seemingly have higher requirement). Canola is more tolerant of low Cu but does respond to fertilizer in very deficient soils.

B) Cropping system:

Copper uptake is less than a 100 g/ha/yr in Prairie cropping systems. For example, a 50 bu/ac wheat crop will take up about 35 g Cu. Alleviating deficiency only requires delivering a few extra grams per ha to the plant. However, the nutrient use efficiency of Cu fertilizer is very low in the year of application and rates must be considerably higher than the marginal requirement in order to be effective. Overall the most likely scenario for Cu deficiency is wheat or barely grown in coarse textured black soils in Central Alberta. Copper is immobile in soil and plant and soil application need to consider the aspect of root interception and positional availability. Annual application (1- 2 lb actual Cu/acre) can be made or a one-time application (3 – 5 lb actual Cu/acre) can be used to supply several (perhaps 7 – 10 yr) year's worth of Cu requirements. Annual applications can be made with any of the products previously mentioned, large one-time applications tend to be met with sulphate or oxysulphate forms.

C) Crop growth stage:

The more severe the deficiency, the earlier the need for Cu. Confirmed deficiency should be met with pre or at plant Cu application. However, distribution can be an issue with granular products. Seed treatment is an option, but care needs to be taken in product choice as Cu can be quite toxic in the seed row. Deficiency that manifest itself after the crop has emerged is best met with a foliar Cu application. Some foliar products are compatible with post emergent herbicides and/or fungicides. Care needs to be taken to ensure that the Cu product and the herbicide are actually compatible, and the combination is supported and proven effective. Foliar application can be quite effective as only small amounts are required to relieve deficiency. The greater the leaf area, the more product gets on the leaves and the greater the uptake. Timing for later growth stages (4 leaf to flag leaf) can be more effective than earlier timing. Copper can be effective in yield recovery up to the flag leaf in cereals.

D) Soil test or tissue test:

Soil testing may be somewhat mis-leading if used as a stand - alone diagnostic tool. Combining soil test information (e.g. texture, pH, organic matter, manure application history) with plant tissue testing, understanding of production issues, crop responsiveness and any previous history denoting potential Cu deficiency, will improve usefulness of the soil and tissue test information. In soils that have not received manure, the critical soil test values for canola appears to be lower (0.25 ppm) compared to cereals (0.4 ppm). High manure rates can confirm soil test interpretation. Crops grown on manured land may be responsive to Cu additions at much higher soil test levels than those stated above. Manure can form complexes with Cu that make it unavailable to crops. This is particularly relevant to coarse textured black soils that have received manure.

E) Timing of application:

Copper can be applied the previous fall, pre-plant or at planting and in-season. Different timing will dictate product selection, placement method and rate. In-season foliar applications tend to range around 0.3 lb actual Cu/acre while higher rates (1-3 lbs Cu/acre) may be required for soil application. Research on the Prairies shows that seed row placement can perform poorly compared to foliar placement in the first year of Cu application but improves with repeated application. Foliar application of Cu tends to be more effective in cereals between the 4-leaf stage and stem elongation. Poorer performance from earlier foliar application appears to be due to lack of available leaf surface. The Cu lands on the ground instead of the leaf and is immobilized at the soil surface. This idea can be generalized to other micronutrient with low soil mobility.

Performance Objective 6. Discuss considerations to determine the proper source, rate, timing and placement of zinc based on the:

Available Zn products are similar in chemistry to Cu products. Complexed zinc-ammonia (10% Zn) is a fluid fertilizer form that blends with most other fluid fertilizers.

A) Crop type and variety:

Sensitive crops should have readily available Zn applied at the recommended rate based on accurate soil testing (see below), and with confirmation via plant tissue analysis. Cereals grown on sandy soils low in organic matter, flax grown on high pH soils, edible beans and corn tend to be most responsive to Zn. Eroded soil areas and areas with high manure application rates are also potentially predisposed to Zn deficiency. Most crops are tolerant to high Zn levels, cereals are not. Applying too high a rate of foliar Zn can result in Zn toxicity.

B) Cropping system:

Overall the most likely scenario for Zn deficiency is irrigated beans or corn grown on coarse textured soils. Zinc is immobile in soil and intermediately plant mobile; soil application needs to consider the aspect of root interception and positional availability. Surface applied Zn can become inaccessible in no-till systems. Annual application (1- 2 lb actual Zn/acre) can be made or a one-time large application (3 lb actual Zn/acre) can be used. Unlike Cu, Zn does not appear to provide large residual benefit to the cropping system, so annual applications tends to be the more effective approach. Annual applications can be met with any of the products previously mentioned, large one-time applications tend to be met with sulphate or oxysulphate forms.

C) Crop growth stage:

The more severe the deficiency, the earlier the need for Zn. Confirmed deficiency should be met with pre or at plant Zn application. Deficiency that manifest itself later in the growing season is best met with a foliar Zn application and this commonly uses a chelated form. However, by their nature chelates were designed for soil application and protection of the micronutrient; there may be lower cost foliar products available. In-season foliar applications tend to range around 0.3 lbs actual Zn/acre.

D) Soil test or tissue test:

Soil testing for Zn may be somewhat misleading if used as a stand-alone diagnostic tool. Work on the Prairies has been somewhat ambiguous in terms of confirming the DTPA extraction as a suitable soil test; establishing critical limits; and finding yield responses to added Zn. The exception may be work on irrigated dry beans in S. Alberta where yield responses were found on soils testing below 3 ppm or 1.5 ppm for coarse and medium/fine textured soils respectively. Combining additional soil test information (e.g. texture, pH, organic matter) with plant tissue testing, understanding of production issues, crop responsiveness and any previous history denoting potential Zn deficiency, will improve usefulness of the Zn soil and tissue test information. Practitioners should also monitor soil test P levels. High levels of STP point to potential antagonism and can induce Zn deficiency in sensitive crops like corn.

E) Timing of application:

Zinc can be applied the previous fall, pre-plant or at planting and in-season. Product selection will be predicated on application method and time. Rates should be set to be compatible with source, time, and place practices. Zinc is immobile in soil. Other than foliar application; Zn should be banded or incorporated to insure root access.

Performance Objective 7. Discuss considerations to determine the proper source, rate, timing and placement of iron based on the:

A) Crop type and variety:

Sensitive crops should have readily available iron (Fe) applied at the recommended rate based on accurate soil testing, and with confirmation via plant tissue analysis. Fruit and vegetable crops grown on high pH, calcareous soils, and with high soluble salts would likely be the most responsive situations; general field crops in the prairie region rarely require Fe. An exception would be soybean and iron deficiency induced chlorosis (IDC).

B) Cropping system:

Soybeans grown on calcareous soil in S outhernManitoba is the most likely scenario for iron deficiency on the Prairies. Chelated Fe forms are applied at 0.5 to 1.0 lbs Fe/acre when required. Iron sulphate may also be soil applied. Correction of Fe deficiency can be difficult with soil applications when managing high pH, calcareous soils – in this case, foliar spray application is recommended.

C) Crop growth stage:

Iron deficiency may be transient in early season as wet soils drain and dry, and the ionic form of Fe changes from unavailable to available form. When deficiency is confirmed, a foliar chelate application is the most common method of remediation.

D) Soil test or tissue test:

Soil testing may be somewhat mis-leading if used as a stand-alone diagnostic tool. Combining soil test information (e.g. texture, pH, organic matter) with plant tissue testing, understanding of production issues, crop responsiveness and any previous history denoting potential Fe deficiency, will improve usefulness of the soil and tissue test information. Practitioners should also monitor soil test P levels as well as free lime and soluble salt content of the soil.

E) Timing of application:

Iron fertilizer amendments are typically applied when a deficiency of Fe is recognized. Corrective in-season application may often be cosmetic and not may not produce a yield response. In the case of soybean, it would be prudent to select an IDC tolerant soybean variety and plant soybean to fields with low carbonate and soluble salt levels.

Performance Objective 8. Discuss considerations to determine the proper source, rate, timing and placement of manganese based on the:

A) Crop type and variety:

Sensitive crops should have readily available Mn applied at the recommended rate based on accurate soil testing, and with confirmation via plant tissue analysis. Recognize that cereals grown on sandy soils low in organic matter, cereals grown on peat soils, soybean, corn and peas tend to be most responsive to Mn. Oats is particularly sensitive and develops a physiological disease, grey speck, when grown without sufficient Mn.

B) Cropping system:

The most likely scenario for Mn deficiency is cereals grown on well-drained peat soils that have received relatively high rates of Cu fertilizer. Manganese is immobile in soil and plant and soil application needs consider the aspect of root interception and positional availability. In no-till systems, annual applications (1- 2 lb actual Mn/acre) banded is generally sufficient. Seed placed Mn should be done at rates and using sources that are not toxic to seedlings. Large broadcast applications are uneconomic and lack effectiveness relative to seed placed Mn or foliar applied Mn. Annual applications can be met with any of the products previously mentioned.

C) Crop growth stage:

The more severe the deficiency, the earlier the need for Mn. Confirmed deficiency should be met with pre or at plant Mn application. Deficiency that manifest itself later in the growing season is best met with a foliar Mn application; chelated Mn sources have not proven to be any more effective than other liquid Mn forms. In-season foliar applications rates of around 1.0 lb actual Mn/acre are usually adequate.

D) Soil test or tissue test:

The DTPA soil test for Mn, may be somewhat misleading if used as a stand-alone diagnostic tool on mineral soils but is reasonably well calibrated for organic soils. Crops grown on well-drained peat soils tend to respond to Mn application when the soil test level is less than 5 ppm. Combining soil test information (e.g. texture, pH, organic matter) with plant tissue testing, understanding of production issues, crop responsiveness and any previous history denoting potential Mn deficiency, will improve usefulness of the soil and tissue test information. Practitioners should also monitor soil test pH levels as Mn toxicity can occur when soil pH level dropping below 6.

E) Timing of application:

Manganese is immobile in soil and can be applied the previous fall, pre or at planting and in-season. Annual application is required as Mn undergoes soil reactions to become less available and soil building for Mn is not recommended. Product selection will be predicated on application method and time, to ensure plant available Mn is applied in a safe and effective manner.

Performance Objective 9. Discuss considerations to determine the proper source, rate, timing and placement of boron based on the:

A) Crop type and variety:

Sensitive crops should have readily available B applied at the recommended rate based on soil testing, and with confirmation via plant tissue analysis. Canola and alfalfa are the Prairie region crops most likely to exhibit deficiency symptoms. Production fields most likely affected would include: sandy soils, soils low in organic matter and fields in high rainfall geographies. Boron applications may not produce a profitable yield response even when crops are symptomatic.

B) Cropping system:

The most likely scenario for B deficiency is canola grown on coarse textured Gray soils. Boron is mobile in soil and subject to leaching events. Given its mobility, surface application methods such as broadcast or foliar work well. Boron can be toxic to seed at relatively low concentrations. Only seed save products should be used and rates should not exceed maximum rates suggested by manufacturers. Annual broadcast applications of borate or borax can be used - rates should not exceed 0.5 lb. actual B/acre for cereals and 1.5 lb. actual B/acre for canola. Up to 3 lb actual B/acre can be used when establishing an alfalfa forage field and in-season requirements can usually be met with 1 lb actual B/acre. Foliar applications of B should not exceed 0.3 lb B/acre.

C) Crop growth stage:

The more severe the deficiency, the earlier the need for B. However, the majority of B deficiency tends to occur later in the production season (e.g. pre-bolting/pre-flower for canola). Confirmed deficiency should be met with pre or at plant B application. Deficiency that manifests itself later in the growing season is best met with a foliar B application.

D) Soil test or tissue test:

Studies on the Prairies have not confirmed the generally used critical limit of 0.35 ppm. In one such study conducted over 40 sites, Canola was unresponsive to added B and high yields were obtained in the checks at soil tests well below 0.35 ppm. Combining soil test information (e.g. texture, pH, organic matter) with plant tissue testing, understanding of production issues, crop responsiveness and any previous history denoting potential B deficiency, will improve usefulness of the soil and tissue test information. deficiency, will improve usefulness of the soil and tissue test information.

E) Timing of application:

Boron is mobile in soil and annual application is required in low B soils to maintain sufficiency. In marginal cases, B application can be limited to the sensitive crops in the rotation. Fall applications may be at risk of leaching loss in low lying areas of fields. Product selection should be matched with application method and time to ensure plant available B is applied in a safe and effective manner.

PERFORMANCE OBJECTIVE 10. DISCUSS CONSIDERATIONS TO DETERMINE THE PROPER SOURCE, RATE, TIMING AND PLACEMENT OF CHLORIDE BASED ON THE:

A) Crop type and variety:

Sensitive crops should have readily available Cl applied at the recommended rate based on accurate soil testing, and with confirmation via plant tissue analysis. Spring seeded cereals and winter wheat are the responsive prairie region crops. Varieties differ in their tolerance of low Cl. Deficiency in cereals may lead to the development of physiological leaf spotting. Production fields most likely affected would include sandy soils, soils low in organic matter, and fields in high rainfall geographies. While less likely, Cl deficiency symptoms may show up on finer textured soils particularly in depressions.

B) Cropping system:

The most likely scenario for Cl deficiency is winter wheat growing in lower slope positions following a wet or series of wet years. Chloride is highly mobile in soil and can be lost through leaching. Given its mobility, broadcasting with or without incorporation is effective in getting Cl into the root zone. Band or seed row placement (within safe rate guidelines, use 0-0-60 limits) is also effective. Foliar application of Cl is not recommended. The common K fertilizer 0-0-60 contains about 47% C, K fertilizer applications result in a near 1:1 application of Cl on an elemental basis. Keep in mind that while the Cl is mobile the K is not.

C) Crop growth stage:

The more severe the deficiency, the earlier the need for Cl. However, the majority of Cl deficiency tends to occur between stem elongation and heading as the plant is moving into peak water use periods. Confirmed deficiency should be met with pre or at plant KCl application. Uncertainty of need, or deficiency that manifests itself later in the growing season is best met with a top-dressed Cl containing fertilizer.

D) Soil test or tissue test:

Chloride concentrations like sulfate-S can vary considerably across the landscape and vertically in the profile. Sampling to 24 inches (typically as a 0-6 and 6-24 inch samples to accommodate testing of immobile nutrients in the 0-6 inch) is the standard for Cl testing. Combining soil test information with texture, with plant tissue testing, recent precipitation history, and history of K use is helpful in determining whether a Cl deficiency is the probable cause of poor performance. Landscape directed soil sampling where lower slopes and depressions are sampled separately from upper slopes is useful in detecting Cl deficiency. Cereals grown on soils testing below 30 lbs Cl/acre in the top 24 inches are likely to respond to added Cl while soils testing over 60 lbs Cl/acre are unresponsive.

E) Timing of application:

Chloride is mobile in soil and annual application is required. Fall application may be at risk of leaching loss and should be avoided when using KCl to correct low Cl rather than to supply K. Fall-application for winter cereal production would be the exception.

PROFICIENCY AREA 6
DETERMINING THE RIGHT RATE, TIMING AND PLACEMENT OF SOIL AMENDMENTS AND THEIR EFFECTS ON MANAGEMENT OF NUTRIENTS

A soil amendment is a material added to soil to improve its physical or chemical properties. Lime is the most commonly thought of soil amendment; it is a calcium or calcium and magnesium compound used to reduce soil acidity. Other common soil amendments are gypsum and elemental S. Less commonly used soil amendments are biochar (a biomass-derived carbon product that is a by product of the pyrolysis processing of any organic feedstock), humic materials (composed of humins, humic and fulvic acids) and biostimulant materials (plant growth regulators which positively influence a plant's metabolic processes). Some amendments may supply nutrients; the main difference between a fertilizer or nutrient source material and an amendment is that fertilizers are applied as a specific nutrient(s) source while an amendment is applied to alter soil chemical or physical properties.

COMPETENCY AREA 1. DETERMINING THE PROPER SOURCE, RIGHT RATE, TIMING AND PLACEMENT OF LIMING MATERIALS FOR PH ADJUSTMENT

Performance Objective 1. Understand reasons to use liming materials.

Lime is primarily used to reduce soil acidity, improve soil physical and biological properties, reduce potential toxicities (e.g. aluminum and/or manganese), improve N fixation, improve nutrient availability and supply Ca and Mg. Most Prairie agricultural soils are well buffered against acidification as a result of having developed on medium to fine textured calcareous parent materials and containing significant quantities of soil organic matter.

Acidification of soils is a natural process as soils age that is accelerated by certain farming practices. When carbon dioxide dissolves in rainwater, it forms carbonic acid. As a result, rainfall is naturally acidic and becoming more acidic as atmospheric carbon dioxide levels increase. Rainwater infiltrates the soil profile and reduces soil pH over time. The natural development of acid soils on the Prairies is in large part associated with forest vegetation and higher moisture regimes. Acid soils are least common in the brown soil zone and most common in the gray soil zone. Even in the brown soil zone there can be extensive areas of acid soils such as the Milk River Ridge and the Cypress Hills. These areas where not glaciated during the last glaciation and contain older soils. Soils in the Luvisolic and Brunosolic orders have acidic surface horizons. Well-developed Solonetzic soils (azonal soils that can occur in any soil zone) in the Solodized Solonetz and Solod great groups tend to have acidic surface horizon.

