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Value of direct seeding mulch-based cropping system to field crop farmers in Quebec

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ABSTRACT

Direct seeding mulch-based cropping system (DMC) is often touted for providing diverse ecosystem services, but its implementation may impose private costs that often limit its adoption by farmers. This study uses a contingent valuation method and a double hurdle model to estimate Quebec farmers' willingness to accept (WTA) compensation for adopting DMC and to analyze the underlying factors associated with WTA. Results show that farmers would demand, on average, 161 Canadian dollars per hectare as compensation for adopting DMC. Our results also indicate that farmers are willing to convert only 25.5 % of their farm size to DMC. While the adoption of DMC is positively influenced by the ease of implementation and farmers' perception of DMC yield, the WTA for adopting DMC increases with the perceived risk and yield, as well as farm size. Conversely, it decreases with the age of farmers and if the farmers know a DMC producer. The findings of the study suggest that compensating farmers for adopting DMC is encouraging, but compensation alone may not be sufficient to induce the conversion of entire farms to DMC. The study, therefore, calls for further research to investigate why farmers are willing to convert only a quarter of their farms to DMC.

1. Introduction

The present study aims to estimate Quebec farmers' willingness to accept (WTA) compensation for adopting the direct seeding mulch-based cropping system (DMC) and to identify the underlying factors associated with farmers' WTA. DMC is an agricultural practice that combines three sustainable management practices: no-till or direct seeding, crop rotation, and the use of cover crops. Although DMC was initially developed for tropical regions [1], it is now promoted in northern latitudes such as Quebec by some organizations as an alternative to conventional tillage.

In addition to reducing production costs through decreased farm work, labor, and external inputs such as chemical fertilizers and fuel consumption [1], DMC also provides ecosystem services. These include a reduction in eutrophication and stream pollution caused by fertilizer and pesticide leaching [2], a reduction in soil compaction and an increase in soil organic matter content [3], a reduction in greenhouse gas emissions through carbon sequestration and reduced fuel consumption [4]; [5], a reduction in soil erosion [6], and the protection of biodiversity [1], among other benefits.

Despite the numerous benefits of DMC, farmers are reluctant to adopt it because the ecosystem benefits provided by DMC cannot be sold under traditional market conditions. Moreover, the transition to DMC often requires an initial investment (e.g. new machinery, technical assistance) [7] while the resulting private benefits are only maximised over years [8]; [9]. Under such circumstances, the quantity of ecosystem services provided to society tends to be below the social optimum.

In various countries, payment for ecosystem services (PES) programs are often used by governments to promote the adoption of environmentally friendly agricultural practices ([10]; [11,12]). Under such programs, farmers are compensated in kind or cash for their voluntary adoption of DMC [13]. However, the success of PES programs depends on a good tariffication of ecosystem services and the attributes of PES contract. For example, if the compensation proposed to farmers for adopting DMC is above their minimum willingness to accept, then the excess amount will be considered as a transfer. On the contrary, if the compensation is below their minimum willingness to accept, many farmers will not participate in the PES program and the level of DMC

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adoption will remain low [14]; [11,15].

Sometimes, even attractive economic compensation fails to attract many farmers if the attributes of the PES program contradict the values of the targeted farmers [16]. Previous studies have shown that farmers' willingness to participate in a PES program may also depend on attributes such as the nature of compensation (cash or kind) [15], mode of payment (individual payment, community payment, or both) [14], contract duration [17], inclusion of additional assistance in the PES contract, such as the provision of equipment and labour [14]. Other influential factors include coordination, policy framing of the PES program coordination [18], whether the program is recommended by farmers or scientists, the neighboring effect, and participation in another PES program [19].

Apart from the attributes of PES programs, it has also been shown that farmers' participation in PES programs may depend on farm and farmer characteristics. For example, past studies have demonstrated that farmers' willingness to participate in PES programs is associated with factors such as age[20], level of education [21], income [22], family labour [23], farmers' perception regarding the role of ecosystem services [22]; farm size [24], perception of the environmental performance of conservation practice [11], knowledge about the environmental issues, access to credit [21], access to information concerning the PES program [23], among others.

