Exploring the Potential of a 4R Fertilizer Program for the Horticulture Sector: A Case Study of the Holland Marsh

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January 30, 2025

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1.0 Introduction

The Holland Marsh Growers' Association (HMGA) has initiated a project to evaluate whether a 4R Nutrient Stewardship Program could be developed and implemented by Fertilizer Canada for the vegetable horticulture sector in Ontario. The project was initiated in November 2024 and will conclude in March 2025 with a draft framework for Fertilizer Canada's consideration.

This document explores the potential for implementing a 4R program for vegetable growers in the Holland Marsh, with a focus on improving sustainability, reducing nutrient runoff, and enhancing grower productivity.

The information gathered stems from both domestic and international published scientific papers, as well as industry-led innovations identified in web research and through interviews with growers and industry personnel. Key comments and considerations from the scientific and industry roundtable discussion held in January 2025 have also been incorporated into this document, The information is focused primarily on data collected from research on high organic soil, however where there is a lack of data, research on mineral soils has been used.

Partial funding for this project was provided by the Ontario Ministry of Agriculture, Food and Agribusiness.

Continued input is appreciated. P**lease return comments to:** **Charles.lalonde73@gmail.com**.

2.0 The Holland Marsh

The Holland Marsh, located in Ontario, is one of Canada's most productive agricultural regions, known for its rich, high organic soils and extensive vegetable production. Stretching across 7,000 acres of marshland and an additional 8,000 acres of surrounding uplands, it is home to over 60 vegetable crops, with carrots, onions, celery, and mixed greens being the most prominent. Upland water including that of a municipal sewage treatment plant drains through the canals and the East Holland River.

The marsh has predominantly histosol (muck) soils, known for their high organic content, which contributes to the fertility of the region. Despite its high organic content, additional fertilizers including nitrogen (N), phosphorus (P), and potassium (K) are important crop inputs required for vegetable production. These macronutrients must be managed properly to prevent environmental harm.

The region faces unique environmental challenges. The eutrophication of Lake Simcoe, which is partially influenced by agricultural runoff, has become a major concern. A study by Vivekananthan reports that the contribution of phosphorus from the Holland Marsh to Lake Simcoe is between 3 to 4 tons per year (O'Connor et al., 2017), which is less than 5% of all sources.[1&2]

When left unchecked, algae blooms can affect drinking water as experienced in Toledo, Ohio in 2014. As a portion of the phosphorus load to Lake Erie comes from Ontario farmland, a Canada-US effort aims to reduce phosphorus loading to Lake Erie by 40% by 2025.[3] Excessive phosphorus in water can lead to harmful algae blooms that produce toxins harmful to humans, animals, and fish.[4] As algal blooms decompose, it depletes oxygen in water creating dead zones.[5] While urbanization has a larger impact on water quality, agricultural practices in the Holland Marsh still contribute to the nutrient loading that affects nearby water bodies. Extreme weather because of climate change can lead to nutrient runoff, which in turn contributes to water quality degradation.

The horticulture sector, particularly in regions like the Holland Marsh, face increasing pressure to improve sustainability, reduce environmental impact, and enhance productivity. As consumer demands for transparency in food production grow and environmental concerns intensify, there is a clear need for innovative programs to address these challenges. Canadians are becoming increasingly concerned about the eutrophication of lakes and rivers, particularly the impact of nutrient runoff, which can cause harmful algae blooms and degrade water quality.

Federally, there are efforts to reduce greenhouse gases emitted during food production. Much of the discussions to date have focused on the national emission reduction target of 30% below 2020 levels from fertilizers.[6] As such, implementing a program like the 4R Nutrient Stewardship Program could help mitigate environmental challenges while potentially generating revenue for growers. Farm Credit Canada is one entity offering

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[1] Vivekananthan, K., Kimberley Schneider, Mary Ruth McDonald, University of Guelph & Merrin L Macrae, University of Waterloo, 2023

[2] O'Connor, E. M., Aspden, L. P., Lembcke, D., Young, J., Lucchese, M., Stainsby, E. A., & Winter, J. G. (2017). Annual water balances and total phosphorus loads of Lake Simcoe (2010-2011). Lake Simcoe Region Conservation Authority. https://lsrca.on.ca/wp-content/uploads/2023/07/Annual-Water-Balances-Total-Phosphorus-Loads.pdf

[3] Great Lakes Water Quality Agreement. Progress Report of the Parties. 2021

[4] Pearl, H.W. et al. Mitigating Eutrophication, Water Research 2018

[5] Diaz, R.J. & Rosenberg, R. Spreading dead zones and consequences for marine ecosystems. Science 2008

[6] Environment and Climate Change Canada, A Healthy Environment and a Healthy Economy. 2020

incentives to grain growers in Western Canada to participate in the 4R Program based on emission reductions and certified acreage.[7]

Given these challenges, there is an interest among growers in the Holland Marsh to adopt more sustainable farming practices, particularly in terms of fertilizer use and regenerative agricultural practices. Holland Marsh growers recognize the importance of transferring sustainability information throughout the supply chain, from local markets to export destinations. By adopting a 4R Nutrient Stewardship Program like that of the grains and potato sectors, vegetable growers could not only help reduce their environmental impact but also enhance their competitiveness in the market, as sustainability becomes a key selling point for consumers.

3.0 The 4R Nutrient Stewardship Program

The 4R Program - Right Fertilizer, Right Rate, Right Place, and Right Time has already demonstrated success in the grain sector, and there is significant interest in applying this model to the horticulture sector.[8]

Right Fertilizer – Selecting the appropriate type of fertilizer for specific soil conditions and crop needs is critical to improving nutrient use efficiency. Different crops and soils have unique nutrient requirements, and using a tailored approach to fertilization can ensure that crops receive the nutrients they need to optimize production.

Right Rate – Applying the correct amount of fertilizer is key to minimizing waste and preventing nutrient runoff. Over-fertilization not only increases costs but also contributes to environmental problems such as nutrient pollution in water bodies.

Right Place – Proper placement of fertilizers ensures that nutrients are delivered directly to plant roots, where they are most needed. This reduces the likelihood of nutrient loss through runoff or volatilization into the air, helping to protect both soil, air and water quality.

Right Time – Applying fertilizers at the optimal time ensures that plants can take full advantage of the nutrients. This practice helps maximize crop yields and reduces the chances of nutrients being lost to the environment due to leaching and volatilization.

