Towards a Business Case for Soil Health: A Synthesis of Current Knowledge on the Economics of Soil Health Practices in Ontario

Possibility grows here.

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The Greenbelt Foundation is committed to promoting awareness and education about Ontario's Greenbelt. To this end we occasionally publish research and general interest papers that explore our three program areas: viable agriculture and viticulture; vibrant rural communities; and, a restored and protected natural environment.

Towards a Business Case for Soil Health: A Synthesis of Current Knowledge on the Economics of Soil Health Practices in Ontario
Prepared by Aaron De Laporte, Ph.D., Daniel Schuurman, M.Sc., Alfons Weersink, Ph.D., Claudia Wagner-Riddle, Ph.D., Paul Smith, B.Sc., M.A.
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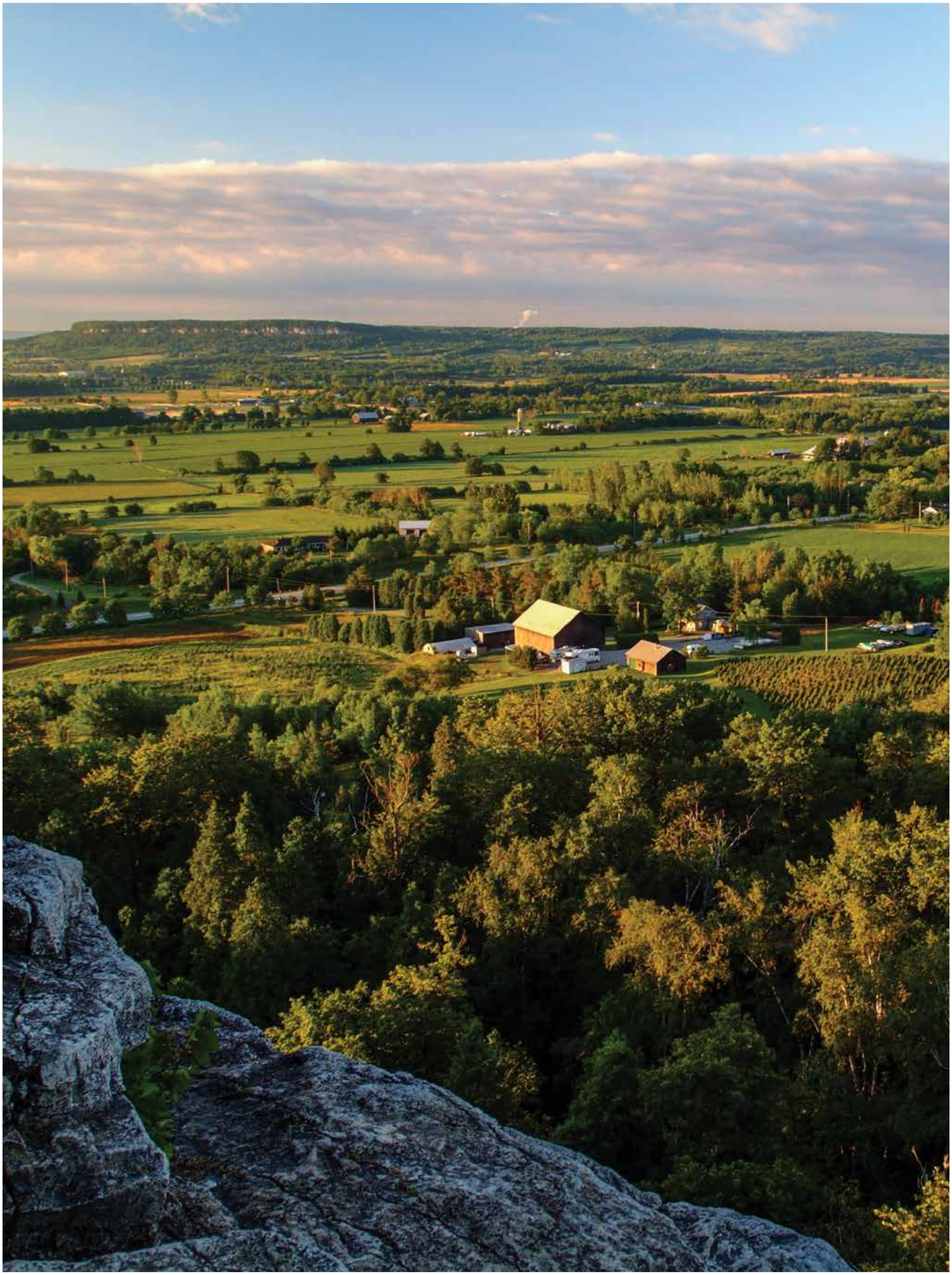

Foreword

Since its creation, the Greenbelt Foundation has worked to strengthen the Greenbelt's sustainable food systems through initiatives that increase market access for farmers, build or improve supply chains, protect prime farmland, help new farmers, raise public awareness about sustainably produced food, and bring about positive changes in public policy. In recent years, the Foundation has undertaken programs that emphasize the importance of soil health and the need for increased adoption of management practices.

Investing in soil health is more important than ever as farmers are facing significant challenges on several fronts, including more frequent and extreme weather events. Research has shown that healthy soils not only strengthen food security, build productivity and profitability for farmers but also provide co-benefits for biodiversity and climate change mitigation and adaptation. When farmers build soil organic matter, more water can be captured and stored, reducing the risk of flooding and increasing resilience in times of drought. When farmers increase diversity in soil bacteria and other beneficial organisms, ecological nutrient cycles function better, often meaning less pesticides and fertilizers are required. Soil health is not the answer to all the challenges facing farmers but it has a very important role to play.

Since 2020, the Foundation has partnered with Équiterre with the extensive engagement of leading farm organizations, government, academic institutions and other sector groups on 'The Power of Soil' project. Through this project we are seeking to inform government policy and farm decision-making to increase the adoption of on-farm soil health management practices by Canadian and Greenbelt farmers to benefit farm profitability, environmental quality, and climate resilience. In 2021, we released a joint report, *The Power of Soil: An Agenda for Change to Benefit Farmers and Climate Resilience*, that included research on how and why farmers adopt soil health practices.

This latest research addresses one of the main recommendations from that report, to "make the business case for soil health", especially within Ontario's large and diverse landscape. This is important because improving agricultural soil health requires thousands of farmers to choose to change their soil management practices in order to achieve the widespread adoption required to make a difference in climate resiliency and long-term farm productivity. But it is important to remember that farming is also a business, and the financial implications of any new venture is an important factor. Understanding the potential return on investment can therefore not only influence decisions but also provide farmers with important information on how to manage the risks associated with changing practices.

Reflecting the typical approach of an academic journal article, this publication is a departure from the Foundation's traditional style of report. It has four objectives:

- Present the best economic data currently available of the costs and benefits of farmers using management practices that have been shown to improve soil health. This can help inform policy and program design.
- Provide a resource that can be the basis of ongoing outreach and education to Greenbelt farmers that we will take forward with the team from Soils at Guelph.
- Identify specific additional research and information needs that other organizations and institutions can take forward.
- Provide recommendations to guide future research, policy, and program design.

We hope that this research will inspire and influence farmers in the Greenbelt and beyond. Protecting and enhancing our agricultural soils is critical for regional food security and helping to mitigate and adapt to climate change.

Sincerely,

Edward McDonnell
Chief Executive Officer, Greenbelt Foundation

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List of Abbreviations

ac	acre
bu	bushels
CO_2e	carbon dioxide equivalent
gal	gallon
ha	hectare
hd	head
K	potassium
kg	kilogram
lb	pound
N	nitrogen
N_2O	nitrous oxide
P	phosphorous
yr	year

Executive Summary

Many agricultural areas in Ontario, Canada and across the Greenbelt are losing soil organic matter, are at high risk of soil erosion and may cause a net loss of CO_2e into the atmosphere. Improving agricultural soil health will provide many benefits but it requires thousands of farmers to choose to change soil management practices. Farming systems focused on soil health have the potential to increase profit, environmental quality, and climate resilience (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020). However, the business case for soil health focused farming practices has not been well considered, especially with the variety of soil properties and climate conditions present across a large and diverse landscape like Ontario. The Power of Soil report recommended that evidence needed to be accumulated to "make the business case for soil health" (Équiterre and Greenbelt Foundation, 2021), and Ontario's Soil Health and Conservation Strategy also stressed the need to "develop methods to quantify economic aspects of soil health" (OMAFRA, 2018).

Farmers make decisions based on many different factors, and, as businesses, the financial implication of those decisions is a very important factor. Understanding the potential returns and costs can not only influence decisions, but also provide farmers with important information on how to manage the risks associated with changing practices, should they make that choice. **Therefore, this study aims to mobilize current knowledge to help build the business case for soil health on farms in the Greenbelt and Southern Ontario to aid decision making by farmers and their advisors.** The analysis uses current knowledge on quantified costs and benefits while recognizing that many benefits remain unquantified. Thus, the analysis is an important foundation to build on and the estimates are likely conservative in nature and will evolve with new knowledge. It is hoped that this work will stimulate further research documenting costs and benefits.

The analysis determines a range in net returns from the adoption of six different soil health practices: 1) tillage intensity; 2) cover crops; 3) diverse crop rotations; 4) nutrient management; 5) organic amendments; and 6) rotational grazing. Using data from literature synthesis and financially representative farm-level budgeting techniques for Southern Ontario, the study found that most of these practices have a range of net returns, from negative to positive, implying the financial benefits to farmers are sensitive to certain conditions. The ranges in profitability highlights inherent differences between practices and differences in implementation. Extension work can often identify the factors contributing to success.

Results Summary

Tillage Intensity

For a typical grain farm with a corn-soybean crop rotation, tillage reduction appears to present less variability than other practices, with a small range in net returns and small gains or losses (Table ES1). Initial costs from corn and soybean yield losses ease over about 5 years, eventually returning to similar yields as conventional tillage. Costs savings occur in all years, resulting in more favourable net returns for both crops after 5 years. Over the corn-soybean rotation the net return is better for no-tillage after year 5, with gains in the soybean year compensating for losses in the corn year.

Table ES1 *The difference in returns from conventional and no-till based on a corn-soybean rotation ($/ac). Negative values indicate when conventional net return is higher than no-tillage. Revenue change and crop net return estimates have high and low estimates.*

		Year 1		Year 5	
		Corn	Soy	Corn	Soy
Yield Change (%)		-9	-5	-2	0
Revenue Change ($/ac)	High	-56.40	-11.70	-31.30	0.00
	Low	-93.30	-15.50	-51.90	0.00
Cost Savings ($/ac)		36.00	27.00	36.00	27.00
Crop Net Return ($/ac)	High	-20.40	15.30	4.70	27.00
	Low	-57.30	11.50	-15.90	27.00
Rotation Net Return ($/ac)		**-12.70**		**10.70**	

Photo courtesy of Dr. Dave Hooker, University of Guelph, Ridgetown Campus

Cover Crops

Cover cropping of mixed varieties has higher initial costs that move towards sustained positive values over 5 years due to increases in crop yields (Table ES2). Revenue benefits increase over time through five years as yields build, while costs, N credit, and weed control benefits remain constant. Cover crop mixes including legumes tend to have higher returns than a single non-legume cover crop like cereal rye. When the price of crops (50% higher) and the costs of N are high (doubled), cover cropping has positive net returns immediately. It is important to control the costs of cover cropping by choosing appropriate seed mixes and seeding rates

Table ES2 *The difference in returns from consecutive cover cropping in a corn-soybean rotation ($/ac), assuming 60 lb N supply from a cover crop mixture (50% legume, 50% cereal), $0.50/lb N, weed control benefits, and historical crop prices through 2020.*

		Year 1		Year 3		Year 5	
		Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)		0.5	2.1	1.8	3.5	3	5
Revenue Change ($/ac)	High	5.20	15.50	18.70	25.90	31.10	37.00
	Low	3.10	11.70	11.30	19.50	18.80	27.90
Added Costs ($/ac)	High	93.00	93.00	93.00	93.00	93.00	93.00
	Low	21.80	21.80	21.80	21.80	21.80	21.80
Nitrogen Credit ($/ac)	Mean	30.00	0.00	30.00	0.00	30.00	0.00
Weed Control ($/ac)	High	32.50	32.50	32.50	32.50	32.50	32.50
	Low	13.00	13.00	13.00	13.00	13.00	13.00
Crop Net Return ($/ac)	High	45.90	26.20	59.40	36.60	71.80	47.70
	Low	-46.90	-68.30	-38.70	-60.50	-31.20	-52.10
Mean Rotation Net Return ($/ac)	**Mean**	**-10.78**		**-0.80**		**9.05**	

Diverse Crop Rotations

Adding winter wheat to a corn-soybean crop rotation also has initial costs, but like tillage and cover crops, the benefits become positive over time, as soon as the second year, with maximum sustained benefits by the fourth year (Table ES3). This stems from yield benefits increasing over time as the land in rotation grows winter wheat piece by piece, increasing revenue and costs.

Table ES3 *Profitability of a corn-soy rotation transitioning in increments to a corn-soy-winter wheat rotation over four years (to all land having grown winter wheat), with literature-based yield increase. Ranges represent two standard deviations from the mean crop yield. For example, the corn yield range is 119 bu/ac (Low) to 192 bu/ac (High).*

		Year 1			Year 4		
		Corn	Soy	Wheat	Corn	Soy	Wheat
Yield Change (%)		0	0	0	7%	12%	0
Cost ($/ac)	High	-804.5	-444	-435.4	-826.5	-461.2	-451.7
	Low	-654.6	-409	-399.4	-573.2	-422	-415.7
Revenue ($/ac)	High	955.4	722.1	620.6	1022.2	808.8	620.6
	Low	588.4	545.1	386.3	629.6	610.6	386.3
Crop Net Return ($/ac)	High	150.9	278.1	185.2	342.3	347.6	185.2
	Low	-66.1	136.1	-13.1	110.1	188.6	-13.1
Portion in Crop		2/6	3/6	1/6	2/6	2/6	2/6
Mean Net Return ($/ac)		132			193.4		
Change from C-S ($/ac)		**-9**			**52.4**		


Photo courtesy of Dr. Dave Hooker, University of Guelph, Ridgetown Campus

Nutrient Management

Of the 4R nutrient management practices examined, rate reduction has the smallest range in net returns, followed by split N application (Table ES4). Inhibitors and precision application have the largest ranges, with relatively high upside for inhibitors and relatively low downside for precision application. When crop prices are high, changes in yield and revenue are more pronounced. When N costs are high, 4R practices that save on these costs have a greater effect on net returns.

