Canadian
4R Research Network

Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

nutrient stewardship

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Introduction

A Canadian Research Network to Improve 4R Nutrient Stewardship for Environmental Health and Crop Production

The Canadian 4R Research Network aims to quantify the benefits of the 4R Nutrient Stewardship's advanced fertilizer-management system Composed of leading Canadian researchers, it seeks to advance knowledge about science-based management practices that will benefit the environment and crop production in all major agricultural regions of Canada. The foundation of our sustainability strategy and initiatives are based on applied research through the Canadian 4R Research Network. Under this project, the 4R Research Network is focusing on the following major environmental issues related to fertilizer management in Canada:

- Greenhouse gas and ammonia emissions
- Losses of phosphorous to surface water
- Nitrate leaching in ground water
- Synergizing research and policy development

The activities under the Canadian 4R Research Network have been selected to overcome gaps in adoption of **4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®)** such as lack of Best Management Practices (BMPs) evaluation of multiple nutrient loss pathways of Nitrogen (N) and Phosporus (P), evaluation of BMPs under the diverse soils, weather and cropping systems in Canada, and decision making tools for tailoring BMPs to local needs and conditions. It will provide needed support with a focus on measuring and documenting the economic, social and environmental benefits of 4R Nutrient Stewardship based on grower uptake of BMPs. In particular the research will focus on reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters and nitrate leaching in groundwater. These research activities will assist to expand 4R Nutrient Stewardship beyond being solely an industry outreach effort and towards becoming a viable, evolving strategy providing defendable benefits to improve cropping system productivity and reduce nutrient losses to the environment.

Network activities will include field trials and other projects in Alberta, Saskatchewan. Manitoba, Ontario, Quebec, Nova Scotia and Prince Edward Island covering key field crops: wheat, irrigated wheat, corn, potatoes, triticale, peas, canola barley and forages. Results of the project will be communicated through websites, scientific journal publications, meetings and decision support systems. This will provide information as a basis for 4R Nutrient Stewardship knowledge extension to reach stakeholders in all major agricultural regions of Canada. In doing so, reductions in greenhouse gas emissions, N losses to the atmosphere and groundwater, and P losses to surface waters will be realized across Canada. This will position Canadian agricultural systems as a leader in environmental stewardship.

The 4R Research Network aims to substantiate and improve 4R Nutrient Stewardship BMPs through research, conducts research in major crop production regions with particular soil, weather and crop production systems across Canada. The network simultaneously considers the major nutrient loss pathways having environmental and economic impacts (nitrous oxide emissions, nitrate leaching, ammonia volatilization and phosphorus runoff) from cropping systems, and provides decision support systems tailored to grower location and production system requirements.

Fertilizer Canada provided a total industry financial contribution of $1.1 million to the project over the three years, leveraged by a 1:1 match from the Canadian government under its *AgriInnovation Program: Growing Forward II*. The project will emphasize collaboration with university researchers, professional advisors, provincial agriculture departments and Agriculture and Agri-Food Canada researchers.

"Hard-working farmers could not grow and provide quality agriculture products without the right tools. Fertilizer Canada and its member companies do an excellent job of providing them with the right expertise and fertilizer. Over the next 30 years, the world will need to increase food production by 70 percent. I look forward to working with farmers and Fertilizer Canada to ensure Canada seizes this exporting opportunity."

Francis Drouin, M.P.
Glengarry–Prescott–Russell, Ontario
House of Commons (May 18, 2016)

Canadian 4R Research Network Projects Overview

PRINCIPAL INVESTIGATOR	4R PROJECT
N STUDIES – develop and substantiate 4R BMPs through evaluation of major Nitrogen loss pathways, complements of practices and improved understanding of loss pathways across major production regions and cropping systems in Canada	
David Burton (Dalhousie University)	Can the use of in-season foliar urea increase the efficiency of N use and reduce nitrous oxide emissions and nitrate leaching in potato production in Atlantic Canada?
Claudia Wagner-Riddle (University of Guelph)	Can single application of enhanced efficiency fertilizers at planting reduce N losses from grain corn production in Ontario?
Craig Drury (AAFC, Ontario)	Combined effects of Nitrogen fertilizer placement and enhanced efficiency fertilizers to reduce N losses from grain corn production in Ontario
Mario Tenuta (University of Manitoba)	Reducing rates and not total nitrification to limit loss of fall applied N fertilizer in the humid condition of Manitoba using enhanced efficiency fertilizers
Linda Hall (University of Alberta)	Nitrogen stabilizers to enhance Nitrogen use efficiency and reduce greenhouse gas emissions in Alberta
Miles Dyck (University of Alberta)	Coordinated Nitrogen and sulfur management in S-deficient soils and in-crop N fertigation in irrigated systems to reduce N losses in the western Prairie environment of Alberta
P STUDIES – target 4R BMPs to reduce runoff losses of phosphorus in the contrasting production systems and environment of the Great Lakes-St. Lawrence Lowlands and Prairie Canada	
Jeff Schoenau (University of Saskatchewan)	Placement of phosphorus fertilizer to limit snowmelt P losses in the Canadian Prairies
Ivan O'Halloran (University of Guelph)	Synergists: Management of placement timing of phosphorus fertilizers to reduce P runoff losses in the Lake Erie watershed
SYNTHESIS – Foster the assimilation of discoveries of the Canadian 4R Nutrient Stewardship Research Network into decision support system tools and outreach for improved environmental health and crop productivity in Canada	
Nicolas Tremblay (AAFC, Quebec)	Development of decision support mechanisms for 4R optimization of Nitrogen fertilization placement, rate and timing based on the integrated use of soil, weather and market data
Alison Eagle (Duke University)	Integrating results of the Canadian 4R Nutrient Stewardship Research Network for improved environmental health and profitability

Dr. David Burton

Can the use of in-season foliar urea increase the efficiency of Nitrogen (N) use and reduce nitrous oxide emissions and nitrate leaching in potato production in Atlantic Canada?

Prince Edward Island (PEI) receives 100 per cent of its drinking water from groundwater, making it unique compared to other regions. An important component in protecting PEI's drinking water source is sustainable nutrient management planning.

Dr. David Burton is a professor in soil science the Department of Plant, Food, and Environment at Dalhousie University and a member of Fertilizer Canada's 4R Research Network, a group of nine leading Canadian researchers who will quantify economic, social, and environmental benefits resulting from advanced fertilizer management systems under 4R Nutrient Stewardship. The project emphasizes collaboration between Canadian university researchers, professional advisors, provincial agriculture departments, and Agriculture and Agri-Food Canada. The research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater.