The 4Rs was designed specifically to manage phosphorus and nitrogen fertilization. Research has shown that implementing the 4R principles reduces nutrient losses to water bodies, mitigates eutrophication, and improves water quality while minimizing greenhouse

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[7] https://www.fcc-fac.ca/en/about-fcc/media-centre/news-releases/2024/program-launch-4r-nutrient-stewardship

[8] Fertilizer Canada, https://fertilizercanada.ca/our-focus/stewardship/

gas emissions.[9&10] For growers it improves fertilizer use efficiency while enhancing crop yields. The 4Rs optimize nutrient application to meet precise crop needs, reducing waste while ensuring plants have the critical nutrients at critical growth stages. Measured on corn, yields increased by 15% compared to conventional practices.[11] Furthermore, variable rate technology used with 4Rs led to decreased fertilizer cost by 20%.[12] Combining evidence from lower cost inputs and yield increases in wheat production, growers realized greater profitability.[13] Producers certified under the 4R designation in Canada reported better access to high-end markets obtaining an additional $15 per ton.[14] Intangible benefits would include improved soil health and more resilience to climate variability.

The program is supported by an individual farm planning document, a 4R certification program for its ag retailers, and intensive education and promotion effort throughout the grain sector. Grain grower designation levels fall into three categories: basic, intermediate and advanced. In its guidance document, Fertilizer Canada outlines the progression possible based on the following definitions:

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.[15]

Individually, ag retailer companies supported their certified crop advisors (CCA) to become 4R certified. Many ag retailers offer farm data management systems to growers to capture

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[9] Fixen, P.E. et al., The scientific principles of 4R nutrient stewardship. IPNI 2012

[10] Snyder, C.S. et al., Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems & Environment, 2009

[11] Zhang, W. et al. Impact of Precision nutrient management on corn yield. Journal of Sustainable Agriculture, 12(3) p. 45-60. 2020

[12] Roberts, T et al. Economic impacts of 4R nutrient stewardship. International Fertilizer Development Center

[13] International Plant Nutrition Institute. Case studies on 4R implementation. 2021

[14] Farmers Edge. Market Benefits of Sustainability Certification in Agriculture. 2022. www.farmersedge.ca

[15] Fertilizer Canada, 4R Practices Guidance Document. https://fertilizercanada.ca/wp-content/uploads/2019/06/4R-Guidance-Tables.pdf

fertilizer related information. Other companies partnered with privately owned data management services to support on-farm management of nutrients.

While a formal program has yet to be offered for the horticultural sector, growers and their CCAs informally follow 4R principles. In the future, an individual farm planning document prepared by a CCA and a grower would be imperative to set goals to achieve over time. For example, Holland Marsh farms located in the Lake Simcoe basin could have an environmental sustainability goal regarding nutrient loss mitigation in addition to productivity goals often expressed as yield increases.

Ultimately, a 4R program for vegetable production can be successfully implemented if all the following considerations have been met:

Considerations	Status / Comment
Demand for a program	Several growers have confirmed sustainability claims are part of their marketing strategy.
Industry and grower leadership	Ag retailers, Fertilizer Canada, HMGA, and the horticulture sector have expressed interest and support. Grower associations will need to identify market pull opportunities.
Specific over-arching environmental issues that need addressing	E.g. Preventing soil loss and mitigating water quality issues.
A continuum of choices within a best management practice (BMP) to help growers move towards better environmental and productivity outcomes	Industry innovation to improve nutrient use efficiency has created a continuum of choices.
Sufficient science to support 4Rs for vegetable crops grown in the Holland Marsh	The concepts of the 4Rs have been supported by research for over 20 years. Research is on-going.
Field data capture system to support claims	Grower fertilization data is being recorded though their ag retailer’s database. It is accessible to growers and their ag retailer.

4.0 The Holland Marsh and Its Soil

Holland Marsh soils are highly productive organic soils, with organic matter content exceeding 50%. These soils are rich in carbon, oxygen, and hydrogen, which makes them ideal for intensive vegetable farming. The upland areas surrounding the marsh have a mix of clay and sandy soils and are also used for vegetable production. Despite the fertility of the muck soils, they are not without challenges. The Holland Marsh 2028 Strategic Plan outlines the need to address wind and water erosion, nutrient runoff, and subsidence as some of the major issues affecting soil quality.

Muck soil in the Holland Marsh varies in depth, ranging from less than a foot at the edges to several feet in the central areas. Being a polder, the sub-soil base is a hard clay with little water infiltration capacity.[16] The topsoil profile includes various layers, such as the humic organic layer, the deeper fibric layer, and the thicker terric layer. These layers play a significant role in soil fertility and water retention. In the top 40 cm, the soil is of humic composition with the organic matter in the 50 to 80% range.

Muck soils have unique properties that are quite different from mineral soils. Table 2 of Pandey's MSc Thesis, compares various properties from muck soil to mineral soil as presented below.[17]

Parameters	Organic Soil	Mineral Soil
Bulk Density (g/cm^{-3})	0.10 to 0.35 [a]	1.0 to 1.8 [a]
Porosity (pore space) (cm^3/sample cm^3)	0.80 to 0.95 [a]	0.30 to 0.50 [a]
Saturated Hydraulic Conductivity (cm/ s^{-1})	0.05 to 0.35 [a]	Sand: $5X10^{-3}$ [b]
		Loam: 5×10^{-4} [b]
		Clay: 5×10^{-5} [b]
Potential of Lower Water Availability (kPa)	-10 to -30 [c]	-10 to -60 [b]

Subscripts identify the data source: [a] Lucas 1982; [b] Brady & Weil 2002; [c] Périard et al. 2012

Table 3.4 of the Pandey Thesis (shown below) summaries all the key soil characteristics (0-15 cm) including chemical, biological, and microbial parameters as reported by Pandey. These results are based on soil sampling of 30 fields in the Holland Marsh in 2022 and 2023 and reported into three subgroups: low (n=4), medium (n=15), and high (n=11) productivity.

