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Adoption of beneficial management practices to improve soil health

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Abstract

Healthy soils are fundamental to building prosperous and resilient farms and to efforts to reduce greenhouse gas emissions and enhance overall environmental impacts from agriculture. Understanding the adoption of beneficial management practices (BMPs) that promote soil health is necessary for these benefits to be obtained. Drawing from a survey of Ontario farmers ($n = 247$) with 60% being crop producers and 22% livestock farmers, we explore the variation in adoption for six soil health BMPs: cover crops, crop rotations, no-till, soil testing, conservation buffers, and organic amendments. Soil testing had the highest rate of adoption, while conservation buffers had the least. The majority of farmers (73%) implemented four or more BMPs as the use of practices such as a rotation with winter wheat, cover cropping, and no-till tend to be positively correlated. Adopters of the BMPs tend to operate larger farms both in the area operated and farm cash receipts than non-adopters. Improving soil health was the most widely selected motivation for adoption across all six BMPs. The most effective interventions to enhance adoption among non-adopters include financial incentives, easily accessible information and advice, and farmer-to-farmer learning. Our results suggest that farmers that adopt BMPs do so primarily to enhance soil health rather than solely for economic considerations. Encouraging use among non-adopters may require monitoring and promoting the benefits of soil health. The results should aid in the development of strategic frameworks that facilitate innovations in policy to enhance soil health.

Key words: adoption, BMP, soil health, indicator

Résumé

Des fermes prospères et résilientes ont besoin de sols vigoureux, sans lesquels on ne pourra d'ailleurs pas réduire les émissions de gaz à effet de serre ni atténuer les répercussions générales de l'agriculture sur l'environnement. Pour que de tels avantages se concrétisent, il faut comprendre l'adoption des bonnes pratiques de gestion (BPGs) qui confèrent au sol sa vitalité. Partant d'un sondage auprès des agriculteurs ontariens ($n = 247$), pour 60 % spécialisés dans les productions végétales et pour 22 % dans les productions animales, les auteurs ont examiné dans quelle mesure variait l'adoption de six BPGs associées à la vitalité du sol : cultures-abris, assolements, non-travail du sol, analyse du sol, bandes de préservation et amendements organiques. L'analyse du sol est la pratique la mieux acceptée, alors que les bandes de préservation se situent à l'opposé du spectre. La plupart des agriculteurs (73 %) appliquent quatre BPGs ou davantage et les pratiques comme l'assolement avec le blé d'hiver, les cultures-abris ainsi que le non-travail du sol présentent une corrélation positive. Ceux qui épousent les BPGs ont tendance à exploiter de plus grandes fermes que ceux qui ne les ont pas adoptées, tant au niveau de la superficie qu'à celui des recettes en espèces. Rendre le sol plus fertile est sans doute la raison principale qui motive l'adoption des six BPGs. Parmi les meilleurs moyens pour inciter les agriculteurs réticents à opter pour les BPGs figurent un incitatif monétaire, la facilité d'accès de l'information et des conseils ainsi que la transmission des connaissances entre producteurs. Ces résultats laissent croire que les agriculteurs qui adoptent les BPGs le font plus pour accroître la fertilité du sol que pour des raisons purement économiques. On devrait peut-être suivre les encouragements prodigués aux agriculteurs réticents ainsi que la promotion des bienfaits de telles pratiques pour le sol. Les résultats de cette étude devraient faciliter l'élaboration de cadres stratégiques qui conduiront à des innovations dans les politiques visant à améliorer la vitalité du sol. [Traduit par la Rédaction]

Mots-clés : adoption, BPG, vitalité du sol, indicateur

Introduction

Healthy soils are a key element in enhancing agricultural production, environmental sustainability, and food system resilience (Rejesus et al. 2021). The USDA Natural Resources Conservation Service defines soil health as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" (Pankhurst et al. 1997). One key challenge with sustainable soil management is to preserve ecosystem functions and services while maximizing agricultural yields. Financial pressures have intensified agricultural systems and enhanced the use of practices that are often unsustainable and pose significant threats to the health of soils (OMAFRA 2020).