Over the past decade Dr. Burton and his colleagues at Agriculture and Agri-Food Canada and the PEI Department of Agriculture and Fisheries have been working with potato producers in PEI to develop more efficient Nitrogen (N) fertilizer management practices.

The main components of the 4R Nutrient Stewardship are: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so it will be available when the crop requires nutrients most.

"Understanding which soils pose a risk of nutrient loss in the province can assist agricultural producers on the island in managing nutrients more efficiently and in protecting the environment. Adjustments in the crop nutrient source and application rate, timing, and placement method may greatly reduce the risk of nutrient losses," said Dr. Burton.

Potato production is central to the economy of PEI, accounting for over a billion dollars annually. Increasing the yield and quality of potatoes produced while reducing impacts of potato production on greenhouse gas emissions (N_2O) and groundwater quality (NO_3-) is critical to sustaining this industry in Atlantic Canada. Increasing the efficiency of Nitrogen use in potato production has economic, agronomic and environmental benefits. PEI potato producers do not currently have an effective means of quantifying site-specific differences in soil N supply on their farm in developing Right Rate N fertilizer recommendations.

Over the past three years, in collaboration with the PEI Potato Board, significant research was undertaken to measure the soil N supplying capacity of soils in a potato cropping system.

"We have quantified the magnitude and variability of soil N supply in 26 farms in PEI as a function of climate, soil type or agricultural management, allowing an assessment of the opportunity for site-specific N recommendations to reduce the risk of nitrate leaching to groundwater and nitrous oxide emissions," said Dr. Burton.

This information has demonstrated the potential for the use of site-specific soil N supply level measurements as a means of determining the Right Rate of fertilizer N application rates to improve production and reduce the potential for environmental impact.

The survey of the magnitude of Nitrogen availability in PEI soils and the discussion of the potential for this measure to inform N application rates will raise producer awareness of the importance of the soil as a N source and the importance of maintaining soil quality in potato production. The inclusion of site-specific soil N testing will provide citizens of PEI greater confidence that the potato industry is being proactive in optimizing their management of Nitrogen fertilizer and reducing the potential for environmental impact.

"In addition, we are evaluating the ability of simple measures that can be undertaken on-farm to estimate nitrous oxide losses," explains Dr. Burton.

These measures would provide a practical means for producers to evaluate how well their Nitrogen management strategies have been able to meet plant N demand while reducing N_2O losses. The measurement of Nitrogen exposure based on biweekly soil sampling or placement of ion exchange membranes were highly correlated with measured cumulative N_2O emissions over three years of study.

These tools have formed the basis of a project funded by Fertilizer Canada to assess the potential for foliar urea applications to provide N to potato plants during times of water stress and to limit N_2O emissions. This is a practice being adopted by potato producers in PEI. This project will provide important information to determine how N fertilizer application rates should be adjusted to reflect these N applications and to assess the N_2O emissions associated with this practice.

The good news is many PEI farmers have been embracing 4R Nutrient Stewardship over the last few years resulting in increased yields and minimized impacts on the environment. While support for 4R Nutrient Stewardship is still growing across Canada, Dr. Burton's findings support the application practices to improve on-farm stewardship.

"Understanding which soils pose a risk of nutrient loss in the province can assist agricultural producers on the island in managing nutrients more efficiently and in protecting the environment. Adjustments in the crop nutrient source and application rate, timing, and placement method may greatly reduce the risk of nutrient losses."

Dr. David Burton
Dalhousie University

Dr. Claudia Wagner-Riddle

Can single application of enhanced efficiency fertilizers at planting reduce Nitrogen (N) losses from grain corn production in Ontario?

The image of golden corn fields, growing high against a blue sky is an indelible image of Canadian farming.

Corn is one of Canada's traditional crops, grown by First Nations, early Canadians, and across the country today.

Most Canadian grain corn is produced in Ontario and Quebec, due in large part to regional climate. Corn needs a longer and warmer growing season. In spite of the amiable nature of the climate of these areas, corn requires fertilizer to prevent soil depletion and ensure productive yields.

While Nitrogen is a naturally occurring element, many crops, like corn, depend on the addition of fertilizer to maximize its efficiency. Dr. Wagner-Riddle, with the University of Guelph, is researching grain corn production and the effects Nitrogen fertilizer has on the environment.

"You get a very low yield if you don't apply Nitrogen fertilizer, so farmers use it to increase yield. This is a good thing because it means less land is needed to produce the same amount of food. Intensive production, but in smaller areas. The issue with Nitrogen fertilizer is that it is very mobile. You apply it to the soil, and hope that it goes to the plant, but there is a potential for environmental losses of Nitrogen through this process."

The system of applying fertilizer properly to ensure high-yield crops is the basis of the 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®). This framework prevents environmental losses, incorporating **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively. By following these principles, farmers across the country can fertilize effectively, resulting in abundant crops, with minimal environmental impact.

Environmental stewardship has been a long-standing priority of the fertilizer industry in Canada, working to make improvements that will benefit the environment and improve on-farm economics.

Further, Fertilizer Canada is working with leading Canadian agricultural researchers to undertake research projects such as Dr. Wagner-Riddle's. This research covers many areas of environmental focus including the reduction of greenhouse gas (GHG) emissions and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater.

Through careful selection of Nitrogen fertilizer using 4R Nutrient Stewardship, the nitrous oxide emissions per unit of crop produced can be substantially reduced, in some cases by up to half. The practices that reduce nitrous oxide emissions also tend to increase Nitrogen use efficiency and the economic return.

Dr. Wagner-Riddle outlines how this happens, "4R Nutrient Stewardship aims to improve the management of the Nitrogen that is applied so the environmental losses are reduced. Our job on this project is to look at some of the 4R Nutrient Stewardship practices and actually quantify the losses. Some of the practices have been proposed because they make sense from what we understand of the Nitrogen cycle, but we need to quantify what the improvement is in terms of the losses."

"The public is very keen on consuming products that are grown in an environmentally friendly way. We think this type of research addresses these concerns. In the end, not only will we have numbers quantifying the impact of Nitrogen loss, but we can then look at what farmers can do to minimize that impact. This increases the confidence of consumers."

Nitrogen exists in many different forms within the Nitrogen cycle. When Nitrogen is applied to the soil, it is in a form that plants can absorb. Microbes in the soil also use Nitrogen. A by-product of microbial processes is the emission of nitrous oxide, a greenhouse gas.