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[16] http://www.hmgawater.ca/blog/polders-the-holland-marsh

[17] Pandey, Neem. MSc Thesis University of Guelph, P 99-104

Indicator	Category	Unit	Low	Medium	High	*P* -value
P-bicarb	Chemical	mg L^{-1}	53	45	54	0.12
P-bray	Chemical	mg L^{-1}	122 ab	92 a	134 b	0.03
K	Chemical	mg L^{-1}	224 ab	201 a	283 b	0.04
Mg	Chemical	mg L^{-1}	367	337	339	0.63
Ca	Chemical	mg L^{-1}	4786	3901	3737	0.12
Na	Chemical	mg L^{-1}	80	68	85	0.40
pH	Chemical		6.6 b	6.0 a	6.0 a	0.03
CEC	Chemical	Meq/100 g	30	27	26	0.27
S	Chemical	mg L^{-1}	67	52	77	0.19
Zn	Chemical	mg L^{-1}	13	12	14	0.56
Mn	Chemical	mg L^{-1}	8.4	6.6	6.3	0.10
Fe	Chemical	mg L^{-1}	108	107	107	0.97
Cu	Chemical	mg L^{-1}	8.5	8.6	10.0	0.60
B	Chemical	mg L^{-1}	3.0	2.6	3.0	0.33
Al	Chemical	mg L^{-1}	114 b	40 a	49 a	<0.01
NO_3-N	Chemical	mg L^{-1}	45	37	44	0.47
Cl	Chemical	mg L^{-1}	149	92	133	0.05
EC	Chemical	dS m^{-1}	0.83	0.71	0.80	0.29
SOM	Biological	g kg^{-1}	31 a	57 b	60 b	<0.01
PMN	Biological	mg L^{-1}	32	29	28	0.48
CO_2-C – 1d	Biological	mg L^{-1}	49	41	38	0.45
ACE	Biological	mg g^{-1}	86	111	111	0.15
SOC	Biological	g kg^{-1}	21 a	32 b	34 b	<0.01
TN	Biological	g kg^{-1}	14 a	22 b	25 b	<0.01
C:N	Biological		15	15	14	0.62
AC	Biological	mg kg^{-1}	9054	9930	9917	0.54
Pseudomonas population	Microbial	Functional index	2274	2369	2666	0.62
Nitrogen fixers	Microbial	Functional index	2132	2221	2209	0.30
Rhizobium and related	Microbial	Functional index	890	738	1028	0.20
Gram positive	Microbial	Functional index	1978	1808	1897	0.84
Actinomycetes	Microbial	Functional index	2448	2514	2580	0.20
General bacteria	Microbial	Functional index	2333	2291	2361	0.31
General fungi	Microbial	Functional index	1944	1428	1592	0.28
Trichoderma	Microbial	Functional index	343	385	488	0.20
Anaerobic bacteria	Microbial	Functional index	786 b	417 a	646 ab	0.03

Total gram negatives	Microbial	Functional index	5376	5505	5856	0.46
Total bacteria	Microbial	Functional index	12136	12111	12608	0.62
Total microbial activity	Microbial	Functional index	15209	14277	15460	0.22
Fungal to bacterial ratio	Microbial		0.19	0.15	0.17	0.36

Means within the same row (bold faced) followed by different letters are significantly different at P = 0.05, Tukey's HSD test. CEC - cation exchange capacity; NO3-N - nitrate nitrogen; EC – electrical conductivity, SOM – soil organic matter, PMN – potentially mineralizable nitrogen, CO2-C – Solvita CO2 released in 24 hours, ACE – autoclaved citrate extractable protein, SOC- soil organic carbon, TN – total nitrogen, C: N – TOC to TN ratio, AC – active carbon.

Based on the reported data above, 26 out of the 30 samples had an average pH of 6.0. This can be interpreted that there are many fields with a pH below 6 which can potentially impact phosphorus stability in the soil and the subsequent plant uptake from the soil.

Also, the carbon-to-nitrogen ratios for muck soil were between 14.0 and 15.0. Residues with a C:N ratio >20 provides little N availability when the biomass decomposes. Accordingly, N is supplemented to crop recommendations annually.

In a recent literature review for the HMGA, Vivekananthan summarized the test issue as follows:

"A recent study conducted on Ontario organic soils reported poor performance of soil P testing methods designed for alkaline conditions (e.g., Olsen P) and acidic conditions (Mehlich-3 P) in predicting surface runoff and leaching soluble reactive P (SRP) concentrations from organic soils (Zheng et al., 2014, 2015). Interestingly, runoff SRP concentrations from Ontario organic soils which were collected from Lake Simcoe (where the Holland Marsh is located) and Lake Erie watersheds were more closely associated with the Bray P1 soil P test, which employs a weak acid for extraction."

A&L Laboratory worked with Dr Tiequan Zhang, AAFC, to adopt a modified Mehlich III test to assess P in acidic organic soils that is highly correlated to readily available P in plants.[18] The Mehlich III test is a preferred test for acidic organic soil as the extraction of available P is not affected by the presence of Fe and Al ions and provides a more accurate result. A&L Laboratory has measured yield responses and has confirmed that growers report high yields based on appropriate fertilization that includes other nutrients such as boron and magnesium in balance. Both boron and magnesium together with potassium play an important role in P uptake. The Olsen test is the official soil test for Ontario. It is an accurate predictor of plant available phosphorus. The need to officially calibrate the Olsen test for horticultural crops has never become a top research priority, but it should as part of the supporting research for a horticulture 4R strategy.

[18] www.alcanada.com/pdf/technical/fertilizer/Soil_Analysis_Guide.pdf

Note to the reader: Both Dr Zheng and Dr Zhang work together at the Harrow Research Station at the time of the project.

Most Ontario organic soils have a neutral or slightly acidic pH (Zheng et al., 2014).[19] Soil pH that is below 6 needs to receive lime to increase the pH to 6.5-6.8 range which will also result in an increase in the calcium saturation level. Pandey reports calcium levels in the range of 3,700 to 4,800 ppm level based on 30 field samples taken throughout the marsh. Zhang's research also reported calcium saturation levels in the 65 to 75% range for marsh soil, which is consistent to what regional CCAs observe. At higher calcium saturation levels, the phosphorus stabilizes in the soil and becomes available to the plant. In fields with high P levels and without adequate Ca or less than ideal pH, added P fertilizer is likely wasted.

Accordingly, growers orient their fertilization strategy by providing phosphorus as a starter fertilizer. No further fertilization is required for carrots as their root system makes them good scavengers. Onions, on the other hand receive a P top-up either as a broadcast or sidedress surface application. At the time of seeding, soil temperatures are still cool which significantly slows the soil microbial activity that is required to release P in a form the plants can use. Both carrots and onions need readily available P applied as their root systems are in the initial stages of development.