Table ES4 *Estimates of the range of changes in yield, revenue, costs, and net returns, in dollars per acre, from 4R management practices including split N application (Right Timing), nitrification and urease inhibitor application (Right Source), modest N rate reductions (Right Rate), and variable rate N application (Right Placement).*

	Practice							
	Split N Application		Inhibitor Application		Rate Reduction		Variable Rate N Application	
	Low	High	Low	High	Low	High	Low	High
Change in Yield (%)	-1.2	3.7	0.3	9.3	-2.8	0	-2.1	4.4
Change in Revenue ($/ac)	-$11.13	$34.31	$2.78	$86.25	-$25.97	$0.00	-$19.48	$40.81
Change in Cost ($/ac)	$11.00	$11.00	$32.37	$16.19	-$44.00	-$22.00	$20.62	$12.00
Change in Net Return ($/ac)	-$22.13	$23.31	-$29.59	$70.06	$18.03	$22.00	-$40.09	$28.81

Organic Amendments

Chicken manure use has a high potential upside, but beef manure barely breaks even with mineral fertilizers (Table ES5). However, this is only true if the price of manure is zero and transportation distances are short. When the price of N is high, manure represents greater cost savings and reasonable transportation distances increase. Manure also has a host of other unmonetized benefits, including application of carbon, additional micronutrients, and soil microbes.

Table ES5 *Liquid hog, dairy, beef, and poultry manure, and biosolids, composition and cost of application relative to traditional mineral fertilizer application in Ontario. Includes the break-even transportation distance of free manure. Assumes a corn enterprise applying 154 lb N/ac, 71 lb P/ac and 48 lb K/ac.*

Manure Type	Hog	Dairy	Beef	Poultry	Biosolids
Total Manure Costs ($/ac)	96.47	130.17	135.91	43.74	559.05
Mineral Fertilizer Cost ($/ac)	137.75	137.75	137.75	137.75	137.75
Change in Net Returns ($/ac)	41.28	7.58	1.84	94.01	-421.30
Transportation Cost ($/mile)	5.88	7.93	8.28	2.67	32.12
Break-Even Transportation Distance (miles)	7.0	1.0	0.2	35.3	

Rotational Grazing

Rotational grazing can have relatively small costs and benefits, depending upon the intensity of grazing, with greater intensity having potentially greater net returns, but much higher upfront capital fencing and water costs (Table ES6). Cow-calf operations in Ontario appear to have negative net returns, overall, but management intensive grazing can relatively increase net returns.

Table ES6 *Changes in grazing days, stocking rates, feed costs per head, fencing costs, and cash net returns from adopting 8 paddock rotational grazing and 16 paddock management intensive grazing, including the change in net returns from continuous grazing.*

	Continuous Grazing	Rotational Grazing	Management Intensive Grazing
Grazing Days (days)	155	162	194
Stocking Rate (hd)	95	99	119
Decreased Feed Cost ($/hd)	0	17	97
Increased Fencing Costs ($)	0	5,014	10,028
Cash Net Return ($)	-6,758	-9,913	-4,044
Change in Net Return ($/ac)		-19.72	16.96

Conclusion Summary

Putting all the potential benefits together, the long-term sustained increase in Ontario farm net returns from increasing no till, cover crop, crop rotation, the specified 4R practices (split application, inhibitors, rate reduction, and variable rate application), manure, and rotational grazing adoption by 10% of the relevant agricultural area would be approximately **$14.6 million dollars per year**.

All these benefits can change when the prices of commodities change. For example, when crop prices are high, it exacerbates the degree of revenue change, so positive and negative changes in yield become more important. When N fertilizer prices are high as in 2022, practices like cover cropping, N rate reduction and soil amendments become more attractive. Higher fuel and other input costs make additional farm machinery use more expensive.

The study also identifies several research gaps, including a lack of long term spatial and temporal data for all the practices, asymmetric levels of information among these practices, insufficient research on the adoption of multiple practices, and the role of policy, risk, and tenancy on adoption. Limited research has been conducted outside of popular field crops and livestock, including vegetables and fruit. Further information is also needed on additional soil health promoting agricultural practices.

In light of the research gaps, this study recommends:

1) Development of extension tools to aid Ontario farmers and advisors in adoption decisions based on the available information in this report and future endeavours;
2) Expansion of economic research on soil health to additional commodities and production systems;
3) Synthesising economic knowledge on appropriate soil health practices in other parts of Canada;
4) Gathering greater spatial and temporal data on multiple soil health practices;
5) Examining the effects of land ownership and tenancy on soil health practice adoption;
6) Studying extension and other non-financial factors influencing soil health practice adoption; and
7) Using knowledge of the economic benefits and costs of practices in the design of policy and incentives.


Photo courtesy of Callum Morrison

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Introduction

Many agricultural areas in Ontario, Canada and across the Greenbelt are at high risk of soil erosion and may cause a net loss of CO_2e into the atmosphere. However, improving soil health across the country will provide many benefits. Through shifts in farm practices, we can sustain farm incomes, strengthen food security, stabilize water cycles, contribute to human health, and conserve biodiversity. Healthy soil practices also capture carbon to build soil organic matter and reduce agricultural greenhouse gas (GHG) emissions. It is a real win-win-win for people, profit, and the planet.

Improving soil health requires thousands of farmers to choose to change soil management practices. Farmers make decisions based on many different factors, and, as businesses, the financial implications of those decisions are very important. Understanding the potential returns and costs can not only influence decisions, but also provide farmers with important information on how to manage the risks associated with changing practices, should they make that choice.

Therefore, this study aims to mobilize current knowledge to help build the business case for soil health on farms in the Greenbelt and Southern Ontario to aid decision making by farmers and their advisors.

Farming systems focused on soil health have the potential to increase profit, environmental quality, and climate resilience (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020). However, the business case for soil health focused farming practices has not been well considered, especially with the variety of soil properties and climate conditions present across a large and diverse landscape like Ontario. The Power of Soil report recommended that evidence needed to be accumulated to "make the business case for soil health" (Équiterre and Greenbelt Foundation, 2021), and Ontario's Soil Health and Conservation Strategy also stressed the need to "develop methods to quantify economic aspects of soil health" (OMAFRA, 2018). Similarly, the Ontario Cover Crops Steering Committee (2017, 2020) identified the need for economic analysis.

In this report, soil health is defined as "continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" and is acknowledged to have physical (e.g., aggregate stability, bulk density, water holding capacity), chemical (e.g., fertility, pH, cation exchange), and biological (e.g., organic matter, microbial biomass, biological diversity) components (Équiterre and Greenbelt Foundation, 2021; OMAFRA, 2018).

There are numerous on-farm practices that can influence soil health and environmental sustainability. These include, but are not limited to, tillage intensity, cover crops, diverse crop rotations, nutrient management, organic amendments, and rotational grazing. Extensive literature has been published on these practices, particularly regarding their environmental effects. From a public standpoint, the environmental benefits of soil health enhancing practices appear to be positive. For example, while simultaneously enhancing soil health, including carbon sequestration, some of these practices influence greenhouse gas emissions. However, in the absence of well-established markets, such as those for carbon, the public benefits of soil health are typically non-monetary, with difficulty establishing the value of biodiversity inherent in healthy soil ecosystems, for example.

While the private benefits of soil health are likely positive, overall, the costs of adoption are certainly primarily private in nature, with some public support through extension services and financial incentives. Furthermore, the net benefits are less certain given specific spatial considerations (e.g., climate and soil) and there can be temporal considerations that result in considerable upfront costs for gains in later years. **Therefore, detailed, context-specific, multi-year estimates of the on-farm financial effects of these practices are necessary to establish the 'business case for soil health' and give farmers greater confidence before adopting a new set of practices.**

Promotion of soil health practice adoption has long been supported by information, advice, and financial incentives in various formats. Extension staff, fact sheets, booklets, videos, field days, workshops, demonstration sites, and farm tours are among the variety of extension or knowledge mobilization tools used. Financial incentives have been offered by federal and provincial governments, conservation authorities and some private organizations (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020). However, the economic costs and benefits of practices have not always been identified in the design of these learning resources and financial incentives.

A growing body of literature includes the economic effects of soil health practices, but applicability to Southern Ontario is much more sporadic, with adaptations from similar growing conditions, such as those of nearby US states, being necessary. For example, in the US, the American Farmland Trust (2021), the Soil Health Institute (2021a; 2021b) and Soil Health Partnership (2021) have all released farm-level case study or state-level data on some soil health practices. Larger scale aggregate economic information for a variety of practices is present in Yanni et al. (2021) for Ontario and for regions in Canada (De Laporte et al., 2021a). Some practice specific literature has been recently released for Ontario, including studies on nutrient management in Ontario (De Laporte et al., 2021b), split N application at Elora (Kabir et al., 2021), cover crops (Chahal et al., 2020), and crop rotation (Janovicek et al., 2021). However, other sources exist, and the available information has not been particularly well synthesised to be accessible to most Ontario farmers. Furthermore, there is insufficient financial information about many practices and further research is required. Additionally, some private, often non-monetized, costs and benefits of soil health practices, including changes in labour, management, and planning time affecting the balance of off-farm work, along with mental health, have not been well considered.

Given this context, the purpose of this project is to examine available academic and extension data and research on selected soil health practices in Ontario, including relevant information from comparable jurisdictions, to guide farm decision-making on well-studied practices, reveal potential gaps in information, and guide future research, policy, and program design. The specific objectives are to:

1. Synthesise currently available information on the economic costs, savings and benefits associated with the adoption of selected soil health practices, translating data into relevant and comparable timeframes across methods of analysis;
2. Use the costs and benefits identified to estimate the on-farm effect of adopting soil health practices in Ontario, by commodity and production system, allowing the subsequent production of extension fact sheets and other materials;
3. Identify and assess the knowledge gaps regarding soil health practice adoption by commodity or production system, and soil-climate region, in general, and for Ontario; and
4. Provide recommendations on the approaches and methods that should be used to undertake an empirical inventory of the costs and benefits of insufficiently studied soil health practices in Ontario, in conjunction with potential additional stakeholders, researchers and partners.

This project uses current knowledge on quantified costs and benefits while recognizing that many costs and especially benefits remain unquantified. Thus, the analysis represents a launching point to encourage further conversation and the estimates are likely conservative in nature and will evolve with new knowledge. It is hoped that this work continues this crucial conversation and stimulates further research documenting costs and benefits.

1.1 Selected Soil Health Practices for Ontario

Based on previous reviews (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020.), six soil health practices were targeted for analysis in the Ontario context. These are: 1) tillage intensity; 2) cover crops; 3) diverse crop rotations; 4) nutrient management; 5) organic amendments; and 6) rotational grazing. These practices were selected based on their relative perceived ease of implementation, financial feasibility, effectiveness for soil health improvement, and rate of adoption in Ontario.

Tillage breaks down complex structures in the soil, creating a higher quality seed bed, but also contributes to the loss of carbon through enhanced organic matter decomposition, erosion, and reduced soil aggregate stability. Therefore, reducing tillage may help maintain, for example, carbon levels in the soil, leading to healthier soils. From a cost standpoint, tillage is a machinery (and labour) heavy operation and lowering tillage intensity should decrease planting costs. However, the impact on yields and revenues of this practice remains uncertain.

Cover crops can increase biological activity, biomass (and carbon) input to soil, and provide ground cover that can reduce erosion, increase moisture retention and infiltration, and reduce pest and weed pressure. Planting cover crops, however, requires additional seed, labour, planting, and termination expenses. Cover crops may also affect yields, leaving the net effects uncertain.

Diverse crop rotations are also beneficial for soil health, especially in terms of soil quality measures of soil carbon and aggregate stability, providing benefits such as reduced pest pressure and yield stability. Crop rotations can be costly to the farmer if the expected net returns from the additional crops in the rotation are lower than those of the best performing crops. However, if crop rotation increases the yield of these other crops and yield stability from year to year, then crop rotation can increase net farm revenues.

Nutrient management can lower greenhouse gas emissions, reduce runoff, and improve soil biological communities. 4R (right time, right source, right rate, right place) nutrient management practices can increase or decrease costs and may impact yields. There are many different combinations of practices under this nutrient management umbrella, likely resulting in a range of changes in net return, depending upon the combination selected.

Organic amendments, such as manure and compost, have the advantage over chemical or mineral fertilizers of also adding carbon and a direct injection of diverse microbes to the soil. Economic benefits of the added carbon and diverse microbes are not well documented. While manure can be beneficial to soil carbon and microbial communities, acquiring manure can be locationally dependent. The costs of the product are often lower than mineral fertilizers, but the transportation costs are higher, making changes in net revenue dependent upon availability and the nature of the farm operation.

Rotational grazing has the potential to improve grass management, resulting in greater biomass yields, soil carbon, and soil biodiversity. These benefit grazing cattle and allow higher stocking rates. However, there are upfront capital costs of paddock installation, and management and labour costs increase.

Each of these selected practices have the potential to increase soil health, and they can also increase farm net returns. We will examine the business case for each of these soil health practices in the subsequent sections of this study.

1.2 Methods

The methods used to assess the business case for soil health include literature review and synthesis, multi-year farm financial modelling, and gap analysis. The economic analysis employs a model farm that is representative of Ontario in costs of production and yields. Based on overall enterprise budgets defined below in Table 1.2.1 and Table 1.2.2, this analysis considers partial budgets for the financial effects that the adoption of each of the practices has on the overall enterprise. Partial budgeting allows the changes in net returns to be calculated for each practice. The study area of this report is centered in Southern Ontario, home to Ontario's Greenbelt.

Literature review and synthesis were used to extract the potential range of costs and financial benefits that adopting each of the selected practices entails. These costs and benefits were then compared to a representative Southern Ontario farm to derive a range of changes in net returns for adopting these practices in Southern Ontario, using partial budgeting techniques.

The representative model farm assumes a set of baseline practices. For the crop portion of the farm, the basic rotation is corn-soybean. The enterprise budgets for these crops, grown conventionally, are given by OMAFRA (2021a), summarized in Table 1.2.1. This table also includes an enterprise wheat budget for use in the analysis of crop rotations. A representative cow-calf enterprise budget is also presented (Table 1.2.2). The use of model enterprises for Southern Ontario allows the calculation of representative financial effects for the region also using partial budgeting techniques.