Employing agricultural beneficial management practices (BMPs) can potentially mitigate the negative impacts of agriculture on the environment and promote the conservation of soil and water health without forgoing productivity relative to existing cropping practices. Natural climate solutions, including diversified crop rotation, conservation tillage, and restoration (conservation buffers), can significantly reduce net annual greenhouse gas (GHG) emissions for Canada (Drever et al. 2021) and the United States (Fargione et al. 2018) while also offering other environmental co-benefits. For example, crop rotations with cover crops can sequester carbon and conservation tillage, reduce soil erosion, prevent nutrient leaching, and provide habitat for beneficial insects and pollinators (Carlisle 2016; Sharma et al. 2018). The ability of BMPs to improve soil health specifically has been recently assessed by Groupe Agéco (2020). The extent to which any of the BMPs can mitigate GHGs and improve soil health varies depending on several factors such as geography and the BMP selected (Drever et al. 2021).

In addition to enhancing environmental quality including soil health, BMPs can increase profit and are thus often promoted as win-win technologies. Yanni et al. (2021) provide a comprehensive review of the environmental (public) and economic (private) effects of 10 BMPs for mitigating soil-related GHG emissions for Ontario corn farms. Seven of the 10 are win-win, but the extent of the gains varies depending upon the geographic location and financial situation of the farmer. Another factor is the time frame of analysis. Rejesus et al. (2021) find in their review that often the short-term, private benefits of BMPs are less than the implementation cost and note the lack of long-term economic studies on the relationships between BMPs, soil health indicators, and economic outcomes. Examples of such studies are Chahal et al. (2021), Janovicek et al. (2021), and Congreves et al. (2017) who determine that the long-run use of cover crops in a diversified crop rotation with reduced tillage in Ontario enhances soil health and improve both the average and resiliency of yields. This was also seen in the United States, where Bowles et al. (2020) found that long-term diverse crop rotations improved not only the yields of corn but also their resiliency to extreme weather events.

The potential environmental benefits associated with BMPs have prompted governments to develop policies and programs that promote their adoption and implementation (Norris et al. 2020). However, enhancing adoption requires understanding the current level of uptake and the perceived benefits and limitations of the BMPs. The perceived relative net environmental and financial benefits of a BMP will vary depending on farm location and characteristics (Hyland et. al 2018; Traxler and Li 2020; Gitau et al. 2004; Hickey and Doran 2004). In addition, the decision to adopt a BMP at any location is determined by factors other than profit maximization (Weersink and Fulton 2020). Every farmer has their own unique combination of demographic factors, personality, previous experiences, routines, and goals, as well as economic, cultural, family influences, and perceptions of soil health (Ghazalian et al. 2009). The differences also lead to variations in the perception of the level of soil health, and the role technologies can play in altering its quality (Mann et al. 2021). This heterogeneity in farmer characteristics has led to literature inconsistencies in determining the factors that influence the adoption of BMPs (Knowler and Bradshaw 2007; Baumgart-Getz et al. 2012; Prokopy et al. 2019). Furthermore, much of the BMP research has been conducted outside of the Canadian context and (or) focused on small watersheds (Ranjan et al. 2019; Liu and Brouwer 2022). Information on farmers' motivations and barriers to the adoption of soil BMPs will is critical for policies and programs to be effective in encouraging wider adoption of these practices and promoting soil health across the province.

The purpose of this paper is to analyse the determinants that contribute to the adoption of BMPs for Ontario farmers as well as understand the constraints that inhibit adoption. The research focuses on the adoption of six soil health BMPs: cover crops, crop rotations, reduced tillage, soil testing, conservation buffers, buffer strips, and organic amendments. These BMPs have been identified as key practices for soil health (Kimble et al. 2016; Agricultural Soil Health and Conservation Working Group 2018; Groupe Agéco 2020; Norris et al. 2020). By understanding the factors that influence non-adoption and low adoption levels for several soil health BMPs, the results of this research can be used to develop a set of recommendations to inform policy and programming considerations aimed at improving soil health.