Application of ammonium-based fertilizer contributes to acidification through the nitrification process. Legume crops contribute ammonium to the system which also nitrifies over time. Manure application can contribute to soil acidification but the use of calcium supplements in animal diets often results in manure having a mildly liming effect.

Lime and Lime Spreading	
	
Photos Courtesy of IPNI	

Performance Objective 2. Discuss suitability of sources of liming materials:

A) Industrial by-products used for liming:

Liming materials are produced as by-products of the iron and steel processing industries. More commonly on the Prairies, by-product liming materials are produced during the burning of coal (fly ash, bottom ash), sludge from water treatment plants, flue dust from cement manufacturing, and beet lime from sugar beet processing. All such products need be analysed for Ca and Mg content as well as contaminants such as heavy metals. Products should also be characterized for particle size and Calcium Carbonate Equivalence (CCE) to determine whether they will be an effective lime source.

B) Agriculture liming materials:

The most common agriculture liming materials are ground or pelleted calcitic (calcite) and dolomitic (dolomite) limestone. Chemical reactivity/neutralizing value, particle size, impurity level (e.g. clay content) and moisture content are important factors in determining suitability. Additionally, product choice may also be predicted on the need for Ca or Mg. Marl, a calcium carbonate rich mud or mudstone laid down by freshwater, is locally available in some regions of the Prairies and can be used as liming material. Other sources include quick lime and hydrated lime. These two products react quickly and have high neutralizing potential. They may be suitable for dealing with smaller areas of acidity but need to be used cautiously as unlike the other sources of ag lime, they can drive pH well above 8 if over applied.

Liming Material	Chemical Formula	CCE%
Calcitic limestone (Calcite)	$CaCO_3$	100
Dolomitic limestone (Dolomite)	$CaMg(CO_3)_2$	110
Quick Lime (Calcium Oxide)	CaO	180
Hydrated Lime	$Ca(OH)_2$	140
Marl	Variable	70-90
Wood Ash	Variable	55-65

C) Wood ash:

Wood ash is the end product of wood combustion. The most common bulk sources are associated with pulp and paper processing where waste wood is used for generation of electricity and/or heat. Wood ash is low in moisture content (usually around 2%), has fine particle size and is quickly reactive. Its neutralizing value is often between 55 – 65% calcium carbonate equivalent (CCE). Wood ash can vary considerably in composition and Ca form. Some can be higher in calcium carbonate while other may be higher in calcium oxide. Care needs to be taken to not overapply. Wood ash contains varying amounts of other nutrients including P, K and micros. Nitrogen levels are typically very low as the N escapes as gas during combustion.

D) Cost/benefit:

The return on liming investment will depend on a number of factors. The liming material, transport to the site, and application are the major cost factors. Additional costs may include soil and material sampling and any costs associated with professional advice. Typically, the crop production gained from lime application, pay for the lime expense within two to four years. The beneficial effects of a lime application may be as long as 15 to 20 years.

E) Contaminants:

Material such as clay (open pit mined sources), additional nutrients and heavy metals are potential contaminants in lime sources. Liming materials available from commercial sources may/should have information on contaminant levels. A laboratory analysis to characterize contaminants should be completed for use of non-traditional liming materials.

F) Particle size:

Finer particle size leads to quicker acid neutralizing reactions. Finer and smaller particles have increased surface area for soil reactions. Sieving to determine different particle size fractions is performed as a standard test in determining the effectiveness of liming materials. Finer materials react more quickly but tend to be harder to handle. Lime dust can be hazardous if inhaled or if it comes in contact with skin and eyes.

G) Calcium carbonate equivalent (CCE):

Liming material neutralizing value is expressed as a percentage of CCE. Calcium carbonate is set at 100% and lime application calculations are conducted to determine rate of lime material application based on the CCE of the material to be applied. Relative to calcium carbonate a lower CCE material requires a higher rate and a higher CCE requires a lower rate to achieve the same change in soil pH. Note that CCE is a relative index of chemical equivalency. Physical characteristics such as particle size also control effectiveness.

Performance Objective 3. Discuss considerations to determine the proper rate, timing, and placement of liming materials (e.g. agricultural lime, industrial by-products and wood ash) based on:

Rate, time and placement of a liming material depends on the source, the target pH (typically 6.5), soil type and the crops to be grown. The table below provides a general overview of liming.

Effects of Liming on Soils of Different pH.

Rating	Soil pH	Direct effects on crops	Indirect effects on crops
Slightly acid	6.1 to 6.5	No direct effect of liming on most crops.	Liming may improve the physical properties of some medium and fine textured soils (particularly Gray and Dark Gray Wooded soils).
		Fields with an average pH just above 6.0 may have areas where the pH is below 6.0. Alfalfa and sweet-clover yields will be increased on the more acid areas.	Improved soil structure and reduced crusting will be particularly beneficial for small seeded crops such as canola.
Moderately acid	5.6 to 6.0	Improved survival and growth of rhizobium bacteria which fix nitrogen in association with alfalfa and sweet clover.	Liming may improve the physical properties of some medium and fine textured soils as indicated above.
		Yields of alfalfa and sweet clover are increased.	Plant availability of phosphorous fertilizers is improved.
			Increased microbial activity and release of plant nutrients.
		Small increases in yield of barley occur in the first two or three years following lime aplications with larger increases (25-30 per cent) occuring in subsequent years. Yields of wheat and canola will be increased less than barley. Yields of more acid tolerant crops may be increased as a result of indirect effects of lime as outlined above.	
Strongly acid	5.1 to 5.5	Increased nitrogen fixation and yield of legumes.	Indirect effects as outlined above for moderately acid soils.
		Soluble aluminium and manganese are reduced to nontoxic levels.	
		Yields of most crops are increased as a result of reduced levels of aluminum and manganese and improved availability of phosphorus and other nutrients.	
Very strongly acid	Less than 5.1	Direct effects as outlined above for strongly acid soils.	Indirect effects as outlined above for moderately acid soils.
		Yields of most crops are severely reduced unless the soil is limed. Very strongly acid soils are very infertile. Acid tolerant crops (oats and some grasses) moderately well if adequately fertilized.	

Source: Alberta Agriculture

A good place to start in estimating the required lime rate for a field is to look up theoretical lime rates for the soil type and region. Theoretical lime rates are generally based on pure dry calcium carbonate as the liming material. Setting an actual lime rate needs to take into account the relative neutralizing power of the material used compared to the calcium carbonate standard. This includes consideration of the chemical composition and purity of the source, the fineness of the particles, and the moisture content.

Theoretical Lime Rates for Different Soil Types	
Soil type	**Amount of lime to increase soil pH one unit (i.e. from 5.0 to 6.0)**
Medium and fine textured Gray Wooded soils and coarse textured Dark Brown soils	1-2 t/ac
Fine textured Dark Gray and Dark Gray Wooded soils and medium textured Dark Brown, Thin Black, and Black soils	2-3 t/ac
Fine textured Black soil, organic, and peaty soils	3-4 t/ac
Source: Alberta Agriculture	

Effective Neutralizing Value[1] (ENV) is a quality index used to express the effectiveness of liming materials for neutralizing soil acidity. This quality index is based on both purity and fineness. Purity is measured as the calcium carbonate equivalent (CCE) which is the theoretical acid neutralizing capacity of a liming material relative to pure calcium carbonate which is 100. The reactivity of limestone depends on how finely it is ground. The percentage of a liming material in various particle size fractions determines the reactivity or efficiency factor of the material. The efficiency factor used for various limestone size fractions is as follows:

Efficiency factor of various limestone size fractions	
Limestone size fraction	**Efficiency factor**
passing 60 mesh	100
30 to 60 mesh	50
10 to 30 mesh	20
retained on 10 mesh	5
Source: Agdex 534-1	

Using the efficiency factors in the table above, total fineness efficiency is calculated as shown in the table below.

Calculation of total fineness of good quality agricultural lime			
Limestone size fraction	**% lime per size fraction**	**Efficiency factor**	**Fineness efficiency**
Passing 60	70	100	70
mesh 30-60 mesh	20	50	10
10-30 mesh	10	20	2
Retained on 10 mesh	0	5	0
Total Fineness efficiency			82
Source: Agdex 534-1			

The Effective Neutralizing Value (ENV) is obtained by multiplying the total fineness efficiency by the calcium carbonate equivalent

1 Effective Calcium Carbonate Equivalent (ECCE) is an analogous term. Note that there is no universal accepted standard for calculating ENV or ECCE. Different regions may use slightly different approaches or may have specified methods that must be used to meet regulatory requirements for marketing liming materials. The method shown is based on Alberta Agriculture's Liming Acid Soils Fact Sheet, Agdex 534-1.

(CCE). For an ag lime source with a CCE of 97% and a total finenesss efficiency of 82% the ENV would be:

82 x 0.97 = 80%

If a lime requirement test indicates that 2 tonnes/ ac is needed, the application rate should be:

2 tonnes/ac x 100/80 = 2.5 tonnes/ac

While the coarser mesh sizes (10-60 mesh) are less effective for neutralizing soil acidity, they improve the handling properties of the material. Very fine limestone powder is difficult to handle and apply. On the other hand, if the limestone contains a high proportion of coarse material, higher rates of application are required. The coarser fraction will eventually dissolve but the timeline is likely to be years rather than weeks or months.

The above assumes that the liming material is dry or nearly so. For materials with significant water content, an estimate of dry matter needs to be worked into the rate calculation.

Marl is an example of a moist liming material. The CCE is usually in the range of 70 to 90% due to impurities of silt, clay, and organic matter. The fineness efficiency can be assumed to be approximately 85 per cent and the moisture content is usually in the range of 10 to 30% (70 to 90% dry matter). Note that all of the above can be determined precisely through lab analysis.

The ENV of marl with a CCE of 80% a fineness efficiency of 85%, and a dry matter content of 85% can be estimated as follows:

ENV = 80 X 0.85 X 0.85 = 58%

If the recommended lime rate of is 2 tonnes/ac, the amount of this particular marl that should be applied is:

2 tonnes/ac x 100/58 = 3.4 tonnes/ac

A) Target pH by crop:

Crops typically have pH ranges in which they grow best. Liming is considered to improve crop production potential when soil pH falls below an optimal tolerance range. For example, in the table below alfalfa will still grow in soils with pH range 5.5 to 6.0 but it grows best above 6.0.

Tolerance to Soil Acidity Common Annual and Perennial Crops

Non-tolerant Crops: Alfalfa, sweet clover	Tolerate pH 5.5 to 6.0
Moderately Tolerant Crops: Barley, wheat, canola, alsike, red clover, trefoil	Tolerate pH 5.0 to 5.5
Tolerant Crops: Brome, timothy, creeping red fescue, flax, oats	Tolerate pH 4.5 to 5.0

Adapted from: Alberta Agriculture and Forestry.

Annual grain and oil seed legumes vary considerably in their tolerance of acid (or alkaline) soil. Most stop fixing N when soil pH drops below pH 6. Growing these crops on acid soils may require supplementing with N fertilizer. While fertilizing may be a short term approach, liming the soil into the range that supports N fixation is the longer term fix of the problem.

Tolerance to Soil Acidity of Pulse Crops and Soybean

Crop	pH range*
Lentil	6 - 8.2
Pea	4.8 – 8.2
Chickpea	< 8.2 lower limit unknown
Dry Bean	< 8.2 lower limit unknown
Fababean	6.5 -8.2
Soybean	6.0 – 7.5

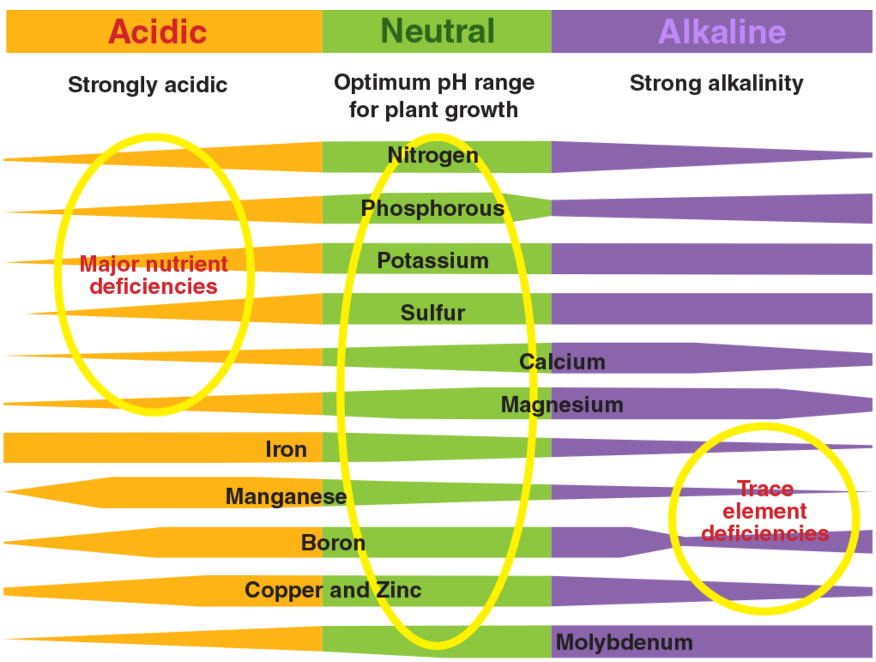
*Tolerance at lower end of range may vary by variety and/or inoculum strain.

Soil pH influences the solubility and plant availability of nutrients and other elements in soil. Most nutrients have a soil pH range in which they are most available. Nutrient and non-nutrient elements that are more soluble in acid soils may reach toxic levels as the soil acidifies. Aluminum and/or manganese toxicity is typically the cause of poor crop performance in acid soils on the Prairies. As noted above, crops vary in their tolerance. In alfalfa and other non-tolerant legumes, the symbiotic strains of *Rhizobium* have low tolerance for soluble Al and Mn.

Lime rates need to be sufficient to ensure that the final pH achieved removes the acidity restrictions. This is usually done by setting a target pH at or just above the lower limit of the optimal range for intended crop. Setting above the lower limit helps account for variability in pH across a field. For example, pH should be adjusted to above 6 for an intended alfalfa stand but between 5.5 and 6.0 would be adequate for a red clover stand. Crops are generally grown in rotation and liming rates that raise the pH to a point where limitations on the most sensitive crop is a typical strategy. Using 6.5 as a target pH when setting lime rates is adequate for almost all crops and is also the pH at which phosphorus is most available.

B) Soil test pH and buffer pH, and magnesium:

A standard soil pH is a measure of active acidity and an indicator of general soil pH condition; it is not a useful indicator of lime requirement. Soils are highly buffered systems and much of the acidity is held in reserve as exchangeable aluminum. When a liming agent is added, it neutralizes the active acidity which is quickly replaced by release of reserve acidity, which is in turn neutralized and so on. Buffer pH measures reserve acidity and can be used as a relative measure of soil pH change when a liming material is added to the soil system. Buffering capacity (and the amount of exchange acidity) is related to soil clay and organic matter content. Given the same initial acid pH, a coarse textured soil low in organic matter content will require less lime than a clay soils higher in organic matter to reach the same target pH.



Soil pH and Nutrient Availability
(Source: Bluedale - http://www.bluedale.com.au)

Soil testing for exchangeable Mg content will aid in determining the lime source to be applied. In soils low in exchangeable Mg, dolomite can act as an Mg source as well as neutralizing acidity.

C) Timing of application:

Most liming materials are low solubility compounds that react slowly in the soil. As a result, the change in pH following a lime application take place over a period of months or even several growing season. The lime materials ENV also determines how quickly the material will react. The finer the material, the higher the surface area and the faster the material will dissolve.

The point is that the target pH may not be reached for several seasons. Sensitive crops planted immediately after lime application may show little or no improvement. Crop sensitivity and the position of more sensitive crops in the cropping sequence can determine lime application timing. Setting a rotation from least sensitive to most sensitive following liming may increase overall benefits following lime applications. For example, liming a strongly acid soil at pH 5.2 in spring, following with a rotation such as oats, canola, peas, barley will do better than a rotation that has a sensitive crop like barley earlier in the rotation.

As a general rule, fall application is preferable to spring as it provides more time for neutralization prior to a subsequent crop.

D) Method of application:

Lime is typically more effective when broadcast with thorough incorporation. Pelleted lime can be broadcast without incorporation but is more effective when incorporated. Lime application rate will be influenced by depth of incorporation and tillage scheme in practice. Deeper incorporation may be reflected in higher recommended application rate as there is more soil volume to neutralize. For reduced and no-till systems where shallow N placement has resulted in surface acidity – shallow placement of the lime material is often all that is required. Keep in mind when deciding on a method of placement that the neutralizing effects are largely confined to the incorporation depth.

E) Major nutrient contribution from lime:

As previously discussed, – lime may contain Ca or Ca and Mg depending on the source. Note that Ca and Mg are seldom deficient in Prairie soils even acid one. It should also be noted, that although not a lime contribution to nutrient addition – liming will reduce toxicity of Al and Mn that is generally the cause of suppressed yields. Raising the pH to a target of 6.5 also makes P more available. Liming materials may contain micronutrients in different combinations and varying quantities; however, most of the micronutrients become less available as pH increases so liming is not likely to increase micronutrient availability. Molybdenum and Chloride are the exceptions. Availability of Mo increases with pH while Cl is unaffected.