Methods used here suit the data available and differ from those used in recent economic analysis in the US by the Soil Health Institute, American Farmland Trust, and others, which employ farm case study data from in-depth interviews and surveys. Similarly, partial budgeting is then done on these case studies; however, this depth of information is not available for Ontario.

Table 1.2.1 *Enterprise budgets including variable and fixed costs for conventional Roundup Ready corn (174 bu/ac), non-GMO soybeans (47 bu/ac) and soft red winter wheat (87 bu/ac) production in Ontario (OMAFRA, 2021a).*

	Expense ($/ac)	Corn (174 bu/ac)	Soybean (47 bu/ac)	Wheat (87 bu/ac)
Variable Costs	Seed	$111.10	$65.35	$69.45
	Nitrogen	$75.95		$64.10
	Phosphorous	$29.80	$16.60	$21.40
	Potassium	$18.00	$24.40	$11.75
	Fertilizer Application	$12.00	$12.00	$12.00
	Chemical	$25.25	$69.90	$55.55
	Chemical Application	$11.00	$11.00	$33.00
	Fuel	$37.85	$28.60	$28.60
	Maintenance	$26.15	$26.45	$24.85
	Marketing	$1.75	$1.80	$1.90
	Risk Management	$19.10	$11.60	$14.00
	Drying	$96.95		
	Trucking	$39.85	$11.50	$21.30
	Storage	$41.60	$12.00	
	Labour	$15.30	$12.65	$12.65
	Operating Interest	$9.70	$5.25	$10.60
Fixed Costs	Depreciation	$39.75	$38.75	$37.85
	Interest	$12.55	$13.55	$13.25
	General	$4.40	$6.00	$5.85
	Total Cost	**$628.05**	**$367.40**	**$438.10**

The costs listed in Table 1.2.1 reflect the expected costs of production entering the 2021 growing season. Over the course of the past year, looking forward to the 2022 growing season, the prices of many commodities have begun to spike. Fuel costs have increased, leading to increases in the estimated (custom) costs of production for field operations. Grain drying will likely increase in costs with increases in natural gas. US fertilizer costs have doubled from roughly $0.50/lb to around $1/lb (Quinn, 2021). The prices of grain crops, which also move with commodity markets, have also risen.

For beef cattle, the study assumes a cow-calf operation employing continuous grazing on tame pasture. In the base model, from OMAFRA (2020) the cows are kept on pasture for 155 days, with the remaining 210 days on a ration of mostly hay. Calves are kept until approximately 625 lbs, with an expected sale price of $1.98/lb (Ontario Beef, 2021). The baseline herd size is 95 cows on approximately 160 acres (a quarter section). The total costs per head for the herd are given in Table 1.2.2.

Table 1.2.2 *Costs of maintaining a representative Ontario cow-calf operation in dollars per head (OMAFRA, 2020).*

Cow Herd Costs	Cost ($/hd)
Winter Feed Cost	$749
Pasture Cost	$121
Health Expenses	$80
Breeding	$60
Marketing/Trucking	$40
Yardage	$118
Interest	$26
Replacements	$103
Total Cow Costs	**$1,297**

2

The Costs and Benefits of Adopting Soil Health Practices in Ontario

Photo courtesy of Credit Valley Conservation

2.1 Tillage Intensity

Determining the profitability of reducing tillage intensity to improve soil structure and health requires an understanding of the short-term yield changes and management costs. **For corn and soybeans, switching to no-till saves $36/ac and $27/ac, respectively, based on mean operating costs from across Ontario** (Table 2.1.1) (OMAFRA, 2021a). The costs savings are primarily due to lower equipment costs, which include depreciation, fuel consumption, and repairs. However, there are costs which increase due to an increased herbicide requirement for weed control.

Table 2.1.1 *Differences in crop production costs ($/ac) under conventional and no-tillage management.*

	Corn		Soybeans	
Expense ($/ac)	**CT**	**NT**	**CT**	**NT**
Fuel	38	21	29	19
Repair	26	15	26	14
Labour	15	8	13	9
Depreciation	40	22	39	21
Interest	13	7	14	7
Herbicide	25	37	14	27
Custom Work	23	34	23	34
Subtotal	**180**	**144**	**157**	**130**

The reduction in fuel, labour, and equipment costs, may come at the cost of short-term declines in production. While changing tillage methods can also involve upfront capital costs, the costs of the tillage practices have been estimated using sustained average and custom costs. Furthermore, incentives for no-till or reduced tillage equipment acquisition and modifications have been offered for decades under federal and provincial agri-environmental programs. Some meta-analyses find that reduced and no-till lower yields, at least initially (Pittelkow et al. 2015; Toliver et al. 2012; Van Kessel et al. 2013). However, authors observed greater yield losses in arid conditions than in humid regions such as Ontario.

Different crops respond differently to tillage intensity. Pittelkow et al. (2015) found a 7.6% reduction in corn yield and a 2.6% reduction in wheat yield. Similarly, other meta-analysis by Ogle et al. (2012) and Toliver et al. (2012) found no-till to lower corn yields. A focus on more regionally relevant studies leads to competing findings regarding yield changes. Field trials in Ottawa by Morrison et al. (2017) found switching to no-till increased corn yields in the first year with no significant yield differences in the years following. Further East into Quebec, Almaraz et al. (2009) observed similar corn yields after the first year, with greater no-till yields after just 2 years, possibly due to increased moisture. Conversely, field trials in Elora, Ontario found no-till lowered first-year corn yields by roughly 8% compared to conventional tillage, in a corn-corn-soy-soy rotation, but only 3% in a more diverse corn-corn-soy-wheat rotation (Janovicek et al. 2021). In Michigan, Grandy (2006) found slight increases in corn yields, but only in some years. In Illinois, Benhke (2018) found no yield differences for corn or soybeans between no-till and chisel plowing.

For soybeans, meta-analysis consistently finds small, non-significant reductions to soybean yields. (Pittelkow et al., 2015; Ogle et al., 2012; Toliver et al., 2012). Janovicek et al. (2021) find modest reductions of 7.6% in soybean yields under no-till in Elora, but slight improvements in Ridgetown, Ontario. The results from Elora are consistent with observation by Al-Kaisi et al. (2016) in northern Iowa. Across all crops, the returns to tillage are dependent on time. Over time, initial reductions in yield lessen in wheat, corn, and legumes (Pittelkow et al., 2015).

Due to the heterogeneity of soil textures and climate across Ontario, the business case for no-till is likely spatially dependent. Shakoor et al. (2021) found yield responses to no-till to be more positive in coarse soil more negative under finer textured soils. These soil-specific findings support previous work which attributed reduced yields in response to no-till to waterlogging and poor establishment (Rusinamhodzi et al., 2011).

In addition to the discussion surrounding no-till and conventional tillage, there are alternative methods of conservation tillage. For example, rotational tillage involves planting no-till corn or wheat into soybean ground, but then more aggressive tillage to break-up corn stalks and straw. Situational tillage passes may be necessary, particularly due to compaction events following wet harvesting conditions.

Strip tillage is a unique reduced tillage system where only a narrow strip for the seed bed is prepared. Vetsch et al. (2007) finds four-year average corn yields are highest under strip till (ST) with little difference between ST, spring-cultivation (SC), and no-till. Multiple articles and farmers featured in the "Strip-Till Farmer" mention increased water-use efficiency, particularly important for irrigated crops with high water costs or regulation; labour and fuel savings; and greater soil health. Switching to strip-tillage often requires investment into new equipment which may slow uptake. However, in a recent strip-till survey with most respondents in the corn belt, 26% of respondents were doing so for the first time (Gerlach, 2021). In general, OMAFRA (forthcoming 2022) estimates that strip till on corn costs approximately $37/ac less than conventional tillage and $18/ac more than no-till. Anecdotally, many ST growers feel that they do not experience yield loss (and may even experience situational gain) when converting from conventional or full width tillage (personal communication, OMAFRA specialists). Therefore, ST appears to be worth serious future consideration.

2.2 Cover Crops

The net returns of cover cropping largely depend on the species, the number of years, and the value the farmer places on future productivity (Arbuckle and Roesch-McNally, 2015; Bergtold et al. 2019; Schuurman, 2021). In a recent study of cover cropping in Ontario, Morrison and Lawley (2021) found that cover cropping does occur after (or intercropped with) soybean and corn, but mostly occurs after wheat. Respondents identified common cover crops, including oats (~63%), rye (~41%), radish (~38%), red clover (~31%), and forage peas (~28%), with about 60% of farmers employing multi-species mixes. Farmers in this survey did indicate trends toward more incorporation of mixes over time. Similarly, over 60% of all cover crop users surveyed in the United States employ cover crop mixtures, with the majority using between 2 and 4 species (SARE, 2020). There are limited long-term studies examining the use of legumes alone on crop yields.

The upfront costs can pose a barrier to adoption as the N credits from fixation (in the case of legumes) and/or residual biomass are not realized until the following cropping seasons, and yield benefits from improved soil health require multiple years. The establishment costs of planting red clover and rye, for example, as cover crops include the seed and planting (Table 2.2.1). Seed prices range with differences in quality and species, from $2.5/lb to $4.5/lb for red clover (Hoorman, 2015; MARD, 2020), and $0.3/lb to 0.5/lb for rye (Schnitkey et al., 2018a; Swanson et al., 2018). Roughly 70% of farmers surveyed in Ontario who seed red clover use 6.2-8 lb/ac (Ogilvie et al., 2020). However, our budgeting includes a higher seeding rate for red clover of 10 lb/ac where farmers report less issues with stand uniformity (Hoorman, 2015; Ogilvie et al., 2020). For rye, the seeding rate ranges from 20-80 lb/ac (OMAFRA, 2019; Schnitkey et al., 2018a) with recommendations suggesting over 20.3 lb/ac (Swanson et al., 2018). These seed costs compare favourably to a recent survey of Ontario cover cropping (Morrison and Lawley, 2021), where the mode seed cost was between $16/ac to $20/ac, with the average being somewhere above that, likely between $21/ac to $30/ac.

In Ontario, custom broadcast seeding costs $6/ac, while direct drilling costs $25/ac (OMAFRA, 2019). An Ontario-based survey found 97% of producers using red clover broadcast seeded in spring (Ogilvie et al., 2020). Rye and mixtures of cereals and legumes are typically drilled, raising the cost of establishment in comparison to red clover (OMAFRA, 2018).

Cover crops can by terminated in the fall or spring either mechanically or with herbicides, such as dicamba and glyphosate. OMAFRA estimates the cost of burndown herbicide to be $14.3/ac ($31.51/ha) and custom application to be $11.2/ac ($24.71/ha), with mechanical costs from $5/ac to $13/ac. The costs of establishment and termination are likely quite variable across Ontario with the greatest differences arising from seeding rate and custom operating costs (Table 2.2.1).

Table 2.2.1 *Breakdown of cover cropping costs between a legume, a cereal, and a two-way mix.*

	Red Clover (Legume)			Rye (Cereal)			Mixed (50/50)		
	Low	Mean	High	Low	Mean	High	Low	Mean	High
Seed ($/lb)	2.5	3.5	4.5	0.3	0.4	0.5	0.82	0.85	0.94
Seed Rate (lb/ac)	6.2	8.6	10.0	20.0	50.0	80.0	13.1	29.3	45.0
Seed ($/ac)	15.5	29.9	45.0	6.0	20.0	40.0	10.8	25.0	42.5
Seeding ($/ac)	4.0	6.0	8.0	19.8	25.0	30.2	4.0	6.0	8.0
Termination ($/ac)	5.0	17.0	25.5	5.0	17.0	25.5	5.0	17.0	25.5
Total Cost ($/ac)	**24.5**	**52.9**	**78.5**	**30.8**	**62.0**	**95.7**	**19.8**	**48.0**	**76.0**

Cover crops provide many soil health benefits which increase productivity, decrease inputs, and decrease risk of crop failure under adverse weather conditions. Legume cover crops biologically fix nitrogen which can be credited for a subsequent nitrogen-requiring crop such as corn or wheat.

Studies of red clover estimate 39 to 87 lb N/ac (44-98 kg N/ha) may be available for the following crop (Coombs et al., 2017; Thilakarathna et al., 2015; Vyn et al., 2000). Hairy vetch can supply 35 to 200 lb N/ac (40 to 224 kg N/ha) (Lu et al., 2000; Sievers and Cook, 2018). While cereals such as rye may scavenge 24 to 51 lb N/ac (SARE, 2013) and have a cumulative contribution of nearly 35 lb N/ac over the growing season, the N released in the first four weeks is less than 10 lb/ac (Sievers and Cook, 2018). In concert, Pantoja et al. (2015) finds no significant influence of a rye cover on corn nitrogen requirements.

> **In addition to fertilizer savings, yields may change following cover crop inclusion. The type (legume or cereal) or mixtures of cover crops influence yield changes differently.**

Rye is a common cover crop used in corn and soybean rotations; however, its role on yield improvements is limited. De Bruin et al. (2005), Pantoja et al. (2015), and OSCIA (2020) found no change in soybean yield following rye cover. Wheat yield following rye decreased in a study in Colorado and Nebraska by Nielsen et al. (2016) but rose in a Kansas study (Blanco-Canqui et al., 2012). Pantoja et al. (2015) found corn yields to decrease by 6%; however, Miguez and Bollero (2005) and Bourgeois et al. (2021) found no significant corn penalty in their meta-analysis.

Miguez and Bollero (2005) and Basche et al. (2016) find limited effect of a rye cover on corn yields. Rye grown following corn increased soybean yields by 2.5% to 9.8% (Moore et al., 2014). Soybean yields following a rye cover crop grown after corn was not significantly different in a study out of Minnesota (De Bruin et al., 2005). Further, corn yields may decline in rye cover cropping systems (Thelen and Leep, 2002). However, proper termination methods can maintain (Kreuger et al., 2011; Patel et al., 2019) or even improve (Duiker and Curran, 2005) corn yields.

Field trials in Elora found no difference in soybean yields and a slight increase in corn yields in a four-year rotation (CCSW+rc) which included legume cover crops (Janovicek et al., 2021; Chahal et al., 2021). Under future climate projections, Jarecki et al. (2018) predict the greatest yield increases under diversified rotations which include a legume cover crop. This suggests the combination of the two soil management practices may have synergistic benefits over the long-term.