Scientists at A&L Laboratory contributed the preparation and analysis of Chapter 23: "Soil physical and nutritional balance are essential for establishing a healthy microbiome" published by Dr. James White in his 2021 book titled "Microbiome Stimulants for Crops". This work at A&L Laboratory was the basis for their soil health test offered to growers. It is reported that desirable microbial responses occur when soil P levels are in a medium range. High and low P levels in soils corresponded with a less desirable microbial population. Therefore, recommendations need to ensure sufficient P is available for both the plant and microbial activity. Based on the phosphorus bicarbonate test results reported by Pandey, Holland Marsh soils appear to be in the mid-range for optimal microbial development and attaining high crop yields. Furthermore, as each crop has specific requirements, it is difficult for growers to remain at the bottom range recommended throughout the field rotation.

Subsidence, the gradual net disappearance of the soil, is a major concern for the Holland Marsh. The primary cause of subsidence is the exposure of muck soil to atmospheric oxygen, which accelerates the biochemical decomposition of organic matter. Pandey's study found that subsidence rates in the region range from 1.78 cm/year to 3.3 cm/year.[20]

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[19] Vivekananthan, K. et al. Literature Review prepared for the HMGA and OMAFRA.
[20] Pandey, Neem. MSc Thesis University of Guelph, P 99-104

Additionally, both wind and water erosion contribute to soil loss, which further exacerbates the issue of subsidence. The chemical process of subsistence releases nutrients into the soil each growing season but there is no known research that quantifies the nutrient release amounts.

Another study reports a similar degradation in Quebec organic soil used for vegetable production.[21] The authors examined a biomass addition versus a copper addition to the soil as a means of controlling subsidence. They concluded that growers had variable results using copper whereas a biomass mixture of straw and untreated wood chips had a greater positive effect. More research continues with blends of biomass and the impact on vegetable crops before a recommendation can be established.

Water management plays a crucial role in the maintenance of soil quality in the Holland Marsh. The polder sub-soil base is a hard clay with slow water infiltration capacity.[22 & 23] The marsh is equipped with a series of canals, dikes, and pumping stations that help regulate the water table at ideal levels for vegetable crop growth. During high discharge periods, excess water is pumped out of the marsh into the Holland River, most commonly during the spring thaw and prolonged rain events that can occur throughout the year. In times of drought, water can be pumped back into the marsh to maintain optimal conditions for crop growth. Under normal weather conditions, growers can also mitigate nutrient losses by managing water in their field tile drainage system.[24] Furthermore, many growers create circular water flow conditions from field tiles and surface runoff by utilizing this water for irrigation purposes throughout the growing season. This limits the transfer of water from the fields into the canals and the Holland River which flows to Lake Simcoe, mostly to the early spring period only.

Individual growers in secondary marshes also manage the water table on their lands to mitigate nutrient loss in a similar manner.

5.0 Crop Nutrients

Nitrogen, phosphorus, and potassium are the major fertilizer ingredients for crop production. Together with key essential micronutrients crop yields have increased over time. Fertilizer use in Canada has increased significantly, with a 60% rise since 2010,

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[21] Bourbon, Karolan et al. Agricultural Peatlands Conservation, Soil Science Society of America Journal, Vol. 85 (4) 2021

[22] http://www.hmgawater.ca/blog/polders-the-holland-marsh

[23] Milligan, R and Bajc, A. Geology of the Holland Marsh watershed. Ontario Geological Survey presentation. www.hmgawater.ca/uploads/1/7/2/8/17281360/riley_mulligan,_ogs.pdf

[24] Grenon, Genevieve, PhD Thesis p 13-14; McGill University, 2020

contributing to increased agricultural output.[25] However, this increase in fertilizer use has also raised concerns about the environmental impact of nutrient runoff and water impairment. Though data specific to vegetable crops in the Holland Marsh is not available, growers report higher yields over time, attributing these improvements to better genetics, fertilizers, and agronomic practices, including better equipment.

The following describes some challenges related to phosphorus (P) and nitrogen (N) losses from soils, and to a lesser extent potassium (K) and the role of micronutrients.

5.1 Phosphorus (P) Loss and Forms:

- Phosphorus fertilization plays a crucial role in carrot cultivation, significantly influencing root development and overall yield. Adequate phosphorus levels are essential for the formation of robust roots, which directly impacts the quality and storability of harvested carrots.
- Phosphorus in organic soils is mostly in organic form, but fertilization for vegetable crops often relies on mineral (inorganic) phosphorus. Over time, the phosphorus in the soil has shifted towards inorganic forms.[26]
- The form of phosphorus mineral complex affects its availability to plants. Fe-bound P, for instance, is associated with higher concentrations of soluble reactive and total phosphorus as evidenced in effluent from field tiles, whereas Ca-bound P is more easily retained in organic soils. Similarly, aluminum binds phosphorus in soil by forming insoluble chemical compounds with phosphate ions, particularly in acidic conditions, where aluminum is more readily available in solution; essentially, when the pH is low, aluminum ions readily attach to phosphate ions, creating a bond that makes phosphorus unavailable to plants by locking it into a solid form within the soil particles.[27]
- Despite being rich in organic matter, organic soils have low intrinsic phosphorus content, necessitating frequent early spring fertilization to meet the high phosphorus demand for vegetable crop production. However, research in the Holland Marsh shows that high levels of fertilization does not result in significant increases in crop yield, primarily due to phosphorus losses through runoff and leaching rather than being retained in the soil (Grenon 2022); (McDonald).[28]

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[25] Statista, https://www.statista.com/statistics/1330033/canada-fertilizer-consumption-by-nutrient/
[26] Grenon et al., 2022, Linking soil phosphorus pools to drainage water quality in intensively cropped organic soils. Agricultural Water Management, 272, 107860. https://doi.org/10.1016/j.agwat.2022.107860
[27] https://www.nutrien.com/growers
[28] McDonald, M.R., Vander Kooi, K., Kessel, C., & Nemeth. D. (2013). Evaluation of phosphorus requirements on organic (muck) soil in carrots, 2013. In: M.R. McDonald et al., editors, Muck vegetable cultivar trial & research report 2013. University of Guelph Muck Crops Research Station. Report No. 63. p. 52–54.

Phosphorus leaching is an environmental concern in muck soils. Its high organic matter reduces the soil's ability top bind phosphorus making it prone to leaching (Khiari et al. 2019).