COMPETENCY AREA 2. DETERMINING THE PROPER SOURCE, RIGHT RATE, TIMING AND PLACEMENT OF AMENDMENTS FOR SODIC AND SOLONETZIC SOILS

The chief characteristic of sodic soils from the agricultural stand point is that they contain sufficient exchangeable sodium to adversely affect soil structure. Structural issues can lead to poor germination through crusting, poor root penetration through hardpan formation, and poor water infiltration. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil, with consequent reduction in crop growth. Sodic soils lack appreciable quantities of neutral soluble salts such as sodium sulphate but contain appreciable quantities of salts capable of alkaline hydrolysis such as sodium carbonate. As a result, the pH of saturated soil pastes is 8.5 or more and in extreme cases may be above 10.5.

Saline and sodic soils are classified based on their electrical conductivity (EC), sodium adsorption ratio (SAR) and pH; all determined on a saturated paste extract. Most agriculture labs performing standard soil tests, measure EC using a 2:1 water:soil method and then convert and report it as a saturated paste equivalent value. Soil pH is generally performed at the same time and on the same extract as the EC. The EC and pH reported on a standard agricultural soil test tend to be very close to values obtained by the saturated paste extract.

SAR cannot be calculated from the exchangeable sodium, magnesium, and calcium values reported on a standard agricultural soil test. Solution concentrations measured in the saturated paste extraction are converted to millequivalents/liter prior to calculating the SAR.

$$SAR = \frac{(Na)}{\sqrt{\frac{1}{2}(Ca+Mg)}}$$

To calculate ESP the exchangeable sodium value and the cation exchange capacity must be expressed in appropriate units of me/100g soil or cmol(+)/kg soil.

$$ESP = Na/CEC \times 100$$

Characteristics of Saline and Sodic Soils					
Classification	**Electrical Conductivity[1] (dS/m)**	**Soil pH**	**Exchangeable Sodium Percentage %**	**Sodium Adsorption Ratio**	**Soil Physical Condition**
Saline	>4.0	<8.5	<15	<13	Normal
Sodic	<4.0	>8.5	>15	>13	Poor
Saline-Sodic	>4.0	<8.5	>15	>13	Normal

Most sodic soils on the Prairies fall into the Solonetzic order. Solonetzic soils developed from parent materials that were salinized with salts high in sodium. They have a Solonetzic B horizon (Bn or Bnt) that is hard and relatively non-permeable and typically columnar. The Solonetzic B is in effect a hardpan that results in a shallow rooting zone with less available water and smaller rooting volumes to draw nutrients. Soils of this order tend to have a neutral to acidic A horizon. Solonetzic soils are commonly found in associations with Chernozemic soils. Over time the B horizon migrates down the rooting zone and they become more Chernozemic like. Areas of fields with Solonetzic soils may yield as well as associated Chernozems in good rainfall years but tend to show the effects of drought in drier years.

Prairie soils that show white salt crusting are often referred to as alkali soils. This is generally incorrect as most salt crusts are associated with neutral salts such as sodium or magnesium sulphate. These soils are saline not alkali as the pH is typically in the neutral range. Soils containing alkali salts such as sodium carbonate have high pH and are typically sodic soils. Mildly saline soils may yield well in good moisture years but will show the effects of drought earlier and more severely in drier years.

Unlike Solonetzic soils, saline soils do not generally have structure problems. Reductions in crop growth are due to the reduction in available water; high osmotic potential, not a shallow rooting zone, prevent the plants from taking up water.

Solonetzic B Horizon in a Soil Near Camrose Alberta

Clay has moved down the profile to create a dense Bnt horizon. High exchangeable Na causes clay dispersion and swelling when wet that prevents water penetration below the B.

Performance Objective 1. Gypsum

A) Understand the soil and site properties where gypsum or elemental sulphur use is beneficial:

Gypsum ($CaSO_4 \cdot 2H_2O$) is a source of both Ca and S and is neutral in its soil reaction. Gypsum would be of beneficial use where no change in soil pH is desired and the addition of Ca is beneficial to soil structural properties (e.g. replacing Na on the soil exchange). Gypsum is used as a soil amendment on sodic soils.

In the treatment of sodic soils, elemental S can be used to reduce soil pH and aid in solubilizing soil Ca. There must be adequate Ca available in the soil and at an appropriate depth to displace Na from the soil exchange. The oxidation of elemental S produces sulphuric acid which dissolves calcium carbonate and releases calcium ion. The calcium ion displaces sodium from the exchange complex. The calcium ion will also react with the sulphate ion to form gypsum. Although calcium ion may be released and exchange with sodium, the pH will not drop until all the calcium carbonate has been neutralized. Because gypsum supports a higher ionic activity in solution than calcium carbonate, salinity tends to go up slightly when gypsum or elemental S is added to sodic soil.

$2S + 3O_2 + 2H_2O \rightarrow 2H_2SO_4$

$H_2SO_4 + CaCO_3 \rightarrow Ca^{2+} + CO_2 + H_2O + SO_4^{2-}$

$Ca^{2+} + 2Na\text{-}Exch \rightarrow 2Na^+$ and Ca-Exch

$Ca^{2+} + SO_4^{2-} \rightarrow CaSO_4$

Solonetzic soils benefit more from deep plowing or ripping to mix calcium carbonate and/or gypsum from the C horizon into the upper sodic horizons and disrupt the hard pan. Deep plowing usually involves displacing the A horizon, disrupting the B horizon and inverting plus mixing with the C horizon; and replacing the A horizon. Ripping physically disrupts the hard B with some mixing of A, B, and C.

B) Indicate the additional requirements and mechanisms for remediation of sodic and Solonetzic soils when using gypsum or elemental sulphur.

Ameliorating sodic soils can be a very slow process. The problem is not really solved until the sodium displaced from the CEC is leached out through the profile. Amelioration will tend to occur more quickly in higher rainfall areas or under irrigation. Since one of the issues with sodic soils can be water infiltration, additional organic amendments such as manure may help with structure and water infiltration provided they do not increase sodium levels. Gypsum or elemental S rates need to be calculated based on the quantities of exchangeable sodium present and application need to be incorporated. Sodicity issues are variable across fields, often only a portion of the field needs to be treated. This requires mapping of the problem areas.

COMPETENCY AREA 3. BE AWARE OF CONSIDERATIONS IN USING SOIL AMENDMENT AND SOIL/PLANT ADDITIVES AND THE ROLE THEY MAY PLAY IN MANAGEMENT OF SOIL AND PLANT NUTRIENTS

Performance Objective 1. Understand the role the following amendments can play in nutrient management and soil health.

A) Biochar:

Biochar, a form of activated carbon, is the by-product of pyrolysis. Pyrolysis involves the heating or roasting of organic feedstocks under low temperature and low oxygen and is used to produce biogas a renewable energy source. The production process can be highly varied and results in varying characteristics of the end product. Biochar additions to soil are considered a form of carbon sequestration. The biogas is a renewable biofuel and land application of the biochar locks a portion of the carbon into the soil and potentially creates a carbon credit.

Slow pyrolysis biochar	Fast pyrolysis biochar
	
Willow biochar: Chunky Low temp: < 500 °C and longer residence time of minutes to hours.	Wheat Straw biochar: Fine High temp > 500 °C and shorter residence time of seconds to minutes.
Source: Jeff Schoenau, Dept. of Soil Science, University of Saskatchewan.	

Biochar can potentially benefit plant growth through modification of soil chemical and physical properties, which may be attributed to: a liming effect, addition of essential elements, increasing nutrient retention (increase in soil CEC), increasing soil particle aggregation, and improving soil water holding capacity.

Biochars vary considerably in nutrient content and are generally not added as a nutrient source but to ameliorate soil problems or alter soil processes.

Biochar Type	C	N	P	S	C:N
	-----------%-------------				
Willow	91.3	0.92	0.15	0.05	99
Oat Hull 71.4		1.54	2.95	0.12	46
Source: Jeff Schoenau, Dept. of Soil Science, Univ. of Sask					

Although there are numerous studies globally that confirm the beneficial effects of biochar, studies on the Prairies have been less definitive. Biochar applications on Prairie soils may increase pH through the liming effect and increase soil organic matter. Little or no effect on yield has been observed in the year of application or subsequent years when biochar has been applied to non-degraded soils. In a study in Saskatchewan, biochar reduced emissions of the greenhouse gas nitrous oxide when co-applied with urea. Biochar may also reduce the soil activity and mobility of certain pesticides; however, these interactions are very dependent on the type of char used.

Prairie soils are not highly weathered; have relatively high organic matter and nutrient retention; and have generally low leaching potential. Consequently, the benefits from applying biochar found in other parts of the world with highly weathered soils are not likely to be realized in Prairie soils. Biochar likely has a place in reclamation of degraded and/or polluted soils and in reducing greenhouse gas emissions.

B) Humic materials:

Humic materials are complex organic macromolecules. They are found naturally in soil organic matter and in various types of other natural carbon deposits such as peat and weathered coal. When soil applied at higher rates they increase CEC, improve structure, and improve water holding capacity. In addition to soil effects, humic substances can act as biostimulants . Humic materials contain or stimulate the production of auxin-like molecules that influence or aid in nutrient uptake, germination and seedling development. Humic materials have been shown to activate secondary pathways related to carbon dioxide (CO_2) uptake and plant respiration; the synthesis of adenosine tri-phosphate (ATP); and may play a role in the regulation of genetic pathways.

There is a significant body of scientific research documenting the various beneficial effects of humic material application. Results vary widely based on source, rate, time and place as well as the characteristics of the soil and crop.

Performance Objective 2. Know the different classes of soil/plant additives (supplements), if they need to be registered, and how to check if they are registered:

Note: The classes of soil/plant additives or supplements (biological, nutritional, enzymes/proteins) listed in the Performance Objectives do not match exactly with the terminology used in the Fertilizer Act and Regulations.

A) Biological

Supplements based on living organisms. A common example is Rhizobium sp. inoculum for legume crops.

B) Nutritional

Products that are applied to enhance nutrient availability or uptake.

C) Enzymes/Proteins

Products that applied to enhance a soil or plant reaction or process.

Whether a product must be registered or is exempt from registration falls under the Fertilizer Act and the Fertilizer Regulations. The registration process is managed by the Fertilizer Division of the Canadian Food Inspection Agency (CFIA). The CFIA deals with regular and specialty fertilizers as well as soil amendments or supplements.

As defined in the fertilizer is defined in the Fertilizers Act:

*A fertilizer is any substance or mixture of substances, containing nitrogen, phosphorus, potassium or other plant food, manufactured, sold or represented for use as a plant nutrient.**

A supplement is any substance or mixture of substances, other than a fertilizer, that is manufactured, sold or represented for use in the improvement of the physical condition of soils or to aid plant growth or crop yields.

Supplements may act directly on the plant or in the soil. They may be microorganisms, derivatives from naturally occurring or engineered organisms, naturally occurring materials or chemicals, and synthesized chemicals. They may act to change soil properties, solubilize nutrients, mimic or induce plant hormones, or alter soil or plant properties and processes in any other way that enhances growth.

*All fertilizers and supplements when sold or imported into Canada are regulated under the federal Fertilizers Act and Regulations. Pursuant to these Regulations, the products must be safe with respect to plant, animal, human health and the environment, and properly labelled to ensure safe and appropriate use.**

*Some fertilizers and most supplements are subject to mandatory pre-market assessment and registration by the Fertilizer Safety Section of the Canadian Food Inspection Agency (CFIA), which is responsible for administering the Fertilizers Act and Regulations. As part of product assessment, CFIA officials evaluate safety information/data and review the label to verify product compliance with the Act, Regulations and prescribed standards. Please note that all ingredients in the product (both active and inert) as well as the potential contaminants and degradation products are considered when reviewing product safety.**

*All regulated products, including those requiring registration and those exempt from registration, in the Canadian marketplace must meet all the prescribed standards. Product compliance is verified by CFIA area staff through inspections, product sampling and analysis, and marketplace label verification. Non-compliant products are subject to enforcement actions which may include product detention, and in cases of severe and/or repeated non-compliance, prosecution. Determining the regulatory categorization of a product under the Fertilizers Act and Regulations largely depends on label claims (i.e. how the product is represented in the marketplace). This includes nutrient sources, guarantees and/or product grades.**

Determining the specific product nature, mode of action and intention of use, will aid in understanding regulatory requirements. Generally, if such product(s) does not pose threat or risk to health or environment, use is granted without evidence of efficacy.

Registration of a product is not a guarantee that the product will work as intended or promoted.

Note this is a change in the regulations from what they were previously when products had to show efficacy to achieve registration. CCAs recommending supplements and additives should carefully examine the evidence available on efficacy (when they work, how they work) and ensure that they are a good fit for the client's operation, soils, and crops.

Many common products are exempted from registration because their efficacy or the efficacy of their components and their mode of action are well documented.

*The following types of products are exempt from registration under the Fertilizers Act and Regulations:**

1. *Customer-formula fertilizers which contain a pesticide registered under the Pest Control Products Act for the purpose stated on the label [Section 3.1(1) Fertilizers Regulations].*

2. *Single ingredient fertilizers and supplements that are listed in Schedule II of the Fertilizers Regulations [Section 3.1 (3)(a) Fertilizers Regulations].*

3. *Mixed farm fertilizers that contain nutrients in a mineral form (obtained by extraction or by physical or chemical processes) and that do not contain pesticides [Section 3.1(3)(b) Fertilizers Regulations].*

4. *Supplements sold only for correction of soil acidity or alkalinity [Section 3.1(3)(c) Fertilizers Regulations]*

5. *Supplements that consist of seeds that are treated with a fertilizer or a supplement that: (i) is exempt from registration, or (ii) is registered, and whose label indicates that it is for use in treating seeds [Section 3.1(3)(d) Fertilizers Regulations]*

6. *Peat, peat moss, sphagnum moss, tree bark and other fibrous organic matter that is represented for use only in improving the physical conditions of the soil [Section 3.1(3)(e) Fertilizers Regulations]*

7. *Customer-formula fertilizers (prepared in accordance with a written formula that sets forth the name, amount and analysis of each ingredient, the fertilizer grade of the total mixture and the signature of the person for whose use for fertilizer purposes it has been prepared) [Section 3.1 (3)(f) Fertilizers Regulations].*

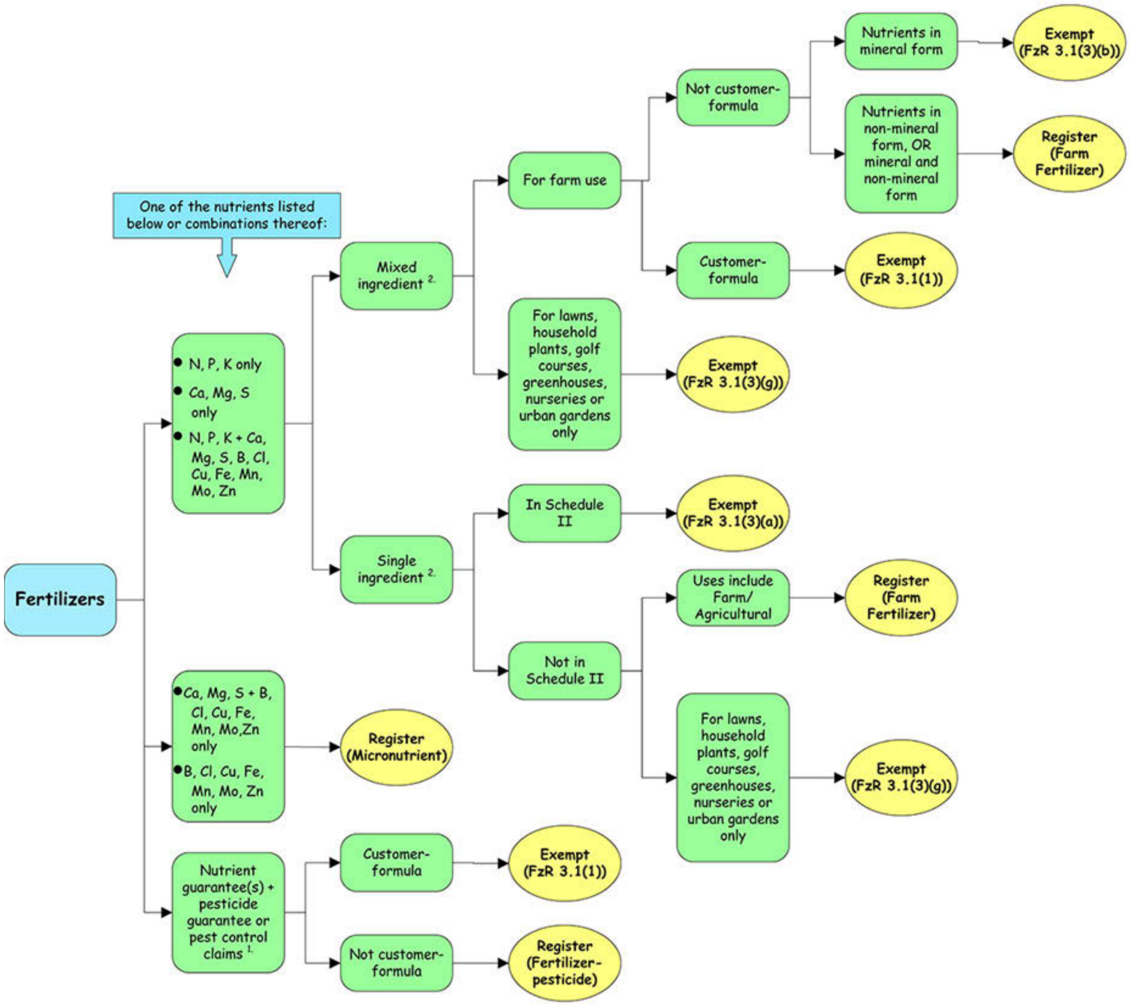
8. *Specialty fertilizers (a fertilizer recommended for use only on household plants, urban gardens, lawns or golf courses or in nurseries or greenhouses) [Section 3.1(3)(g) Fertilizers Regulations].*