A study based in Michigan found legume cover crops to positively influence corn, soy, and wheat yields (Smith et al., 2008). A survey conducted by Sustainable Agriculture Research and Education (SARE) and the Conservation Technology Information Center (CTIC) in 2015 and 2016 found increased years of cover cropping elevated corn and soybean yields. Corn and soybean yields rose 0.5% and 2.1% after a single year of cover crop use, 1.8% and 2.5% after three years; and 3% and 5% after 5 years. A key finding of their survey was the reported crop yields in the drought year of 2012, where fields with cover crops had 6% higher corn yields and 11.4% higher soy yields than farms with no cover crops (CTIC, 2016).

Mixtures of multiple different functional types of cover crops provides promising ecosystem service benefits (Finney and Kaye, 2017). Chu (2017) found an increase in soybean yield using multi-species mixtures in Tennessee. In a meta-analysis, Marcillo and Miguez (2017) found legumes increase subsequent corn yields more than mixtures and cereals, with cereals having no significant effect. Conversely, Hunter et al. (2019) found no effect of cover cropping on soy or wheat yields with a multi-species mixture. Consistent with studies on rye, they found mixtures with more grasses had larger negative influences on crop yields.

The weed control ($13/ac to $32.5/ac), erosion repair ($2.6/ac to $5.2/ac), and soil compaction ($19.89/ac) of cover crops have been estimated by SARE (2019). Weed control can provide direct cost savings, but soil compaction reduction and erosion repair benefits are non-cash. Additional benefits to cover crops do exist, including grazing and potential harvest. However, these benefits were not included in this calculation due to the relatively less certain and less applicable assessment of these benefits.

2.3 Crop Rotation

Corn and soybean rotations are commonly practiced in much of Ontario and across the Corn Belt, primarily due to their high market value. Over the long-term, this rotation reduces soil organic matter and lowers crop yield potential (Gaudin et al., 2015). Compounded with uncertainty in precipitation and greater evaporative demand under the changing climate, improving water drainage and water holding capacity is of increasing benefit. Renwick et al. (2021) found rotation diversification to reduce corn yield losses due to drought by 17%. Improved soil organic matter and structure provide multiple economic benefits to a farmer.

Most of the acreage in the United States and Canada employs some form of rotation between crops, with only 8% of acres engaged in monocropping (Plourde et al., 2013). While continuous corn was relatively common a generation ago in Ontario, advances in soybean varieties and yields have resulted in corn and soybeans becoming the dominant annual crops grown in the province. In Ontario, soybeans constitute roughly 35% to 40% of cropped acreage and corn 30% to 35% (OMAFRA, 2021b). Rotational diversification beyond corn-soy is limited in many regions, although forage crops and winter wheat tend to be more prevalent in livestock and dairy regions. Over the past few decades, the presence of small grains, including oats, barley, and mixed grains in crop rotations continues to decline (OMAFRA, 2021b). **While the business case for increased diversification to improve soil health is strong in the long-term (Bowles et al., 2020; Gaudin et al., 2015; Janovicek et al., 2021) due to increased crop yields and risk reduction, the benefits are more difficult to establish in the short-term.**

> **"Following diversification with winter wheat, corn and soybean yields typically increase to higher sustained levels.**

From field trials in Elora, Ontario, first-year corn yields in a corn-corn-soy-wheat (CCSW) rotation were roughly 2% higher than in a corn-corn-soy-soy (CCSS) rotation when conventionally tilled (CT) and 7% higher under no-till (NT) between 2002 and 2020 (Janovicek et al. 2021). Similar findings are observed outside of Ontario. In Wisconsin, Kazula and Lauer (2018) find corn yields in a corn-soy-wheat (CSW) rotation were 8% higher than in a corn-soy (CS) rotation. At a corn price of $5.33/bu, diversified rotations increase corn revenues by $21.23/ac ($52.46/ha) under CT and $55.20/ac ($136.4/ha) under no-till.

Soybean yields also see a significant benefit from diversification. When winter wheat was included, soybean yields rose 12% (5-6 bu/ac) under both tillage protocols in Elora (Janovicek et al., 2021). This observation is supported by estimates of 6 bu/ac (15 bu/ha) by Kazula and Lauer (2018) in Wisconsin. Similar results are observed by Lehman et al. (2017) who find rotating corn and soy (CS) with field peas and wheat (CPWS) increases soybean yields by 22% in South Dakota. However, results to the contrary are also present. Lund et al. (1993) did not find soybean yields to change upon inclusion of wheat.

These results raise the question - if corn and soybean yields are consistently higher, why are more farmers not using diverse crop rotations?

One of the primary limiting effects is the opportunity costs, or foregone income, farmers face in the first year they plant an alternative grain crop. Across the counties of Southern Ontario, the opportunity cost of planting wheat instead of corn ranges from $260/ac to $380/ac making the transition a substantial investment. Furthermore, this difference can be exacerbated by changes in prices and only grows wider when grain prices increase. To offset these issues, a few jurisdictions offer an incentive to include a small grain in rotations such as that offered by the Practical Farmers of Iowa (PFI, 2021).

Dairy and pork producers also grow extensive crops for feed. For example, crop rotations for dairy production tend to include silage corn and alfalfa, with alfalfa having significant soil health benefits. Nevertheless, diverse crop rotations for these feed crops can also be beneficial (Rotz et al., 2002). Future research could explore these topics.

2.4 Nutrient Management

This report considers 4R nutrient management (right timing, right source, right rate, and right placement) practices due to their widespread recognition. **The specific 4Rs considered include split N application (right timing), enhanced efficiency N fertilizer additives (right source), recommended N rates (right rate) and variable rate N application (right placement).** In general, financial incentives and extension support for crop nutrient planning has been available for quite some time from federal and provincial governments.

Right Timing

Timing is an important aspect of N application, as N is subject to loss if not used by the crop. Applying a portion of N closer to critical growth stages, such as traditional sidedress timing at vegetative growth stage three to four (V3-V4) up to around silking for corn, can increase N use efficiency and reduce N_2O emissions. Delayed and split N applications aim to match crop N supply and demand. However, this does not necessarily increase yield; rather, split N appears to have no statistically significant effect on corn yield when total crop N rates remain constant (Blandino et al., 2015; Fernandez et al., 2020; Nasielski et al., 2020).

The costs of split N can be equivalent to the cost of an extra application pass, which can be estimated using the custom rate of $12.00 ac–1 (OMAFRA, 2020). It is not clear if the specific timing of the second application affects this cost. It may be more costly to apply N at later stages, as high clearance equipment is needed, and the farmer risks additional crop damage. For example, application at vegetative growth stage six (V6) may be less costly than at stage thirteen (V13), but it is hard to estimate as custom application at V13 is rare.

Previous studies have found that split N application can increase profit (Lesoing, 2014) or decrease profit (Nafziger and Rapp, 2020), likely due to a host of soil and weather factors. The most relevant split N study to Ontario is Kabir et al. (2021), which estimates the potential changes in net return from split N application using modeled data calibrated to field trials at Elora, Ontario. This study shows that the yield changes from split N on Corn, applied at either vegetative stage six or thirteen, with fixed total N application, across various weather scenarios, range from -1.2% to +3.7%. However, by changing the N rate (applying less N in dry weather and more N in wet weather), split N application increases profit between 14.6% and 19.5% in dry conditions and between 1.4% and 15.7% in wet conditions.

Given the potential for lost yield should weather or logistics interfere with split application, the US has recently offered conservation insurance for this practice (USDA, 2021). Conservation or BMP insurance has been tried in several US and Canadian jurisdictions to reduce the risk of adopting nutrient management practices (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020).

Right Source

The source of N can influence profit, with different sources being more, or less, expensive, easy to apply, or prone to loss to the environment. Switching between sources often results in increased costs in the absence of custom application. Changes to source include nitrification and urease inhibitors, which are additives that attempt to slow the release of bioavailable N to synchronize with plant uptake phases (Tosi et al., 2020). Agrotain Plus™, a prevalent combined urease and nitrification inhibitor additive, resulted in yield changes from –6.4% to 2.5%, with an average of –1.4%, on Ontario wheat in a year with late application (OSCIA, 2015). Drury et al. (2017) identified yield increases between 0.3% to 9.3% on Ontario corn.

The costs of these additives are difficult to estimate due to varied pricing and relatively uncertain optimal use rates. Yanni et al. (2021) estimates the costs of N additives between $16/ac and $32/ac, with a single additive closer to the lower end and a combined product closer to the upper. As the inhibitors are added to the fertilizer mixture before application, there are no additional application costs.

Right Rate

The yield and revenue responses of grain crops, including corn, to N application have been found to be relatively flat, overall (Pannell et al., 2019). Therefore, modest N rate reductions likely cause small yield losses, which could increase net returns because N application is costly. Even larger reductions in N rates could have small effects on net returns, along with large environmental benefits. For example, an 18 lb N/ac reduction from (152 to 134 lb N/ac [11.8% decrease]) results in no yield loss on corn in average conditions (Yanni et al., 2021). Furthermore, coupled with other 4R practice adoption, an average reduction in N rate from 157 to 111 lb N/ac (46 lb N/ac [29.3% decrease]) may result in average corn yield losses of about 1.1% across the province of Ontario over 30 years of weather (De Laporte et al., 2021b). In Nebraska, N rate reductions of 36 lb N/ac result in yield losses of 2.8% in a corn-soybean rotation (Wortmann, 2019). In specific high yield years, lowered N rates may have a greater effect on yield loss. Conversely, in poor yield years, lowered N rates are likely to result in no yield loss and be financially beneficial.

With relatively small costs from yield decreases, the financial benefits of N rate reduction can be positive, depending on the price of N fertilizer. More specifically, OMAFRA (2021a) estimates N prices at $0.50/lb. However, these prices have increased since the time of this publication. When the price of grain remains constant, higher N prices imply lower N application levels are financially beneficial and economically optimal. As the prices of grain have also risen, it is less clear what the economically optimal N application rate is at this time.

Right Placement

Right placement of N fertilizer considers the methods used to apply fertilizer. For example, broadcast versus injection can have little effect on the cost of application but can have large environmental consequences (De Laporte et al., 2021c). Variable rate application techniques have the potential to increase input use efficiency by optimizing rates based on spatial field needs.

Initial costs of adopting variable rate application include the technology and management; however, in the long run, as computer software and technology are integrated into new equipment, costs are unlikely to be that much higher than current levels. There will be ongoing technical costs, including the production and maintenance of precision maps and enhanced soil testing. The cost of soil sampling services is estimated at $12/ac for an unclear number of cores (OMAFRA, 2019) and at $3.38/ac for 5 samples on a minimum 140 ac field (SWAT MAPS, 2021). General agronomic services cost approximately $1.25/ac, while the cost of prescription map creation is $7.37/ac (SWAT MAPS, 2021). The annual cost of precision agronomic services lowers considerably once fields have been mapped, until they need renewal.

In Ontario, Zhang (2020) found that variable rate N application on corn increases yield between 2.0% and 4.4%, leading to revenue increases of between 7% to 9%. However, if variable rate is not properly implemented, yield losses of 2.1% can occur.

2.5 Organic Amendments

Organic amendments to soil, including animal manure and compost, have the potential to reduce fertilization costs, improve soil organic matter and structure, but could also change application costs, increasing them if new application equipment is required. Furthermore, due to uneven nutrient contents, additional costs could be required to lessen the risk of misapplication, including the use of in-line sensor systems or other nutrient level tests. Both manure and compost can cause increased transportation costs, as they can be bulky and much less mineral dense than chemical fertilizers (Araji et al., 2001). Furthermore, when there are nutrient management restrictions on manure, without available land to spread nearby, it can become a waste product (i.e., there is a need to pay for its removal) at greater transportation distances (Weersink et al., 2004). This can increase the availability and lower costs in particular regions.

Manure has the potential to both increase and decrease the cost of fertilization, depending upon the animal source and the distance transported.

Araji et al. (2001) estimate that manure costs range from 18% to 136% of the cost of mineral fertilizers, with chicken manure on the lower cost end and cow manure on the higher end. Chicken manure breaks-even with mineral fertilizer up to 22 miles away, with cow manure only breaking-even on-site. P-enriched compost increases corn (12% to 18%) and wheat (17% to 24%) yields, compared to single superphosphate fertilization in alkaline and calcareous soils (Majeed et al., 2018). Other studies show that compost can be as effective as mineral fertilizer, depending upon the rate applied (Mamo et al., 1999; Smiciklas et al., 2008; Wolkowski, 2003).

Manure and other organic amendments have the potential to increase the yield of various crops. However, studies of this effect have been mixed. For example, no significant effect on crop yield was found in meta-analyses of European crops (Hijbeek et al., 2017), but increased crop yields were observed in China (Du et al., 2020; Cai et al., 2019). Given the lack of research for Ontario, we did not include any specific parameters for organic amendments as there is insufficient currently documented, specific, and quantifiable yield benefit to soil.

Financial incentives are sometimes offered for organic amendments to offset these types of costs. For example, under the Canadian Agricultural Partnership, the cost, transportation, and custom application of manure may be eligible, as may be equipment modifications to improve manure application.

2.6 Rotational Grazing

Rotational grazing is a livestock management practice that aims to increase the productive capacity and resilience of pasture. It allows for proper rest and regeneration of grasses, potentially allowing for greater forage and livestock production compared to continuous grazing (Teague et al., 2013). There is a range of management practices that can be considered under the umbrella of 'rotational grazing', including the number of paddocks, the frequency of movement, and changes to the stocking rate. **In general, this report considers going from a single enclosed paddock to a minimum of eight paddocks built within the confines of the original paddock, using natural pasture.** It does not consider non-continuous pasture placement. It also does not consider moving from grain to grass as the primary source of feed. The discussion focuses mostly on beef cattle, less on dairy cattle, and not on other grazing livestock.

The benefits of rotational grazing strategies compared to continuous ones are not well defined. Some academic studies indicate that there are no statistically significant differences in forage and livestock production between them (Briske et al., 2008; Manley et al., 1997), while others observe that rotational grazing is perceived to be beneficial, including in farmer surveys (Teague et al., 2013; Wang et al., 2021). This may be due to differences in ranch-specific conditions, including land tenure, farmer and neighbour characteristics, and topography (Chowdhury et al., 2020), or soil and climate heterogeneity (Wang et al., 2021).