Methods

The data used in this study are from an online survey conducted from January to April of 2020. The purpose of the survey, funded by the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), was to gain a better understanding of the reasons behind the seemingly low adoption levels among Ontario farmers for several soil health BMPs and to elicit information on strategies and policy tools that have the most potential to improve adoption rates amongst Ontario farmers. A link to the survey was emailed to members of the Ontario Federation of Agriculture (OFA) through their newsletter. The survey was also advertised at the Southwest Agricultural Conference in January 2020 at Ridgetown, Ontario, where cards containing the survey link were handed out. In addition, a signup sheet was set up for participants, who preferred to participate by phone. To encourage participation, respondents who completed the survey were eligible to participate in a draw consisting of various prizes ranging from

$20 to $100. There was a total of 249 respondents, of which 246 responses were through the online survey and three responses were through the phone survey. Of the 249 respondents, two (0.8%) of the responses were incomplete, lowering the total number of complete responses to 247.

The survey was constructed using Qualtrics and was designed to be completed in 10 to 30 minutes depending mostly on how many BMPs a farmer had adopted. The survey was split into eight distinct sections, each with a unique set of questions which were developed by a team consisting of members from the University of Guelph, the OMAFRA, and the OFA. The first section of the survey posed questions related to general farm characteristics such as the location of the farm, types of primary commodity crops produced, and a general understanding of farmers' perceptions of BMPs. The next six sections focused on individual BMPs: (1) cover crops, (2) crop rotations (more than two crops in rotation), (3) no-till, (4) soil testing, (5) conservation buffers (i.e., windbreaks, buffer strips, naturalized areas), and (6) organic amendments (i.e., manure, biosolids, compost). For each BMP, farmers were asked about their use of the BMP and the reasons for adoption or non-adoption as well as reasons that would increase the likelihood of adoption of a given BMP. The final section gathered socioeconomic data on the respondents, such as age, gender, and education level.

Results

Characteristics of respondents

Demographic characteristics for all participants ($n = 247$) are presented in Table 1. The results are compared where applicable with the 2016 Census of Agriculture (Statistics Canada 2016*a*, 2016*b*). Of the 247 participants, 63% reported working over 30 hours a week on average on the farm. Thus, the survey contained more full-time farmers compared to the 2016 Census in which 34% of farm operators in Ontario worked more than 40 hours a week on average on farm operations and 46.3% of farm operators had an off-farm job. The respondents to the survey were primarily male (89.9%) with onl,y 10.2% of female respondents, which is lower than the approximately 30% of farm operators that are female as reported in the Census. The difference between the survey and Census may be due to the nature of the question. The survey asked for the gender of the person answering the survey, whereas the Census asks for the gender of all farm operators.

The average age of an Ontario farmer according to the Census is 55, with 9.1% of farmers being under 35 years, 36.3% between 35 and 54 years, and the majority (54.5%) are over 55. Survey respondents were slightly younger farmers, with 11.3% under 35 years and 38.1% between 35 and 45 years. 50.6% of the sample was over 55 years. Producers in the sample also had more formal education than the average Ontario farmer. Over two-thirds of the sample had a college diploma or higher while only 15% of all Census farmers have a university degree or diploma at the bachelor's level or above, and 14% hold a post-secondary certificate or diploma. Similarly, less than one-fifth of the survey respondents had finished high school or less, compared to 29% of all Ontario farmers.

The location of the farmer is grouped into five geographical regions in Table 1. Over 70% of the respondents were located in the southwestern portion of the province. Of the remaining farms, 38 respondents were in Eastern Ontario, 25 were from the Central region, and 7 were from the North. The geographic distribution of the sample across the province is similar to the distribution for the location of Census farms. The farms operated by the respondents tend to be larger than the average farm. The mean acreage of the total land area of respondents' farm operation was 517 acres, of which two-thirds was owned and one-third was leased. Approximately one-quarter of respondents had farm cash receipts of less than $100 000, which is significantly smaller than the 62% of Census farms with sales of less than $100 000 (Table 1). The survey respondents were also twice as likely to have sales greater than $1 million annually (12.7%) than the average farm in the Census (6.5%). Grains and oilseed crops are the primary commodity produced by 60% of respondents, and about 20% of respondents are primarily livestock producers.

Overall adoption rates of BMPs

Soil testing was the most employed BMP by respondents (86%), while the least adopted was conservation buffers (53%) (Table 2). The difference may be attributed to the relative costs of adoption. Approximately three-quarters of the respondents used a crop rotation involving more than two crops. Nearly 70% of producers reported incorporating cover crops within their practices, which is significantly higher than the current 30% adoption rate reported by the 2017 Farm Management Survey.