9. *Potting soils that contain a fertilizer or a supplement that: (i) is exempt from registration, or (ii) is registered, and whose label indicates that it is for use in potting soils [Section 3.1(3)(h) Fertilizers Regulations].*

Registered products will have a registration number displayed on the packaging. Registered products are listed on the CFIA website in a searchable database. A search for product registration is enabled through the link: http://www.inspection.gc.ca/active/eng/plaveg/fereng/fereng_dbe.asp

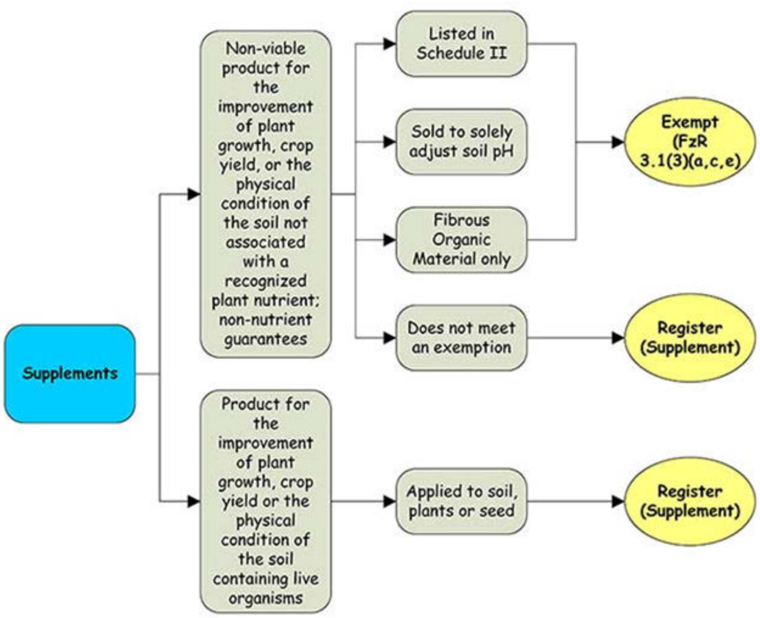
The diagrams below can help to determine if a fertilizer or supplement is exempt from registration or needs to be registered .

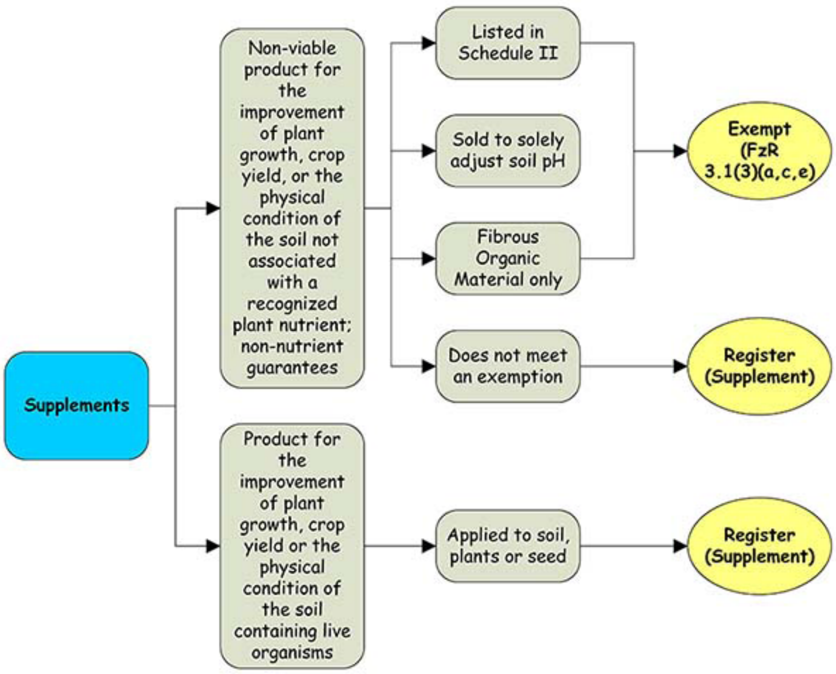
Fertilizers – Product Exemptions and Mandatory Registrations under The Fertilizer Act



Note: Schedule II is part of the regulations and is available at https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.%2C_c._666/page-7.html#h-18
Source: CFIA

Supplements – Product Exemptions and Mandatory Registrations under The Fertilizer Act





Note: Schedule II is part of the regulations and is available at https://laws-lois.justice.gc.ca/eng/regulations/C.R.C.%2C_c._666/page-7.html#h-18 Source: CFIA

D) Health, environmental, and efficacy requirements.

The Fertilizer Safety Section of the Canadian Food Inspection Agency examines evidence pertaining to potential impacts of supplements on human and or animal health and the environment through the registration process. It will not regulate and enforce label statements pertaining to efficacy and/or quality, for example:

• performance claims (e.g. slowly available plant nutrients, improving soil structure, testimonials/endorsements, taller plants, improves yields, etc.) and qualifiers such as organic and natural;

• comparative claims against another product/product type (e.g. best, better, superior, faster-acting, etc.).

A fuller explanation of what is considered acceptable and misleading in product claims can be accessed using the link below.

http://www.inspection.gc.ca/plants/fertilizers/program-overview/clarify-policy-on-the-term-misleading/eng/1393815218767/1393815296946

There are many supplements entering the marketplace. These are promoted under a variety of claims. Some will find a place in Prairie crop production and some will not. Certified Crop Advisors need to proceed knowledgeably and cautiously when recommending new products to their farm clients.

PROFICIENCY AREA 7
MANAGEMENT OF MANURE, COMPOST, BIOSOLIDS, AND WASTEWATER

Note to Users: the Performance Objectives under the various Competency Areas tend to be somewhat repetitive in this Proficiency Area. We have tried to place the bulk of the information under the PO where it is most appropriate and cross reference the different POs. This may require some flipping back and forth on your part.

Manure, compost, biosolids and wastewater are a diverse group of waste products that when handled properly can be beneficial soil amendments and nutrient sources. Mishandling by applying the wrong rate at the wrong time and place can significantly reduce the benefits and lead to soil degradation and off-site environmental damage. Regulation governing land application of these materials are in place in all three Prairie Provinces. Since land application generally falls under provincial jurisdiction, the regulations vary from province to province. As a CCA providing advice on the use of these materials in cropping systems, it is important to understand the regulations in place for the province where the receiving land is located. General definitions are provided below but keep in mind that the sources, characteristics, and classification of products vary widely and in many cases the materials cannot be narrowly defined.

Manure – unprocessed animal wastes. They may have been stored for some time prior to application or applied almost immediately. Manure may be applied directly by the animal through grazing of stubble, cover crops or perennial pasture. They are also deposited at livestock wintering sites. Bulk sources of manure available for application in annual crop production are typically associated with confined feeding operations (CFO).

Compost – material created by the aerobic decomposition of plant or animal wastes. Many different feedstocks can be composted or included in compost feedstocks including manure solids, biosolids, food processing wastes, dead animals, landscaping wastes (grass and tree clippings), and municipal solid wastes. Solids may be amended with liquid or slurries such as liquid manure, sewage sludge, or food processing liquids to achieve a desired moisture or carbon to nitrogen ratio (C:N).

Biosolids –are organic wastewater solids that may be land-applied after suitable sewage sludge treatment processes leading to sludge stabilization such as anaerobic digestion and composting. Typical source on the Prairies is municipal sewage treatment plants.

Wastewater – is the effluent from food processing, sewage treatment, or other processes that result in an organic and nutrient enriched water that can be beneficially land applied. Septage, the untreated sewage from septic tanks may contain solids and may be land applied in all three provinces. Regulations vary by province.

Information Sources

Nutrient Management Planning Guide (Agdex 400/28-3) – This is a comprehensive guide for nutrient management with a strong emphasis on manure management. Principles and practices covered generally apply to all three provinces. Keep in mind that regulatory information is based on Alberta's Agricultural Operations Practices Act (AOPA) framework. Available on line in PDF or eBook. It is strongly recommended that you consult this resource in order to get a more fully understanding of various topics covered under the POs. Also, the Guide is a great source of examples and worked calculations.

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw11920

Tri-Provincial Manure Application and Use Guidelines – This publication was developed jointly by the three Prairie Provinces to provide guidance on best management practices for manure use. There are three versions of the guide one for each of the provinces which incorporate some of the province specific concerns and regulation differences.

[1] These will be referred to collectively as waste materials, materials, or organic amendments in this Performance Area.

Alberta

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/epw8709

Saskatchewan

Search for *"manure application and use guidelines"*.

Manitoba

https://www.gov.mb.ca/agriculture/crops/guides-and-publications/pubs/manure-application-and-use-guidelines.pdf

Units

Various conversions come in handy when working with manure and other waste derived material. Some of the more common ones are shown below. Math behind conversions is explained fully with examples in the Tri-Provincial Guide Manitoba Edition referenced above.

Starting Unit	Multiply By	Desired Unit
	Solid Manure	
%	10	kg/t
%	20	lb/tn
kg/t	2	lb/tn
mg/kg	0.001	kg/t
g/kg	1	kg/t
t/ha	0.4461	tn/ac
	Liquid Manure	
%	10	kg/m³
kg/m³	1	kg/1000 L
%	100	lb/1000 gal
kg/1000 L	10	lb/1000 gal
mg/L	0.001	kg/1000 L
g/L	1	kg/1000 L
ppm	1	mg/kg and mg/L
L/ha	0.089	gal/ac

Unless otherwise indicated imperial gallons are used in this guide. An imperial gallon of water weighs 10 lb. The density of liquid manures is generally taken as 10 lb/gallon unless an actual density is stated.

Source: Nutrient Management Planning Guide

COMPETENCY AREA 1. SOURCE, OF MANURE, BIOSOLIDS AND WASTEWATER

Performance Objective 1. Discuss the availability of manure, compost, biosolids and wastewater in the Prairie Region.

Availability depends largely on location. All the products listed are bulky and cost of transportation tends to limit availability for land application to areas within a relatively short distance of the production site.

Manure is produced and tends to be available and applied within a few kilometers of CFOs. Other sources of smaller volumes may also be available from operations that produce manure but fall below the regulatory threshold of a CFO. Paunch manure (the waste material from animals' GI tract) is produced at animal slaughter facilities.

Compost tends to be available in close proximity to the composting site. Compost is reduced in mass and of lower water content than the feedstocks (for example feedlot manure) so it can be distributed more widely than the feedstock. Nutrients tend to be more concentrated as most of the mass reduction is through drying and respiration releasing carbon dioxide. Some N is usually lost as volatile ammonia during compost.

Biosolids are produced by municipal sewage plants and may be available for land application around major municipal centres.

Wastewater for land application is available in close proximity to the generating facility. Some examples include packing plants and potato processing plants. Wastewater is often applied through irrigation equipment and wastewater producers must have storage or alternative disposal during the winter. Septage is produced locally in rural areas mainly from small community or private septic systems.

Performance Objective 2. Discuss the most common sources of manure, compost, biosolids and wastewater used in Prairie Region.

Manure sources in volumes that can be collected for land application away from the site where it is deposited include: cattle feedlots and wintering sites, dairy operations, hog barns, and poultry barns. Other animal operations such as horse barns may produce manure in limited quantities.

Compost has a number of sources, the major one is feedlots where solid manure is composted. Liquid manure systems where solid separation is used may compost the solids. Several urban centres compost municipal solid wastes typically joined to some form of garbage separation. Other minor composting sources are tied to various forms of waste processing. Compost offered for sale is regulated by CFIA under the *Fertilizer Act*. Land application of compost from some sources is regulated provincially and not all composts can be applied unrestricted to land.

Biosolids from municipal wastewater treatment plants are land applied around a number of major urban centres including Calgary and Saskatoon. Edmonton land applies some of their biosolids and has directed a portion to their composting program. Winnipeg has moved towards land application starting with a pilot project in 2017. Other municipalities may have programs as well. Smaller communities may occasionally have biosolids from sewage evaporation ponds. Biosolids may undergo various recovery processes aimed at removing heavy metals and other undesirable components prior to land application. The trend in biosolid management is to find beneficial used for biosolids including land application and steer them away from landfills.

Wastewater suitable for land application is usually associated with food processing facilities located in or near rural areas. This may include operation such as potato processing plants.

Performance Objective 3. Discuss considerations that may be used to determine the right source of manure, compost, biosolids, and wastewater based on:

A) Crop type

Depending on material and source, certain cropping systems may be excluded from receiving land application or use of crop products restricted in the year of application and subsequent years. The restrictions are greatest on crops consumed directly by humans where the harvested portions may be in direct contact with the waste material (vegetables, root crops, fruits). Grazing of forages receiving waste materials may be restricted for a period following application. Restrictions may be lower depending on material on annual crops where the timing of the application doesn't overlap with the growing of the crop. Regulations are complex and vary by province, CCAs should consult the relevant provincial regulations.

B) Tillage and cropping system

Choosing the right source for the tillage and cropping system requires knowledge of the regulatory framework as well as the nutrient requirements of the crop and the environmental risks. A good understanding of the processes and interactions after application is also important in matching source with the tillage regime.

Solid manure, composts and dried or composted biosolids fit well with conventional tillage systems where the material can be incorporated as soon as possible after application. Application to forages and direct seeded land is allowed with some restrictions under the regulations in all three provinces. Losses of N through volatilization can be significant when solid manure is surface applied without incorporation. Volatilization is less with composted material, but losses prior to land application can be significant.

Liquid manure, biosolid slurries and wastewaters can be surface applied and incorporated or injected. Injection fits well with no-till systems. Wastewaters applied through irrigation may be compatible across tillage systems, but tillage may not be required if the application volume is sufficient to move nutrients into the soil.

C) Crop growth stage

On annually cropped land all sources are typically applied prior to seeding or after harvest. Liquid sources surface applied on forage stands tend to have lower N losses if the crop is actively growing.

D) Soil test or tissue test

Soil testing prior to application is a 4R BMP for fields receiving manure or composted manure. In Alberta and Manitoba, livestock enterprises regulated as CFOs must soil test before application. However, there are exceptions based on operation size and amount of manure produced. In Saskatchewan, soil testing is a recommended but not required practice for manure application.

Soil testing should at a minimum include salinity (EC measurement), soil test nitrate, soil test phosphorus and texture. A more complete analysis including K, S, micronutrients, pH, and soil organic matter provides baseline values prior to application.

Soil testing is typically a regulatory requirement for application of certain classes of composts, biosolids, and wastewaters. In addition to the agronomic considerations, receiving sites may need to be characterized for trace metal content. Note that some plant nutrients are trace metals (examples copper, zinc, molybdenum, and nickel) but not all trace metals are plant nutrients (examples cadmium, lead, and mercury). Soil testing for trace metals in regulatory situations is typically based on total rather than extractable metals and the values obtained are not an indicator of plant availability or nutrient sufficiency. Sodium adsorption ratio (SAR) and/or Exchangeable Sodium Percentage (ESP) may also need to be tested for prior to application.

Tissue testing of crops prior to application can provide baseline information on parameters such as trace metal uptake. Testing the crops after application can provide information on whether or not the waste material is providing sufficient nutrients. More specialized tissue testing may be warranted or required with certain source and crop combinations. This may include testing to characterize trace metal uptake or detecting biological contaminants including pathogens.

E) Analysis of manure, biosolids and wastewater

These materials may vary considerably and determining the right rate requires knowing the concentration and form of the nutrients they contain.

For manures, analysis of total N (total Kjeldahl nitrogen or TKN) and ammonium-N are required to calculate the availability of N in the year of application and subsequent years. Organic-N is calculated by difference:

Organic N = Total-N – Ammonium-N

Nitrate-N values tend to be low and are usually ignored in manures. Ammonium-N values vary widely and can be as high as 50% of total-N in liquid manures and up to 75% of total-N in poultry manures.

Additional analysis should include total P and K, moisture content for solid manures and dry matter or total solids for liquids. Electrical conductivity and pH are also useful characterizations.

For planning purposes where manure analysis is not available (for example a new barn), book values for the animal type and housing can be used but are not a good substitute for analysis of the actual manure that will be applied. Testing manure prior to or at time of application over several years and developing an average for the operation can provide both a good estimate of the typical composition and an understanding of the variability.