In this study, we surveyed maize and soybean producers from Quebec to estimate their willingness to accept (WTA) compensation for adopting DMC and to identify the underlying factors associated with their WTA. Such a study is relevant for agricultural and environmental policymakers, as well as for scholars, as it contributes not only to the existing debate on farmers' participation in PES programs but also sheds light on the conditions necessary for the large-scale adoption of DMC in Quebec. Contrary to most contingent valuation studies that estimate farmers' WTA and merely compute the total cost of a PES program by multiplying the mean WTA by the total farm size [25,26], the present study estimates both the WTA for adopting DMC and the corresponding farmland that farmers are willing to convert to DMC. The study also employs both the provision point mechanism (PPM) suggested by Bush et al [27] and a combination of payment card and open-ended formats to minimize the impact of strategic bias and ensure the validity and reliability of the WTA estimate.

The results show that although farmers were willing to accept an average of 161 dollars per hectare for adopting DMC, they were ready to convert, on average, only 78.87 ha, corresponding to approximately 25.5 % of their farm size.

2. Material and methods

2.1. Survey design: combining payment card and open-ended formats

The contingent valuation method (CVM) was used to estimate farmers' willingness to accept (WTA) compensation for adopting DMC. CVM is a nonmarket valuation technique that relies on a simulated market to determine the monetary value of a non-market good, such as ecosystem services. Although CVM has been criticized for several biases, such as hypothetical bias and the embedding effect, which affect its validity and reliability [28],it remains appropriate for this study. CVM allows the valuation of goods that do not currently exist in a market, making it impossible to apply the revealed preference approach [29,30]. Nevertheless, different strategies have been used to minimize the impact of hypothetical bias and ensure the validity and reliability of the WTA estimate. These strategies were mainly obtained from Johnston et al. [31].

Firstly, following Mahieu et al. [32], both payment card and opened ended formats were used to elicit farmer's willingness to accept. The combination of these two elicitation formats allows farmers to become familiar with the evaluated good and the operating rule of the contingent market, thereby providing a consistent valuation [33].

Secondly, as the WTA is often suspected to overestimate welfare losses [28] and that respondents may strategically provide wrong information about their preferences to influence the provision of environmental goods [15], the provision point mechanism (PPM) was also used to minimize the impact of strategic bias as recommended by Bush et al [27].

Thirdly, to further improve the validity of WTA, farmers were also asked to provide their WTA while considering the benefits and costs associated with the adoption of DMC.

Data used in this study come from an online survey carried out from February to April 2021. The online survey was preferred over the traditional face-to-face survey not only because it limits social desirability bias [24] and eases answers to sensitive questions [34], but also because it allowed us to conduct the survey while maintaining the social distancing imposed by the government during the COVID-19 pandemic. As we did not have a list of maize and soybean producers for sampling, the invitation to participate in the online survey was sent to all members of *Producteurs de grains du Québec*.[1] This strategy also allowed us to maximize the response rate, as the response rate for mail surveys tends to be low [34]. The questionnaire was designed by the first author in collaboration with the two other authors. The questionnaire, which was designed for a broader study, included eight sections in the following order: Section 1 (Information and consent), Section 2 (Identification), Section 3 (General information), Section 4 (Farm characteristics and knowledge of conservation agriculture), Section 5 (Characteristics of maize and soybean plots), Section 6 Contingent valuation), Section 7 (maize and soybean producers' perceptions) and Section 8 (determination of risk preference). Under the contingent valuation section, we first provided respondents with a description of the PES program and DMC (see Table 1 for description of DMC).

The description of the PES program was validated by an agronomist specializing in the promotion of DMC. After presenting the PES program description, we asked respondents to vote for or against the PES program. If the respondents voted against the PES program, they were asked to provide their reasons for rejecting it. If they voted for the PES program, they were then invited to provide their minimum willingness to accept (WTA) for adopting DMC in two steps by answering the following questions.

- ❖ What is the minimum amount among the amounts below that you are willing to accept for adopting DMC (the three pillars simultaneously) on 1 ha?
- ❖ What is the exact minimum amount that you are willing to accept for adopting DMC (the three pillars simultaneously) on 1 ha?

This latter question was systematically repeated for each pillar of DMC (no-till or direct seeding, crop rotation, and use of cover crops).

Table 1
DMC description.

Pillars	Definitions
Direct seeding (or broadcasting seeding)	Crops are planted on no-till soil while maintaining most crop residues on the ground surface
Permanent vegetation cover	Cover crop must be planted on the plot and must be present on the plot (either as death plants or living plants) during the growth of the main crop and after harvesting.
Crop rotation	Crops must be rotated on the plot year after year and involving at least three cash crops over three successive years.