Some forms of Nitrogen, such as nitrates, are highly mobile and easily transported in water, meaning the Nitrogen can wind up in surface waters, such as rivers or lakes, or in groundwater. Nitrates affect drinking water quality and the habitat of aquatic organisms.

Dr. Wagner-Riddle is testing different ideas, "In theory, when you apply fertilizer later when the plant is already growing, the plant can take up that Nitrogen in the soil, minimizing the (nutrient) losses. Or, if you apply a form of fertilizer that is not very mobile, it will be preserved in the soil for longer for the plants to take up later, which could also be beneficial."

And the benefits are numerous.

If researchers find ways to manage the Nitrogen so that more ends up in the plant, greater crop yields will occur. In turn, less Nitrogen will be leached into the environment, minimizing harmful impacts. Larger yields, managed in an environmentally sustainable manner can lead to bigger economic payback as well.

As Dr. Wagner-Riddle says, "It's a win-win situation."

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Dr. Claudia Wagner-Riddle
University of Guelph

Dr. Craig Dury

Combined effects of Nitrogen fertilizer placement and enhanced efficiency fertilizers to reduce Nitrogen (N) losses from grain corn production in Ontario.

Ontario landscapes are home to the Great Lakes, a watershed representing vibrant ecosystems and a significant portion of Canada's most viable and productive farmland.

In order for farmers to continue utilizing this highly efficient farmland, special attention and care must be paid to ensure Canada's precious waterways are protected.

The use of fertilizers, mainly providing Nitrogen and phosphorus, is integral to producing high-yield crops. When applied using 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place®) environmental impacts from food production, such as water runoff, can be significantly reduced.

Dr. Craig Drury, a federal soil biochemist with Agriculture and Agri-Food Canada, is involved with studies involving nutrient efficiency and environmental stewardship in collaboration with Fertilizer Canada. Dr. Drury's research focuses on the combined effects of Nitrogen fertilizer placement and enhanced efficiency fertilizers to reduce nutrient losses from grain corn production in Ontario.

The 4R Research Network is composed of nine leading Canadian researchers who will quantify economic, social, and environmental benefits resulting from advanced fertilizer management systems under 4R Nutrient Stewardship. The project emphasizes collaboration between Canadian university researchers, professional advisors, provincial agriculture departments, and Agriculture and Agri-Food Canada researchers. The research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions and nitrogren (N) losses.

The main components of the 4R Nutrient Stewardship are: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so it will be available when the crop requires nutrients most.

4R Nutrient Stewardship offers agri-retailers in Ontario credibility and provides a strategic opportunity for farmers to help meet provincial objectives to improve the water quality of the Great Lakes and contributing watersheds while increasing agricultural productivity.

Dr. Drury's findings suggest significant benefits of applying fertilizer using 4R Nutrient Stewardship, compared to traditional practices. This will continue to ensure the effective protection and conservation of Ontario's agricultural soils, water quality, and ecosystem health as they relate to nutrients. Because every farm is different, the implementation of 4R Nutrient Stewardship practices are being adapted to Ontario's agricultural production and unique climate and soil conditions in order to maximize these benefits.

4R Nutrient Stewardship can be used as a guideline for farmers to increase production and profitability while enhancing environmental protection and improving sustainability. Dr. Drury's research is concluding that varying 4R Nutrient Stewardship application and timing methods can increase nutrient efficiency and dramatically reduce Nitrogen losses to the environment.

Dr. Drury says that the difference between Nitrogen inputs and crop removal has increased in some regions of the country. Over 30 years, the amount of residual N that's typically left over in Canadian fields has crept up to 20 to 21 kilograms per hectare from nine kilograms per hectare in 1981.

That creates challenges in terms of crop profitability and risks of nitrate leaching through water or denitrification, he says.

Because Ontario has higher precipitation levels than Western Canada, there is potential for higher yields and a greater range of crop, and that means higher amounts of Nitrogen tend to be applied. The combination of these factors also creates more risk of loss in Eastern Canada. Add in a drought, flood, or disease, it can be more difficult for crops to take up the Nitrogen applied, and the risk of loss climbs even higher, making the need for application using 4R Nutrient Stewardship even more beneficial to farmers.

In a two-year study, Dr. Drury and his colleagues evaluated the effectiveness of the use inhibitors combined with urea of urea ammonium nitrate (UAN) fertilizer to help mitigate Nitrogen loss using three different types of delivery: broadcast, streaming and injection. The results are promising and with the inhibitor helping to slow Nitrogen loss.

The ammonia volatilization loss was "extremely high up to 50 per cent of the amount of N fertilizer applied," said Dr. Drury, especially when urea was broadcast onto the soil surface. But even injection, known to reduce losses compared to broadcast, resulted in some ammonia loss albeit at a lower rate as a result of the reopening of the injection slot.

However, Dr. Drury and the team of researchers at Agriculture and Agri-Food Canada found that ammonia volatilization losses could be reduced by using urease inhibitors such as Agrotain and by improved N placement (injection). Further, when these practices were combined, N losses could be reduced by up to 95 per cent compared to broadcasting urea which resulted in greater corn yields.

Dr. Drury's findings suggest significant benefits of applying fertilizer using 4R Nutrient Stewardship, compared to traditional practices. This will continue to ensure the effective protection and conservation of Ontario's agricultural soils, water quality, and ecosystem health as they relate to nutrients.

Dr. Craig Dury
Agriculture and Agri-Food Canada

Dr. Mario Tenuta

Reducing rates and not total nitrification to limit loss of fall applied Nitrogen (N) fertilizer in the humid condition of Manitoba using enhanced efficiency fertilizers

As Canadian and global populations continue to grow, it is expected that Canada's agriculture industries will strengthen to meet demand.

Farmers need to achieve maximum efficiency and quality from their crops while working to ensure land is cultivated in a sustainable and environmentally friendly manner.

The use of fertilizers, mainly providing Nitrogen and phosphorus, is integral to producing high-yield crops, but the environmental impacts of these products must be studied.

Dr. Mario Tenuta, Canada Research Chair in Applied Soil Ecology at the University of Manitoba, is an advocate for the research being done with Fertilizer Canada, "We have a research network, with ten projects across Canada, in every major agricultural region. This research is tackling nutrient use issues and opportunities, using, what we refer to, as the 4R Nutrient Stewardship approach."

The 4R Research Network is composed of nine leading Canadian researchers who will quantify economic, social, and environmental benefits resulting from advanced fertilizer management systems under 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®). The project emphasizes collaboration between Canadian university researchers, professional advisors, provincial agriculture departments, and Agriculture and Agri-Food Canada. The research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater.