From an economic perspective, this lack of clarity on the productivity effects of the practice leaves mixed results too. Rotational grazing may be cheaper than confinement for diary (Rust et al., 1995) and adoption has increased over time (Winsten et al., 2010). For beef cattle, the adoption of rotational grazing amongst producers may exceed 50% of farms (Wang et al., 2021). However, some studies have found no significant economic effects between grazing strategies (Beck et al., 2016; Harmel et al., 2021; Manley et al., 1997), mixed results (Windh et al. 2020), and benefits (Wang et al., 2018). However, many of the economic benefits may relate to changes in reasonable stocking rates (Windh et al., 2019), where rotational grazing has an advantage over continuous grazing. Furthermore, farmers perceive economic benefits from rotational grazing, including up to a 20% increase in net returns (Sitienei et al., 2019). Financial incentives for rotational grazing in Ontario have existed under a variety of programs including the Canadian Agricultural Partnership, Species at Risk Financial Incentive Program, and others, covering items such as fencing and watering systems.

Switching from continuous to rotational grazing of any type involves up-front capital costs related to fencing and water installation, followed by maintenance costs and long-term management labour. In Manitoba, total costs have been estimated at $15.67/ac, over a 20-year lifespan for a 4-paddock quarter section (160 ac) (MARD, 2020). In South Dakota, over 30 years, Wang et al. (2018) found pasture capital and maintenance costs ranging from $1.19/ac/yr to $4.12/ac/yr (mean=$2.37/ac/yr).

From the above discussion, rotational grazing allows increased stocking rates. According to Wang et al. (2018) the annual average 30-year benefits of rotational grazing range from $1.43/ac/yr to $19.40/ac/yr across stocking rates from 15 to 55 steers per 247 ac. The net benefits listed here are all positive, although lower for lower stocking rates.

Another important benefit of rotational grazing is increasing the number of days available for grazing. This results in an effective increase in forage production. According to Wang et al. (2021), rotational grazing between 5 and 15 paddocks increases the available forage days by 7, while management intensive grazing (16 or more paddocks) increases forage days by 39.

Photo courtesy of Credit Valley Conservation

3

The On-Farm Effects of Soil Health Practices on Ontario Farm Returns

3.1 Tillage Intensity

The returns to reducing tillage intensity depend on the duration for which the practice is maintained. In the first couple years, the fuel, labour, and maintenance savings are offset by yield reductions. **After several years, reduced tillage is expected to be profitable in corn-soy rotations due to smaller yield reductions over time (Table 3.1.1).**

Table 3.1.1 *The difference in returns from conventional and no-till based on a corn-soybean rotation ($/ac).*

		Year 1		Year 3		Year 5	
		Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)		-9	-5	-5	-4	-2	0
Revenue Change ($/ac)	High	-56.40	-11.70	-31.30	-19.50	-31.30	0.00
	Low	-93.30	-15.50	-51.90	-25.90	-51.90	0.00
Cost Savings ($/ac)		36.00	27.00	36.00	27.00	36.00	27.00
Crop Net Return ($/ac)	High	-20.40	15.30	4.70	7.50	4.70	27.00
	Low	-57.30	11.50	-15.90	1.10	-15.90	27.00
Mean Rotation Net Return ($/ac)		**-12.70**		**-1.00**		**10.70**	

The results presented in Table 3.1.1 use provincial averages for yield and inflation corrected prices from 2012-2020. The range is the result of one standard deviation adjustments in historical prices and mean crop yields. The trade-off between cost savings and yield losses depends on productivity, soil type, local climate, and crop prices. The business case for tillage will be stronger for less productive areas due to smaller initial yield penalties and reduced erosion on these more marginal lands. Similarly, tillage is moderately more beneficial for coarse soils than fine soil suggesting the optimal choice may be at the field-level (Shakoor et al., 2021). In general, land managers in Ontario can expect smaller yield reductions due to the humid climate conditions in comparison to the more arid regions such as the prairies or great plains (Pittelkow et al., 2015).

Changing prices of crops can change some of the analysis here. For example, when crop prices are high, initial yield losses have a greater value. Especially if crop prices fall later in the process, prices introduce an element of risk to the adoption of long-term soil health practices. Given the cash flow described in Table 3.1.1, the time to break-even is approximately 5.5 years.

Summary of Findings

Tillage reduction appears to be a less variable practice, with a small range in net returns and small gains or losses.

3.2 Cover Crops

As discussed in Section 2.2, the net benefits to cover cropping can be initially negative due to the up-front investment, but they become more positive in subsequent years as yields and soil benefits increase. From the discussion of cover crop trends in Ontario (Section 2.2), due to the prevalence of mixes and grasses like oats and rye, this section presents analysis on a single cereal and a mixture.

Due to no yield change and nitrogen savings for soybean, the cereal (rye) analysis focuses on a single year of corn (Table 3.2.1), whereas the two-species mix appears to have yield benefits that accrue over time (Table 3.2.2).

Table 3.2.1 *The change in net returns from cover cropping rye into corn ($/ac), assuming 10 lb N supply from cereal rye residue.*

	Corn		
Costs	**High**	**Moderate**	**Low**
Costs ($/ac)	95.70	62.00	30.80
Benefits	**Low**	**Moderate**	**High**
Weed Control ($/ac)	13.00	22.75	32.50
N Savings ($/ac)	5.00	5.00	5.00
Change in Cash Return ($/ac)	-77.70	-34.25	6.70
Soil Benefits ($/ac)	22.49	23.79	25.09
Overall Net Return ($/ac)	***-55.21***	***-10.46***	***31.79***

The net return from cereal rye is negative on average due to the cost outweighing the input savings, even considering the value of non-cash soil benefits. With high 2021 nitrogen prices, the input savings are still not sufficient to make a strong business case for the use of cereal rye into corn alone.

Table 3.2.2 *The difference in returns from consecutive cover cropping in a corn-soybean rotation ($/ac), assuming 60 lb N supply from a cover crop mixture (50% legume, 50% cereal), $0.50/lb N, weed control benefits, and historical crop prices through 2020.*

		Year 1		Year 3		Year 5	
		Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)		0.5	2.1	1.8	3.5	3	5
Revenue Change ($/ac)	High	5.20	15.50	18.70	25.90	31.10	37.00
	Low	3.10	11.70	11.30	19.50	18.80	27.90
Added Costs ($/ac)	High	93.00	93.00	93.00	93.00	93.00	93.00
	Low	21.80	21.80	21.80	21.80	21.80	21.80
Nitrogen Credit ($/ac)	Mean	30.00	0.00	30.00	0.00	30.00	0.00
Weed Control ($/ac)	High	32.50	32.50	32.50	32.50	32.50	32.50
	Low	13.00	13.00	13.00	13.00	13.00	13.00
Crop Net Return ($/ac)	High	45.90	26.20	59.40	36.60	71.80	47.70
	Low	-46.90	-68.30	-38.70	-60.50	-31.20	-52.10
Mean Rotation Net Return ($/ac)	**Mean**	**-10.78**		**-0.80**		**9.05**	

Nation-wide surveys in the United States found the yield benefit to increase over time with corn and soy yields increasing to 3% and 5% after 5 years of continuous cover cropping (SARE, 2019). The survey does not distinguish between species of planted cover crops. Based on historical crop prices and $0.50/lb N, for a representative corn-soybean rotation, the net benefit is negative over the first three years, becoming positive in the fourth year, with a payback period of about 5.1 years. For counties with higher expected crop yields, and years with greater commodity prices and higher nitrogen fertilizer costs, the returns to cover cropping will be greater. For example, increasing the fertilizer price to $1/lb N and increasing crop revenue expectations by 50% results in Table 3.2.3.

Photo courtesy of Credit Valley Conservation

Table 3.2.3 *The difference in returns from consecutive cover cropping in a corn-soybean rotation ($/ac), assuming 60 lb N supply from a cover crop mixture (50% legume, 50% cereal) considering weed control benefits, $1/lb N and 50% higher crop revenue.*

		Year 1		Year 3		Year 5	
		Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)		0.5	2.1	1.8	3.5	3	5
Revenue Change ($/ac)	High	7.80	23.25	28.05	38.85	46.65	55.50
	Low	4.65	17.55	16.95	29.25	28.20	41.85
Added Costs ($/ac)	High	93.00	93.00	93.00	93.00	93.00	93.00
	Low	21.80	21.80	21.80	21.80	21.80	21.80
Nitrogen Credit ($/ac)	Mean	60.00	0.00	60.00	0.00	60.00	0.00
Weed Control ($/ac)	High	32.50	32.50	32.50	32.50	32.50	32.50
	Low	13.00	13.00	13.00	13.00	13.00	13.00
Crop Net Return ($/ac)	High	78.50	33.95	98.75	49.55	117.35	66.20
	Low	-15.35	-62.45	-3.05	-50.75	8.20	-38.15
Mean Rotation Net Return ($/ac)	**Mean**	**8.66**		**23.63**		**38.40**	

In the high crop price and higher fertilizer price scenario, we see that the estimated value of cover cropping increases. In this scenario, adopting cover crops pays off immediately due to the N savings and the yield gains over time only increase the magnitude. This sensitivity analysis does not consider increased costs with high commodity prices, but operations for seeding and termination will also increase in cost to some degree. Similarly, weed control benefits will also increase under these circumstances.

Additional factors may contribute to profitability of cover cropping. Cost-share programs, such as those under the Canadian Agricultural Partnership, Conservation Authorities, the Ontario Soil and Crop Improvement Association, and the Ecological Farmers Association of Ontario, help farmers in overcoming the initial investment, such as the cost of seed. Other programs offer an annual per-acre grants as well.

Cover cropping also reduces exposure to weather-risk, supporting greater yields during conditions such as the 2012 drought (O'Connor, 2013). These benefits are currently understudied but provide additional value. Finally, effective management of cover crops may improve the net benefit. Several strategies, including weed control, lower N inputs, grazing, and easing the transition to no-till, improve the benefits to cover cropping. A study funded by the Iowa Department of Agriculture and Land Stewardship (IDALS) found cover cropping to be profitable ($64.26 ac–1) for cattle-cow operations (PFI, 2019).

Summary of Findings

Cover cropping has the potential to be either beneficial or not, financially, with cover crop mixes including legumes having higher returns than a single crop like cereal rye. However, increasing returns to cover cropping from positive yield effects take time, with initial costs.

3.3 Crop Rotation

Using a simple net present value model based on provincial production costs, commodity prices, county-level yield estimates and financially relevant agronomic information from the literature (i.e., nitrogen carry-over and yield benefits under rotation) corn-soy-wheat (CSW) rotations are compared to the typical CS rotations. Beyond the crop budgets outlined by OMAFRA, the pattern in which crops are grown influences the bottom line. Legumes, such as soybeans, provide nitrogen credits for the subsequent crop ranging from 22-32 lb/ac (Ding et al. 1998; Goss et al. 2002). Based on mean nitrogen prices in Ontario for urea (43%) of $0.65/lb N from 2014 to 2020 (McEwan, 2020), the credit for soybeans is $14.5/ac to $20.8/ac.

Extending the common two-year CS rotation to include a small grain, such as winter wheat, barley, or oats is not strictly profitable on a short-term annual basis but becomes profitable over time (Table 3.3.1).

Table 3.3.1 *Profitability of a corn-soy rotation transitioning to a corn-soy-wheat rotation over four years, with literature-based yield increase. Ranges represent two standard deviations from the mean crop yield. For example, the corn yield range is 119-192 bu/ac.*

		Year 1			Year 2		
		Corn	Soy	Wheat	Corn	Soy	Wheat
Yield Change (%)		0	0	0	3.5%	0	0
Cost ($/ac)	High	-804.5	-444	-435.4	-731.6	-444	-451.7
	Low	-654.6	-409	-399.4	-535.7	-409	-415.7
Revenue ($/ac)	High	955.4	722.1	620.6	988.8	722.1	620.6
	Low	588.4	545.1	386.3	609	545.1	386.3
Crop Net Return ($/ac)	High	150.9	278.1	185.2	322.5	278.1	185.2
	Low	-66.1	136.1	-13.1	97.9	136.1	-13.1
Portion in Crop		2/6	3/6	1/6	2/6	2/6	2/6
Mean Net Return ($/ac)		132			167.8		
Change from C-S ($/ac)		**-9**			**26.8**		

Table 3.3.1 *Continued…*

		Year 3			Year 4		
		Corn	Soy	Wheat	Corn	Soy	Wheat
Yield Change (%)		7%	6%	0	7%	12%	0
Cost ($/ac)	High	-826.5	-452.6	-451.7	-826.5	-461.2	-451.7
	Low	-573.2	-415.5	-415.7	-573.2	-422	-415.7
Revenue ($/ac)	High	1022.2	765.4	620.6	1022.2	808.8	620.6
	Low	629.6	577.9	386.3	629.6	610.6	386.3
Crop Net Return ($/ac)	High	342.3	312.8	185.2	342.3	347.6	185.2
	Low	110.1	162.4	-13.1	110.1	188.6	-13.1
Portion in Crop		2/6	2/6	2/6	2/6	2/6	2/6
Mean Net Return ($/ac)		183.3			193.4		
Change from C-S ($/ac)		**42.3**			**52.4**		

These results are based on county-level averages which may not represent the vast range in productivity across the province. Further, these results are sensitive to alternative factors such as land rental rates, farmers' values on future profits and risk behaviour, field-specific yields, and soil quality, selling the straw, and weather events. These predictions are a simplification of the yield benefits and cost changes to rotation diversification. The transition described above for Year 1 involves taking one-third of the land in soy in Year 0 and transitioning to wheat, taking two-thirds of this land to corn, and transition all the corn land in Year 0 to soybean. For Year 2, the wheat in Year 1 goes to corn, the corn goes to soybean and the soybean goes one-third to corn and two-thirds to wheat, equilibrating the system to even shares of the three crops.

Given the sequence of cash flows in Table 3.3.1, the time to break even on crop rotation is approximately 2 years. Increases in crop prices can change the relative benefits of rotation, providing that the relative prices of the three crops change.

Summary of Findings

Crop rotation also has initial costs, but the benefits appear firmly positive over time.

3.4 Nutrient Management

Unlike the previous examples, changes in net return from the adoption of various 4R management practices do not typically take multiple years to realize. This analysis assumes that the producer is using custom application and that the custom costs for different services are the same. That means that a custom operator would charge the same price for applications pre-plant as they would at any time after planting. Furthermore, the custom operator would not charge a premium to apply a variable rate application, but they would charge the costs of creating the prescription maps. While these scenarios are somewhat unlikely, the degree of the premium for these services remains unknown. With the information presented in Section 2.4, the net returns to the four examined 4R nutrient management practices are given in Table 3.4.