[1] *Producteurs de grains du Québec* is an association of Quebec grain producers which gathers more than 9500 grain producers [49].

The range of amounts for the former question is presented in Table 2. The range of amounts was determined by the authors according to the cost to farm 1 ha of maize. This range starts from zero dollars up to 550 dollars and above, where 550 dollars represent approximately a quarter of the cost to farm 1 ha of maize [35].

Once the minimum WTA for adopting DMC was provided by the respondents, we also asked them to state the number of hectares of maize and soybean they would be willing to convert to DMC. To encourage respondents to disclose their true minimum WTA for adopting DMC, we presented the following conditions: the program would be implemented if (1) enough farmers agreed to participate and (2) the overall amount of money demanded by participating farmers did not exceed the budget allocated for the program. To further improve the validity of WTA, farmers were also asked to provide their WTA while considering the benefits and costs associated with the adoption of DMC.

Prior to the proper survey, the questionnaire was first sent to colleagues and friends for corrections and then to some farmers. Their feedback allowed us to improve the quality of the questionnaire. The number of questions was then reduced from 119 to 103. In total, 298 soybean and maize producers participated in the survey, but only 44 of them were retained for this study due to missing values or inappropriate completion of the questionnaire by some respondents. For example, farmers who provided a WTA outside the range they selected at the payment card level were removed from the database. Among the 44 surveyed farmers, 59.1 % (26 farmers) agreed to participate in the PES program. The distribution of farmers' WTA for adopting DMC is presented in Fig. 1.

2.2. Theoretical framework of willingness to accept

Following Gutierrez-Castillo et al [36], we used the random utility framework to analyze the farmers' willingness to accept for adopting DMC. According to this framework, a farmer will participate in the PES program and accept e dollars per hectare if the utility derived from participation (U_{iP}) is greater than the utility derived from nonparticipation (U_{iN}). We assume that farmer i can be represented by the indirect utility function below:

$$U_{ij} = V_{ij}(Y_i + e, ES_i(e), X_i) + \varepsilon_{ij} \quad (1)$$

Where V_{ij} *and* ε_{ij} represent respectively the deterministic component and the stochastic component of the utility function of farmer i. Y_i, $ES_i(e)$ and X_i are respectively the farmer's income, the quantity of ecosystem services supplied by the farmer and a vector of socioeconomic and institutional factors susceptible to influence the farmer's preference. The farmer i will face two policy situations. If the farmer i accepts to participate in the PES program, his income will be augmented by e dollars and he will enjoy $U_{iP} = V_{iP}(Y_i + e, ES_i(e), X_i) + \varepsilon_{iP}$.

However, if the farmer decides not to participate into PES program, the supply of ecosystem services will not be increased, and his utility will be $U_{iN} = V_{iN}(Y_i + 0, ES_i(0), X_i) + \varepsilon_{iN}$. $ES_i(0)$ and $ES_i(e)$ are respectively the quantities of ecosystem services supplied by the farmer when he does not participate and do participate in the PES program respectively. $ES_i(e)$ is supposed to be greater than $ES_i(0)$. Thus, the minimum amount of money says *WTA* that the farmer i is willing to accept to participate in the PES program is obtained when the farmer is indifferent between the two policy situations that is when:

Table 2
Payment card.

0 to 22$	23 to 44 $	45 to 66 $	67 to 88 $	89 to 110 $
111 to 121 $	122 to 132 $	133 to 143 $	144 to 154 $	155 to 165 $
166 to 176 $	177 to 187 $	188 to 198 $	199 to 220 $	221 to 242 $
243 to 264 $	265 to 308 $	309 to 330 $	331 to 352 $	353 to 374 $
375 to 396 $	397 to 418 $	419 to 440 $	441 to 495 $	496 to 550 $
Over 550 $				