4R Nutrient Stewardship can be used as a guideline for farmers to to increase production and profitability for farmers while enhancing environmental protection and improving sustainability.

The main components of the 4R Nutrient Stewardship are: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

The research being done by leading Canadian agricultural researchers focusing on using the 4R Nutrient Stewardship to study many areas of environmental concern including reducing greenhouse gases, ammonia emissions, loss of phosphorus to surface waters, and nitrate leaching in groundwater.

The outcomes of this research aim to overcome gaps in the adoption of 4R Nutrient Stewardship by farmers including differences in regional growing conditions in Canada.

"As an industry, fertilizer researchers recognized that the agriculture industry is a dominant player in the reduction of greenhouse gases. Therefore, using the 4R Nutrient Stewardship approach seemed to be a good way to evolve practices to address environmental issues."

Dr. Mario Tenuta
University of Manitoba

"We do want famers to use the 4R Nutrient Stewardship, and each farmer is working with different equipment, different climates, different soils, and different crops. With so many variables, we cannot prescribe the ultimate combination of practices for everyone," says Dr. Tenuta. "What works in Alberta and Saskatchewan may not work in Manitoba. What we want to develop is a combination of practices that are tailored to specific areas."

Dr. Tenuta's research is focused on the Prairie provinces, and how to reduce nitrous oxide emissions. "My project mainly tackles the issue of nitrous oxide reduction, using 4R Nutrient Stewardship. The main components being timing, so comparing Fall versus Spring applications, as well as the source of fertilizer, whether granular urea or anhydrous ammonia."

Nitrous oxide (N_2O) is a by-product produced through the transformations of ammonium to nitrate in the soil, followed by the loss of nitrous oxide to the atmosphere as a gas. Nitrous oxide is 300-fold more potent than carbon dioxide as a greenhouse gas, and it impacts the environment and climate.

"As an industry, fertilizer researchers recognized that the agriculture industry is a dominant player in the reduction of greenhouse gases. Therefore, using the 4R Nutrient Stewardship approach seemed to be a good way to evolve practices to address environmental issues."

Through the research, Dr. Tenuta and his team hope to collect information pertaining to how best to keep the Nitrogen in the plants where it is most useful, while reducing the amount released into the atmosphere. His results will help create the best management practices for applying the appropriate fertilizer and a beneficial time to increase crop production and minimize environmental impacts.

Dr. Tenuta is also looking at the enhanced efficiency fertilizers which control the Nitrogen absorbed by the plants, and how these modern fertilizers will reduce nitrous oxide emissions.

"Some of the enhanced efficiency fertilizer have been developed in Canada. I think this is where we may go in the future. This is a great opportunity for research and the development of new products. The industry can only grow, and Canada is at the forefront of this innovation.

Canada is at the forefront of promoting and encouraging the use of the 4R Nutrient Stewardship, and Dr. Tenuta praises the work done by Fertilizer Canada. "They have done a very successful job in packaging the 4Rs as an approach and concept farmers can easily pick up on. What Canada has done, is made this idea accessible to farmers. This is innovative. The approaches we have used in research for a long time, are now accessible to each farmer, giving them more options as to handle their situations."

The 4R Nutrient Stewardship framework delivers Canadian farmers the information they need to enhance competitiveness and increase productivity and adaptability to market desires while addressing the sustainable intensification of agriculture. The result will be science-based data that demonstrates, through agronomic research, the benefits of the 4R Nutrient Stewardship for improved farmer decisions on economics, protecting the environment and feeding the world.

Dr. Miles Dyck

Coordinated Nitrogen (N) and Sulfur (S) management in S-deficient soils and in-crop N fertigation in irrigated systems to reduce N losses in the western Prairie environment of Alberta

Agriculture has a long and storied past in Canada and continues to be a large part of the country's economic drivers.

Farmers make their living off the land, and while management practices have varied over the decades, farmers are readily adopting agriculture in a way that is environmentally sustainable, and economically beneficial.

Sustainable farming is the future.

Dr. Miles Dyck, an associate professor at the University of Alberta, is studying how long-term management of agricultural soil affects crop growth and greenhouse gas emissions. His research uses the concepts laid out under 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®).

4R Nutrient Stewardship works to increase production and profitability for farmers while enhancing environmental protection and improving sustainability. This framework incorporates the: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

Dr. Dyck and other leading Canadian agricultural researchers across Canada, through Fertilizer Canada's 4R Research Network, cover many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater. The results will be science-based data that quantitatively demonstrate the benefits of 4R Nutrient Stewardship for improved farmer decisions on economics, protecting the environment and feeding the world.

The University of Alberta has a long-term research site near Breton, Alberta, established in 1930, and it is here where Dr. Dyck studies years of land management practices. "We have had consistent management of the sites since 1930. We have measured different levels of soil and organic matter, and different productivity regarding crop yield and crop growth. It allows us, at one site, look at how different or varying management practices over the years might affect crop yield and nitrous oxide emissions from the soils."

This type of long-term data is important to understanding how Nitrogen remains in the soil for extended periods of time, and how it interacts with yearly fertilizer application.

"Our research - and many other people's research, in Canada and around the world - shows that nitrous oxide is produced not just from fertilizer but from the natural Nitrogen cycling processes in the soil. There is a certain amount we control with 4R Nutrient Stewardship, affecting the behavior of the Nitrogen cycling."

When Nitrogen fertilizer is applied to the soil it can be converted into different forms, some which can be taken up by plants. The soil also has a legacy Nitrogen supply from previous crop residues, providing a pool of organic Nitrogen in the soil before nutrients have been added. This legacy Nitrogen supply also needs to be considered in the long-term management of the land.

"Those two pools of Nitrogen interact, and during the growing season, as the soil gets warmer, micro-organisms use that Nitrogen in their metabolism converting it from organic Nitrogen forms to inorganic forms which are available to the plant."

"During that process, nitrous oxide is produced and released into the atmosphere. We want to determine how (nutrient) management affects that natural process, the natural production of nitrous oxide. We also want to find out which management practices produce the most usable crops."

Dr. Dyck's two projects with Fertilizer Canada allow him to explore different parts of the spectrum with regards to land management. He can study the effects of different crops, crop rotations, fertilizer applications and how these variables affect crop growth, crop uptake of Nitrogen, the production of nitrous oxide in the soil, and release of that nitrous oxide to the atmosphere. His team is also looking at new fertilizer technologies and products. Enhanced efficiency fertilizer behaves differently than traditional fertilizer, in that they tend to reduce the loss of nutrients to the environment, while increasing its availability to the crop.