Table 3.4.1 *Estimates of the range of changes in yield, revenue, costs, and net returns, in dollars per acre, from 4R management practices including split N application (Right Timing), nitrification and urease inhibitor application (Right Source), modest N rate reductions (Right Rate), and variable rate N application (Right Placement).*

	Practice							
	Split N Application		Inhibitor Application		Rate Reduction		Variable Rate N Application	
	Low	High	Low	High	Low	High	Low	High
Change in Yield (%)	-1.2	3.7	0.3	9.3	-2.8	0	-2.1	4.4
Change in Revenue ($/ac)	-$11.13	$34.31	$2.78	$86.25	-$25.97	$0.00	-$19.48	$40.81
Change in Cost ($/ac)	$11.00	$11.00	$32.37	$16.19	-$44.00	-$22.00	$20.62	$12.00
Change in Net Return ($/ac)	-$22.13	$23.31	-$29.59	$70.06	$18.03	$22.00	-$40.09	$28.81

The practices, except for Right Rate, have a range that includes negative and positive values. This shows that each practice has a time and place and may not be suitable in all weather and soil conditions, for example. In the case of split N application and inhibitor use, the lower end of the change in net returns occurs in dryer conditions, while the higher end occurs in wetter ones. For rate reductions, the more severe the reduction in the N rate, the more likely it is to result in a financial loss, as the benefits of not applying the first unit of N are the greatest and continually decrease. For variable rate N application, the effectiveness of the prescription drives the range in net returns, with better prescriptions resulting in greater benefits.

Changes in crop prices alter the changes in revenue directly. When crop prices are high, then changes in revenue from changes in yield are more pronounced.

Similarly, with N costs, 4R practices that save on N costs have a greater effect on farm net returns when N prices are high. When commodity prices like fuel are high, the costs of increased machinery and diagnostic passes increase. Similarly, the costs of fertilizer additives like nitrification and urease inhibitors also increase.

Separating the 4Rs into individual practices is somewhat difficult and these practices are likely better employed in tandem. For example, increasing N use efficiency, through split N, inhibitor, and variable rate application likely all unlock the ability to lower N rates. Further refinements to each of the techniques are also best practice. For example, with split N application, in dry years, it likely does not make sense to apply the in-season N rate. The optimal practice is to change the N rate given that more information is known. This converse is true with wet years – the optimal practice could be to apply additional N during the in-season application (Kabir et al., 2021).

Summary of Findings

Of the 4R nutrient management practices examined, rate reduction has the smallest range in net returns, followed by split N application. Inhibitors and precision application have the largest ranges, with relatively high upside for inhibitors and relatively low downside for precision application.

3.5 Organic Amendments

The analysis in this section focuses on the net benefits of utilizing manure from different livestock. It assumes that the price of manure is zero. The net returns to utilizing different types of manure are given in Table 3.5.1. Only the fertility value of manure is considered here as the economic value of other effects of manure have not been well documented.

Table 3.5.1 *Liquid hog, dairy, beef, and poultry manure, and biosolids, composition and cost of application relative to traditional mineral fertilizer application in Ontario for current and double current fertilizer prices. Includes the break-even transportation distance of free manure. Assumes a corn enterprise applying 154 lb N/ac, 71 lb P/ac and 48 lb K/ac.*

Manure Type	Hog	Dairy	Beef	Poultry	Biosolids
N (lbs/1000 gal)	22.4	16.6	15.9	49.4	4.1
P (lbs/1000 gal)	10.7	8.3	7.4	25.8	5.5
K (lbs/1000 gal)	20.6	27.1	24.8	32.4	0.0
Custom Work Units (N)	6.9	9.3	9.7	3.1	37.6
Custom Work Units (P)	6.7	8.6	9.6	2.8	13.0
Custom Work Units (K)	2.3	1.8	1.9	1.5	
Custom Work Costs ($/ac)	96.47	130.17	135.91	43.74	527.05
Additional Fertilizer Costs ($/ac)	0.00	0.00	0.00	0.00	32.00
Total Manure Costs ($/ac)	96.47	130.17	135.91	43.74	559.05
	2021 Fertilizer Costs				
Mineral Fertilizer Cost ($/ac)	137.75	137.75	137.75	137.75	137.75
Change in Net Returns ($/ac)	41.28	7.58	1.84	94.01	-421.30
Transportation Cost ($/mile)	5.88	7.93	8.28	2.67	32.12
Break-Even Transportation Distance (miles)	7.0	1.0	0.2	35.3	
	Double 2021 Fertilizer Costs (2022 Expectation)				
Mineral Fertilizer Cost ($/ac)	261.50	261.50	261.50	261.50	261.50
Change in Net Returns ($/ac)	165.03	131.33	125.59	217.76	-315.55
Transportation Cost ($/mile)	5.88	7.93	8.28	2.67	32.12
Break-Even Transportation Distance (miles)	28.1	16.6	15.2	81.7	

The mineral composition of the different types of liquid manure and biosolids were taken from OMAFRA (2015). The custom work cost of liquid manure application is $14/1000 gal (OMAFRA, 2019). **Table 3.5.1 shows that poultry is potentially the best source of manure due to its high mineral content. This lowers the cost of application, as lower amounts of manure are required.** This also means that chicken manure sourcing can be as far as 35.3 miles from the site and break-even with traditional fertilizer application at a transportation cost of $0.388/ton/mile (De Laporte and Ripplinger, 2019). It also means that a price for chicken manure can probably be established for farmers. Biosolids do not appear to be financially advantageous. Using manure to provide sufficient N does result in significant overapplication of K and some overapplication of P.

When considering increase value for fertilizers, manure appears to be a more attractive option. For example, when N prices double, reasonable transportation distances increase significantly, giving rise for opportunities to ship hog, beef, and dairy manure. Chicken manure may become more of a commodity. These benefits could be somewhat lessened by increased fuel prices and application prices with high commodity prices.

Summary of Findings

Chicken manure use has a high potential upside, but beef manure barely breaks even with mineral fertilizers. However, this is only true if the price of manure is zero and transportation distances are short.

3.6 Rotational Grazing

The straightforward quantifiable financial benefits of rotational grazing appear to be twofold – an increase in the amount of forage produced leading to additional days on pasture, and an increase in the reasonable stocking rate, driven by the first benefit.

There is also the possibility of increased harvested winter feed. From the costs in Table 1.2.2, in the baseline case for a cow-calf operation, the annual cost of cattle is $1,297/hd, with more than half of this cost being related to winter feed. The annualized cost of implementing rotational grazing (20-year fencing life cycle) is approximately $2,507 for the cross-fences for a 4-paddock enclosure on a quarter section (160 acres). Assuming that this pasture is square, every increase in 4-paddocks costs roughly the same amount of money. According to Wang et al. (2021), adopting rotational grazing (between 5 and 15 paddocks – assume 8) increases the available forage days by 7, while management intensive grazing (16 or more paddocks – assume 16) increases forage days by 39. Using these assumptions, the increase in days grazing results in reduced feed cost and allows a higher stocking rate, approximately directly in line with the increase in pasture days. The changes in the expected net return for the representative Ontario cow-calf operation are given in Table 3.6.1.

Table 3.6.1 *Changes in grazing days, stocking rates, feed costs per head, fencing costs, and cash net returns from adopting 8 paddock rotational grazing and 16 paddock management intensive grazing, including the change in net returns from continuous grazing.*

	Continuous Grazing	Rotational Grazing	Management Intensive Grazing
Grazing Days (days)	155	162	194
Stocking Rate (hd)	95	99	119
Decreased Feed Cost ($/hd)	0	17	97
Increased Fencing Costs ($)	0	5,014	10,028
Cash Net Return ($)	-6,758	-9,913	-4,044
Change in Net Return ($/ac)		-19.72	16.96

The first observation here is that at current costs and prices, the cow-calf operation does not appear to be profitable under current circumstances. However, rotational grazing does not appear positive financially, management intensive grazing does seem to have benefits. However, the management and labour costs of moving the cows are not included. These costs can be minimized by efficient fencing and enclosure design (Undersander et al., 2002).

High commodity prices increase the costs of non-grazed feed by a significant margin. This could increase the attractiveness of rotational grazing. Similarly, if rotational grazing allows additional feed to be harvested, prices could further decrease. From some anecdotal reports, rotational grazing allows more weaned pounds per acre but less pounds per calf. This could cause decreased financial performance. On the other hand, increased commodity prices can drive up the costs of building materials, making fence and water installations more expensive.

Summary of Findings

Rotational grazing can have relatively small costs and benefits, depending upon the intensity of grazing, with greater intensity having potentially greater net returns, but much higher upfront capital fencing and water costs.

4

Knowledge Gaps in the Adoption of Soil Health Practices in Ontario

In the previous sections, we estimated the net farm returns from adopting a series of six soil health promoting agricultural practices. However, even considering these six relatively well studied practices, we had significantly different depths of data available. For tillage and crop rotation, there are many studies of yield effects available over many years in relevant areas of Ontario. There is a growing literature on the effects of 4R nutrient management practices and cover crops on yields and net returns, but high-quality data on these practices are relatively recent and there are few Ontario specific examples. In the cases of soil amendments, particularly manure, and rotational grazing, there is a mix of information, with some references from the turn of the century along with more recent developments, but much less Ontario-specific information. Few studies have been done on the economic effect of soil health practices in field horticulture. The economics of soil health practices for dairy, pork and other livestock producers are also not well documented. General interest in soil health has reinvigorated these discussions, but quality data on rotational grazing is just emerging, while recent manure studies seem sparse.

Other practices that promote soil health that are not examined explicitly in this report typically fall into the categories identified above, from well documented recently to not well documented at all, including specifically for Ontario. Some practices, like cropland use change to trees and perennial grasses have been shown to be lacking financial feasibility (De Laporte et al., 2014; 2016). Other newer practices, like biocoal or biochar soil amendments, have not been particularly well-defined, in general, and specifically in Ontario. Some practices require additional study, while others have shown poor enough financial performance that their business case is lacking.

In general, most of the field information that we have used comes from studies that are site and time limited. This implies that further studies on all soil health practices are needed across the soil and weather conditions in Southern Ontario.

This is unsurprising given the nature of field trials and funding streams. While there are examples of long-term studies, such as those at the University of Guelph fields in Elora, newer practice innovations have only been added to those recently. However, with the interest surrounding the 4Rs and cover crops, for example, we have seen more frequent release of shorter field studies, along with some more comprehensive modelling efforts to piece together some of the less well studied soil and weather conditions.

Regarding specific spatial and temporal research gaps, the United States has begun gathering some of the detailed spatial farming data through various studies incorporating significant data from multiple farmers across states, particularly in the Midwest. For example, the Illinois Corn Growers Association and the Illinois Soybean Association began gathering detailed spatial precision agriculture data from 300 farmers in the state. This includes tracking practices pass-by-pass, and financial information. The Soil Health Institute has also implemented a study on 100 farms in the corn belt, finding that those which used soil management practices had lower per acre production costs and increased profitability by $55/ac to $65/ac. These types of farm level studies have not been conducted in Ontario and Canada at this scale.

There is also a limited understanding and quantification on the effects of adopting multiple soil health practices simultaneously. This makes conclusions on the net effect of multiple practices difficult, as there can be significant variability regarding baseline practices. Not only do measures of soil health depend on the collection of practices farmers use, but the adoption of a single conservation practice similarly depends on farmers' existing practices. For example, in Iowa, one farmer saw a 0.1% increase per year in soil organic matter using cover crops and strip-tillage in a corn-soy rotation (Gronau, 2021), but this increase could be significantly different just based on previous practices for another.

> **"Soil health management requires a systems approach to be most successful.**

Farmers typically find value in management practices which reduce risk. An under-studied facet of soil health is the role of soil health promoting practices as a risk management tool. With weather patterns changing under climate change, uncertainty will increase. Crop yields and farm revenues are subject to considerable fluctuations on an annual basis, where increased soil health management may improve yield stability (Gaudin et al., 2015; Bowles et al., 2020) and reduce risk of crop failure (Cong et al., 2014; CTIC, 2016).

However, there is a debate as to whether business risk management programs, such as crop insurance which compensate farmers for crop failure, may limit the value of soil health's ability to reduce risk (Bryant and O'Connor, 2016). Despite general knowledge that soil health mitigates water and heat stress, the financial value is not known.

Furthermore, farm risk is also managed through government support programs. The presence of alternative risk management programs and government support programs may preclude or be substitutes for soil building practices. Therefore, risk perception may be an important factor in adopting beneficial practices (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020). Insurance against losses due to soil health practice adoption has been tried in some jurisdictions, including by the USDA and PEI, as previously mentioned (Équiterre and Greenbelt Foundation, 2021; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020; USDA, 2021).

Limited work investigates how short-term tenants and landlords may reach agreements regarding soil conservation. Over 40% of agricultural land is rented and managed by tenants in Ontario. The previous section demonstrated that soil health practices typically take several years to become profitable. While short-term rental agreements have been shown to discourage such practices, management choices for longer-term contracts (at least 5 years) were not appreciably different (Deaton et al., 2018).


Photo courtesy of Paul Smith

5

Recommendations for Future Action Regarding Soil Health Practices in Ontario

Develop Extension Tools to Aid Ontario Farmers and Advisors

The economics and return on investment for soil health practices are crucial information for on-farm decision making by farmers and their trusted advisors. Getting that information into the hands of farmers and advisors is the most important task. Work in the US by the Soil Health Institute, American Farmland Trust (AFT) and others provide decision support tools to farmers. The AFT has built a Retrospective Soil Health Economic Calculator using their case studies of partial budget analysis to allow farmers to calculate how much their profits have changed due to practice change. They are also developing a Predictive Soil Health Economic Calculator to estimate how much a farmer may gain or lose by adopting different practices. Tools like these would be a useful long-term goal for Canada.

Ontario farmers and their advisors use many extension tools to help them plan their crop production. Translating this current synthesis of knowledge into practical tools should be straightforward. As additional economic data becomes available, the tools can be added to and amended. Other players such as non-operator landowners, farm financial lenders, and the real estate industry may also benefit from this knowledge. So, a variety of tools are needed to reach the range of diverse audiences like fact sheets, videos, demonstrations, work sheets, and calculators.

Expand Economic Research on Soil Health to Other Commodities and Production Systems

Grain and oilseed production has received the most attention regarding the economic effects of soil health practices in Ontario and elsewhere. But other systems such as field horticulture, and dairy, pork and other livestock production could also benefit from knowledge of the economics of soil health practices.