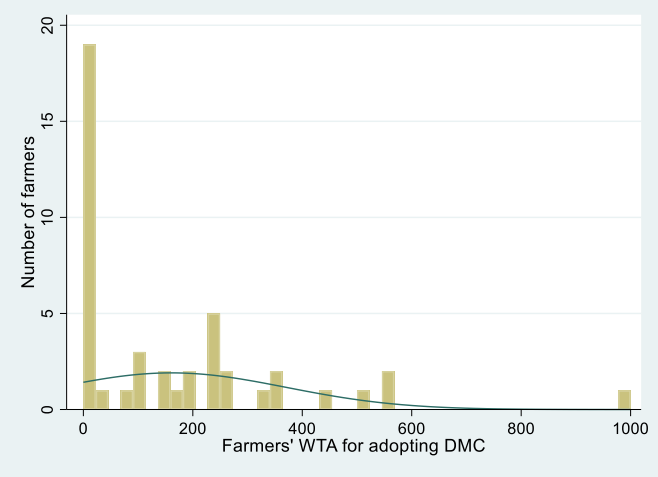

Fig. 1. Distribution of farmers' WTA for adopting DMC.

$$V_{iP}(Y_i + WTA_i, ES_i(e), X_i) + \varepsilon_{iP} = V_{iN}(Y_i + 0, ES_i(0), X_i) + \varepsilon_{iN}. \quad (2)$$

2.3. Econometric specification and method of estimation

The minimum willingness to accept can be modelled by the following equation:

$$WTA_i = Z_i\beta + u_i \quad (3)$$

Where WTA_I is the vector of minimum willingness to accept for adopting DMC, Z_i is the vector of explanatory variables, β the vector of parameters to be estimated and I the error term. Given that $WTAI_i$ is censored at zero, a Tobit model [37] or a double hurdle model (DHM) [38] could be used for estimating equation (3). However, the DHM was used in this study because it has the advantage of considering that factors explaining the participation in the PES program might not necessarily be the same as those explaining the minimum amount that farmers are willing to accept for adopting DMC. The DHM is then modelled is two steps as follows:

Step 1 is the participation decision

$$D_i = \begin{cases} 1 & if \ \ WTA^*_{1i} > 0 \\ 0 & otherwise \end{cases} \quad \text{with } WTA^*_{1i} = Z_{1i}\beta + \varepsilon_{1i}$$

Step 2 is the participation intensity or WTA equation

$$WTA_{2i} = \begin{cases} WTA^*_{2i} & if \ \ WTA^*_{2i} > 0 \\ 0 & otherwise \end{cases} \quad \text{with } WTA^*_{2i} = Z_{2i}\delta + \varepsilon_{2i}$$

D_i and WTA_{2i} represent respectively the participation decision and the stated minimum willingness to accept for adopting DMC. WTA^*_{1i} and WTA^*_{2i} are respectively the latent variables associated with D_i and WTA_{2i}. Z_{1i} and Z_{2i} are the vectors of covariates that explain respectively the participation decision and the participation intensity. The list of covariates included in Z_{1i} and Z_{2i} is presented in Table 3. β and δ are the vectors of parameters to be estimated. ε_{1i} and ε_{2i} are the errors terms. The following question was asked to characterize the farmers' perception regarding the degree of difficulty of implementing DMC: Is DMC easy to implement? The model is estimated by the maximum likelihood method using *churdle linear* command in Stata.

3. Results and discussion

Table 4 presents the descriptive statistics of the sample. Out of the 44

Table 3
Definition of variables

Variables	Measurement
Dependent variable	
Farmers' willingness to accept for adopting DMC	Canadian dollars per hectare
Independent variables	
Easiness of implementing DMC	1 = DMC is very difficult to implement 2 = DMC is difficult to implement 3 = DMC is easy to implement 4 = DMC is very easy to implement
Proportion of rented farm	Percentage
Farmers' perception of risk of DMC	Mean of the expected yield of DMC over 20 years[a]
Farmers' perception of yield of DMC	The variance of the expected yield of DMC over 20 years[a]
Age of the farmer	Years
Education of farmer	1 = primary, 2 = secondary, 3 = college and 4 = university
Agricultural training	1 if farmer has received an agricultural training and 0 otherwise
Farm size	Number of hectares
Maize and soybean revenue (log)	Canadian dollars
Membership to agri-environmental organization	1 if the farmer belongs to an agri-environmental organisation and 0 otherwise
Know a DMC producer	1 if the farmer knows a DMC producer and 0 otherwise

a = Annex 1 presents how the farmers' perception of yield and risk of DMC are computed.