Respondents were likely to use more than one of the BMPs. Only 5% of the farmers used none (1%) or only one (4%) of the six BMPs (Table 3). In contrast, approximately one-third (71) adopted five of the practices and one-fifth (42) used all six. If multiple BMPs are adopted, the practices that are adopted together are indicated by the correlations given in Table 4. The adoption of cover crops is positively correlated with a diverse crop rotation ($r = 0.36$), no-till ($r = 0.17$), and organic amendments ($r = 0.25$). The most likely combination of BMPs is the use of more than two crops in a rotation and no-till ($r = 0.42$). The correlation is expected since those that include a third crop (winter wheat) into a corn–soybean rotation tend to plant it directly without tillage in the fall after soybean harvest, and a cover crop is planted into the wheat. Soil testing is also likely to be correlated with cover crop, crop rotation, and tillage BMPs. In contrast, the adoption of conservation buffers tends not to be correlated with any of the other five BMPs.

Cover crop adoption

The majority of respondents (70%) used cover crops in their operation, and 93% reported that they plan on continuing their use of cover crops. A small percentage (7%) said cover crops were not applicable to their farm operation. The mean acreage of land planted with cover crops is 169 acres, of which 66% (112 acres) is owned and 33% (57 acres) is rented.

Table 1. Socioeconomic characteristics of respondents.

Characteristics	Number of observations	Frequency (%)	Census (%)
Farmer			
Full-time farmer (Yes = 1)	244	63.1	34.0
Gender (Male = 1)	245	89.9	70.3
Age	239		
Less than 40	27	11.3	9.1
40–49 years	21	8.8	36.3
50–59 years	70	29.3	9.1
60–69 years	86	36.0	54.5
70 and over	35	14.6	36.3
Education	245		
High school or less	48	19.6	29.0
Some high school	33	13.5	42.0
College diploma	92	97.6	14.0
University degree	72	29.4	15.0
Farm			
Location	244		
South	98	40.2	34.3
West	76	31.1	32.7
Central	25	10.2	14.4
North	7	2.9	4.0
East	38	15.6	14.6
Acreage (operated)		517.1	249.0
Farm cash receipts	229		
<$100 000	82	36.2	63.5
$100 000–$249 999	51	22.3	11.4
$250 000–$499 999	35	15.3	11.8
$500 000–$999 999	31	13.5	13.4
>$1 000 000	29	12.7	7.1
Primary commodity	232		
Grains and oilseeds	149	64.2	
Livestock	52	22.4	
Other	31	13.3	

Table 2. Adoption rate of BMPs in sample.

BMP	Percentage of farmers
Cover crop	69.5
Rotation (>2 crops)	75.9
No-till	55.8
Soil testing	86.3
Conservation buffers	53.0
Organic amendment	62.8

Table 3. Number of farmers adopting multiple BMPs.

Number of BMPs adopted	Number of farmers (%)
0	2 (0.9%)
1	9 (4.1%)
2	20 (9.1%)
3	28 (12.8%)
4	47 (21.5%)
5	71 (32.4%)
6	42 (19.2%)
Total	219 (100%)

The differences in demographic characteristics of adopters and non-adopters for cover crops are listed in Table 5. Of the farmers who adopt cover crops, 68% work full-time on the farm and the majority are male (90%), which is similar to the overall numbers (see Table 1). Of the female respondents, 17 (68%) adopt cover crops while three do not use cover crops. Producers from both adopter and non-adopter groups display no relative differences in education levels nor age (i.e., they are aged between 50 and 69 and hold college diplomas).

Farms adopting cover crops tend to be larger than farms not using cover crops (see Table 6). The mean acreage of adopters is higher (590 acres) than that of non-adopters (439

Table 4. Correlation among adoption of BMPs.

	Cover crop	Crop rotation	No-till	Soil test	Buffers	Organic amendments
Cover crop	1	**0.3913***	**0.1996***	**0.2686***	0.0697	**0.2546***
Crop rotation	–	1	**0.4177***	**0.1985***	0.0487	**0.1546***
No-till	–	–	1	**0.1963***	– 0.0227	0.0522
Soil test	–	–	–	1	– 0.0703	0.0568
Buffers	–	–	–	–	1	0.0699
Organic amendments	–	–	–	–	–	1

Note: An asterisk (*) indicates significance at the 5% level.