Sample Layout of Manure Analysis Report

Billing Information	**Sample Information**	**Sample Processing Information**
Bill to: NMP Consulting Ltd. **Report to:** NMP Consulting Ltd. Box 2007 Anywhere, AB X0X 0X0 **Attn:** I.M.A. Consultant **Phone:** (780) 222-2222 **Fax:** (780) 222-2221 1	**Producer:** ABC Livestock Ltd. **Sample ID:** A1 **Sample Description:** Cattle manure **Lab Assigned Code:** A430-2007 2	**Date Received:** March 30, 2007 **Date Reported:** April 04, 2007 **Sample Retained:** April 29, 2007 **Arrival Condition:** Good **Report Number:** 983395 3

Parameter 4	**As Received (%)**	**As Received (per tonne or per 1000 L)** 5	**Dry Basis (%)**	**Analytical Method Reference** 6
Moisture	37.8%			
EC (manure)	36.8			TMECC-04.10
Total Nitrogen	0.95%	9.5 kg	1.51%	AOAC-993.13
Total Phosphorus	0.522%	5.2 kg	0.830%	AOAC-985.01
Total P_2O_5	1.20%	12.0 kg	1.90%	
Total Potassium	1.08%	10.8 kg	1.72%	AOAC-985.01
Total K_2O	1.30%	13.0 kg	2.08%	
Sodium	0.205%	2.0 kg	0.327%	AOAC-985.01

Comments:

7

Notes on Reading a Manure Analysis Report: Reports will identify the person receiving the report as well as information that helps identify the sample and type of the manure (#1 and #2 in above). When reviewing test reports, verify that the information is accurate and review any comments included on the report (#7). The report should include dates when the sample was received and processed (#3). Review these handling dates to see if there were any unusual delays in shipping that might affect the accuracy of the results. If not stated on the report, contact the lab to determine whether samples are retained for a period following analysis, in case analysis must be repeated to verify unusual results. Some reports will also include reference to the procedure or analytical method used for individual nutrients or parameters (#6). If using different labs from year to year, this information can help verify that labs are using the same analytical procedures so that comparisons of nutrient content between years are valid. Finally, the reporting units for each analytical value reported should be clearly stated as well as whether the values are expressed on an “as received” or moist basis or dry basis.

Source: Adapted from Nutrient Management Planning Guide Agdex 400/28-3

Composts, biosolids and wastewaters generally require more extensive analysis than manure and analysis of certain types may be required under regulation. Compost that is sold, for example, is regulated under the Fertilizer Act. Composts are exempt from registration in most cases, but the seller is expected to provide grade information to the buyer based on analytical results for NPK nutrient claims.

The key areas of concern with composts, biosolids and waste waters are as follows: trace elements (mostly metals), foreign matter, pathogens, and organic contaminants. For trace elements, the focus is on Arsenic (As); Cadmium (Cd); Cobalt (Co); Chromium

(Cr); Copper (Cu); Mercury (Hg); Molybdenum (Mo); Nickel (Ni); Lead (Pb); Selenium (Se); and Zinc (Zn). Note again that analysis is on a total rather than plant available basis. Analysis of trace metals is used as the criteria for separating compost into Category A: unrestricted use or Category B, restricted use. The restrictions are set by the provinces and the CCA making recommendations on the use of compost should make sure they understand the applicable regulatory standards. Foreign matter includes material such as sharps (broken glass, old needles, metal scraps etc.) that can cause damage or injury during handling. Pathogens of concern include fecal coliforms such as *E. coli* and *Salmonella sp.* Some compost feedstocks may contain trace amounts of persistent or bio-accumulating organic contaminants, such as dioxins, furans, pesticides, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH) or herbicides (e.g. clopyralid). However, levels of these organic contaminants are low in common feedstocks used for composting in Canada and routine testing is generally not required. For specific sampling requirements for compost and biosolids refer to the provincial guidelines in the province where the material will be applied.

The Canadian Council of Ministers of the Environment (CCME) developed a national standard *Guidelines for Compost Quality* in 20015. A link to the guidelines is provided below. See also CA6,PO4 in this performance area.

https://www.ccme.ca/files/Resources/waste/organics/compostgdlns_1340_e.pdf

F) Timing and placement of application.

Source characteristics that need to be considered when choosing timing and placement options include nutrient availability in relation to period of high crop demand, risk of nutrient loss, and potential for crop damage. This may be best illustrated by a series of examples.

Sub-surface placement of solid manures requires tillage with substantial inversion of the soil surface. Obviously, this placement is not compatible with in-season timing for most annual cropping systems.

Subsurface injection of liquid manures is compatible with both minimum and more conventional tillage systems. Injection into forage or close seeded annual crop stands while feasible may cause considerable damage.

Surface application of liquid manures into actively growing forage stands tends to reduce N loss through volatilization compared to application on a dormant stand.

Certain solid manures, poultry for example, may contain levels of ammonia that may damage crops when surface applied in-season.

Solid manures with high C:N ratios (for example, cattle manure containing bedding materials such as straw or sawdust) may not breakdown fast enough to meet crop demand for N in the year of application. They may increase N immobilization and induce an N deficiency.

Application on frozen and snow covered ground is prohibited in all three provinces except in emergency situations or for operations that have been allowed to continue winter spreading (grandfathered) as a practice they were using before prohibitions were introduced. Manitoba regulates application times with a fall stop date and a spring start date. The date may be varied from year to year depending on weather.

CCAs working with operations that winter spread need to carefully evaluate the land base receiving the manure as there is an elevated risk of runoff.

Performance Objective 4. Discuss how managing the 4Rs for manure, compost, biosolids and wastewater influences nitrogen and phosphorus losses to surface water and groundwater.

Developing and implementing 4R BMPs for waste materials follows the same principles as for fertilizer. There is often an additional layer of regulatory requirements that must be met but these are generally not at odds with 4R principles. A key starting point is to understand the N and P content, forms, and availability in the source material. Since rates of N and P often exceed the crop requirements of the immediate year extra care must be taken with timing and placement to reduce risk of loss. This includes observing setbacks from water features, avoiding application in frozen or saturated soil, and incorporating materials where feasible and/or required by regulation. Characterizing the risk of loss on a field by field basis including assessment of landscape features, soil types, and preapplication levels of N and P through soil testing all assist in developing a set of 4R consistent BMPs that lessen the risk of loss.

There will always be a degree of leakage of N and P from cropping systems. Managing manure, compost, biosolids, and wastewaters using a 4R approach within the regulatory framework will create greater understanding of the environmental risks involved and should over time greatly reduce losses from the present levels.

COMPETENCY AREA 2. RATE, TIMING AND PLACEMENT/METHOD OF MANURE, COMPOST, BIOSOLIDS AND WASTEWATER

Performance Objective 1. Interpret how soil test levels relate to crop yield response and potential environmental impacts.

Soil test and yield response as a probability function have been covered in detail in the proficiency areas on N and P (PA3, CA2, PO1 and PA4, CA2, PO1).

The nitrate-N test (STN) is a measure of not only readily crop available N but also soluble and therefore easily mobile N in the cropping system. Nitrogen can be lost from cropping systems through a number of pathways. The risk of loss to surface and groundwater and GHG emissions would both be expected to increase at higher STN levels.

Increased risk due to high STN following waste material application will result in higher actual losses under environmental conditions that enable N leaching or denitrification. Crop uptake of N will reduce that risk by reducing the nitrate pool. Application rates that result in nitrate-N levels in excess of crop needs increase the risk of loss and subsequent environmental impact. Much of the N in manure and other waste materials is in organic form and is released more slowly. In liquid manure or other liquid wastes, ammonium-N may account for a high proportion of the N. Since ammonium-N converts quickly to nitrate, it will show up in the soil test within a few weeks of application.

The phosphorus soil test measures a number of different inorganic mineral (Pi) and organic (Po) forms in soil. While STP levels correlate with risk of loss, the relationship between added P and STP is not one to one. When STP is low, it may require 10 or more lb P2O5/acre to raise STP 1 ppm. Phosphorus is highly reactive in soil and soluble forms are adsorbed, precipitated, or immobilized rapidly when added to soil. In manures, a significant portion of the Pi may be in microcrystalline form as Calcium-P or other compounds at the time of application. Soils hold on to Pi less tightly as STP levels increase. Typically manure applications contain more P than is required during a single growing season. Repeated manure applications that cause STP levels to rise, increase the risk of loss regardless of the frequency of application. Once agronomic needs are satisfied, additional P creates risk with no offsetting benefit.

Performance Objective 2. Describe how rates may be affected by soil characteristics, which may include:

A) Cation exchange capacity (CEC)

A higher CEC increases the amount of ammonium-N and P that can be held by the soil. Although P sorption involves anionic forms (H2PO4- or HPO42-), soil with higher CEC tend to have higher P sorption capacity. Phosphorus sorption measurements don’t differentiate among precipitation of insoluble compounds, surface adsorption and/or anion exchange. Soils with high CEC hold more phosphorus.

B) Organic matter

Soils with higher SOM tend to mineralize more N. The quantity of N supplied through mineralization needs to be included when determining the application rate. Rates can also be adjusted to build SOM in areas of fields, such as eroded knolls, where there will be greater benefits per unit of material applied.

C) Texture

Finer soil textures have higher CEC, greater water holding capacity, and typically more SOM than coarser textured soils. They are generally more fertile than coarse textured soils and have higher yield potential. While there is a lower likelihood of N leaching in fine textured soils, there is a corresponding increased likelihood of losses of N and P through surface runoff. (Keep in mind that a frozen sandy loam and a frozen clay loam are both impermeable during spring runoff.)

D) Clay type.

Particle size and chemistry differ among clay types. These differences are reflected in CEC and water holding capacity and result in some variability in these attributes among soils that fall within the same textural class. Certain non-expanding 2:1 clay types, may fix ammonium. Soils with a high proportion of expanding clays may cause soil cracks when dry that can be conduits for preferential flow of N and P below the rooting zone.

Whether the application rate should be adjusted up or down on a clay loam compared to a sandy loam across the road, will require careful consideration of the aforementioned factors as well as the landscape, climate, crop selection, soil test values, and manure source.

Performance Objective 3. Discuss considerations to determine the proper rate, timing and placement based on the following:

Considerations are similar to those discussed earlier in the N section (PA3) and the P section (PA4). Also see CA1,PO3 this section. Comments below would largely apply to annual and perennial cropping systems that are receiving manure on a three to five-year cycle rather than every year.

Regulations may dictate acceptable rate, time, place for different cropping systems.

A) Crop type and variety;

Use of lodging resistant crop types and varieties is recommended when high N rates are applied as organic sources. Keep in mind that in forage production, high N levels will tend to suppress nitrogen fixation. Grasses may have a competitive advantage in mixed stands until N levels are reduced.

B) Cropping system;

Differences among cropping systems, annual or perennial, row or solid seeded, conventional or minimum tillage need to be considered when making rate, time, and place decisions. Matching availability timing to crop demand becomes more difficult when using multi-year rates and surplus N or P increases risk of environmental impacts through nutrient losses.

C) Crop growth stage;

Volatilization losses when surface applying to perennial forage stands tend to be reduced if the crop is actively growing. Some sources high in ammonium, for example solid poultry manure, may cause burning if applied to growing crops or at too high a rate too close to seeding.

D) Soil test or tissue test;

Soil tests are useful and often required before or after application to determine rates and ensure that limits for N and P are not exceeded. For biosolids, pre-application testing for metals is generally required to determine if the field qualifies and for setting rates. Tissue testing can be useful to monitor sufficiency during the growing season particularly when the N release characteristics of the material are unknown. For example, a compost or manure from a new source.

E) Timing of application;

Application timing in annual crops is typically before seeding or after harvest except for wastewater which may be applied to actively growing crops through irrigation equipment. Application of multi-year rates based on N or P prior to seeding a forage stand is common practice. In established stands, application in early spring or late fall are common practice, but volatilization losses tend to be reduced if the crop is actively growing. Weather can have a significant effect on nutrient loss, generally application during cool moist weather reduces volatilization losses. Application on frozen or snow-covered ground is to be avoided and is generally only allowed as an emergency exception under regulations.

F) Method of application;

Sub-surface placement either through banding or surface application followed by immediate incorporation results in smaller losses than other methods. For surface applications of solid manures, delaying incorporation can result in large N losses through volatilization. Another aspect of placement that needs to be considered is offsets or setbacks from common water bodies, wells, and drainage channels. Required setbacks may involve prescribed distances or based on specific risk assessment of the receiving site. (An example of setbacks from a common water body based on slope is shown in CA6, PO5G.)

G) Relative balance of available nutrients.

The balance of nutrients in source materials may not match the balance required by crops. The most important imbalance on the Prairies is between relatively low N and high P as these are the two nutrients are most commonly deficient. They are also the two nutrients where poor management resulting in losses can impact water quality. Losses of N during loading, transportation and application can further displace the ratio between N and P from that required by crops. The differences among crops must also be considered. Application rates based on meeting N requirements generally lead to the accumulation of P (and K). Basing rates on P use, typically results in a shortfall of N that requires supplementation with N fertilizer.

The total amount of a nutrient in an applied material may be quite different than the available amount. For example, manures may be relatively high in Cu due to feed supplementation, but the copper may be bound up and not readily plant available. Consideration also needs to be made for synergistic and antagonistic interactions. For example, heavily manured fields accumulate P; high soil phosphorus may interfere with Zn uptake; yields of crops susceptible to zinc deficiency, like silage corn under irrigation, may suffer.

COMPETENCY AREA 3. WHOLE-HERD OR WHOLE-FLOCK TOTAL ANNUAL MANURE AND NUTRIENT PRODUCTION

Performance Objective 1. Recognize differences in calculating animal units for different Provinces and be able to calculate the total number of animal units in an operation given appropriate information.

The concept of an animal unit allows equivalencies in manure quantity to be developed across different animal species and for different classes (size, age, or use) of animals within species. The definition of what constitutes an animal unit varies among the three Prairie Provinces. The standard for comparison may be volume of manure produced or the mass of nutrient excreted. When based on nutrient (N is usually used as the standard), the “units” may be described as “nutrient units” rather than animal units. The division of animals of the same species into classes also varies as does the terminology used to describe the different animal type. For exam preparation, the suggested approach is to spend a few minutes looking at animal units by province using the links below.

Alberta – Animal units are based on volume of manure produced with volume from the mythical 1000 lb. cow with calf taken as the standard for 1 animal unit. The equivalencies among species are laid out in Schedule 1 of the AOPA regulations.

http://www.qp.alberta.ca/1266.cfm?page=2001_257.cfm&leg_type=Regs&isbncln=0779749383

Saskatchewan – Animal units are based on animal mass (1000 lbs). Equivalencies are listed in Table 1 of the appendix to the Agricultural Operations Regulations.

http://www.publications.gov.sk.ca/freelaw/documents/English/Regulations/Regulations/A12-1R1.pdf

Manitoba – The definition of the animal unit is the number of animals required to excrete a total of 73 kilograms (160 lb) of nitrogen in a 12-month period. See Part B in the linked MB nutrient management regulation form for specifics of animal units.

https://www.gov.mb.ca/waterstewardship/wqmz/pdf/livestock_manure.pdf

Comparison of Animal Units Across the Three Prairie Provinces		
Alberta	**Saskatchewan**	**Manitoba**
One cow	One cow	0.8 beef cow
Two feeder cattle	1.5 feeder cattle	1.3 feeder cattle
3.6 calves	4 calves	.5 dairy cow
0.56 sows, farrow to finish	3 sows and boars	0.8 sows, farrow to finish
5 feeder pigs	6 feeder pigs	7 finishers
18.2 weanlings	20 weanling pigs	30 weanlings
100 hens	100 hens	100 hens
500 broiler chickens	200 broiler chickens	200 broiler chickens
75 turkey hens	50 turkeys	100 turkeys
5 ewes and rams	7 ewes and rams	5 ewes and rams
21 lambs	14 lambs	16 lambs
Source: Provincial Agriculture departments		

Performance Objective 2. Discuss the use of software and/or charts to estimate the total amount of manure produced in a year by an operation.

Standard daily manure production values for use in estimating manure production for CFO permitting and manure management plans are appended to the governing regulations of the specific province. These values can be used with the appropriate time step and animal numbers to calculate total manure production. Sample portion of the Alberta AOPA chart is shown for illustration purposes on the next page.

Standard daily manure production values for different classes of livestock.