The average minimum willingness to accept (WTA) for adopting DMC among respondents is about 161 Canadian dollars per hectare, representing approximately 7.7 % of the cost of 1 ha of maize production. This amount is lower than the least compensation (CAN$190/hectare) recently offered by the government to farmers for adopting DMC, although the maximum amount of compensation a farmer can receive is fixed at CAN$ 50,000, and the maximum farm size admissible for compensation is only one-third of the farm size. However, when the minimum WTA is asked for each pillar of DMC individually, the average minimum WTA for adopting DMC is CAN$ 297/hectare (105.7 + 60.4+130.9 = 297) with CAN$ 105.7, 60.4, and 130.9/hectare, respectively, for adopting direct seeding, crop rotation, and permanent vegetation cover. These results suggest that it is economically advantageous to promote the adoption of the full package (DMC) rather than promoting the adoption of each pillar individually. The lower WTA for adopting DMC (161 < 297) can be explained by the complementarity between the different pillars that allow farmers to maximize the benefits associated with the adoption of DMC.

This complementarity was also acknowledged by Pittelkow et al. [40] when they said that no-till combined with crop rotation and permanent covers might be a profitable system due to its reduced cost in terms of energy. Pittelkow et al. [40] have also shown that under a dry climate, the implementation of no-till in conjunction with residue retention and crop rotation increases yield by 7.3 % [40].

A priori, One might assume that farmers would convert their whole farm into DMC if offered a compensation of CAN$ 161 per hectare.

Table 4
Description of variables.

Variables	Full sample					Non-participation			Participation		
	Obs	Mean	SD	Min	Max	Obs	Mean	SD	Obs	Mean	SD
Ease of implementing DMC	44	1.82	0.62	1	3	18	1.67	0.69	26	1.92	0.56
Proportion of rented farm	44	0.16	0.23	0	1	18	0.14	0.25	26	0.17	0.217
Farmers' perception of risk of DMC	44	0.74	0.58	0	2.51	18	0.79	0.65	26	0.70	0.54
Farmers' perception of yield of DMC	44	8.28	1.33	6	11	18	7.94	1.35	26	8.51	1.30
Age of the farmer	44	52.82	12.19	25	74	18	53.72	12.87	26	52.19	11.91
Education of the farmer	44	3[a]	0.72	2	4	18	2.94	0.64	26	3.04	0.77
Agricultural training	44	0.77	0.42	0	1	18	0.78	0.43	26	0.77	0.43
Farm size	44	341.40	446.58	25	2680	18	260.42	213.09	26	397.47	551.51
Maize and soybean revenue (log)	44	12.65	1.52	9.184	18.95	18	12.27	1.28	26	12.92	1.64
Membership to agri-environmental organization	44	0.59	0.50	0	1	18	0.67	0.49	26	0.54	0.51
Know a DMC producer	44	0.66	0.48	0	1	18	0.61	0.50	26	0.69	0.47

[a] Stands for median instead of mean.

surveyed maize and soybean producers, 59.1 % accepted to participate in the PES program. Most surveyed producers are male farmers (41) with an average age of 52.8 years. Only 3 producers out of the 44 are organic producers, and 77.3 % have received agricultural training. 59.1 % are members of an agri-environmental organization, and 65.9 % know at least one producer that practices DMC. Farmers' perception of risk and yield of DMC are 0.74 and 8.28 tons per hectare, respectively. Farmers' perception of yield is obtained by averaging the farmer's expected yield of DMC over 20 agricultural campaigns, and farmers' perception of risk of producer is the variance of the farmer's expected yield of DMC over 20 agricultural campaigns.[2] It is important to note that farmers' perception of yield of DMC (8.28 tons per hectare) is lower than 9.9 tons per hectare, which is the average yield of maize obtained in Quebec in 2022 [39]. The mean farm size is 341.4 ha, and 29.55 %, 59.09 %, and 11.36 % of the surveyed farmers consider DMC to be very difficult, difficult, and easy agricultural practices, respectively. Most farmers have a collegial education level (50 %), while 25 % and 25 % have a secondary and university education level, respectively.

[2] This way of deriving farmers' perceptions of yield and risk was adapted from [51].

However, this is not the case because our results indicate that farmers would be willing to convert into DMC on average only 78.87 ha, corresponding approximately to 25.5 % of the farm size.