- Ammonium phosphates or polyphosphates (MAP & DAP) are used for field vegetable production and the P is supplied in PO_4 form. Its effectiveness is affected by the fertilizer product solubility, companion ions supplied (coated granules), and soil pH (Gaskell 2011).
- Tindall reported on the use of dicarboxylic polymers with P fertilizer minimizes P precipitation with soil calcium and aluminum.[29] Slow release or coated fertilizers products will reduce solubility increasing the time that P fertilizer remains available to plants.[30]

5.2 Nitrogen (N) Loss and Water Quality:

- Nitrogen fertilizer is available in the form of urea, ammonium, or nitrate or a combination of these forms. Urea and ammonium fertilizers are readily converted to nitrate through hydrolysis and nitrification reactions. The presence of denitrification bacteria in the soil also leads to volatilization of ammonium-based products such as urea.[31] Ammonia and urea fertilizers are more prone to volatilization as NH_3 and NO_2. Although newer ammonium-based products such as ammonium sulfate on carrots remains available for longer time periods.
- In cool soils, a nitrate fertilizer may provide faster nitrogen uptake by the plant, but it is still subject to leaching as it is water soluble and can move easily through a soil profile.[32 & 33] The nitrate fertilizer in the soil is converted to ammonium with some of the ammonium converting back to nitrate. Plants mostly absorb nitrogen in the ammonium form and to a lesser amount as nitrate. Nitrate, however, is subject to leaching, volatilization, and surface runoff. Newer coated products such as ammonium fertilizer with calcium sulphate coating remains available for longer time periods and requires sidedressing during the growing season.

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[29] Tindall, T.A. 2007. Recent Advances in P fertilizer Technologies – Polymer Coating-. Proceedings Western Nutrient Management Conference 7:106-110.

[30] Chen, J., et al. Controlled release fertilizers as means to reduce nitrogen and phosphorus loses. Journal of Environmental Quality. 2008

[31] Jones, C. et al. Factors affecting nitrogen fertilizer volatilization. University of Montana, 2013 accessed at https://landresources.montana.edu/soilfertility/documents/PDF/pub/Urea%20vol%20factors%20BMP%20combo.pdf

[32] Gaskell, M, Hartz, T., Application of the 4R Concepts to Horticultural Crops, Hort. Technology, December 2011, 21 (6) p.663-666.

[33] www.Kochagronomicservices.com.

- Ammonia and urea are not used in vegetable production in the Holland Marsh. Growers prefer nitrate-based products avoiding the issues associated with ammonium-based products.[34] The use of non-urea-based fertilizers coupled with deep placement and irrigation, significantly decreases ammonia volatilization.[35] Adjusting irrigation amount can also mitigate ammonia volatilization.[36]
- Nitrogen use efficiency (NUE), the amount used by the crop compared to the amount applied, is an industry measure of efficiency. Research has shown NUE can be as low as 40% when a nitrogen source is used without a coating or inhibitors to prevent volatilization and leaching. NUE can improve by as much as 25% when inhibitors are used.
- Residual nitrogen in the soil after harvest is important in the breakdown of crop residue after harvest.
- The agricultural sector often receives criticism for overuse of nitrogen despite its high cost to growers. Nitrogen, together with phosphorus, while essential for food production, is a major factor in water quality degradation, contributing to the growth of harmful cyanobacterial algal blooms in lakes and rivers, impacting water quality, including drinking water.
- Nitrogen fertilization can also contribute to water impairment, especially due to leaching. The U.S. Congressional Research Office describes nitrogen as a mobile nutrient, undergoing transformations in the soil that result in significant losses to both water (via leaching) and air (via volatilization).[37]

5.3 Potassium

Potassium is an essential plant nutrient but considered as an immobile nutrient in the soil. It is not associated with environmental impairments in agriculture. Muriate of potash is superior to potassium chloride in muck soils. Muriate of potash is often recommended for muck soils because the soil tends to be naturally low in potassium, and muriate of potash is a readily available and a highly soluble source of potassium, which is crucial for healthy plant growth and can significantly improve crop yields on these types of soils. It also helps with root development, disease resistance, and overall plant vigor in conditions where potassium might be limited.[38]

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[34] HMGA interviews with ag retailer CCAs Dec 2024.
[35] Pan, B. et al. Ammonia volatilization from synthetic fertilizes and its mitigation strategies. Agriculture, Ecosystems & Environment V.232 P. 283-289, 2016.
[36] He et al. in Ammonia volatilization from synthetic fertilizers and its mitigation strategies, Agriculture, Ecosystems & Environment by Pan. B et al. Vol 232 pg 283.
[37] Congressional Research Service, https://crsreports.congress.gov R43919
[38] Personal communication with Joe Uyenaka, Nutriag December 2024

5.4 Other Macronutrients and Micronutrients

Magnesium, calcium, and sulfur are classified as macronutrients and are required in varying amounts for each of the vegetable crops. Micronutrients including boron, copper, iron, manganese, molybdenum, and zinc are required in smaller amounts than the macronutrients, but they are still important to a plant's overall nutrition. Without all minerals being in balance for the crop, the fertilizer efficiency will not be reached.

5.5 pH Adjustment

Soil pH plays an important role in fertilizer use efficiency. The assumption is that the acid muck soil has received lime to bring the pH to a 6.5 to 6.8 level.