"Certainly Canada has a long history of this type of research, and we do have a strong fertilizer industry. Western Canada has been at the forefront adopting new technologies and trying to improve or become more efficient."

The information collected by Dr. Dyck will be used to create best management practices under the 4R Nutrient Stewardship framework. By implementing site-specific management practices under 4R Nutrient Stewardship farmers can optimize the efficiency of their fertilizer use, and potentially reduce emissions of greenhouse gases.

Dr. Dyck is confident his research involving 4R Nutrient Stewardship will help produce best management practices for Canadian crop producers, matching the right nutrient supply with crop requirements, and minimizing nutrient losses, resulting in good crop yields.

"The 4R Nutrient Stewardship framework is a guideline. Every farmer could practice 4R Nutrient Stewardship, but every farmer could have different management practices. They are flexible enough the farmer can adapt these ideas to their own operations, so it makes sense on their farm. The idea is that these guidelines will help producers make management decisions that will increase their production and at the same time reduce the environmental losses of fertilizer."

Dr. Miles Dyck
University of Alberta

Dr. Jeff Schoenau

Placement of Phosphorus (P) fertilizer to limit snowmelt P losses in the Canadian Prairies

Estimates are that by 2050, the world will need to increase food production by 70 per cent to keep populations fed.

Land for agriculture and global food production is becoming limited. Fertilizer, essential to producing high crop outputs, will help keep soils around the world productive and able to supply enough food for growing populations.

The international fertilizer community, understanding these needs, recognized more had to be done to ensure, not only sustainable development but good environmental practices as well. To this end, the 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®) is a guideline for sustainable and efficient food production.

4R Nutrient Stewardship works to increase production and profitability for farmers while enhancing environmental protection and improving sustainability. To achieve those goals, 4R Nutrient Stewardship incorporates the: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

Fertilizer Canada emphasizes the importance of managing and balancing the supply of nutrients to prevent both over and under fertilization, the key tenants of 4R Nutrient Stewardship. By working with leading Canadian agricultural researchers, Fertilizer Canada is doing research in how the 4R Nutrient Stewardship are applicable in Canada.

This research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater. Activities, including field trials, cover key field crops across Canada and were selected to overcome gaps in adoption, such as: lack of best management practices (BMPs), evaluation of multiple nutrient loss pathways of Nitrogen and phosphorus, evaluation of BMPs under the diverse soils, weather, cropping systems in Canada, and decision-making tools for tailoring BMPs to local needs and conditions.

Dr. Jeff Schoenau is a professor of soil fertility and a professional agrologist at the University of Saskatchewan. Growing up on the family farm in Saskatchewan, and continuing to be involved in farming today, he has hands-on experience in applying the 4R Nutrient Stewardship to his crops.

Currently, Dr. Schoenau is working with Fertilizer Canada to research fertilizer placement strategies, the different forms and amounts that are left behind in the soil at the end of the growing season, and finally how placement strategies influence the potential for movement off of the field in snowmelt runoff water.

His research is determining how effective fertilizer placement can reduce pollution and greenhouse gas emissions.

"We want to get the phosphorus into the crop, rather than staying on the soil surface where it is susceptible to movement, in runoff water, which then can potentially enter water bodies like lakes and streams."

Fertilizer is essential to sustainable crop production, and Canada is among the most efficient agricultural producers in the world. In the last twenty years, the industry has achieved significant reductions in greenhouse gas emission levels, while increasing total crop production.

Dr. Schoenau explains how this works. "Any type of fertilizer management strategy that increases recovery of nutrient in the crop and yields will tend to result in less of that nutrient being lost to the environment. In the case of phosphorus, the concern – and this applies to both commercial fertilizers and manure – is that when not applied using appropriate methods, there is a risk of excessive amounts of phosphorus entering into water, leading to the stimulation of algal bloom and the deterioration of water quality."

His research has contributed to how best apply fertilizer phosphorus to achieve maximum effectiveness and minimal environmental impact.

Working with his students, Dr. Schoenau found that by placing phosphorus fertilizer in the soil - with the seed, in a band, or broadcast followed by incorporation - resulted in greater recovery of the phosphorus by the crop and produced a higher yield compared to a broadcast application alone.

Because broadcast application alone resulted in higher concentrations of phosphorus on and near the soil surface, the runoff loss of phosphorus in simulated snowmelt was highest in this treatment while by placing the fertilizer in a band at depth, the runoff loss of phosphorus was similar to that of an unfertilized control.

"This reinforces that we get the best response out of the phosphorus if it is placed in the soil in bands, or incorporated into the soil and that this also mitigates the possibility of that phosphorus leaving the system through snow melt runoff."

Dr. Schoenau's work is demonstrating the benefits of 4R Nutrient Stewardship for the agriculture industry in Saskatchewan, Canada, and globally, "What the research work quite squarely shows, is that from a 4R Nutrient Stewardship standpoint, the right placement increases crop recovery, yield response, economic response, and minimizes the risk of phosphate leaving the system in runoff water."

"In my role as a professor who works in the area of soil fertility management, 4R Nutrient Stewardship principles are integral to sustainable agricultural production. And in my role as the Saskatchewan Ministry of Agriculture Strategic Research Chair in soil nutrient management, it is important to be looking at approaches that can improve the crop nutrient recovery of fertilizer and also minimize its entry into the environment."

Dr. Jeff Schoenau
University of Saskatchewan

Dr. Ivan O'Halloran

Synergists: Management of placement timing of Phosphorus (P) fertilizers to reduce P runoff losses in the Lake Erie watershed

Ontario farmers are the largest producers of mixed grains and soybeans in the country.

With the province representing some of Canada's most viable and productive farmland, water quality is a vital issue. The success of the agriculture industry in Ontario depends on finding a balance between fertilization application practices and addressing environmental issues in the Great Lakes and St. Lawrence River basin in a sustainable manner.

Dr. Ivan O'Halloran, from the University of Guelph, studies soil fertility management and land stewardship, including how to improve management practices to increase the effectiveness of manure and fertilizer applications while mitigating risks to water resources.

His current project with Fertilizer Canada looks at the impact of fertilizer placement and timing, and the potential phosphorus runoff from agricultural land.

"In general, what we are doing is comparing losses under various scenarios of different nutrient sources in terms of commercial fertilizers and animal manure."