Species/Class		Solid				Liquid			
		Weight		Volume		Weight		Volume	
		kg	lbs	m³	ft³	L	gal[1]	m³	ft³
Beef	Feeders	3.8	8.4	0.0062	0.21	---	---	---	---
	Finishers - Open lot	6.0	13.1	0.0094	0.32	---	---	---	---
	Finishers - Paved lot	9.0	19.8	0.0126	0.43	---	---	---	---
	Feeder calves < 550lbs	1.5	3.3	0.0023	0.08	---	---	---	---
	Cow/calf pair	8.1	17.8	0.0129	0.44	---	---	---	---
	Cows/bulls	7.5	16.5	0.0117	0.40	---	---	---	---
Dairy (* count lactating cows only)	Free stall: Lactating cow only[2]	---	---	---	---	98.6	21.7	0.099	3.50
	Fee stall: Dry cow	---	---	---	---	43.0	9.5	0.042	1.50
	Fee stall: Lactating with dry cows only*[3]	---	---	---	---	116.8	25.7	0.116	4.11
	Tie stall: Lactating cow only	63.5	139.7	0.0779	2.66	---	---	---	---
	Loose housing: Lactating cow only	66.5	146.3	0.0815	2.78	---	---	---	---
	Dry Cow	31.8	70.0		1.30	---	---	---	---
	Replacement heifers	19.5	42.9	0.0240	0.82	---	---	---	---
	Calves	1.3	2.9	0.0021	0.07	---	---	---	---
Swine (* count sows only)	Farrow-to-finish*	39.3	86.4	0.0510	1.74	65.7	14.44	0.065	2.31
	Farrow-to-wean*	12.1	26.6	0.0158	0.54	20.2	4.44	0.020	0.71
	Lactating sow*	9.7	21.3	0.0126	0.43	15.9	3.50	0.016	0.56
	Weaner pig	1.3	2.8	0.0018	0.06	2.3	0.50	0.002	0.08
	Feeder pig	3.7	8.2	0.0050	0.17	7.1	1.56	0.007	0.25

The table values are drawn from Alberta's AOPA framework. For the full complement of species and types consult your provincial guidelines.

Source: Nutrient Management Planning Guide Agdex 400/28-3

Software and or spreadsheets can be used to estimate annual manure output based on animal units. Alberta and Manitoba have provided calculation software in the past through their respective websites. When using manure management software to calculate manure production per animal unit, make sure it is configured to the appropriate animal units as outlined in the regulations of the various provinces.

A manure output calculator based on Manitoba data and regulations is available in Excel format at the website below:

https://www.gov.mb.ca/agriculture/environment/nutrient-management/land-base-requirements-for-new-and-expanding-livestock-operations.html

Alberta's Manure Management Planner (MMP) software can be downloaded from the website below:

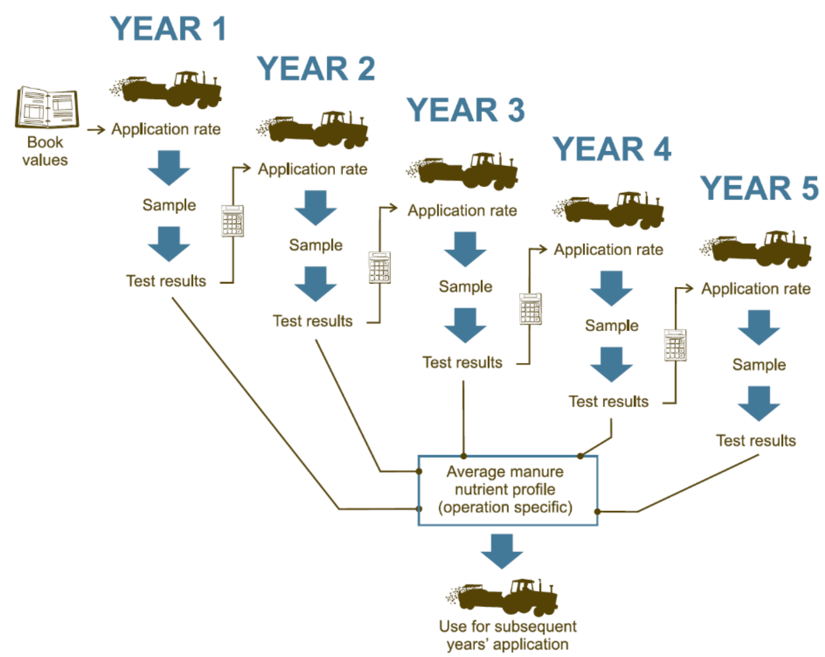
https://www1.agric.gov.ab.ca/$department/softdown.nsf/main?openform&type=MMP&page=download

Performance Objective 3. Discuss the pros and cons of operation specific nutrient tests versus book values with respect to developing a nutrient management plan.

Book values have the advantage of availability and are generally based on averaging a large number of samples from many different operations over many years. They are useful for start-up operations that have no history of manure analysis. They are also useful as a reference set or baseline for comparison of manure analysis from a specific operation or batch of manure.

While book values are a reasonable starting point, the type of livestock, feeding ration, bedding, added liquid quantity and quality, and storage system all affect the final nutrient form and concentration. Actual analysis provides an operation specific profile of the nutrients and other characteristics of manure. The disadvantages are manure is highly variable, difficult to sample, requires special handling, analysis take time and costs money, and results may vary by season. It generally takes several years, and multiple samplings to develop a good profile of an operation's manure quality.

Developing an Operation Specific Manure Nutrient Profile



Source: Nutrient Management Planning Guide Agdex 400/28-3

Performance Objective 4. Calculate the total nitrogen, phosphorus and potassium in the manure produced by an operation in a year using published or test values of manure nutrients.

Calculating total NPK in manure require the following information:

- Total animal units by species and type that were contributing manure.
- Residence time of each species and type.
- Manure output per time unit for each species and type in appropriate form (liquid or solid) and were applicable relevant housing units. (see table in PO2 above).

- Published or test values for NPK in manure for each manure type.

The table below provides "book values" for various manure types. These have been adapted from Alberta's AOPA and are shown here for illustration purposes. Regulations in other provinces may require the use of slightly different values.

Standard Manure Nutrient Characteristic (as removed) for Common Classes of Livestock Adapted from the Agricultural Operation Practices Act (Province of Alberta 2001).

Species/Class		Typical Nutrient Content (% of fresh manure)					
		Moisture[1]	Total N[1]	Avail N	Crop N	Total P[2]	Total K[3,4]
Beef	Feeders Finishers Feeder calves Cow/calf pair Cows/bulls	50 (30-70)	1.0 (0.65-1.25)	0.26	0.32	0.24	0.67
	Paved feedlot	65 (50-75)	0.7 (0.45-0.80)	0.27	0.25	0.09	0.38
Dairy	Free-stall housing	92 (85-95)	0.40 (0.35-0.60)	0.18	0.17	0.09	0.42
	Tie-stall housing Loose housed Replacements Calves	80 (70-85)	0.50 (0.45-0.65)	0.21	0.19	0.09	0.42
Swine	Liquid	96 (90-99)	0.35 (0.20-0.55)	0.16	0.16	0.11	0.17
	Solid	50 (40-70)	0.80 (0.60-0.90)	0.32	0.31	0.15	0.23
Poultry	Caged layers, belt removal (solid)	40 (30-60)	3.01 (2.50-3.50)	2.01	1.89	1.54	1.0
	Caged layers, deep pit (solid)	50 (30-60)	2.41 (2.00-3.00)	1.60	1.51	1.23	0.83
	Caged layers (liquid)	90 (85-95)	0.60 (0.50-1.00)	0.40	0.38	0.25	0.20
	Broilers replacement pullets	35 (30-50)	3.41 (3.50-4.00)	1.95	1.84	0.95	1.00
	Broiler breeders	35 (30-50)	3.01 (1.60-2.10)	1.72	1.63	0.95	1.00
	Turkey breeders	35 (30-50)	1.75 (1.50-2.00)	1.00	0.95	0.59	0.63

Source: Nutrient Management Planning Guide Agdex 400/28-3

A sample calculation is shown below. You may want to create your own scenarios for various animal types and become familiar with the math.

Sample Calculation for a Small Beef Feedlot in an Open Lot System Using Book Values.
Number of animals on site annual average 1000 feeders and 500 finishers
Manure Output Feeders: 1000 animals X 365 days X 8.4 lb/day = 3,066,000 lb Finishers: 500 animals X 365 X 13.1 lb/day = 2,390,750 lb Total: 3,066,000 lb + 2,390,750 lb = 5,456,750 lb manure
Total N Produced 5,456,750 lbs X 1% N = 54,567 lbs N
Total P Produced 5,456,750 lbs X 0.24% P = 13,096 lbs P
Total K Produced 5,456,750 lbs X 0.67% K = 36,560 lbs K

Performance Objective 5. Use record keeping to measure the total manure produced by an operation in a year.

The type of data required to estimate annual manure production based on animal units is covered in point form in PO4. Records need to include the type of animal, when they entered the system and when they exited in order to calculate the residence time. Once the residence time is known for each animal or lot of animals the manure production can be calculated and summed.

COMPETENCY AREA 4. ADEQUACY OF THE LAND BASE FOR APPLYING MANURE, COMPOST, BIOSOLIDS, AND WASTEWATER

Performance Objective 1. Discuss the risk of loss of nutrients (N, P) and odour from a field, how it may be assessed, and how it may exclude some fields from receiving manure, compost, biosolids, and wastewater and/or require setbacks.

N and P loss

The loss mechanisms for N and P are covered in PA2, PA3, and PA4. The factors that need to be evaluated when assessing loss potential or risk from cropping systems receiving manure include:

Soil texture – Coarse textured soils provide less of a barrier to movement of N to groundwater and have lower retention of ammonium-N and P due to low CEC.

Landscape – Slope length and steepness and connectivity and continuity of runoff source areas with offsite drainage needs to be considered. Nearness to common water bodies and the need for setbacks is also a consideration.

Cropping System – Type of tillage, annual or perennial crop, and erosion potential are factors that depending on practice may ameliorate or increase loss of nutrient loss.

Climate and Weather – Risk of loss through water tends to be lower in drier climates. Weather can have a significant effect on N loss from manure depending on application method.

Odour[12]

Land application of manure, biosolids, and wastewater can cause odour issues. Odours from these materials, are the compounded result of different volatile compounds associated with material decomposition. The more offensive gases are by-products of anaerobic decomposition. Liquid manure storage systems promote anaerobic decomposition, particularly deeper in the manure storage structure. Liquid manure sources tend to create bigger odour issues than solid sources when surface applied.

Sensitivity to odour varies greatly from one individual to another and can be affected by a number of factors. Frequency, Intensity, Duration, Offensiveness and Hedonic Tone will impact odour tolerances. This is sometimes referred to as FIDO(H). Hedonic Tone in this sense could be loosely translated as how annoying the individual finds the odour. Although odour is generally treated as a nuisance issue, it can be a source of psychological stress, and in some cases, is reported to be the source of physical symptoms including nasal irritations, headaches and nausea. To date, studies have not demonstrated significant health hazards to neighbouring residents caused by manure odours; however, data from clinical and engineering studies suggest that further research is warranted.

This is sometimes referred to as FIDO(H) or Frequency, Intensity, Duration, Offensiveness and Hedonic Tone. Hedonic Tone in this sense could be loosely translated as how annoying the individual finds the odour.

Odours released during land application can cause nuisance. Odour emission is a function of the type and form of the manure, its exposure to the air and the length of time it is exposed. Fine manure droplets that spend more time exposed to the air will have the greatest opportunity to release manure gases. The “big gun” manure or wastewater irrigation system has the most potential for creating odour nuisance. The high-pressure spray nozzles form a fine mist of liquid manure that is projected into the air and can travel long distances with maximum air contact. For this reason, they are not recommended.

Minimizing the exposure of the manure to the air can greatly reduce odours. Injection or incorporation as soon as possible after application is very effective in reducing or eliminating odours during land application.

There are various practices that can be implemented to minimize odour nuisance, including:

- considering neighbours before applying manure, biosolids, or wastewater;
- informing neighbours in advance of agitating and applying;

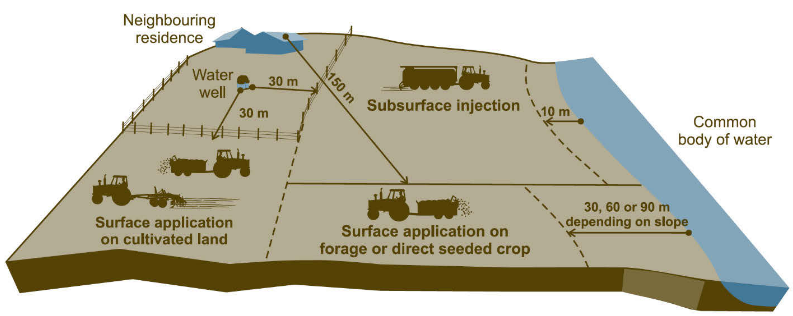
1 The odour section is adapted from The Tri-Provincial Manure Application and Use Guidelines

- avoiding land application on weekends if neighbours are located downwind where odour can be a nuisance;
- injecting manure or biosolids (may be required) into the soil whenever possible;
- using low-level application equipment if injection is not possible and incorporating the material as soon as possible after application;
- discontinuing the use of "big gun" irrigation systems for materials with a high potential to cause nuisance odours;
- manure treatment options may be considered where nearby land uses may be sensitive to odours (e.g. Composting).

Excluding land and/or setbacks

Regulations may require exclusion of certain fields or areas of fields from receiving organic waste materials based on risk of N and P loss and/or odour control. Site assessment while determining the adequacy of the land base needs to account for exclusions and setbacks. Tools such as aerial or satellite images combined with GIS can be used to map sensitive areas; determine required setbacks or excluded areas; and calculate the area eligible to receive material. As a general rule, manure and other organics can only be applied to arable land, which generally includes tame hay or seeded forage land. Regulations may allow for some exceptions, but poorer quality land used for pasture is generally excluded. Required setbacks vary by province and the CCA needs to be well acquainted with their local regulations when undertaking manure management planning.

Examples of Required Setbacks



Common Body of Water - the bed and shore of a water body that is common to or shared by more than one landowner. This can be a lake, slough, creek, river, irrigation canal, and drainage ditch. Water features that terminate on the landowner's property or are completely contained on a landowner's property are generally not considered common water bodies. Roadside ditches are not considered common water bodies even though they may flow on occasion.

Source: Nutrient Management Planning Guide

Performance Objective 2. Evaluate the adequacy of the cropland available for spreading manure, biosolids, and wastewater by comparing the total available product to the land base.

The underlying concept in a 4R approach is to balance inputs from manure with crop removals over the long term. Although in the short term, manure application-rates can be made to meet crop N demands, in the longer term, the adequacy of the land base must be based on P rather than N. When applying manure to meet N demand, P is usually over applied and starts to accumulate in the soil. Once STP reaches a certain level, there are no further agronomic benefits from applying P. The different provinces deal with this N and P imbalance in different ways. Manitoba restricts the quantity of manure that can be applied to a field once certain STP levels are reached. Alberta requires operations to acquire access to sufficient land to balance P inputs from manure application with P removals by crops over the longer term.

In determining if the adequacy of the cropland available for manure application is sufficient, the first step is calculating a threshold application rate:

Threshold Application Rate = Annual Manure Production ÷ Eligible Application Area

The second step is determining the application strategy and the actual rates to be applied:

Sample Strategies

N strategy – N sufficiency for one or two year.

P strategy – P removal for multiple years.

Step 3 is to compare the calculated rate to meet the nutrient strategy to the threshold rate.

If the calculated rate is higher than the threshold rate there will be sufficient land for application. The total amount of manure will be applied on only a fraction of the available acres. If the calculated rate is lower than the threshold rate (surplus manure left after the available land base is used), then the land base is not adequate and additional land will have to be found.

Study Hint: Fully laid out examples of the threshold concept as well as examples for calculating rates based on various strategies can be found in Chapter 6.1 of the Nutrient Management Planning Guide. Strongly recommended that you work through the examples in the Guide. The Guide is available on-line and is referenced at the beginning of this Proficiency Area.

Performance Objective 3. Understand restrictions on crops, vegetables, or forages based on application of manure, biosolids or wastewater due to build-up of nutrients, metals, pathogens, and salinity.

Build-up of Nutrients

The Provincial regulations may have limits based on soil test N and/or P to prevent excessive build-up. These limits will determine how much manure can be applied or may preclude the application of manure entirely on fields. The regulations may in some cases allow limits to be exceeded if certain conditions are met and methods are outlined in a manure management plan. CCAs working with manure application need to be aware of the limits in their province and understand how they may affect manure rates. There are two main approaches. One is to base the limit on a post manure application value and adjust the rate such that the limit is not likely to be exceeded. The other is to limit the application rate based on pre-application soil test. The soil test N limits from Alberta and the soil test P limits from Manitoba are shown here to illustrate the different approaches.

Alberta Nitrate-Nitrogen limits in soil

Farming method	Soil group	Sandy (>45% sand and water table <4 m)	Sandy (>45% sand and water table >4 m)	Medium and fine textured soils
	Brown	80 kg/ha (75 lb/ac)	110 kg/ha (100 lb/ac)	140 kg/ha (125 lb/ac)
Dryland	Dark Brown	110 kg/ha (100 lb/ac)	140 kg/ha (125 lb/ac)	170 kg/ha (150 lb/ac)
	Black	140 kg/ha (125 lb/ac)	170 kg/ha (150 lb/ac)	225 kg/ha (200 lb/ac)
	Grey	110 kg/ha (100 lb/ac)	140 kg/ha (125 lb/ac)	170 kg/ha (150 lb/ac)
Irrigated	All groups	180 kg/ha (160 lb/ac)	225 kg/ha (200 lb/ac)	270 kg/ha (240 lb/ac)

Note: The values specify the nitrate-nitrogen levels that may not be exceeded in the top 60 cm of soil after manure application.

Source: Alberta Agriculture Agdex 096-5

In the table below , the STP values are based on a 0-6 in sample taken before application.