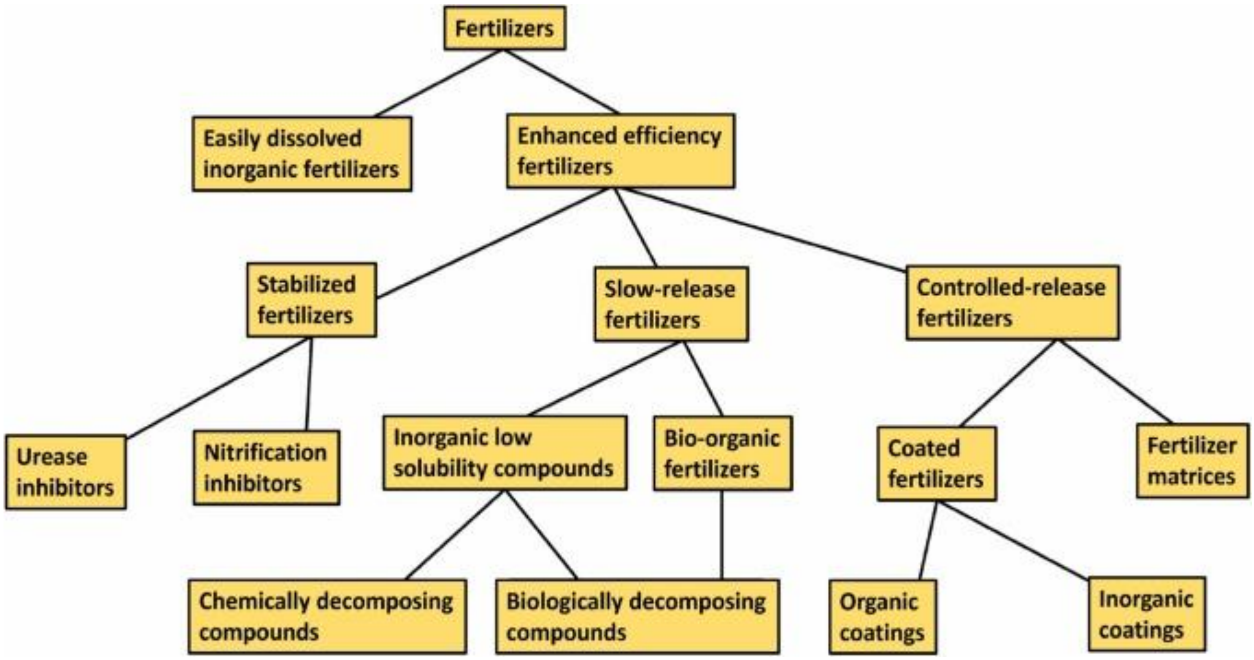
6.0 Fertilizer Advancements

6.1 The Right Type

In a 2024 literature review, Osadu presents an organization structure for fertilizer types according to their main properties.[39] Starting at the top of the chart, the "easily dissolved inorganic fertilizers" represent what was available historically. The industry has moved its formulation to enhanced efficiency fertilizers which then fall into three subgroups: stabilized fertilizers with inhibitors, slow-release fertilizers, and controlled-release fertilizers, each capable of increasing NUE and protecting the environment.

With the upgrading of fertilizer facilities, mineral-coated and polymer-coated products have come on stream and vegetable growers have shown an interest with respect to coating of granular fertilizers with micronutrients to evenly distribute essential micronutrients. Nitrification inhibitors are routinely used on N granules in the Holland Marsh. Inhibitors for N volatilization are not used as growers manage this environmental risk through the choice of non-urea-based fertilizers.

[39] Osadu,A.O. et al., Enhanced Efficiency Fertilizers, Environmental Pollution and Management 1 (2024) p.32-48.



The Association of American Plant Food Control Officials defines Enhanced Efficiency Fertilizers (EEF) as fertilizer products that can reduce nutrient losses to the environment while increasing nutrient availability for the plant of the crop.[40] These fertilizers can either slow the release of nutrients for uptake or alter the conversion of nutrients to other forms that may be less susceptible to losses. Three categories of EEF include slow and controlled-release nitrogen fertilizers, nitrogen stabilizers, and phosphate management products.

High purity soluble complete blends used primarily in greenhouses are being used as a response stimulant to deal with various growth challenges that emerge from time-to-time. Growers elect to do a foliar application in response.

Based on 2024 grower and CCA interviews in the Holland Marsh, the preferred form of fertilizer is granular due to other production practices with a wide continuum of products from soluble inorganic forms to coated products with essential micronutrients and biologicals. With the addition of micronutrients to the macronutrients increases the overall efficiency of the nutrient.

At the University of Guelph Crop Research Center – Bradford, Dr M.R. McDonald is initiating trials to measure new bacterial endophytes such as Enviva and Utrisha N that can fix nitrogen in the leaves and reduce the amount of nitrogen needed for crop growth. When

[40] https://www.aapfco.org

completed, the research will contribute towards updating fertilizer recommendations for carrots, onions, and celery.

Growers must consider both economics and logistics when choosing a fertilizer type. They want the best return-on-investment from the fertilizer but the type of spreading equipment they have access to will also affect what fertilizer they will choose.

6.2 The Right Rate

In the 2023 Guide to Vegetable Production in Ontario, the approach to fertilization rates is based on both plant growth and soil maintenance. There is no reference to yields. When soil phosphorus levels are high, it is recommended to reduce the amounts applied for soil maintenance. In most regions, building up soil phosphorus is not recommended.

Growers can also affect the rates applied by banding, a practice that growers abandoned many years ago in favor of broadcasting.

Many agricultural retailers have published their company pledges on the 4Rs of nutrient management. With respect to the "right rate", nutrient recommendations are determined on "meeting the crop need followed by a build and maintain basis." "Soil build-up is a practice not encouraged in the Great Lakes basin. When there is no yield response on growth and maintenance, growers should consider a lower application rate to drawdown the phosphorus levels as guided by soil testing. For example, when soil tests indicate high nutrient levels, recommendations aim for slightly lower amounts than crop removal to encourage drawdown of P levels while ensuring that nutrients are neither deficient (limiting crop performance) nor excessive (increasing environmental impact). Unfortunately, there is no numerical guideline on drawdown. To consider drawdown, growers need to have confidence in their soil test results and the method of analysis for post-harvest phosphorus levels. Researchers are uncomfortable recommending a rate until there is more research results available based on soil test calibration to yield.

In the Holland Marsh, soil phosphorus buildup is not occurring on some farms but not others. There are fields with high post harvest P test results. Therefore, the focus moving forward will be to determine the optimal phosphorus levels for crop removal and associated soil health functions less drawdown.

6.3 The Right Time

The concept of the "right time" involves supplying nutrients when the plant requires them most, while mitigating nutrient losses to the environment through leaching, volatilization, and runoff. By keeping nutrients in the soil and available to plants, growers can make better economic decisions. Nutrient use efficiency is also influenced by the placement of nutrients in the soil relative to the plant.

In the Holland Marsh, phosphorus is typically applied and incorporated just prior to seeding, with many growers completing all three operations on the same day. Growers also sidedress their onions with additional phosphorus providing the plant with the nutrient when it is most needed. During early crop development, phosphorus is primarily needed to build plant biomass.

In contrast, nitrogen is required throughout the growing season, with the amount needed increasing as the plant grows. To meet this demand, growers typically use granular nitrogen as a starter fertilizer at seeding, followed by additional applications later in the growing season. Both granular and liquid nitrogen are used for these subsequent sidedress applications. Many growers also coordinate the use of their irrigation systems to help move granular nitrogen into the soil, where it is needed by the plant. Alternatively, some rely on rainfall to transport the applied nitrogen into the soil.