Many valuable nutrients, including Nitrogen and phosphorus, are effective fertilizers. However, these nutrients can also become a source of pollution, resulting in water contamination or greenhouse gas emissions.

Fertilizer Canada emphasizes the importance of managing and balancing the supply of nutrients to prevent both over and under fertilization, the key tenants found in the 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®).

4R Nutrient Stewardship works to increase production and profitability for farmers while enhancing environmental protection and improving sustainability. To achieve those goals, 4R Nutrient Stewardship incorporates the: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

Working with leading Canadian agricultural researchers, Fertilizer Canada is supporting research in how the 4R Nutrient Stewardship can best be applied in Canada.

The research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater. Activities, including field trials, cover key field crops across Canada and were selected to overcome gaps in adoption, such as: lack of best management practices (BMPs), evaluation of multiple nutrient loss pathways of Nitrogen and phosphorus, evaluation of BMPs under the diverse soils, weather, cropping systems in Canada, and decision-making tools for tailoring BMPs to local needs and conditions.

"In general, what we are doing is comparing losses under various scenarios of different nutrient sources in terms of commercial fertilizers and animal manure."

Dr. Ivan O'Halloran
University of Guelph

The 4R Nutrient Stewardship approach is based on key scientific principles in crop and soil science. Since it is principle based it will work for any cropping system and all nutrient sources, including fertilizer. Practices, of course, will vary depending on the nutrient source or sources used on the farm. Farmers using mixed systems with both fertilizer and manure will in all likelihood find that adopting 4R Nutrient Stewardship will allow them to use their manure more effectively.

Dr. O'Halloran's research is focused on using 4R Nutrient Stewardship to better understand the mechanism of phosphorus runoff losses from the soil due to different source and placement practices, which should lead to improved decision support tools.

"Obviously we try to keep phosphorus in the soil, where it is best for the plants. Research suggests, if phosphorus is banded at planting, it is the most efficient use of that fertilizer. It also seems to solve the runoff problem, if it (the fertilizer) is not on the surface, but rather it is in the ground, near the plant root and away from water running off the soil surface."

Yet, Dr. O'Halloran explains, this is not the whole story.

"Depending upon the level of phosphorus in the soil and the tillage and cropping system used, it may not be possible to effectively band all the require fertilizer in the soil. Therefore, there may be circumstances where surface applications are the only option. People often say the longer the material stays on the field prior to the first runoff event, the better because less material is lost. But this is likely to depend upon the environmental conditions, particularly precipitation and temperature that occurred since the material was first applied. The more precipitation events we get that help break down the fertilizer and only move it into the soil, the less loss we would expect when we finally get the first runoff."

BMPs that optimize fertilizer placement and timing are important to ensure nutrients are taken up by the plant efficiently. Efficient plant uptake reduces fertilizer rates and fertilizer runoff and protects the environment.

"You have to look at it from the perspective of when does that first event occur, and has the material been sitting in the field for different lengths of time and under different conditions prior to that."

With rainfall comes phosphorus runoff. Phosphorus moves off the land either in overland flow and erosion, or through the soil and tile lines that remove excess water from the soil. This runoff could have detrimental implications on water quality, resulting in algal blooms through eutrophication.

"There is a challenge with phosphorus runoff. We can lose phosphorus and not see an agronomic impact, but there could be an environmental impact. A farmer would probably have to lose 60-70 kilos per hectare to see an agronomic effect half a kilo would have an environmental impact."

The importance of keeping Canada's waterways clean are evident, especially as phosphorus runoff, leads to the potentially harmful algal blooms such as those prominent in Lake Erie, making science-based solutions like 4R Nutrient Stewardship a tool to protecting the environment.

"We know there are better practices. We know there are more efficient uses for the nutrients. We need to come up with another way of managing losses. The environment can't take it anymore like seen in Lake Erie, where the situation demanded a push for this type of research."

Dr. O'Halloran is helping to demonstrate the benefits of 4R Nutrient Stewardship. This research is leading to advances in creating the most effective fertilizer application while minimizing environmental impact in Ontario and across Canada.

"Understanding soil differences, or site differences, is what the 4R Nutrient Stewardship is about. I think this idea is applicable in other areas of Canada it just has to be tailored to understanding those other climates."

"The 4R Nutrient Stewardship are about managing your systems the best you can; not to the provincial average, not to a county average, or county value, but from a very specific management aspect for your farm. I will always argue for site-specific management that provide farm or field specific BMPs. What is the best thing you can do, where are your risks, and what can you do to mitigate those risks?"

Dr. Nicolas Tremblay

Development of decision support mechanisms for 4R optimization of Nitrogen fertilization placement, rate and timing based on the integrated use of soil, weather and market data

Canada is a vast nation, with varied climates and landscapes from coast to coast.

And for a country reliant on the agriculture and agri-food industry these variances, combined with weather patterns, efficiently cultivating crops can be difficult.

Dr. Nicolas Tremblay, a researcher with Agriculture and Agri-Food Canada, through a project with Fertilizer Canada's 4R Research Network, is digging deeper into these uncertainties and how to create better management practices for Nitrogen fertilizer application.

"The uncertainty lies in it being hard to determine an appropriate rate of Nitrogen, the timing of applying the Nitrogen to the crops, and the most profitable management system that can be used," he explains.

Nitrogen is an essential nutrient for plant growth, and while found naturally, applying it as a fertilizer helps create efficient, and effective crop growth.

Plants require a balanced supply of Nitrogen, phosphorus, potassium, and sulphur, and extract these nutrients from the soil during the growing season. These nutrients must be replaced, through fertilizers, to ensure a productive crop.

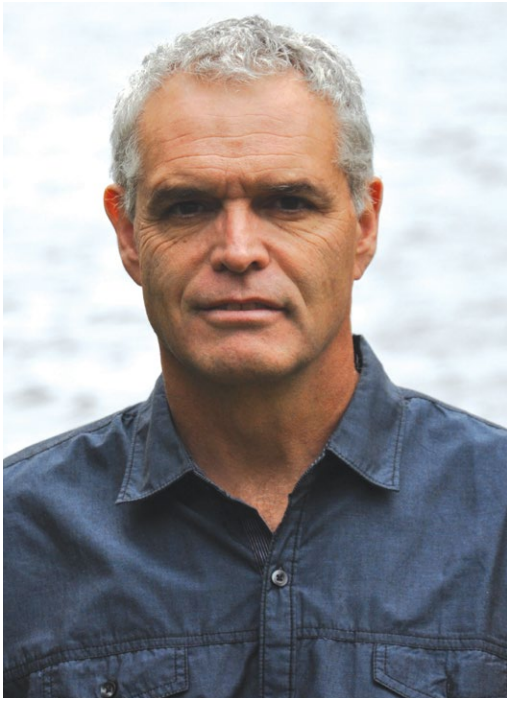
If Nitrogen is not applied at the right time, or at the right rate, it can affect the quality of the crop as well as the local ground and surface water. The balance lies in applying the fertilizers with control, to match the needs of the crop, and to ensure the environment is being protected.