Phosphorus based manure application limits under Manitoba regulations.	
Soil Test Olsen-P (0-6 in)	Allowable Phosphorus
≤ 60 ppm	No restriction
60 – 120 ppm	the rate of livestock manure application must not exceed two times the annual crop removal rate of P2O5.

120 – 180 ppm	the rate of livestock manure application must not exceed the annual crop removal rate of P2O5.
>180 ppm	No application allowed
Exception1 60 – 180 ppm	May apply a rate up to five times the annual crop removal rate of P2O5. In this situation, no further manure can be applied until (a) a number of years has passed equal to the multiple of the crop removal rate of P2O5 that was applied; or (b) soil test phosphorus levels do not exceed the soil test phosphorus levels before the last application of livestock manure to that area. This exception is in the regulations primarily to allow growers establishing perennial stands to front load a multiyear P rate.
Source: Livestock Manure and Mortalities Management Regulation	

High rates of manure can cause environmental issues through N and P loss; they may also cause production issues. Excess available N, cereals may be prone to lodging and all crops may experience delayed maturity.

Zinc sensitive crops such as corn grown on soils with excessive P levels may experience Zn deficiency.

Cattle grazed on land with excessive K levels may develop grass tetany (a form of magnesium deficiency in ruminants). The problem is in the animal, the grass is not Mg deficient.

Metals

Metals are primarily a concern in biosolid applications. The provinces limit application of biosolids to soils that test below a threshold for trace metals. There are also limits on the frequency and total number of times biosolids can be applied to a field. The limits are designed to ensure that trace metals do not reach problem levels. Although, some of the regulated trace metals are plant nutrients many are not. See CA1, PO3 in this section for more information on trace metals in biosolids.

Animal rations are often supplemented with mineral mixes containing nutritionally required trace elements. Repeated manure and manure based compost applications may also lead to metal accumulations in soil. Metals such as copper and zinc may be accumulating but may not be plant available due to tie up by various organic fractions in the manure.

Pathogens

Livestock manure, biosolids, and wastewater contains bacteria, viruses, protozoa and parasites, some of which may be pathogenic (cause disease) in humans. These pathogens can enter surface water, if animals have direct access to the water or through the discharge of sewage treatment systems. Many of these pathogens can also be found in faeces from wildlife, birds, pets and open defecating humans (yes that's a thing), so livestock is not the only source.

Pathogens can also enter surface water through runoff from agricultural fields that have received manure, biosolids. or waste water. Soil tends to act as a natural filter that protects groundwater from contamination by pathogens. However, there may be a risk of micro-organisms moving through the soil profile to groundwater where the water table is shallow and overlain by coarsely textured material. Microbial transport to groundwater may also be a concern in areas where fractured bedrock is found at or near ground surface or in areas characterized by Karst features such as sinkholes. Pathogens can also reach groundwater directly through wells that are not properly sealed to prevent water moving down the bore hole on the outside of the well casing.

Management practices that reduce nutrient movement also tend to reduce pathogen movement into surface and groundwater. These include offsets or setbacks from water bodies and wells. Application of waste materials to crops that are directly consumed by humans or grazed by animals may be restricted entirely or may be confined to periods well ahead of harvest. In Alberta, for example, the recommended practice is to exclude direct grazing and root crops for 3 years following biosolid application. Regulations and/or guidelines vary by province and material. CCAs should understand the regulations and guidelines for their province when developing recommendations based on these materials.

Salinity

Manures, composts, biosolids and wastewaters can be high in salts. Salts are often added to the diet of animal (and human) rations. They can be concentrated as solid manure dries down and during composting as moisture and mass is reduced. Salts added with organic amendments can add to an existing salinity problem in soils. There are regulatory requirements for salt loading that must be considered when determining the adequacy of the land base for application. This may include excluding portions of fields that are already saline (EC > 4 dS/m in 0-15 cm) from receiving amendments and/or limits on the acceptable increase in salinity following a waste material addition such as no more than 1 dS/m increase in the top 15 cm. At present there is no simple and reliable way to predict the impact of a one-time organic amendment addition on the post application salinity of the soil. Before and after soil sampling is the most reliable way to monitor changes in salinity.

See CA6, PO3 for more information on salinity.

COMPETENCY AREA 5. CREDITING THE NUTRIENTS IN MANURE FOR CROP PRODUCTION

Performance Objective 1. Use the availability factors for the nitrogen (current and previous applications), phosphorus and potassium in manure as outlined in the Tri-Provincial Manure Application and Use Guidelines.

Sample calculations for various aspects of nutrient availability in manure and application rates are provided in great detail in Sections 4.3 and 6.1 of the Nutrient Management Planning Guide. Review of that material is encouraged. For CCAs unfamiliar with using manure, reviewing the Tri-Provincial Manure Application and Use Guidelines maybe provide supplemental information that will build a better foundation than the brief review provided here. (Links provided at the beginning of this Proficiency Area.)

Nitrogen

Availability factors for N require that the organic-N and ammonium-N content of the manure is know from analysis or estimated from book values. Nitrate-N levels in manure are generally so low that they can be ignored.

Organic-N = Total N (TKN) – Ammonium N

Ammonium-N is immediately available to crops while organic-N becomes available through mineralization. Typically, 20-30% of organic-N becomes available in the year of application, with 25% used as the default value.[2] The amount drops by half and half again in subsequent years:

Year 1: Available Organic-N = Organic-N X 0.25

Year 2: Available Organic-N = Organic-N X 0.12

Year 3: Available Organic-N = Organic-N X 0.06

The N released during mineralization in Year 2 and 3 needs to be accounted for when determining the N rates for the crops grown in those years. For example, an application containing 400 lb/ac of organic-N would supply 100 lb N in Year 1, 48 lb N in Year 2, and 24 lb N in Year 3.

Available ammonium-N[3] will depend on the N content of the manure but needs to be modified for application methods. To calculate available ammonium-N:

Available Ammonium N=Ammonium N X ((100-% Volatilization Loss)/100)

Available Ammonium-N may be called Retained Ammonium-N in some publications.

Percent volatilization losses can be estimated using the following table. Note that when setting rates beforehand, you need to decide which weather scenario applies for the given placement choice. After application if conditions were different than expected, you can

3 Available Ammonium-N may be called Retained Ammonium-N in some publications.

recalculate to determine what rate was achieved. This is sometimes referred to the effective rate of N that is available to the crop.

Application and Incorporation Strategy	Weather Conditions During Application				
	Average	**Cool-Wet**	**Cool-Dry**	**Warm-Wet**	**Warm-Dry**
Incorporated within 1 day	25%	10%	15%	25%	50%
Incorporated within 2 day	30%	13%	19%	31%	57%
Incorporated within 3 day	35%	15%	22%	38%	65%
Incorporated within 4 day	40%	17%	26%	44%	72%
Incorporated within 5 day	45%	20%	30%	50%	80%
Not incorporated	66%	40%	50%	75%	100%
Injected	0%	0%	0%	0%	0%
Cover Crop	35%	25%	25%	40%	50%
Source: Nutrient Management Planning Guide (based on Tri-Provincial Guidelines)					

Phosphorus

When first excreted manure contains primarily organic-P in the solid portion. Some of this converts to soluble inorganic-P forms, so that by the time of application there is a mix of the two forms. With liquid manure storage systems, the P may segregate into the solids at the bottom. Mixing prior to sampling and application will make for more uniform distribution. The Tri-Provincial Guidelines suggest 50% of the Total-P is available in the year of application (Year 1).

Potassium

Potassium in manure is in inorganic forms and generally readily available to crops. The Tri-Provincial Guidelines suggest using 0.90 as a factor for calculating available-K from total-K in manure.

Example Calculation Available N, P, and K per Tonne Solid Manure Based on Manure Analysis.
Given a solid cattle manure with N, P, K content on a wet (as received) basis. Total N = 8.3 kg/t, Ammonium-N = 2.0 kg/t, Total-P = 2.3 kg/t, Total-K = 6.9 kg/t Organic-N = 8.3 – 2.0 Organic- N = 6.3 kg N/t Available Organic-N (Year 1) = 6.3 X 0.25 Available Organic-N (Year 1) = 1.6 kg N/t Manure to be applied under wet-cool spring conditions and incorporated within two day. Available Ammonium-N = 2.0 X 0.87 Available Ammonium-N = 1.7 kg N/t Crop Available-N (Year 1) = 1.6 + 1.7 = 3.3 kg N/t Crop Available P (Year 1) = 2.3 X 0.50 = 1.2 kg P/t Note: this is elemental P Crop Available K = 6.9 X 0.09 = 6.2 kg K/t Note: this is elemental K
Source: Nutrient Management Planning Guide with adjustment of P availability to Tri-Provincial Guidelines

Performance Objective 2. Describe how to credit the phosphorus and potassium in manure for the crop requirements recommended by soil tests using the nutrient recommendations of Tri-Provincial Manure Application and Use Guidelines and how to adjust manure spreading rates accordingly for each field.

Soil tests for P and K are generally interpreted in terms of probability of response and P and K rates adjusted accordingly. This may be best explained by way of example as shown on the next page.

Two fields are going to be banded with liquid hog manure and seeded to barley. One field tests very low or very deficient for P (5 ppm) and the other medium or marginal (15 ppm). The appropriate P_2O_5 rates for each field following provincial sufficiency guidelines are 45 and 30 lbs/ac based on seed placement or side banding. The hog manure contains 0.1 % total P.

Calculate amount of hog manure required to meet recommendations:

Calculate Crop Available P Year 1

0.1% x 0.5 = 0.05%

Convert to P_2O_5:

($\frac{45\ lbs}{acre} \times \frac{1000\ gal}{11\ lbs} = 4090\ gal\ acre^{-1}$

($\frac{30\ lbs}{acre} \times \frac{1000\ gal}{11\ lbs} = 2727\ gal\ acre^{-1}$ ion table beginning of PA7):

0.114% X 100 = 11 lbs P_2O_5/1000 gals

Calculate Rate Field 1

Calculate Rate Field 2

Since banding away from seed as described in the above scenario tends to be less efficient a multiplier could be applied to the above rates to make up for lost efficiency. A similar recommendation can be developed based on interpretation of the K soil test.

Performance Objective 3. Evaluate the strengths and weaknesses of each tool listed below and the situations in which it is appropriate to use each tool:

The following discussion makes reference to various provincial regulations. The references are only to illustrate how the tools might fit into a regulatory framework. You are not expected to know the regulations for all three Prairie Provinces for the exam. However, a CCA should understand the regulation in their province before making recommendations on manure or other organic amendment applications.

A) Fall soil nitrate test (PPNT);

A fall soil nitrate test may be useful prior to application of manure or other organics application in determining a baseline.

Testing before application and then estimating how much N is likely to be added to the nitrate pool before the next cropping season will help ensure an application rate that does not result in excess nitrate buildup.

One of the drawbacks of the fall test when taken post manure application is that it is only a snapshot of available-N and doesn't provide insight into how much N may be released through mineralization in the coming year. Alberta's nitrate-N limits are based on post-application soil test N levels. Manitoba's limits are based on a fall soil test. If the nitrate limit post-harvest is exceeded no further N as manure or fertilizer can be applied until the soils test falls below the limit.

For a more complete explanation of Manitoba nitrate-N limits see the following:

https://www.gov.mb.ca/agriculture/environment/nutrient-management/pubs/residual-soil-nitrate-n-limits.pdf

B) Pre-sidedress soil nitrate test (PSNT);

This test is not currently in widespread use in Western Canada but may become more popular as corn acreage grows. The PSNT relies on a 0-12 in soil sample when corn is 6-12 in tall to determine an in-season rate of N, usually as a top up of earlier before or at seeding N applications.

The PSNT may be superior to spring or fall soil sampling when manure or other organic N sources are applied. Fall or spring sampling following manure application may return low N results as the organic-N has not mineralized and then converted to nitrate-N. Also, manure applied in fall or in spring prior to planting may, depending on source and rate, not release sufficient N during the year of application. This can be an issue with high C:N ratio materials such as solid manure that contains bedding materials such as straw or wood shavings. The PSNT (or other in-season sampling for other crops) can provide insight into whether the applied source is releasing sufficient N to meet crop needs or needs to be supplemented.

Note that little research has been done to calibrate the PSNT on the Prairies. One should approach results of the PSNT with some caution until more data has been collected and test results are more fully understood in the context of Prairie cropping systems.

C) Post-season stalk nitrate for corn;

Another test that is not widely used on the Prairies but may become more popular as corn acreage increases. The post-season stalk nitrate test is based on sampling after the corn is physiologically mature and dry matter is no longer accumulating in the kernels but before harvest. That is one to three weeks after black layer development. Corn mobilizes N out of the stock and lower leaves as the ear is filling. High levels of nitrate-N in the stalk signify that excess N was available. Low levels that there was insufficient N available.

To perform the test, an 8 inch section of stalk is cut starting 6 inch above the soil surface. At least 15 stalks should be collected from the sampling area. Avoid stunted or diseased/damaged plants and strip any leaves and leaf sheaths from the stalk. Store in paper bags (not plastic) and send to lab. The test can be useful as an indicator of N nutrition, but it is a *post mortem* rather than a diagnostic tool. Probably a better fit with fertilizer-based systems where more precise control of N rates is achievable.

Very little calibration work on this test has been done in Prairie cropping systems. Data from Indiana would suggest that the interpretation is as follows:

- Low = Less than 450 ppm nitrate-N = High probability that nitrogen was deficient
- Optimal = 450 – 2000 ppm nitrate-N = Yields were not limited by nitrogen
- Excessive = Greater than 2000 ppm nitrate-N = Uptake exceeded requirements

How applicable values from elsewhere are in interpreting tests from corn growing regions on the Prairies is still being evaluated. Initial indications are that the approach has merit but until more data accumulates one should approach the results cautiously.

D) Grain protein content for wheat;[4]

Wheat protein provides an indicator of N sufficiency in relation to yield potential. Hard red spring wheat testing less than 13.5% protein, or hard red winter wheat testing less than 11.0-11.5% protein was likely yield limited due to insufficient N. In manure amended soils, the test can be an indication of whether or not mineralization provided sufficient N to meet crop demands.

4 This section adapted from Manitoba Agriculture website.

While wheat protein levels are a reasonable indicator of N sufficiency, they are an after the fact test rather than a diagnostic tool. They may aid in future planning. For planning purposes, it is important to identify the possible causes of low protein in what was otherwise an appropriately fertilized crop. Possible reasons for wheat protein falling below these benchmark values in manured fields may be:

- Growing conditions that permitted yield potentials exceeding the supplied N level. In manured fields, this may be a result of source characteristics that limited mineralization, for example, a high C:N ratio.
- Losses of nitrogen through higher risk application methods such as fall applications, broadcast rather than banded or surface applications. In manured fields, surface application without timely incorporation can result in very high ammonia volatilization losses.
- Insufficient nitrogen supply, especially for newer, very high yield potential varieties.

E) Virtual soil test with historical application documentation;

Karamanos and coworkers developed the virtual soil test or VST for use in situations when an N soil test was not available.[5] The Karamanos' VST is based on an N balance approach and requires a previous soil test, crop yield and N uptake estimates for the previous crop, as well as estimates of soil processes including mineralization, denitrification etc.

More recently, two new approaches have been tested on the Prairies. The first is based on mechanistic or process-based cropping system models that have available N as an initial model input and output. While these models show some promise in providing a VST type value during the season and at season end; they require site specific soil and weather data to run. Expect to see them become more widely available, as growers adopt on-farm weather stations, soil moisture probes and other farm and field centric data management systems.

The second new approach is based on advanced analytics (big data or machine learning) techniques that predict a VST value based on analysis of multiple variables. The drawback of the big data approach is that it requires multivariable data sets from hundreds if not thousands of fields to use as training data. The VST approaches are not at present well calibrated for cropping systems that receive manure.

Historical application documentation can provide estimates on residual release of N and assist in setting N rates in the years following manure application.

F) Residual nutrients (P, K, S, and micronutrients);

Application rates based on a single year's N demand will with most waste products result in higher P, K, S rates than can be taken up in the year of application. These nutrients will be available in subsequent years. Soil tests are useful in monitoring the accumulation of residual nutrients. Note that P, K and the micronutrient soil tests do not change on a one to one basis with nutrient additions. With P for example, an addition of 10 lbs P2O5/acre may only increase STP by 1 ppm. Prairie soils tend to be well endowed with K and S, the exceptions being the coarser textured low organic matter soils in higher rainfall areas, and generally deficient in P. Soil test phosphorus values above 60 ppm are generally a result of previous manure or other P rich waste material applications.

G) Nutrient balance.

Two aspects of nutrient balance need to be considered. First, based on the composition of the material applied, the rate of application, the target or expected yield, and an assessment of the soil supply are the crops nutrient needs being met. Typically, materials supplied to meet the N rate will supply sufficient P, K, and S. However, when rates are based on P requirements, N may be under applied and supplemental N fertilizer may be required.

The second aspect of nutrient balance can be thought of as keeping account of inputs and outputs based on waste material and fertilizer additions and crop removals. Calculating post-harvest balances combined with soil tests provides insight into soil supply for subsequent crops.

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5 Rigas E. Karamanos & Karen R. Cannon (2002): VIRTUAL SOIL TESTING: IS IT POSSIBLE?, Communications in Soil Science and Plant Analysis, 33:15-18, 2599-2616.