Economic benefits identified are often those most observable, like nutrient value. Therefore, benefits estimated here are necessarily conservative in nature. Monetization of economic benefits due to improvements in soil health parameters like soil organic matter, aggregate stability, porosity, microbial communities, and others would be beneficial. This would make economic benefit estimates more fulsome.

Synthesize the Knowledge on the Economics of Soil Health Practices in Other Parts of Canada

This report summarizes what is currently know about the economics of soil health practices in Ontario agriculture, primarily grain and oilseed production. Similar syntheses of current knowledge would be beneficial for other regions in Canada, like the prairie provinces, Québec, Atlantic provinces, and British Columbia. An analysis for Québec could build on the information in this report, as much of the data may be applicable to Québec conditions. Farmers across Canada would benefit from such economic analysis in making informed decisions.

Photo courtesy of Credit Valley Conservation

Gather Greater Spatial and Temporal Data on Multiple Soil Health Practices

Programs like the "Economics of Soil Health on 100 Farms" by the Soil Health Institute and "The Business Case for Conservation" by Precision Conservation Management, which examine the agronomic changes and profitability of conservation practices on farms across nine states can provide invaluable data to researchers and farmers. Programs such as this provide quantitative evidence of conservation practices at the farm-level, providing farmers and extension services with realistic information. Perhaps more importantly, these kinds of practices provide policy makers with the types of information required to make efficient and effective agricultural programs. With soil and weather outcomes varying considerably across the province, and the prospect of future increases in weather volatility with climate change, this kind of information must be pursued in the province of Ontario.

Examine the Effects of Land Ownership and Tenancy on Soil Health Practice Adoption

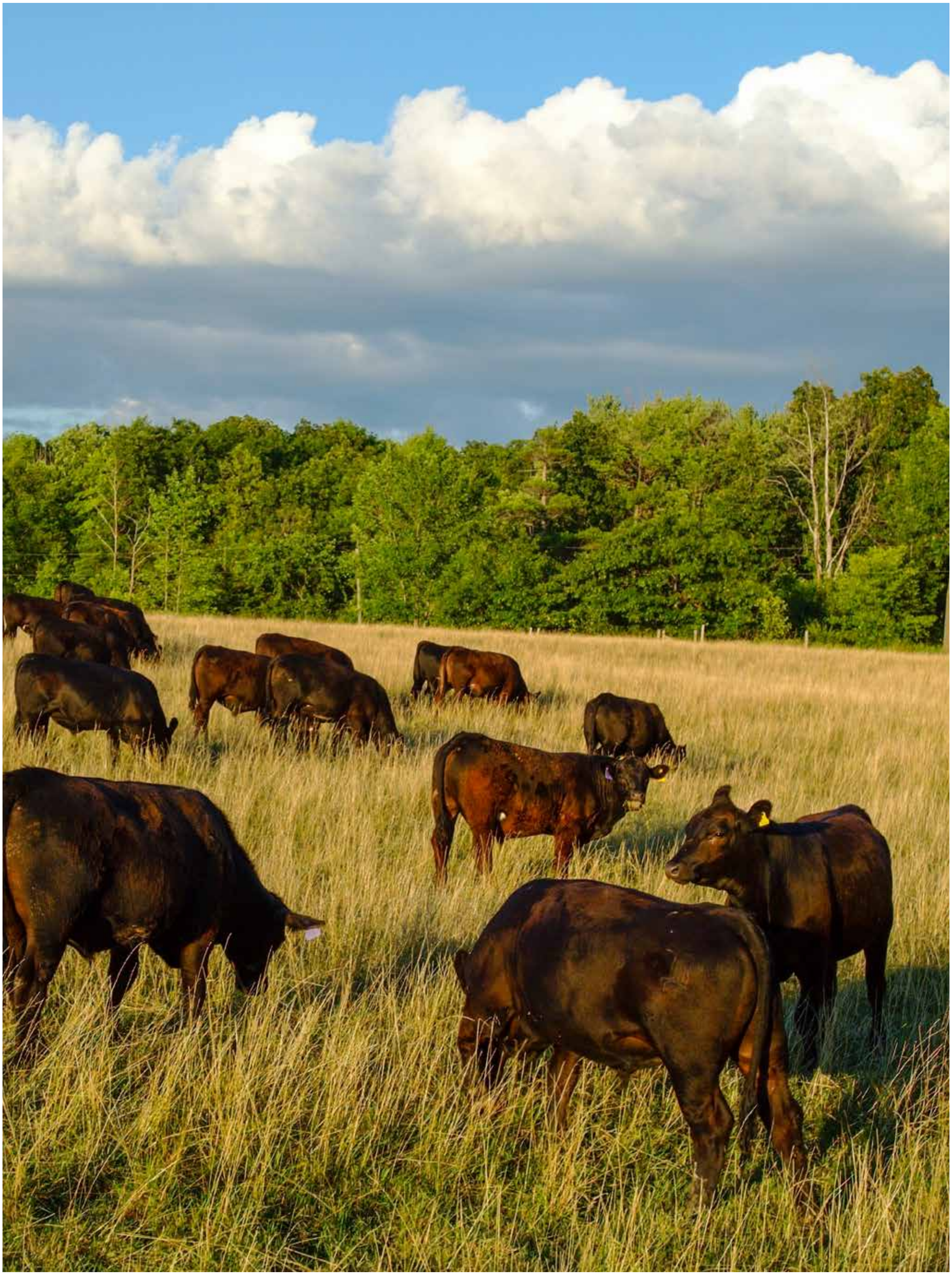
The multiple years required to overcome the upfront costs of many soil health practices can be difficult for farmers farming land under short-term leases or rentals. However, soil health practice adoption tends to be higher with longer duration rental contracts (Deaton et al., 2018). Exploring the design of tenant-landlord farmland management contracts is important to increase the adoption of many soil health practices on rented farmland as has been examined by Food and Farm Care (2021).

Study Extension and Other Non-financial Factors Influencing Soil Health Practice Adoption

While the economic impact of soil management practices is often the largest driver to adopt, other non-pecuniary factors influence the adoption process (Knowler and Bradshaw, 2007; OMAFRA, 2018; Weersink and Fulton, 2020; Groupe AGECO, Équiterre and Greenbelt Foundation, 2020), including social factors. For example, there may be a lack of farmer knowledge or confidence to manage timely top-dressing (OCJ, 2020). There may be insufficient explanation of non-monetary benefits and the conditions under which they can be achieved. For example, farmers cited benefits which do not easily enter a partial budget analysis, such as increased weather resilience and ability to get in the field. Discovering and communicating these benefits and barriers to adoption is important for future success in building soil health.

Economic Benefits and Costs and Incentive Design

Information on the economic costs and benefits of different practices and how those are spread over time can help inform policy and program design. For example, the short-term costs and longer-term benefits of cover crops and reduced tillage illustrate the merits of early, up-front incentives for farmers to offset initial costs of adoption. Innovation in policy design is needed as many types of financial incentives exist but few have been used broadly in Canada (Groupe AGECO, Équiterre and Greenbelt Foundation, 2020). The economic information identified here could help identify the optimal size, duration, and type of incentive for each practice. Inter-disciplinary research encompassing economics, behavioural science, environmental science, agronomy, and policy could help design optimal incentive structure.



6

Conclusion

This study aims to continue to build the business case for soil health, stimulate discussion on the topic, and spur more research on neglected aspects. It determines a range in net returns from the adoption of six different soil health practices: 1) tillage intensity; 2) cover crops; 3) diverse crop rotations; 4) nutrient management; 5) organic amendments; and 6) rotational grazing. Using data from literature synthesis and financially representative farm-level budgeting techniques for Southern Ontario, the study found that most of these practices have a range of net returns including, from negative to positive, implying that they may often be financially beneficial, but not always. Success factors are associated with implementation of most farm practices. Identification of factors contributing to success are often identified in extension work.

The ranges of net returns given in Section 3 highlights this. It also shows the degree of change inherent in each practice, with some practices having a greater range in net returns than others. Tillage reduction appears to be a less variable practice, with a small range in net returns and small gains or losses. Cover cropping has the potential to be either beneficial or not, financially, with cover crop mixes including legumes having higher returns than a single crop like cereal rye. However, increasing returns to cover cropping from positive yield effects take time, with initial costs. Crop rotation also has initial costs, but the benefits appear firmly positive over time. Of the 4R nutrient management practices examined, rate reduction has the smallest range in net returns, followed by split N application. Inhibitors and precision application have the largest ranges, with relatively high upside for inhibitors and relatively low downside for precision application. Chicken manure use has a high potential upside, but beef manure barely breaks even with mineral fertilizers. However, this is only true if the price of manure is zero and transportation distances are short. Rotational grazing can have relatively small costs and benefits, depending upon the intensity of grazing, with greater intensity having potentially greater net returns, but much higher upfront capital fencing and water costs.

Putting all the potential benefits together, the long-term sustained increase in Ontario farm net returns from increasing no till, cover crop, crop rotation, the specified 4R practices (split application, inhibitors, rate reduction, and variable rate application), manure, and rotational grazing adoption by 10% of the relevant agricultural area would be approximately $14.6 million dollars per year. This calculation assumes 2016 Census of Agriculture areas for corn (874,932 ac), soybean (1,126,419 ac) and pasture (525,174 ac).

All these benefits can change when the prices of commodities change. For example, when crop prices are high, it exacerbates the degree of revenue change, so positive and negative changes in yield become more important. When N fertilizer prices are high, practices like cover cropping, N rate reduction and soil amendments become more attractive. Higher fuel and other input costs make additional farm machinery use more expensive.

Analyses of the economics of soil health also depend on methods used to select, document, and analyze the data. The current project relies on peer-reviewed, published comparative studies and Ontario based production budgets. Other methods are used elsewhere; for example, the Soil Health Institute (2021c) used a case study approach for 100 farms with long-term use of no-till and cover crops and recorded average increases in net farm income for corn of $51.60 USD per acre ($65.58 CDN) and for soybeans $44.89 USD per acre ($57.05 CDN). These values are higher than those reported here due largely to the different methodologies used. A variety of approaches are useful to explore different aspects of the issues.

The study also identifies several research gaps, including a lack of long term spatial and temporal data for all the practices, asymmetric levels of information among these practices, insufficient research on the adoption of multiple practices, and the role of policy, risk, and tenancy on adoption. Limited research has been conducted outside of popular field crops and grazing, more is needed on livestock, vegetable, and fruit production systems. Further information is also needed on additional soil health promoting agricultural practices. **Currently documented overall benefits are likely conservative and may change as additional monetized benefits are documented.**

Considering the research gaps, this study recommends:

1) Development of extension tools to aid Ontario farmers and advisors in adoption decisions based on the available information in this report and future endeavours;
2) Expansion of economic research on soil health to additional commodities and production systems;
3) Synthesising economic knowledge on appropriate soil health practices in other parts of Canada;
4) Gathering greater spatial and temporal data on multiple soil health practices;
5) Examining the effects of land ownership and tenancy on soil health practice adoption;
6) Studying extension and other non-financial factors influencing soil health practice adoption; and
7) Using knowledge of the economic benefits and costs in the design of policy and incentives.

This project mobilizes current knowledge on quantified costs and benefits to aid decisions by farmers and their advisors. We also recognize that many costs and especially benefits remain unquantified. The analysis provides a launching point for discussion and the estimates are likely conservative in nature and will evolve with new knowledge. It is hoped that this work continues crucial conversations and stimulates further research documenting a broader range of costs and benefits.

7

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Appendix A: Business Case for Soil Health Economic Fact Sheets

No-till Cropping in Ontario

Tillage breaks down complex structures in the soil, which creates a better seed bed for planting, but also contributes to the loss of carbon through enhanced organic matter decomposition, erosion, and reduced soil aggregate stability. Reducing tillage, or transitioning to no-till, can protect soil structure, help maintain carbon levels in the soil, leading to healthier soils.

From a cost standpoint, tillage is a machinery and labour-heavy operation and reducing tillage decreases these costs. The cost savings are primarily due to lower equipment costs which includes depreciation, fuel consumption, and repairs. However, some costs can increase, including herbicide requirements for weed control. For corn and soybeans, switching to no-till saves $36/ac and $27/ac, respectively, based on mean operating costs from across Ontario.

While changing tillage methods can also involve upfront capital costs, the costs of the tillage practices have been estimated using sustained average and custom costs. Incentives for no-till, and other forms of reduced tillage, equipment acquisition and modifications have been offered under federal and provincial agri-environmental programs.

No-till adoption appears to lower corn and soybean yields short-term. But yield gradually increases over five years, returning to near original levels. Corn yields are affected to a greater degree than soybean yields.

Based on historical crop prices for a representative corn-soybean rotation, putting together the cost savings and the early yield losses, the net returns of no-till adoption appear to be negative over the first few years, becoming positive on average over time.

Changing crop prices can affect some of the analysis here. For example, when crop prices are high, initial yield losses are more costly. Especially if crop prices fall throughout the yield recovery period, the time to break-even on no-till may increase. Prices introduce an element of risk to the adoption of no-till. High fuel prices increase the benefits of no-till.

Difference in returns between conventional and no-till based on a corn-soybean rotation ($/ac)

		Year 1		Year 3		Year 5	
		Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)		-9	-5	-5	-4	-2	0
Revenue Change ($/ac)	High	-56.40	-11.70	-31.30	-19.50	-31.30	0.00
	Low	-93.30	-15.50	-51.90	-25.90	-51.90	0.00
Cost Savings ($/ac)		36.00	27.00	36.00	27.00	36.00	27.00
Crop Net Return ($/ac)	High	-20.40	15.30	4.70	7.50	4.70	27.00
	Low	-57.30	11.50	-15.90	1.10	-15.90	27.00
Rotation Net Return ($/ac)		**-12.70**		**-1.00**		**10.70**	

Mixed Legume Cover Cropping in Ontario

Cover crops can increase biomass (and carbon) input to soil, increase microbial activity, aggregate stability, and provide ground cover that can reduce erosion and increase moisture retention and infiltration, increasing soil health. Cover crops also increase seed, labour, planting, termination, and management costs.

Corn and soybean yields appear to increase over time from cover cropping, even in the first year. Corn and soybean yields may rise 0.5% and 2.1% after a single year of cover crop use, 1.8% and 2.5% after three years; and a maximum of 3% and 5% after 5 years. Legume mixes also provide a 40-80 lb N credit and $13 to $33 per acre of weed control.