Fertilizer Canada emphasizes the importance of managing and balancing the supply of nutrients to prevent both over and under fertilization, the key tenants found in 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®).

4R Nutrient Stewardship works to increase production and profitability for farmers while enhancing environmental protection and improving sustainability. To achieve those goals, 4R Nutrient Stewardship incorporates the: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

Working with industry stakeholders, agronomists, and farmers, Fertilizer Canada is conducting research on how 4R Nutrient Stewardship can best be applied in Canada.

The research covers many areas of environmental focus including reducing greenhouse gas and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater. Activities, including field trials, and cover key field crops across Canada were



"There is a lot of potential benefits in precision farming, most of those benefits is still to be materialized because we need to do this research of, looking at relationships between rainfall and Nitrogen requirements, interaction with soil, different crops, different timings, applications, use of technologies at our disposal."

Dr. Nicolas Tremblay
Agriculture and Agri-Food Canada

selected to overcome gaps in adoption, such as: lack of best management practices (BMPs), evaluation of multiple nutrient loss pathways of Nitrogen and phosphorus, evaluation of BMPs under the diverse soils, weather, cropping systems in Canada, and decision-making tools for tailoring BMPs to local needs and conditions.

Dr. Tremblay's research is focused on the 4R Nutrient Stewardship and BMPs that can be used through unpredictable weather.

"This uncertainty is leading farmers to secure yield by putting too much Nitrogen for what the crop normally needs. With this too high level of Nitrogen it has consequences because whatever is not needed is not profitable, and whatever (Nitrogen) is not needed is going to be lost, and that means it is going to end up as waste in the environment, either in the water, therefore water pollution, or in the air in the form of greenhouse gases."

In fact, when crop producers can find the right amount of the right fertilizer to use, apply it at the right time and in the right place, nutrient loss drops to a minimum, and profits increase.

In Canada, the key for better Nitrogen management is contingent upon the proper handling of uncertainties.

As Dr. Tremblay explains, a major source of uncertainty facing many farmers in Canada is the climate, particularly seasonal rainfall. Rainfall is hard to predict, and this inability to predict precipitation levels has an effect on the decisions a farmer has to make in order to achieve a good yield.

"Farmers know by instinct that rainfall is important. They also know by instinct the type of soil they are working with, and its interaction with rainfall, is an important parameter. Yet, there have historically not been relationships between these factors determined in order to apply in a decision making context."

If Nitrogen is applied to sandy soil, and there is heavy rainfall, the Nitrogen will be lost in a short period of time. The crop will not be as successful as it could be, Nitrogen will be lost to the environment, and the farmer can suffer economic losses.

"4R Nutrient Stewardship is a very good concept in the sense it is putting the management opportunities straight in terms of source, rate, timing, and placement. But that doesn't mean that everything is created equal. These are all management opportunities, but depending on the problem we need to address, maybe you need to look at a different placement technique, or a different rate of application."

He uses the 2012 drought in the United States as a good example of why the 4R Nutrient Stewardship is useful for Canadian crop producers, "The season was bone dry, and Nitrogen fertilizer was applied to the crop in provision of the season, but it was basically all lost. The corn didn't need Nitrogen at all, it needed water."

As Dr. Tremblay speaks of the relationship between weather and Nitrogen fertilizer management, he also praises the benefits of precision farming, which can support farmers to adopt a more advanced level of 4R Nutrient Stewardship on their fields.

"Precision farming is all about new technologies, geomatics, remote sensing, artificial intelligence, web-based products, big data, and if we as Canadians, and with Fertilizer Canada, are able to address this need for better personalization of recommendations through the use of data, appropriate for any farmer's situation we will do a great service not only to Canada but to the rest of North America and the world."

"There is a lot of potential benefits in precision farming, most of those benefits are still to be materialized because we need to research the relationships between rainfall and Nitrogen requirements, interaction with soil, different crops, different timings, applications, and use of technologies at our disposal."

Of course, predicting the weather is never 100 per cent certain, but with the type of information Dr. Tremblay is collecting, farmers will have the best resources on hand to make the best decisions for best management practices.

Dr. Alison Eagle

Integrating results of the Canadian 4R Nutrient Stewardship Research Network for improved environmental health and profitability

Canada is one of the largest agricultural producers in the world. The agriculture and agri-food industry contributes over $100 billion annually to Canada's gross domestic product (GDP).

With such a large production of crops, farmers and producers have to maintain efficient and cost-effective productions. In order to do this, farmers must use fertilizer. Without it, Canadian crop producers cannot properly manage their crops health or address changes in seasonal climates.

Canadians are rightfully concerned with sustainable environmental solutions as they pertain to agriculture.

Fertilizer Canada, in conjunction with leading Canadian agricultural researchers, are undertaking research projects, covering many areas of environmental focus including the reduction of greenhouse gases (GHG) and ammonia emissions, losses of phosphorus to surface waters, and nitrate leaching in groundwater.

These studies, in support of the 4R Nutrient Stewardship (Right Source @ Right Rate, Right Time, Right Place ®), will address best management practices (BMPs), evaluation of multiple nutrient loss pathways of Nitrogen and phosphorus, evaluation of BMPs under the diverse soils, weather, cropping systems in Canada, and decision-making tools for tailoring BMPs to local needs and conditions.

One researcher involved in the 4R Research Network, Dr. Alison Eagle, from Duke's Nicholas Institute for Environmental Policy Solutions, believes 4R Nutrient Stewardship provides an opportunity to inform Canadians on where their food is coming from, how it is produced, and showcases good stewardship practices.

"Many people don't understand where their food comes from," says Dr. Eagle. "Communication is extremely important in having people understand what farmers might or might not be able to do."

Dr. Eagle's research is assessing the results of implementing the 4R Nutrient Stewardship, "Fertilizer Canada is interested in addressing some of the sustainability issues, because there are inevitably some losses (of fertilizer) that happen. We are doing an assessment from different perspectives to look at not only the environmental effects of the 4Rs but also the social and economic implications."