Table 5. Demographic characteristics of adopters and non-adopters of BMPs.*

Demographic characteristics (% in each category)	BMP											
	Cover crops		Crop rotations		No-till		Soil test		Buffers		Organic amendment	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Full-time	68%	54%	70%	44%	70%	50%	66%	44%	64%	62%	71%	49%
Gender (male)	90%	95%	89%	93%	88%	93%	91%	91%	90%	89%	90%	93%
Age												
Less than 40	13%	7%	13%	7%	13%	8%	11%	12%	7%	16%	12%	9%
40–49 years	10%	7%	10%	3%	9%	8%	9%	6%	8%	10%	9%	8%
50–59 years	26%	40%	27%	38%	28%	33%	31%	30%	32%	29%	29%	35%
60–69 years	38%	30%	37%	29%	35%	37%	35%	33%	42%	28%	38%	32%
70 and over	14%	16%	12%	22%	15%	13%	21%	18%	12%	18%	13%	16%
Education												
< High school	20%	19%	20%	19%	19%	21%	18%	27%	15%	25%	19%	23%
Some post HS	11%	23%	11%	21%	14%	13%	14%	12%	15%	11%	13%	15%
College diploma	41%	33%	39%	31%	38%	36%	39%	30%	35%	40%	38%	33%
University degree	28%	25%	30%	29%	29%	29%	29%	30%	34%	24%	31%	30%
Total	170	57	185	58	160	85	206	33	131	114	154	80

*Yes indicates the % of adopters and No indicates the % of non-adopters.

acres). Respondents from both groups have sales under $100 000, but the relative share in the low sales categories is higher for non-adopters. Non-adopters of cover crops represent 35% of respondents with sales less than $100 000 but around 20% of those with sales greater than $100 000. Of the non-adopter group, crop producers make up the majority (80%) while livestock producers make up 14%. This differs from the adopter group where 60% are crop producers and a third are livestock producers (35%).

Crop rotations

Three-quarters of the respondents employ more than two crops in their rotations, which are predominantly soybeans, corn, and winter wheat. The respondents who adopt more complex crop rotations tend to be younger and have higher levels of education than non-adopters (Table 5). The adopters also have significantly larger farms both in terms of area operated and revenue generated compared to non-adopters of diverse crop rotations. Both groups have similar proportions of livestock and crop producers.

Tillage

The adoption rates across different tillage approaches (conventional, no-till, strip till, and reduced till) suggest that many of the respondents use multiple tillage techniques depending on the crop in the rotation. For example, 56% use no-till, with the majority using it in soybean and winter wheat crops. Similarly, the one-third of the respondents that use conventional tillage will do so largely on a corn field. The 55% of respondents using reduced tillage tend to do so across the range of crops grown. Only 6% of the farmers used strip tillage. Adopters of no-till are more likely to be full-time operators, but there is little difference in age and education levels with non-adopters (Table 5). As with crop rotations, adopters of no-till tend to operate larger farms but there is no difference in the primary commodity produced by the operation (Table 6).

Soil testing

Eighty-four percent of the respondents test their soils, with less than 20% taking the actual soil sample themselves.

Table 6. Farm characteristics of adopters and non-adopters of BMPs.

	Farm characteristics								
		Farm cash receipts (in hundreds of thousands)					Primary commodity		
BMP	Farm area (acres)	<$100	$100–$249	$250–$499	$500–$999	>$1000	Crop	Livestock	Other
All	517.1	36.2%	22.3%	15.3%	13.5%	12.7%	64.2%	22.4%	13.3%
Cover crop									
Adopter	580.9	31%	22%	17%	14%	16%	62%	35%	4%
Non-adopter	438.6	43%	24%	13%	13%	7%	81%	14%	5%
Rotation									
Adopter	567.2	8%	26%	18%	15%	14%	68%	29%	3%
Non-adopter	391.8	60%	13%	7%	11%	9%	68%	23%	9%
No-Till									
Adopter	587.6	24%	27%	20%	16%	13%	70%	26%	4%
Non-adopter	388.1	59%	14%	8%	9%	11%	63%	31%	6%
Soil test									
Adopter	579.9	30%	23%	18%	16%	14%	69%	27%	4%
Non-adopter	232.4	67%	21%	3%	0%	9%	60%	35%	4%
Buffers									
Adopter	546.2	35%	22%	21%	9%	14%	64%	30%	5%
Non-adopter	484.1	38%	23%	9%	19%	11%	71%	26%	3%
Organic amendments									
Adopter	611.8	31%	22%	17%	14%	16%	62%	35%	4%
Non-adopter	383.3	44%	24%	13%	13%	7%	81%	14%	5%