COMPETENCY AREA 6. OTHER MANAGEMENT CONSIDERATIONS

Performance Objective 1. Understand practices that contribute to lodging and how this is related to the 4Rs NM concepts.

Lodging in crops is a result of a combination of factors including crop type, cultivar, weather, and nutrient status. Cereal crops growing under conditions of excess nitrogen availability are particularly susceptible. High rates of manure or other nutrient rich materials like biosolids can result in excessive available N in the soil. This may be further exacerbated by mineralization in areas of the field with high soil organic matter and abundant moisture.

Performance Objective 2. Explain the relationship between grass tetany and manure application.

Grass tetany or hypomagnesemic tetany, also known as grass staggers and winter tetany, is a metabolic disease in ruminant livestock caused by magnesium deficiency. Beef cattle, dairy cattle and sheep will develop symptoms usually after grazing on pastures of rapidly growing grass in early spring. High K levels in the forage interferes with Mg uptake in the animal's gut and can induce Mg deficiency and lead to hypomagnesemic tetany.

Several factors contribute to grass tetany on manured land. Frequent applications can raise the available K levels. Potassium is conserved in manure and tends to accumulate when manure applications are based on N rates. The K in manure is readily available, there is no buffering mechanism in the manure that slows its release into the soil.

While hypomagnesemic tetany is often associate with spring grazing on grass, it can also occur when any forage or feed has a low K to Ca+Mg ratio. This can include hay and or cereal green feed fed in winter.

A) Define and be able to apply the tetany ratio to understand the relationship between K and grass tetany.[6]

The tetany ratio is the ratio of K in a feed to the sum of Ca and Mg. When the ratio is less than 2.2, less than 1% of animals develop grass tetany. The incidence of tetany increases when the tetany ratio rises above 2.2. The tetany ratio as [K]/[Ca+Mg] with the concentrations expressed in milliequivalents (mEq) per kg of dry matter. The table below provides the conversion factor from percentages commonly reported in feed or tissue analysis to mEq/kg. High potassium, lowered calcium and lowered magnesium can all cause the tetany ratio to increase and predispose animals to tetany.

Element	To Convert from % to mEq per kg, multiply by:
Potassium	255.74
Calcium	499.00
Magnesium	822.64
Source: Oetzel, 1993.	

Performance Objective 3. Recognize the contribution of soluble salts to soils and crops.

Ionic compounds are formed when a cation and an anion combine to form a solid. Depending on the cation and anion combining, salts can be soluble or sparingly soluble. In the context of soil solutions, soluble salts are those that dissolve readily in water, while sparingly soluble salts are those that mostly stay in solid form in the soil. The salts formed with the nitrate (NO_3^-) and chloride (Cl^-) ions are soluble. Anions like phosphate (PO_4^{3-}) can form soluble salts (for example, $NH_4H_2PO_4$) but when added to soil form sparingly soluble compounds with calcium, iron or aluminum. Sulphate (SO_4^{2-}) tends to fall somewhere in between. Calcium sulphate (gypsum) is sparingly soluble while sodium and magnesium sulphates are soluble. The soluble salts found in saline Prairie soils (soils with an EC > 4.0 dS/m) are typically the neutral salts sodium sulphate and in some areas magnesium sulphate. A special case is the alkali soils which contain sodium carbonate and sodium bicarbonate and have a pH greater than 8.5.

Manure, compost, biosolids, and waste water all contain salts either in solid or dissolved phase. Animal digestion of plant materials concentrates salts in the urine. Salt added to the ration (NaCl) and then excreted can further raises the salt content of manure.

6 This section adapted from the Manitoba Agriculture website.

Composting tends to further amplify the salt content of the feedstock by reducing the mass. The salinity of biosolids varies depending on the sewage treatment methods.

Additions of organic amendments can help ameliorate or cause degradation of soil. Materials with relatively low salt content can improve saline soils by increasing soil water holding capacity. More saline materials may increase the salinity of the soil. The various provinces recognize that manure and/or compost additions can increase soil salinity to detrimental levels. Alberta's regulations, for example, do not permit application on saline soil (>4 dS/m) and application rates on non-saline soils must not increase the EC by more than 1 dS/m.

Waste water is a special case. Used in an irrigation system, mildly saline waste water can maintain available water in a range where the effects of salinity are not felt by the crop. Irrigation with waste water can wash salts down the profile and out of the rooting zone. However, keep in mind that if water does not infiltrate below the rooting zone, salts will accumulate and be drawn back to the surface through evaporation.

Soil salinity rating and electrical conductivity value					
Soil Depth	Non-Saline	Weakly Saline	Moderately Saline	Strongly Saline	Very Strongly Saline
0-60 cm	<2 dS/m*	2 - 4 dS/m	4 - 8 dS/m	8 - 16 dS/m	>16 dS/m
60-120 cm	<4 dS/m	4 - 8 dS/m	8 - 16 dS/m	16 - 24 dS/m	>24 dS/m

Crops vary in their sensitivity to salinity. Salinity reduces available water due to high osmotic potential. At moderate salinity levels, drought tolerant crops will out-perform more drought sensitive crops. At higher salinity levels (> 16 dS/m) salt toxicity can occur and only specialized halophytic plants will grow. More salt tolerant crops may grow at higher salinity levels but that does not mean that their yields are unrestricted. In years with above average moisture, yields of crops on saline soil may be similar to non-saline soils. However, in years with average or below average moisture yields will be reduced.

The link below provides information on salt tolerance of various crops.

https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex9314

Performance Objective 4. Be able to understand the restrictions on heavy metal accumulation when using manure, compost, biosolids, wastewater, and fertilizers.

Metals (and other compounds) in waste materials may be amplified during processing and/or accumulate in soils when these materials are applied to soil. The main metals of concern when materials are applied to soil are shown below. A number of the metals listed are essential to plants and/or animals (yes, that does include arsenic (As) for animals). However, they are generally required in very small amounts and can become toxic at higher amounts. They can also bioaccumulate in the food chain. Consequently, there are good reasons to monitor their levels in soil before application, understand the concentration in the materials applied, and the fate of the metals in the cropping systems. A number of the metals of concern may be added to feed materials as supplements. In biosolids elevated levels, may be from industrial and household waste materials such as cleaners that get into the sewage stream.

	CATEGORY A	CATEGORY B	
Trace Elements***	Maximum Concentration within Product	Maximum Concentration within Product*	Maximum Cumulative Additions to Soil*
Essential or beneficial to plants or animals	mg/kg dry weight		kg/ha
Arsenic (As)	13	75	15
Cobalt (Co)	34	150	30
Chromium (Cr)	210	**	**
Copper (Cu)	400	**	**
Molybdenum (Mo)	5	20	4
Nickel (Ni)	62	180	36
Selenium (Se)	2	14	2.8
Zinc (Zn)	700	1850	370
Other			
Cadmium (Cd)	3	20	4
Mercury (Hg)	0.8	5	1
Lead (Pb)	150	500	100

* These concentrations are the existing standards under the Canadian Food Inspection Agency's Standards for Metals in Fertilizers and Supplements, September 1997 (Trade Memorandum T-4-93).

** Limits for copper and chromium are not established in the Trade Memorandum. Calculated in the same manner as limits for the other nine elements, the trace element additions to soil for chromium and copper would be: chromium = 210 kg/ha and copper = 150 kg/ha. For the trace element concentrations within the compost product, chromium = 1060 mg/kg and copper = 757 mg/kg. Details of these calculations are in the "Support Document for Compost Quality Criteria (National Standard of Canada CAN/BNQ 0413-200, Canadian Council of Ministers of the Environment (CCME) Guidelines and Agriculture and Agri-Food Canada (AAFC) Criteria".

*** Concentrations of other elements may eventually be regulated in certain provinces to accommodate regional and national concerns.

Source: CCME Guidelines for Compost Quality.

To summarize, metals can accumulate in soil when the organic waste materials are applied. At higher levels, they can cause toxicity to plants grown on that soil and (more likely) move up the food chain from plants grown in contaminated soil where they may cause problems for animal and human health.

An example of metals becoming a problem occurred in the 1990s, when Canadian durum was excluded from Europe based on high cadmium levels. Phosphorus fertilizer was implicated as a source of Cd. The solution was in part to use MAP that had been manufactured with source rock that was low in CD and in part to breed varieties that took up less Cd. Managing the rotation was also part of the solution. Flax tends to not only accumulate Cd, it tends to increase the availability of Cd to subsequent cereal crops. Not seeding durum into flax stubble was part of the strategy for reducing Cd content of exported grain. Biosolids (depending on source) can be high in Cd as can municipal solid waste compost.

Performance Objective 5. Discuss unique considerations of manure, compost, biosolids and wastewater application in terms of runoff risk of nutrients and pathogens.

A source of nutrients or pathogens, transport (i.e.-runoff water), and a connection to surface water must all be present in order for surface water contamination to occur. Runoff occurs when infiltration rates are exceeded and there is sufficient slope to induce lateral flow. Factors that reduce infiltration include frozen soil, compacted soil, and crusted soil. Runoff will also occur when surface soils are saturated and the rate of transmission through the profile is less the rate at which water arrives at the soil surface. Runoff on the Prairies largely occurs during spring snowmelt. Infiltration is blocked by frost in the soil and water runs over frozen soil. Various studies have suggested that 70-80% of annual runoff occurs during the spring melt. Intense summer storms can also trigger runoff events, but keep in mind that while snow melt is a broad area phenomenon, storms events tend to be concentrated along a storm path limiting the area of the watershed contributing runoff.

The biggest factor in determining whether runoff reaches surface waters is topography. Much of the Prairie landscape is morainal with many small closed basins that do not contribute runoff to surface waters. A key 4R practice is to understand the landscape and delineate the likely source areas that contribute runoff that leaves the field. Avoiding or reducing applications to high risk areas combined with good time and place practices can effectively reduce or eliminate the risk of nutrient and pathogen transport to surface waters.

A) Edge of field effects.

In addition to water quality problems such as eutrophication and algae blooms, surface runoff may be part of a transport mechanism that moves pathogens from application fields into drinking water sources. This can result in health issues in livestock and humans Application of waste materials at rates above the nutrient requirements of crops resulting in residual nutrient buildup that increases risk of loss and potentially greater downstream impacts.

B) Downstream impacts.

In addition to water quality problems such as eutrophication and algae blooms, surface runoff may be part of a transport mechanism that moves pathogens from application fields into drinking water sources. This can result in health issues in livestock and humans. Application of these materials is often at rates above the nutrient requirements of crops resulting in residual nutrient buildup that increases risk of loss and potentially greater downstream impacts.

C) Tillage and incorporation.

Tillage and incorporation of surface applied manure, composts, and biosolids can reduce the risk of offsite transport of nutrients and pathogens. Poor timing and/or direction of tillage can increase risk of runoff and erosion. Excessive tillage that completely buries crop residue and/or breaks down soil structure may undo the structure improving effects of organic amendments. Contour tillage interrupts runoff flow by creating and inconsistent slope.

D) Use of buffer and filter strips.

Are based on slowing runoff and allowing infiltration of water and nutrient pathogen load into the soil. Subsequent plant uptake can harvest the nutrients. If harvest of the strips does not occur, soil P levels may build up and the strip can become a P source instead of a sink. Buffer and filter strips tend to be less effective on the Prairies than in warmer more humid climates. Most of the runoff in the Prairies occurs as snowmelt and while vegetation may slow the runoff; it will not infiltrate frozen ground.

E) Management of adjacent riparian areas.

Healthy riparian areas act as a barrier to runoff and may interrupt the transport of nutrients and pathogens into surface waters. Encroachment of farming, overgrazing, and other activities that impact the extent and health of riparian areas increases the risk of movement of nutrients and pathogens into the watercourse. Keep in mind that like buffer strips, riparian areas may not be effective barriers during spring snowmelt.

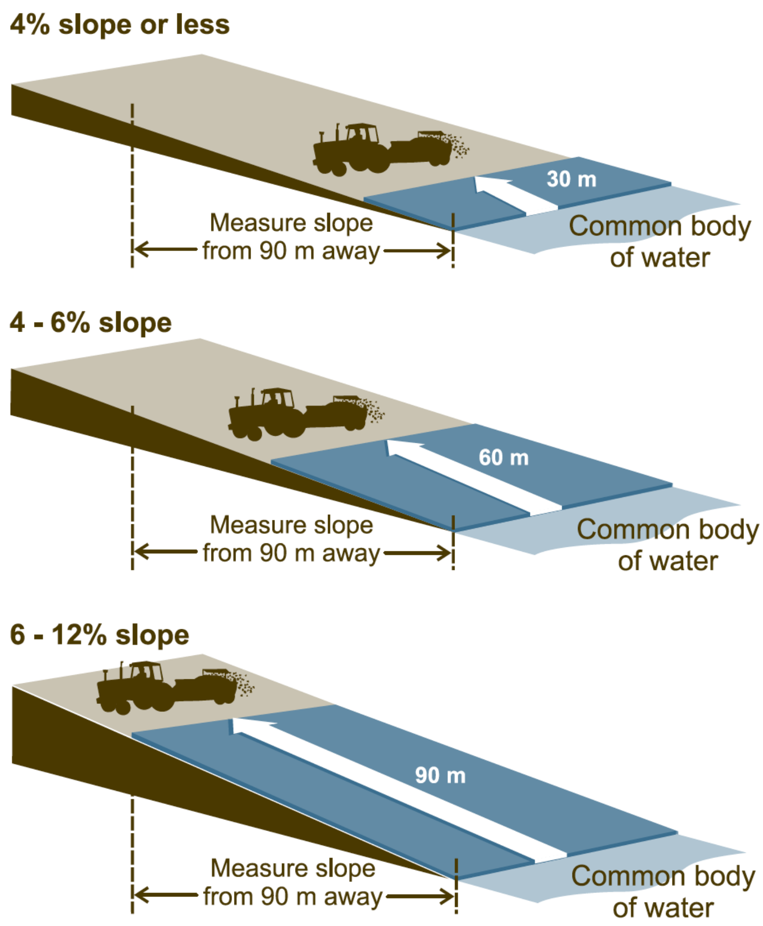
F) Timing of application.

On the Prairies runoff largely occurs during snowmelt. Avoiding application on frozen or snow covered ground is an important 4R practice for ameliorating the risk of nutrients and pathogens moving into surface waters. Surface application in fall without incorporation is a higher risk than with incorporation. Spring application after the risk of runoff has declined is the probably the best option from an environmental risk management perspective but may not be feasible given other operational pressures in spring.

G) Placement of manure in accordance with setback requirements.

Setbacks from common water bodies, wells, and other water features such as springs are, depending on province, specifically set out in the regulations and/or must be explicitly laid out in manure management plans. Considerations in developing setbacks include slope, soil type, tillage system, placement method, and application timing. Setbacks may also vary depending on the water feature. Since, regulatory setback requirements vary by province, the CCA developing manure management plan should ensure they understand the requirements in place for the farm's location. An example of setbacks in relation to slope is shown below.

Required setbacks from common water bodies for surface application of manure to forage stands, direct seeded crops, and snow-covered ground (AOPA).[1]



[1] Application to snow-covered ground only allowed as an exception to regulations. Application not allowed on slopes over 12% leading to common water body.

Source: Nutrient Management Planning Guide Agdex 400/28-3

Performance Objective 6. Explain the relationship between manure and other organic amendments and soil organic matter content.

Manure and other organic amendments add organic carbon to the soil. Organic carbon is the building block of soil organic matter. Organic amendments should be considered a feedstock for increasing soil organic matter. Much like crop residues they will undergo further decay and transformation into the various forms of soil organic matter. Applications can lead to both short and long-term benefits including improved structure with better infiltration and reduced erodibility as well as increased water holding capacity. Organic amendments will typically increase the short and long-term fertility of a soil, which creates a positive feedback loop, with higher crop residue returns further building soil organic matter. Organic amendment applications tend to increase microbial activity and biodiversity in soils. The activity of soil microbes is primarily responsible for good soil structure. The positive effects of organic amendments tend to be greater in low organic matter soils. The beneficial effects of organic amendments occur through stimulation of soil processes as well as building of soil organic matter content. As you can see in the example below, the actual organic carbon added and remaining in the soil is relatively small.

A soil with 4% soil organic matter in the surface 15 cm contains (assuming a bulk density of 1.2 t/m3) approximately 72 t/ha of soil organic matter and 42 t/ha of soil organic carbon.
Banding sufficient liquid hog manure to supply 100 kg N/ha in available N form in the year of application assuming the available N is 2.0 kg N/1000 L:

$$\frac{100\ kg\ N\ ha^{-1}}{2.0\ kg\ N\ 1000\ L^{-1}} = 50{,}000\ L\ ha^{-1} /$$

I [illegible] olids, with C accounting for half the solids or approximate 4% organic carbon.

$$50{,}000\ L\ ha^{-1}\ \times\ 0.04\ C \times \frac{1\ kg}{L} \times \frac{1t}{1000\ kg} \approx 2\ t\ C\ ha^{-1}$$

If approximately half the 2 t C/ha will mineralize (leaving the soil as carbon dioxide) in the year of application and half of the half in the year after. Two years after application the remaining C (0.5 t/ha) would be approximately 1.2% of the C present before application.