The timing of additional nutrient applications can be based on plant tissue analysis or a set number of days after seeding. Growers can now obtain onsite real-time results by using a Picketa monitor. The Muck Crop Research Station will be evaluating the Picketa monitor on onions as a tool to address nutrient deficiency supplementation through foliar applications.[41]

Scouting and technology also play a key role in determining the optimal timing for nutrient applications. By utilizing precision agriculture technologies combined with remote sensing, growers can identify where plant growth issues have emerged and tailor their nutrient applications accordingly. Many companies now offer precision mapping services-based soil test results as well as on a field's vegetative index enabling growers to apply nutrients precisely where and when needed, thereby improving nutrient use efficiency.

6.4 The Right Place

Fertilizer placement as defined by Bryla refers to the application of a nutrient in the soil in a way that maximizes plant nutrient uptake while minimizing nutrient losses.[42] Once a nutrient is in the soil, it moves to the root zone via mass flow, facilitated by water, or through diffusion. In well-watered vegetable crops, mass flow is the predominant method of nutrient movement.

[41] https://farmtario.com/crops/minimizing-fertilizer-use-with-in-field-plant-nutrient-analysis/

[42] Bryla, D.R. Application of the 4R Nutrient Stewardship Concept – Getting Nutrients to the Right Place. Hort technology, December 2011 21(6)

In the Holland Marsh, granular fertilizers are typically broadcast and incorporated before seeding followed by some sidedress application later. Crop seeders have the capability of forming the seedbed and in some cases, rollers are used to firm up the hills. For carrots, this results in 12-inch-wide row hills at the top, with three rows of carrots planted on top and a row of barley on each edge to protect the young plants from wind erosion. Each hill is separated by a deeper ridge, free of surface soil, to facilitate drainage. With high-density planting, the nutrients become "placed" close to the plant because of the shaping of the top layer of soil. Similarly, for onions, the raised seedbed places nutrients near the root zone. As a result, the placement of fertilizer as a sidedress at seeding is not deemed necessary but used later for a subsequent application. Growers proceeding with a sidedress apply granular fertilizers by dropping the fertilizer on the surface next to the plant.

Nutrients commonly broadcasted include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and boron (B). Copper (Cu), zinc (Zn), and manganese (Mn) are typically applied as foliar treatments to improve efficiency. Growers also have access to liquid fertilizers, which include several micronutrient mixtures for foliar application. Another placement method is fertigation; however, it is not practical to use in muck soil.

Note to the Reader: While each of the Rs is supported by its science, there is also multiple research projects addressing the beneficial interactions amongst the Rs which is not covered in this document.

7.0 Grower Practices

The HMGA conducted grower interviews in 2023 as part of the literature review conducted by K. Vivekananthan as well as additional grower interviews for this 4R project to provide additional context and help to categorize production practices into three levels: basic, intermediate, and advanced.[43] Within this project, seven growers and three ag retailers were interviewed.

Consistent with the Fertilizer Canada definitions presented in Section 3 of this report, examples are provided for each of the three levels of grower classification in the following table.

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[43] Vivekananthan, K. Potential of 4R Nutrient Stewardship to Reduce Phosphorus Losses from Organic Soils of the Holland Marsh

Rating	Practice
Basic	A grower utilizes an inorganic fertilizer with no enhancements to reduce nitrogen loses, fertilizes all at once prior to planting by broadcasting and incorporation. Some soil testing occurs, and the grower follows CCA recommendations. Field records are those provided by the ag retailer.
Intermediate	A grower that has addressed some of the 4Rs creating a scenario of higher fertilizer efficiency as a means of achieving environmental protection. Soil testing is done by field grids and mapping is available to vary application rates. The grower utilizes some enhanced efficiency fertilizers and follows recommendations. Field records include those provided by at ag retailer as well as production records.
Advanced	Grower uses advanced production practices to address the 4Rs and aspires to improve soil health or greater environmental protection to air and water, Intermediate level goals have been achieved.

Within the 4R framework, growers can progress from basic practice to advanced practice. In conjunction with the 4R practices, there are a several in-field and edge-of-field BMPs growers can follow. In-field practices are important to optimize nutrient use efficiency regardless of the fertilizer practice whereas edge-of-field practices are critically important to protect the environment while also enhancing fertilizer use efficiency.[44] In-field and edge-of-field agronomic and conservation practices lead to increased soil health while protecting against wind and water erosion.[45] These practices can also be improved over time; thus, a continuum is possible.

In-field BMPs include:

- Using various cover crop varieties to protect against wind and water erosion and improve soil health
- Extending crop rotations improve soil health
- Reducing tillage and/or combining field passes supports better soil health
- Planting nurse crops to protect young plants from wind erosion
- Balancing nutrients for better nutrient uptake by the plant
- Managing weeds and pests to prevent significant yield loss
- Controlling drainage to conserve water for plant growth
- Managing soil pH to enhance fertilizer efficiency
- Irrigating to move surface applied nutrients to the root zone

[44] Fixen, P.E. A brief account of the genesis of 4R nutrient stewardship. Agronomy Journal 112(5)
[45] Upadhaya, S et al. Individual and county level factors with farmers' use of 4R Plus nutrient management practices. J. Soil and Water Conservation, Vol.78-5, 2023

- Using seeds coated with biologicals for fertilizer optimization and increased yields
- Using biologicals to protect the seed from pathogens, pests, and environmental conditions.

Edge-of-field BMPs include:

- Planting buffer strips along streams and ditches to filter nutrients and sediment from runoff
- Building berms to control surface runoff
- Using of controlled drainage to mitigate the impact of free flow field tiles
- Wind shelters to prevent wind erosion
- Field retirement to regenerate soil health.

7.1 The 4R Framework

The 4R Framework is modelled closely to published frameworks for grains and potatoes grown in the various regions across Canada. The practices are presented in tabular form as basic, intermediate, and advanced for each of the 4Rs. In some cases a basic practice may no longer be in use, but it has been included to track the progression and improvement over time. Separate tables are used to present the progression of practices for N and P.