Instead, the majority rely on a soil lab (42%), an input supplier (32%), or a consultant (8%) to obtain the sample, which is then evaluated by a testing facility. Approximately half test their soil every three years, with around one-fifth testing every other year and another one-fifth testing every four to five years; 10% test their soil every year. The frequency of soil testing does not vary significantly between owned and rented land. Like adopters of other BMPs, soil test adopters tend to be full-time farmers. There is little difference in age and education levels of soil test adopters and non-adopters (Table 5). However, respondents who adopt soil testing have larger farms (580 versus 232 acres) and report higher farm cash receipts (half of them earn $250 000 and over versus 13%; Table 6)

Conservation buffers

Approximately half (53%) of respondents have retired unprofitable or fragile cropland to establish conservation buffers, and of these respondents more than half (56%) have established more than one type of buffer. The most common conservation buffer is a windbreak (32%), followed by a buffer strip (20%), and the least common is a wind strip (5%). The difference in the use of these three buffers is likely due to the productivity impacts as buffer strips are usually planted on the edges of the field, whereas wind strips maybe within the field. Approximately 15% of the respondents use either afforestation, perennial forage crops, or other naturalization such as establishing wetlands. In contrast to the other BMPs, non-adopters of conservation buffers tend to be younger than adopters (Table 5), but are similar in other demographic (Table 5) and farm characteristics (Table 6).

Organic amendments

More than half of the responders include organic amendments in their cropping practices. Soil manure is the most common amendment and is used by 64% of producers, followed by liquid manure (28%) and compost (26%). Approximately 40% of respondents apply organic amendments annually which is similar to the percentage of farmers applying manure or other amendments annually according to the 2016 Census of Agriculture. Comparable to many of the other BMP adopters, those who implement organic amendments are mostly full-time producers and tend to be younger than non-adopters. While adopters tend to farm a larger land base (612 acres versus 383 acres), there is little difference in the distribution of farm cash receipts between adopters and non-adopters. As expected, given the availability of manure from their home operation, farms using organic amendments are much more likely to be livestock producers as compared to non-adopters (Table 6).

Implementation of BMPs for soil health

Reasons for implementation

For each BMP adopted, the survey provided a list of reasons to better understand the motivations driving respondents towards implementation. These included economic reasons such as to increase profits or yields, environmental reasons related to improving soil health or reducing run-off and erosion, and social reasons linked to managerial decisions. Respondents could select up to three reasons, and results are presented in Table 7. "To improve soil health" was the most frequently selected reason for many of the BMPs adopted,

Table 7. Percentage of total respondents by reason for using BMP.*

Reasons for use	Cover crops	Crop rotation	No-till	Soil testing	Buffers	Organic amendment
			Beneficial management practice			
Improve soil health	100%	80%	90%	89%	14%	84%
Reduce run-off	56%	1%	44%	11%	32%	
Reduce erosion	56%				70%	7%
Improve yields	37%	67%	18%	49%		
Increase returns	13%	28%	63%	45%	20%	44%
Reduce input costs	3%	24%	53%	28%		97%
Reduce pests	2%	64%	1%			
Management		27%	8%		3%	30%
Optimize nutrients	1%					1%
Other	5%	7%	2%	2%	60%	1%
Total	147	169	153	188	125	154

*Respondents could give up to three reasons for using an individual BMP.

while nutrient optimization was the least frequently selected reason across all BMPs. The valuation of soil health as the primary driver for BMP adoption may have been related to response bias where the participants choose more socially accepted options, like the environmentally conscious option to improve soil health, as opposed to being economically driven.