Many cover crop users employ mixtures of between 2 and 4 species. Common species include oat, rye, radishes, clovers, and peas. In Ontario, seed prices for 50% legume cover crop mixes range from $0.8/lb to $1.1/lb, with seeding rates from 13-45 lb/ac. Custom broadcast seeding costs $6/ac, while direct drilling costs $25/ac. Termination with herbicide costs $25/ac but can also be done mechanically. The mean estimated total cost is around $58/ac, varying based on seeding, termination and seeding rate choices.

Based on historical crop prices for a representative corn-soybean rotation, the net benefit is negative over the first few years, becoming positive on average over time.

Other factors may contribute to the benefits of cover cropping, including pest control, erosion repair, and compaction reduction. Cost-share programs can help farmers in overcoming the initial investment. Cover cropping also reduces exposure to weather-risk, supporting greater yields during drought conditions. Grazing opportunities may also increase net returns.

The returns to cover cropping depend on the prices of crops and N fertilizer. When crop prices are higher, yield gains from cover crops become more valuable. When N prices are higher, the value of the N credit increases. This means that cover cropping may be more attractive with high crop and fertilizer prices. Specifically, doubling N prices and increasing crop prices by 50% results in cover crops having positive net returns in the first year of planting.

Difference in returns from consecutive cover cropping in a corn-soybean rotation ($/ac), assuming 60 lb N/ac supply from a cover crop mixture (50% legume, 50% cereal) and $0.50/lb N

	Year 1		Year 3		Year 5	
	Corn	Soy	Corn	Soy	Corn	Soy
Yield Change (%)	0.5	2.1	1.8	3.5	3	5
Revenue Change ($/ac)	4.15	13.60	15.00	22.70	24.95	32.45
Added Costs ($/ac)	57.40	57.40	57.40	57.40	57.40	57.40
Nitrogen Credit ($/ac)	30.00	0.00	30.00	0.00	30.00	0.00
Weed Control ($/ac)	22.75	22.75	22.75	22.75	22.75	22.75
Crop Net Return ($/ac)	-0.50	-21.05	10.35	-11.95	20.30	-2.20
Mean Rotation Net Return ($/ac)	**-10.78**		**-0.80**		**9.05**	

Corn-Soybean-Wheat Rotations in Ontario

Corn and soybean rotations are commonly practiced in Ontario, primarily due to their high market value. Long-term, this rotation reduces soil organic matter, crop yields, and yield stability. Crop rotations including small cereal grains, like winter wheat, reverse these trends, improving soil health, while providing benefits such as reduced pest pressure.

Corn and soybean yields increase with small cereals and forages in the rotation. After the inclusion of winter wheat, corn yields in a diverse rotation increased up to 7% and soybean yields increased up to 12%.

Since corn and soybean have high returns, substituting a new crop with a lower return can result in initial revenue losses, making the transition an investment in multi-year improvement. Selling wheat straw can increase revenue from wheat with some trade-offs.

Putting together the yield benefits and initial costs of adopting corn-soybean-wheat rotations, the initial result is a loss of about \$9/ac. However, even by the second year, the net return is positive, increasing to about \$52/ac sustained. This assumes that roughly one-sixth of acres are planted to winter wheat initially, transitioning to an even split in the second year.

These results are based on county-level averages which may not represent the vast range in productivity across the province from differences in weather and soil type. These results are sensitive to other factors such as land rental rates, farmers' values on future profits and risk behaviour, field-specific yields, and soil quality, selling wheat straw, and weather events.

Changes in crop prices can change the benefits of rotations, providing that the relative prices of the three crops change. For example, if corn and soybean increase in price more than wheat, the cost of diversification increases. To offset these issues, some areas offer incentives to include small grains in rotation.

Net returns from transitioning into a corn-soy-wheat rotation from corn-soybean over four years

		Year 1			Year 4		
		Corn	Soy	Wheat	Corn	Soy	Wheat
Yield Change (%)		0	0	0	7%	12%	0
Cost (\$/ac)	High	-804.5	-444	-435.4	-826.5	-461.2	-451.7
	Low	-654.6	-409	-399.4	-573.2	-422	-415.7
Revenue (\$/ac)	High	955.4	722.1	620.6	1022.2	808.8	620.6
	Low	588.4	545.1	386.3	629.6	610.6	386.3
Crop Net Return (\$/ac)	High	150.9	278.1	185.2	342.3	347.6	185.2
	Low	-66.1	136.1	-13.1	110.1	188.6	-13.1
Mean Net Return (\$/ac)		132			193.4		
Change from C-S (\$/ac)		**-9**			**52.4**		

4R Nitrogen Management on Ontario Corn

Nitrogen (N) management can lower greenhouse gas emissions, reduce runoff, and improve soil biological communities. 4R (right timing, right source, right rate, right placement) nutrient management practices can increase or decrease costs and yields. There are many different combinations of practices under this nutrient management umbrella, likely resulting in a range of changes in net return, depending upon the combination selected.

Right Timing (Split Application)

Timing is an important aspect of N application, as N is subject to loss if not used by the crop. Applying a portion of N (split application) closer to critical growth stages, such as traditional sidedress timing at vegetative growth stage three to four (V3-V4) up to around silking for corn, can increase N use efficiency and reduce N_2O emissions.

Split N application on corn may have a small effect on yield. With no change to the annual N application rate, yield changes range from -1.2% to +3.7% across various weather scenarios. However, by changing the N rate (applying less N in dry weather and more N in wet weather), split N application can increase profit between 14.6% and 19.5% in dry conditions and between 1.4% and 15.7% in wet conditions.

The costs of split N are estimated at the cost of an extra application pass at a custom rate of $12.00/ac. It is not clear if the specific timing of the second application affects this cost as it may be more costly to apply N at later stages with high clearance equipment.

Split application could also lead to lost yield and revenue if weather or logistics interfere with fertilizer application. Responding to this risk, the USDA has recently offered conservation insurance for this practice which has also been piloted in other jurisdictions.

Right Source (Inhibitors)

The source of N can influence profit. Nitrification and urease inhibitors are fertilizer additives that attempt to slow the release of bioavailable N to synchronize with plant uptake phases. Agrotain Plus™, a prevalent combined urease and nitrification inhibitor additive, could increase corn yield increases between 0.3% to 9.3% on Ontario corn.

The costs of these additives are difficult to estimate due to varied pricing and relatively uncertain optimal use rates. A range of prices puts a single additive closer to $16/ac and a combined product closer to $32/ac. There are no additional application costs since inhibitors are added to the fertilizer before application.

Right Rate (Rate Reduction)

The yield and revenue response curves of corn to N application rates have been found to be relatively flat around the maximum yield, on average, over time, for any given weather and soil conditions. Therefore, modest N rate reductions likely cause small yield losses. For example, an 18 lb N/ac reduction from 154 lb N/ac results in no yield loss on corn in average conditions. Even N rate reductions of 36 lb N/ac may result in yield losses of only 2.8%. In years where yield potential is high, lower N rates will have a greater effect on yield loss.

The financial benefit of N rate reduction depends on the price of N fertilizer. As the prices of grains rise along with N prices, the economically optimal N rate can change if the ratio of the price of corn to the price of N changes.

Right Placement (Variable Rate Application)

Right placement of N fertilizer considers the methods used to apply fertilizer. Variable rate nitrogen application (VRNA) has the potential to increase input use efficiency by optimizing rates based on spatial field needs.

VRNA on corn may increase yields between 2% and 4.4%, leading to revenue increases between 7% to 9%. However, if variable rate is not properly implemented, yield losses of 2.1% can occur.

Initial costs of adopting VRNA include the technology and management; however, in the long run, as computer software and technology are integrated into new equipment, costs are unlikely to be that much higher than current levels. The differences in custom costs are also not clear. There will be ongoing technical costs, including the production and maintenance of precision maps and enhanced soil testing. Soil sampling services cost approximately $12/ac. General agronomic services cost approximately $1.25/ac, while the cost of prescription map creation is $7.37/ac. The annual cost of precision agronomic services drops considerably once fields have been mapped, until they need renewal.

Summary

Most 4R practices have a range that includes negative and positive values. This shows that each practice has a time and place and may not be suitable in all weather and soil conditions. In the case of split N application and inhibitor use, the lower end of the change in net returns occurs in dryer conditions, while the higher end occurs in wetter ones. For rate reductions, the more severe the reduction in the N rate, the more likely it is to result in a financial loss. For variable rate N application, the effectiveness of the prescription drives the range in net returns.

Higher crop prices make changes in yield more significant. Similarly, higher N prices increase the effect of 4R practices. When commodity prices are high, machinery, diagnostic and fertilizer additives become more costly.

In general, financial incentives and extension support for crop nutrient planning has been available for quite some time from federal and provincial governments. 4R practices are likely better employed together. Increasing N use efficiency unlocks the ability to lower N rates.

Range of changes in yield, revenue, costs, and net returns from 4R management practices including split N application, inhibitor application, modest N rate reductions, and variable rate N application

	Practice							
	Split N Application		Inhibitor Application		Rate Reduction		Variable Rate N Application	
	Low	High	Low	High	Low	High	Low	High
Change in Yield (%)	-1.2	3.7	0.3	9.3	-2.8	0	-2.1	4.4
Change in Revenue ($/ac)	-$11.13	$34.31	$2.78	$86.25	-$25.97	$0.00	-$19.48	$40.81
Change in Cost ($/ac)	$11.00	$11.00	$32.37	$16.19	-$44.00	-$22.00	$20.62	$12.00
Change in Net Return ($/ac)	-$22.13	$23.31	-$29.59	$70.06	$18.03	$22.00	-$40.09	$28.81

Manure Use in Ontario

Manure and biosolids aren't simply fertilizer replacements; they also add carbon, a host of micronutrients, and diverse microbes to the soil, but these benefits have not been monetized. While these types of organic amendments can improve soil health, sourcing them can be challenging depending on where you are in the province.

Manure has the potential to increase crop yield. However, studies of this effect have been mixed and are relatively uncertain for Ontario.

On-farm manure is often free, but application and transportation costs must be considered. Manure is bulkier and more expensive to transport than mineral fertilizer. The custom work cost of liquid manure application is $14/1000 gal. Assuming a N cost of $0.50/lb and a transportation cost of $0.388/ton/mile, free chicken manure can be transported 35 miles or be sold for the highest price. Beef, dairy, and hog manure are all too expensive to transport far.

When the price of N increases to $1/lb N, chicken manure can be transported more than twice the distance (81.7 miles) and some of the other manure sources could start moving around the province. These benefits could be somewhat lessened by increased fuel and application costs.

Additional costs could be required to lessen the risk of misapplication, including the use of in-line sensor systems or other nutrient level tests. Financial incentives are sometimes offered to offset manure transport and application costs.

Using manure to provide sufficient N does result in significant overapplication of K and some overapplication of P.

Manure composition and application cost relative to mineral fertilizers in Ontario for 2021 and double 2021 fertilizer prices. Includes the break-even transportation distance of free manure.

Manure Type	Hog	Dairy	Beef	Poultry	Biosolids
N (lbs/1000 gal)	22.4	16.6	15.9	49.4	4.1
P (lbs/1000 gal)	10.7	8.3	7.4	25.8	5.5
K (lbs/1000 gal)	20.6	27.1	24.8	32.4	0.0
Total Manure Costs ($/ac)	96.47	130.17	135.91	43.74	559.05
	2021 Fertilizer Costs				
Mineral Fertilizer Cost ($/ac)	137.75	137.75	137.75	137.75	137.75
Change in Net Returns ($/ac)	41.28	7.58	1.84	94.01	-421.30
Transportation Cost ($/mile)	5.88	7.93	8.28	2.67	32.12
Break-Even Transportation Distance (miles)	7.0	1.0	0.2	35.3	
	Double 2021 Fertilizer Costs (2022 Expectation)				
Mineral Fertilizer Cost ($/ac)	261.50	261.50	261.50	261.50	261.50
Change in Net Returns ($/ac)	165.03	131.33	125.59	217.76	-315.55
Transportation Cost ($/mile)	5.88	7.93	8.28	2.67	32.12
Break-Even Transportation Distance (miles)	28.1	16.6	15.2	81.7	

Intensive Grazing Management in Ontario

Intensified grazing management, including rotational grazing, has the potential to improve pasture, resulting in greater biomass yields, soil carbon, aggregate stability, and soil biodiversity. There is a range of management practices that can be considered under the umbrella of 'intensified grazing', including the number of paddocks and the frequency of movement.

Better pasture benefits grazing cattle and allows higher stocking rates and lower feed costs. Farmers perceive economic benefits from rotational grazing, including up to a 20% increase in net returns. Rotational grazing (8 paddocks) can increase the available forage days by 7, while management intensive grazing (16 paddocks) can increase forage days by 39, allowing a corresponding increase in stocking rates.

Switching from continuous to intensive grazing of any type involves up-front capital costs related to fencing and water installation, followed by maintenance costs and long-term management labour. In a baseline cow-calf operation, the annual cost of cattle is $1,454.23/hd. The annualized cost of implementing rotational grazing (20-year fencing life cycle) is approximately $2,507 for the cross-fences of a 4-paddock enclosure on a quarter section (160 acres). Assuming that this pasture is square, every increase in 4-paddocks costs roughly the same amount of money.

At current calf prices, the cow-calf operation does not appear to be profitable under any circumstance. Beef prices often lag increases in feed prices. While rotational grazing does not appear positive financially, management intensive grazing does seem to have benefits. The management and labour costs of moving the cows are not included, but they can be minimized by efficient fencing and enclosure design.

High crop commodity prices increase the costs of non-grazed feed by a significant margin. This could increase the attractiveness of rotational grazing. On the other hand, increased commodity prices can drive up the costs of building materials, making fence and water installations more expensive.

Changes in grazing days, stocking rates, feed costs per head, fencing costs, and cash net returns from adopting 8 paddock rotational grazing and 16 paddock management intensive grazing

	Continuous Grazing	Rotational Grazing	Management Intensive Grazing
Grazing Days (days)	155	162	194
Stocking Rate (hd)	95	99	119
Decreased Feed Cost ($/hd)	0	17	97
Increased Fencing Costs ($)	0	5,014	10,028
Cash Net Return ($)	-6,758	-9,913	-4,044
Change in Net Return ($/ac)		-19.72	16.96