4R Practices for Nitrogen Management

4R Practice	Basic	Intermediate	Advanced
Right Source	All commercial fertilizer products have guaranteed analysis	Basic plus: Use of enhanced efficiency fertilizers for at least 33% of the total N applied	Intermediate plus: Use enhanced efficiency fertilizers for at least 50% of the total N applied
	Use of fast dissolving fertilizer without inhibitors	Use of a nitrate-based fertilizer	Used a nitrate-based fertilizer with coating for controlled-release
	Ammonium-based fertilizers such as MAP or DAP allowed		
Right Rate	Application based on previous yield history and crop requirements	Basic plus: Soil testing every year to determine crop need	Intermediate plus: Apply according to field yield variability using digitized zone maps for yield
	Adjust for seed variety	Develop an in-field nitrogen application strategy based on estimates of yield variability	Monitor in-season N use using tissue testing, sensors and scouting
		Manage rate based on crop uptake modelling	
Right Time	Pre-planting application only and incorporation	Basic plus: Split application at seeding and during growth	Intermediate plus: Consider weather to avoid severe events
	No frozen ground surface application		
Right Place	Broadcast and incorporate	Basic plus: Apply in sub-surface or bands	Intermediate plus:
	Use enhanced efficiency fertilizer when incorporation is not possible	Use a foliar application	Limit surface application to in-season and use enhanced efficiency fertilizer

4R Practices for Phosphorus Management

4R Practice	Basic	Intermediate	Advanced
Right Source	Use P fertilizer with guaranteed analysis	Basic practices plus	Intermediate practices plus
	Use P sources capable of enhancing P availability in the growing season	Use enhanced efficiency coated fertilizer products	Use enhanced efficiency coated fertilizer products for slow release and for micronutrient dispersion
Right Rate	Use soil test within the past three years	Test each field annually	Intermediate practices plus: Grid sampling
	Adjust rates by field	Consider an entire rotation in developing P rates	Variable rate application by zone and independent of N
	Follow crop guidelines	Adjust rate for yield potential based on historical data	
		Apply to crop needs in fields with optimal P range	
		Consider draw down (less than crop requirement) in fields with P tests beyond optimal range	
Right Time	Apply in the spring	Apply in spring	Apply in spring at seeding
Right Place	Broadcast and incorporate	Broadcast, incorporate, seed into a raised bed if soil test is in optimal range and based on removal	Banding
	Surface apply in fields with limited risk of movement to surface water	Surface apply in field areas with limited risk of movement to surface water	Topical foliar application

			No broadcasting on field edges near water courses

7.2 Other Considerations

Our study included the review of nine data management systems available to growers as either whole farm systems or systems focused on fertilizer management practices to determine the degree of traceability possible to support a 4R nutrient stewardship program.

Holland Marsh growers have access to a web-based data management system provided by their ag retailer to record nutrient use by field, fertilizer type, and application date. Growers can access their records by logging into the site or through their CCA. Several growers use complete farm data management systems in addition to the ag retailer system. With minor data recording improvements to address field names, details on field activities and fertilizer placement, growers have the necessary data to participate in a program such as the 4Rs.

Growers would also need to formalize their goals and targets to achieve over time and record / receive acknowledgement of the certified acreage through their ag retailer CCA.[46] Fertilizer Canada has developed a goal setting and acreage certification form, in use by grain growers, that is easy-to-use during a regular CCA-grower visit.[47] The grain sector maintains a database to capture acreage certification.

8.0 Conclusion

The Holland Marsh is a unique and highly productive agricultural region, with soils that are both highly fertile and susceptible to environmental challenges. Muck soils are unique and require different best practices compared to mineral soils. Examples of the unique qualities and requirements include:

- Soil has > 50% organic matter therefore soil amendments are not used
- Acidic soil requires lime application every 10 years for pH balancing
- Muck soil requires in-season P stabilization through Ca supplementation
- Muck soil produces higher yields over mineral soil
- Muck soil requires nitrate fertilizer to control nutrient losses through volatilization and leaching

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[46] Bruulsema, T. W. et al. A global framework for fertilizer BMPs. Better Crops, V. 92(2), P.13-15. 2008

[47] https://fertilizercanada.ca/wp-content/uploads/2021/06/fc_grower_signature_sheet2021_en_VF.pdf

- Cu is used to control subsidence in muck soil
- The Holland Marsh canal system is used to store field tile water run-off during the growing season and is partly re-used for irrigation.

While the muck soils provide an ideal growing medium for vegetables, issues such as nutrient loss, subsidence, and erosion require ongoing attention. Advances in water management, fertilizer types and fertilization practices, and soil conservation practices will be critical for maintaining the productivity of the region and protecting its soil resources for future generations. A 4R Nutrient Stewardship program could be the catalyst to create a continuous improvement environment. Growers benefit from an excellent relationship with their CCAs. Moving forward represents a small step towards sustainability certification.

As indicated earlier in this document, a 4R program for vegetable production can be successfully implemented if all the following considerations have been met.

Considerations	Status / Comment
Demand for a program	Several growers have confirmed sustainability claims are part of their marketing strategy. Grower associations will need to identify market pull opportunities.
Industry and grower leadership	Ag retailers, Fertilizer Canada, HMGA, and the horticulture sector have expressed interest and support.
Specific over-arching environmental issues that need addressing	E.g. Preventing soil loss and mitigating water quality issues.
A continuum of choices within a BMP to help growers move towards better environmental and productivity outcomes	Industry innovation to improve nutrient use efficiency has created a continuum of choices.
Sufficient science to support 4Rs for vegetable crops grown in the Holland Marsh	The concepts of the 4Rs have been supported by research for over 20 years.
Field data capture system to support claims	Grower fertilization data is being recorded though their ag retailer’s database. It is accessible to growers and their ag retailer.

It is our recommendation to proceed with a program as growers have indicated a desire to participate and most of the data is already captured. The effort required to have a program is incrementally small whereas the benefits are important to environmental sustainability and have a cumulative effect.

9.0 Next Steps

This discussion paper was developed to generate a discussion between the ag sector and the research community. The feedback received was incorporated into this final version. The HMGA recommends the following next steps:

1. The HMGA will develop a draft guidance 4R plan based on the Holland Marsh to share with the horticulture sector and with Fertilizer Canada with a recommendation to proceed with the development and implementation of a formal 4R program for the sector.
2. The HMGA will share the research gaps identified with partners in government, academia, and industry to help with their research priority setting.
3. The HMGA will develop the communication plan to mobilize the horticulture sector to move forward with the 4R Program.