Environmental reasons, specifically related to soil health, were the driver for adoption of all BMPs with the exception of conservation buffers when compared to economic or social reasons. For example, all 147 respondents using cover crops noted improving soil health as one of the three reasons for implementation, except for buffers (Table 7). Cover crop adopters widely selected environmental reasons over economic or social reasons. After soil health, reducing run-off, and reducing erosion, with each selected by more than half of the respondents, were the main driving forces pushing adopters to use cover crops. Environmental reasons were also a major driver for the adoption of no-till and conservation buffers. For no-till, 44% gave reducing run-off as a primary reason for implementation but surprisingly none cited reducing erosion. In contrast, reducing erosion was the primary reason for implementation of conservation buffers (77%), while 32% noted reducing run-off. Reducing run-off and (or) erosion were not major reasons for implementation among the other three BMPs.

Economic factors were a driver in adoption of all BMPs except for conservation buffers. Improving yield was a reason for using cover crops given by two-thirds of the adopters. Similarly, half of the adopters of soil testing gave higher yields as a factor for adoption. The other major financial reason for using crop rotations was the reduction in weeds, pests, and diseases, which was also noted by two-thirds of the adopters. Lowering the threat of pests was not cited as a reason for the use of any of the other BMPs. However, reducing other input costs, such as fuel and fertilizer, was a reason for adoption of several BMPs. As expected, this was the dominant reason for the use of organic amendments as manure could substitute for inorganic fertilizer. Over half of adopters of no-till cited reducing input costs as a reason, as this BMP could reduce fuel costs and machinery repairs. These financial reasons influence profitability, and an increase in net returns was given as a reason by two-thirds of the adopters of no-till. It was also a reason given by nearly half of the adopters of soil testing and organic amendments.

The remaining reasons played little role in the adoption decision of the BMPs apart from management for crop rotations and organic amendments. In the former, 27% of adopters used cover crops as means to spread out labour and machinery demands through the growing season. In the latter, 30% apply organic amendments as a necessary means to empty out waste from livestock barns.

Barriers to implementation

As with the reasons for implementation, the respondents were asked to select up to three reasons why they chose not to implement specific BMPs. Barriers to adoption include cost of implementation, low profits, additional resources required such as equipment, time and labour, land management issues related to tenured land, pre-existing structures, and fragile land. In contrast to the reasons for implementation, there is no consistent reason selected for all BMPs (see Table 8).

The first three barriers to implementation listed in Table 8 influence the bottom line of the farmer. The need for additional resources was cited as a reason by 82% of the 37 non-adopters of cover crops. It was also a major barrier to the adoption of crop rotations (63%) and soil testing (58%) but did not play a role in the non-use of the three other BMPs. In the case of soil testing, additional costs were the primary reason (87%) given for those not determining the fertility of their soil. More than half of non-adopters of cover crops and crop rotations also cited additional costs as a barrier to their implementation. While additional resources and (or) costs were a primary barrier to adoption of several BMPs, the lack of returns played a less significant role. Approximately one-third of the non-adopters of cover crops, crop rotations, and conservation buffers gave insufficient benefits as a reason for their non-use. Non-adopters of soil testing and organic

Table 8. Percentage of total respondents by barrier to implementation of a BMP.*

		Beneficial management practice				
Barrier for not using	Cover crops	Crop rotation	No-till	Soil testing	Buffers	Organic amendment
Additional resources	82%	63%	1%	58%	1%	
Additional costs	55%	4%	52%	87%	13%	32%
Lack of return	39%	28%	7%		38%	12%
Uncertainty of benefits	37%	11%	11%	71%	13%	71%
Management reasons	79%	2%	31%	32%	11%	1%
Land management	8%	9%	32%	6%	27%	3%
Nutrient management	11%	4%	1%			
Nobody else uses it	11%		4%	16%	1%	
Not applicable		39%	2%		70%	1%
Other	24%	13%	7%	26%	5%	22%
Total	38	46	111	31	96	78

*Respondents could give up to three barriers as reasons for not using an individual BMP.

Table 9. Measures to increase the likelihood of adoption of each BMP.*

		Beneficial management practice				
Measure	Cover crops	Crop rotation	No-till	Soil testing	Buffers	Organic amendment
Financial incentives	88%	63%	35%	100%	52%	42%
Better knowledge of benefits	33%	56%	21%	57%	30%	44%
Professional assistance	35%	20%	14%	57%	17%	27%
Workshops or demonstrations	35%	15%	10%	57%	6%	29%
Other farmers recommending	0%	12%	5%	7%	2%	8%
Other	90%	24%	7%	30%	10%	14%
Total	40	41	111	30	101	78

*Respondents could give up to three measures that would increase the likelihood of using an individual BMP.

amendments do not seem to question the existence of potential benefits of these BMPs but 70% of the respondents note the uncertainty of these returns as a barrier to implementation. Uncertainty of benefits is also a barrier to adoption of cover crops for 37% of the non-adopters.