The traditional way to estimate the cost of the program is by multiplying the WTA for adopting DMC by the total farm size of farmers. By doing so, it is broadly assumed that farmers will convert their whole farm into DMC if the compensation is set at their minimum WTA, whereas this is not always the case. We have shown that even if the compensation is set at the farmers' WTA, farmers are willing to convert only 25.5 % of the total farm. Although the reason why farmers are willing to convert only 25.5 % of the total farm into DMC was not explicitly investigated in this study, the uncertainty surrounding the performance of DMC as well as skill development seem to be relevant reasons. These reasons come from the dynamic adoption model developed by [41] that showed that trialing an innovation such as DMC could be used by farmers for skill development and uncertainty reduction of the agricultural innovation.

A double hurdle model was also used to analyze the factors associated with the farmer's WTA. The results, presented in Table 5, indicate that factors explaining farmers' participation in the PES program are not necessarily the same as those explaining their WTA, justifying the use of a double hurdle model. Out of the 11 independent variables included in

Table 5
Double hurdle estimation.

VARIABLES	Participation equation	WTA equation
Proportion of rented farm	1.16	76.42
	(1.29)	(153.83)
Farmers' perception of risk of DMC	0.04	241.64[a]
	(0.38)	(66.57)
Farmers' perception of yield of DMC	0.38[c]	85.84[a]
	(0.23)	(29.21)
Age of the farmer	−0.02	−9.83[a]
	(0.02)	(2.87)
Education of the farmer	0.30	−7.80
	(0.44)	(50.05)
Agricultural training	−0.38	37.15
	(0.77)	(85.92)
Farm size	0.00	0.21[a]
	(0.00)	(0.07)
Maize and soybean revenue (log)	0.12	−28.16
	(0.22)	(25.27)
Membership to agri-environmental organization	−0.25	46.68
	(0.50)	(59.62)
Know a DMC producer	−0.04	−198.40[b]
	(0.55)	(85.08)
Ease of implementing DMC	0.92[b]	
	(0.44)	
Constant	−5.71	250.11
	(3.66)	(462.14)
LR chi2(10)	42.16	
Prob > chi2	0.00	
Pseudo R^2	0.11	
Observations	44	

[a] $P < 0.01$.
[b] $P < 0.05$.
[c] $P < 0.1$.

the model, only two variables, the ease of implementing DMC and farmers' perception of the yield of DMC, are associated with participation in the PES program.

The results show that participation in the PES program increases if farmers consider DMC to be easy to implement. This is further supported by responses to follow-up questions, as 55.6 % of farmers who declined to participate in the PES program cited the complexity of DMC as a reason for non-participation.

Additionally, participation in the PES program also increases with higher expected yields of DMC. Farmers tend to participate in the PES program if they believe DMC will have a greater yield. This is consistent with several studies that have identified farmers' perception of the performance of agricultural innovations as key factors in their adoption [42]; [43]. For example, Ma et al [11] showed, using data from Michigan maize and soybean farmers, that a positive perception of the environmental performance of soil conservation practices had a positive effect on participation in PES programs.

While farmers' perception of the yield of DMC and the ease of implementing DMC are the only significant factors explaining farmers' participation in the PES program, the model demonstrates that several factors are associated with farmers' WTA for adopting DMC. Firstly, the results show that farmers' WTA for adopting DMC increases with their perception of the risk of DMC. The more farmers consider DMC to be risky, the greater their WTA for adopting DMC. This could be interpreted as evidence of the existence of an adoption premium for DMC adoption. This idea of an adoption premium has been demonstrated by Kurkalova et al [44] with the adoption of conservation tillage practices in Iowa. The authors showed that although the adoption of conservation tillage practices may lead to increased expected profit, risk-averse farmers may still require a premium to adopt these practices because they could be riskier than traditional practices and require sunk investment [44].

The results also indicate that the WTA for adopting DMC increases with farmers' perception of the yield of DMC. This finding is somewhat unexpected, as one might assume that farmers with lower expectations of DMC yield would have higher WTA to compensate for the potential loss of yield. The positive effect of farmers' perception of the yield of DMC on WTA suggests that the expected yield of DMC may not be the critical factor in determining farmers' minimum WTA. Instead, the need for new investments in agricultural equipment required for adopting DMC may play a more significant role in determining their minimum WTA.