4R Nutrient Stewardship works to increase production and profitability for farmers while enhancing environmental protection and improving on-farm sustainability. To achieve those goals, 4R Nutrient Stewardship incorporates the: **Right Source** of fertilizers that are in – or are easily converted to – compounds best used by the target crop. Apply the **Right Rate** of fertilizer to match nutrient supply with crop requirements. Apply fertilizer at the **Right Time** so nutrients will be available when crop demand is high. Apply or maintain fertilizer in the **Right Place** where the crop can access the nutrients most effectively.

"Many people don't understand where their food comes from. Communication is extremely important in having people understand what farmers might or might not be able to do."

Dr. Alison Eagle
Duke's Nicholas Institute for Environmental Policy Solutions

Canada's fertilizer manufacturing sector is among the most efficient in the world. In the last twenty years, the industry has achieved a significant reduction in emission levels, while total production has increased. The industry also helps farmers reduce their GHG emissions while achieving the maximum economic yield from their fields.

Nitrogen fertilizer, used commonly in Canada, goes through many different forms in an agriculture system. Abundant in the atmosphere, gaseous Nitrogen in the air can be fixed to produce commercial fertilizer products. When added to the soil, fertilizers provide Nitrogen to the plants for conversion to proteins and other compounds. As plant matter breaks down, Nitrogen returns to a mineral form or remains in the soil as organic matter. During this process, some Nitrogen can be lost, for example through gaseous losses into the air in the form of GHGs.

"It is when Nitrogen is lost to the air in the form of nitrous oxide that it has a negative effect. It is a strong GHG," explains Dr. Eagle. "Applying Nitrogen fertilizers correctly reduces the amount of nitrous oxide emissions into the atmosphere."

"Because of these inevitable losses, the systems can be managed to try to reduce the losses, so we are looking at our typical agriculture system and trying to figure what are some of the best ways we can change practices in order to reduce the losses."

Dr. Eagle and her team are doing an assessment on the environmental, social and economic implications of best management practices in fertilizer application, "We have different levels, environmental, economic, and social implications. How do we put these levels into a framework for decision making? We have to look at the farm level, the watershed level, and even at a national or global level."

Using data from other field scientists involved in the 4R Research Network, the team will advise on the benefits and costs at many different levels of the agriculture and agri-food industry.

In order to make evidence-based decisions on implementing new practices such as improved fertilizer management, farmers and agronomists need to know the monetary costs associated, how changes or implementation will occur, how valuable are the changes from an environmental perspective, and what are the impacts going to be on not only the farming community, but the larger society as well.

Canadians, working in different agricultural regions and with different crops, need to consider different environmental concerns.

"There will be different results in a humid region, like Ontario, versus a drier area like the Prairies. But a lot of the basics are not so different. Many principles of best management practices carry over from place to place, but we have different environmental problems."

Dr. Eagle explains some of the challenges that crop producers face, "Look at Lake Erie where some of the phosphorus and Nitrogen were causing some significant water quality problems. The impetus is to make change happen quickly. Whereas in some places in the Prairies, there isn't very much leaching going on, and where water quality problems aren't as big an issue."

The agricultural industry is responding to these environmental concerns with the 4R Nutrient Stewardship program.

"This is the assessment structure we are putting together. We will then be able to use the data from the field scientists to document the environmental benefits (of fertilizer management), and also the economic cost of doing some of these things at the farm level," explains Dr. Eagle.

In order to implement 4R Nutrient Stewardship practices, on-farm decision makers should know know the financial and environmental benefits to the farmers, and consider the impacts on communities, farming communities, and the larger Canadian society.

Dr. Eagle's research also looks at the social impacts of implementing the 4R Nutrient Stewardship in Canada, "How does this affect the health of people in the area? Do new practices affect employment or jobs? Even on the farm, how much training or new equipment is necessary."

The research and work being done by Fertilizer Canada, researchers, agronomists, and stakeholders, through 4R Nutrient Stewardship, will make steps towards informing Canadians how their food is produced, ensuring a sustainable environment for generations to come.

1 Leverage totals for 4R Nutrient Stewardship Research

$3.3m
$1.1m (federal government grant-AAFC)
$2.2m (from other funding sources)

$2.1m
(from other funding sources)

North American Total
$5.0m
All funds in Canadian Dollars

2 Professional Development in 4R Nutrient Stewardship

124
Research Assistants who work for the Research Leads
83 🇨🇦 41 🇺🇸

43 Undergraduate students (**23** Cdn, **20** US)
47 Graduate students (**33** Cdn, **14** US)
14 Post-doctoral fellows (**9** Cdn, **5** US)
2 Visiting scientists (US)
12 Technicians (Cdn)
6 Research associates (Cdn)

91
of these Research Assistants work directly on 4R Research projects
51 🇨🇦 40 🇺🇸

42 Undergraduates/Baccelaureates (**21** Cdn, **21** US)
21 Graduate students/MSc.PhDs (**12** Cdn, **9** US)
13 Post-doctoral fellows (**6** Cdn, **7** US)
1 Visiting scientist (US)
11 Technicians (**9** Cdn, **2** US)
3 Research associates (Cdn)

3 Communications of 4R Nutrient Stewardship Research

11 Manuscripts in Academic Journals
9 🇨🇦 2 🇺🇸

5 Dissertations/Theses
3 🇨🇦 2 🇺🇸

1 Citation
1 🇨🇦

108 Oral Presentations
41 🇨🇦 67 🇺🇸

8 Articles
5 🇨🇦 3 🇺🇸

19 Poster Presentations
14 🇨🇦 4 🇺🇸

25 Field Tours
11 🇨🇦 14 🇺🇸

24 Workshops/Meetings
18 🇨🇦 6 🇺🇸

20 listed as 'other methods' (e.g. videos, web resources, social media mentioned)

AT LEAST **7,740** people reached on 4R Nutrient Stewardship research
6895 🇨🇦 845 🇺🇸

4 Other success stories commented on by the researchers, as a result of their research on 4R Nutrient Stewardship

Over **2,000,000** crop acres have been captured as being under 4R Nutrient Stewardship in the Western Lake Erie Basin.

Many Indiana farmers are adopting the concept of late-split N for the last **30-50** pounds applied after the V-10 stage. Lots of farmer enthusiasm, despite the low commodity prices.

Awareness of 4R nutrient management from an agronomic and GHG perspective have improved across Canada. Provincial Governments looking closer at how 4R Nutrient Stewardship research can lead to incentives to reduce GHG emissions from agriculture.