There are other non-financial reasons that can prevent the adoption of the BMPs. For example, 79% of the non-adopters of cover crops note the complexity of the management to this BMP as a barrier. The lack of knowledge to effectively implement was also cited by approximately 30% of the non-adopters of no-till and soil testing. A similar percentage of non-adopters also pointed to land management issues as reasons for not implementing no-till and conservation buffers. Land management issues include poor soil drainage, soil types, or delays in planting due to slow soil warming and (or) drying. The effectiveness of no-till in influencing soil carbon levels and consequently its adoption depends on the soil type and region (Angers et al. 2017). Similarly, land management issues related to not owning land or conservation zones already being installed on the farm before purchasing the land were cited as a barrier by 27% of non-adopters of conservation buffers. Conservation buffers were viewed to be non-applicable by 70% of its non-adopters. The only other BMP viewed to be not applicable to their operation was crop rotations. A significant number of other barriers were cited as reasons for non-adoption across the BMPs, which highlights the need to understand the heterogeneity of farmers to encourage the adoption of BMPs related to soil health.

Likelihood of implementation

For the majority of the BMPs discussed, save for organic amendments, financial incentives are the most popular measure that would increase the likelihood of implementing a given BMP (Table 9). Cost-share programmes or rebates would be particularly effective to increase the adoption of soil testing and cover crops according to the non-adopters of these BMPs. The role of financial incentives is lowest among the BMPs for no-till.

Better knowledge of benefits is widely selected as the main reason that would motivate organic amendment non-adopters towards implementation and is the second largest reason selected by non-adopters of other BMP groups. One-on-one advice or assistance from a professional agronomist is ranked as the third reason that would encourage adoption of the six BMPs, which is closely followed by workshops or demonstrations. While the role of professional assistance and demonstration plots suggest that producers may not have the knowledge to implement these BMPs, recommendations from other farmers have a limited influence on increasing the likelihood of adoption of these BMPs. Across all BMPs, but especially for cover crops, other factors aside from the stated measures can increase the likelihood of adoption.

Conclusions

As climate change and food security pressures rise, healthy soils are critical to build prosperous and resilient farms and communities. Beneficial management practices are perceived as measures to enhance environmental quality, including the improvement of soil health, and consequently are being promoted by government efforts. The effective design and implementation of programmes to enhance BMP adoption require assessing current levels of use as well as understanding the factors affecting both the uptake by adopters and the barriers by non-adopters.

This study asked Ontario farmers directly about their motivations surrounding the use of BMPs related to soil health. The majority of the respondents implement more than one BMP in tandem, with soil testing being the most employed among the six soil health BMPs, and conservation buffers being the least. The difference can be attributed to the relative costs of implementation. The fee required to sample and conduct a soil test is relatively small and can result in lower overall input costs by determining the appropriate fertilizer rate. In contrast, conservation buffers involve taking land out of production and require significant costs to plant, establish, and maintain. Nearly three-quarters of the farmers surveyed implemented four or more BMPs as the use of practices such as a rotation with winter wheat, cover cropping, and no-till tend to be positively correlated. Across BMPs, adopters tend to be more likely female, have larger farms, and report higher farm cash receipts than non-adopters. Both members of each group have similar age and education levels.

Environmental reasons, specifically related to soil health, were the driver for adoption of five of the six soil health BMPs except for conservation buffers. The result suggests adopting farmers understand the need for preserving their soils and place more importance on soil health than on economic or social reasons. However, the biggest barriers indicated by non-adopters include the additional costs of BMP implementation, the knowledge required to use the BMP, and the uncertainty of how certain BMPs benefit farmers and soils. Encouraging use among non-adopters may require monitoring and promoting the benefits of soil health along with understanding the heterogeneity that influences the relative net advantage of a BMP for a given farmer. These findings can aid in the development and implementation of strategic frameworks and programme instruments to support farmers in their stewardship of soils and their adaptation to climate change.

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