Age of farmers is also found to have a significant effect on farmers' WTA. The results show that farmers' WTA decreases as the farmer's age increases, suggesting that younger farmers will require higher compensation for adopting DMC compared to older farmers. This negative effect of age has been observed in previous studies [25,26] and could be interpreted several ways. One interpretation is that younger farmers may be more risk-averse than older farmers, leading them to seek higher compensation for adopting a new agricultural innovation such as DMC. This idea is supported by research conducted by Leblanc et al [45] in the Santarém region of Brazil, which showed that younger farmers tend to be more risk-averse.

Another possible explanation is that the negative effect of age reflects the general trend in the Quebec agricultural system, where younger Quebec citizens are less motivated to engage in farming activities. Recent data indicates that the average age of farmers in Quebec is 52.9 years, and the proportion of younger farmers (under 35 years) has decreased from 20 % to 10 % between 1996 and 2016 [46].

Additionally, the neighboring effect also plays a significant role in farmers' WTA. Knowing a farmer who practices DMC reduces the amount of compensation that a farmer is willing to accept for adopting DMC. This could be explained by the diffusion of knowledge that occurs between farmers [50]. A farmer may obtain information about the performance of DMC from neighboring farmers who practice it. Knowing a farmer who practices DMC could also be seen as a signal that it is possible to adopt DMC profitably. Therefore, farmers who know a DMC producer may be more inclined to adopt DMC themselves and may require lower compensation as they see it as a viable and profitable option.

Finally, the results show that farm size also influences farmers' WTA for adopting DMC. In contrast to many previous studies that found either no effect or a negative effect of farm size on farmers' WTA [25,47,48], the present study reveals that farmers' WTA increases with the number of hectares owned by the farmers. However, this is not an isolated result in the literature, as Li et al [26] have also shown the positive effect of farm size on farmers' WTA for planting green manure in China. This positive effect could be interpreted as the difficulties that larger-scale farmers would face when adopting DMC, especially if they had to change all their agricultural machinery for new ones adapted for DMC.

4. Conclusion and recommendations

The objective of the study was to estimate farmers' willingness to accept (WTA) for adopting DMC and to analyze the underlying factors associated with their WTA. Through a survey of 44 maize and soybean producers and a contingent valuation method combining both payment card and open-ended question formats, the study found that farmers' average WTA for adopting DMC is approximately CAN$161 per hectare. Interestingly, when the minimum WTA was asked for each pillar of DMC individually, the average WTA increased to CAN$297 per hectare, suggesting complementarity between the three pillars of DMC. This implies that promoting the adoption of the full DMC package may be more economically advantageous than promoting the adoption of each pillar individually. The study also revealed that farmers are willing to convert only about 25.5 % of their farm size (approximately 78.87 ha) to DMC, even if compensated at their WTA of CAN$161 per hectare. The reasons behind this result require further investigation in future research.

Using a double hurdle model, the study demonstrated that farmers who accept to participate in the PES program are those who consider DMC easy to implement and perceive it as having a higher yield.

Additionally, the study found that farmers with lower WTA for adopting DMC are younger, have smaller farms, perceive DMC as having a lower yield and risk, and know a DMC producer. However, it is important to stress that the study has two main limitations. Firstly, with a sample size of only 44 maize and soybean producers, the findings cannot be generalized. Furthermore, the 44 participants were not randomly selected, meaning that the sample might not be representative of the full population of maize and soybean producers in Quebec. To reach broader conclusions, a larger and randomly selected sample should be surveyed. Despite these limitations, the present study contributes valuable evidence to the literature on PES programs and provides an appraisal of the minimum compensation required by farmers to adopt DMC.

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CRediT authorship contribution statement

Guy Martial Takam Fongang: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jean-François Guay:** Writing – review & editing, Validation, Supervision, Resources, Funding acquisition. **Charles Séguin:** Writing – review & editing, Validation, Supervision, Software, Resources, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Annex 1.

In order to estimate farmers' perception of yield and risk of DMC, it was asked to farmers to distribute a total of 20 coins over a series of possible maize yield values that could be obtained by a DMC producer. Each coin represented an agricultural campaign. The series of possible maize yield of DMC is presented in table below.

Maize yield (ton/hectare)	6 or less	6.5	7	7.5	8	8.5	9	9.5	10	11 and over
Number of coins										

Farmers' perception of yield of DMC is the mean of expected yields.
Farmers' perception of risk of DMC is the variance of expected yields.

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