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A Composite Index Measuring Adoption of Conservation Agriculture among Maize and Soybean Farmers in Québec

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Abstract: Conservation agriculture (CA) has appeared in America since 1970 as an alternative practice to conventional tillage to limit soil degradation. Despite its expansion around the world, socioeconomic analyses of its adoption, as well as its impact on agricultural yields, still suffer from imperfect identification of CA adopters. The present study therefore proposes a new composite index for measuring the adoption of CA among maize and soybean farmers in the province of Québec, Canada. A model of partial adoption of CA both at parcel and farm levels is developed to build the composite index; and experts' judgements and the Analytical Hierarchy Process are used for weight elicitation of principles of CA. Data from 144 maize and soybean farmers are also used to assess the level of adoption of CA in Québec. The new composite index improves on the measure of adoption of conservation agriculture, as it can be used to discriminate among farmers according to the level of adoption of principles of CA. Indeed, the new composite index shows that 77.08%, 21.53% and 1.39% of maize and soybean farmers, respectively, are partial adopters, full adopters and non-adopters of CA, whereas the traditional binary indicator indicates that 83.33% and 16.67% of maize and soybean farmers, respectively, are adopters and non-adopters of CA. The results also show that many maize and soybean farmers (38.89%) have shown a certain flexibility in the adoption of CA.

Keywords: sustainable agriculture; agricultural innovation; maize and soybean producers; conservation agriculture

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1. Introduction

Conservation agriculture (CA) is a sustainable agricultural practice characterised by three principles: no or minimum mechanical soil disturbance, permanent mulch soil cover or cover crop and crop rotation. This practice has emerged as an alternative agricultural practice to alleviate soil erosion caused by conventional tillage systems [1].

Over the years, CA has been the object of many studies around the world. Most of them focus on the performance of CA or on the factors of adoption of CA by farmers. Studies on the performance of CA analyse its effects on soil physical properties, profitability, energy requirements, crop yields, greenhouse gas emissions, farmer's income and food security [2–7]. Those focusing on the factors of adoption seek to identify the main determinants of adoption of CA [6,8,9].

Despite the relevance of the above contributions, most socioeconomic studies are clouded by the weak identification of CA adopters. Indeed, many studies offer a simplistic black-and-white view of the adoption, e.g., adoption/no-adoption by farmer [4], whereas farmers often partially adopt CA precepts [4,10]. Farmers generally adopt the principles of CA while remaining flexible to respond to any stimuli coming out the market outlet or biophysical conditions [11,12]. For example, under intensive systems, crop rotation is often used as a strategic measure by farmers to raise the soil nitrogen level, control for plant disease cycles (biophysical conditions) or maximise crop income when the crop used for rotation faces rising prices (market outlet) [13]. Tillage is also used by farmers to control weed infestation that has become resistant to weed killer or to reduce soil compaction and to facilitate mineralisation [13,14].

Another reason of partial adoption of CA is related to spatial dimensions. Farmers initially tend to adopt CA on limited portions of their land before making a definitive decision to adopt or reject the innovation [15].

The above arguments show the difficulties of discriminating among farmers who are adopters (or not) of CA, of assessing the extent of adoption and of evaluating motives for adoption; however, unfortunately, many adoption and impact evaluation studies of CA are based on a binary approach, which fails to fully take into account the partial adoption of CA [4,7]. Full adoption is observed when farmers keep applying the three PCAs on the whole farm over three successive years while non adoption is observed when farmers do not apply any PCA on any piece of land over three successive years. Partial adoption of conservation agriculture, then, describes any farmer with a situation between full adoption and non-adoption.

Our contribution is based on the postulation that farmers often apply a PCA while remaining flexible to respond to market opportunities or to modifications of the biophysical environment [11,12]. We propose that a meaningful approach to measure the adoption of CA should integrate the complexity of CA and be able to discriminate among farmers, non-adopters, partial adopters and full adopters of CA. That approach should also be based on a three-year timescale, as an ideal CA practice implies a rotation of a minimum of three different crops [1]. Pursuing that objective, we propose a new measure of adoption of CA which fulfills the above-mentioned conditions (integrating all the complexity of CA, discriminating farmers according to the level of adoption of PCA, and using a three-year timescale). Such a measure is helpful for both land conservation programme managers and scholars. Land conservation programme managers can use the new measure of adoption of CA to tailor grants for CA adoption to the corresponding level of adoption of CA of farmers. For scholars, the new measure of the adoption of CA constitutes a flourishing avenue for reassessing the adoption and impact of CA and then contributing to the current debate of the performance of CA.

In summary, the present study contributes to the existing literature on adoption of CA by proposing a new and simple approach (composite index of CA at farm level) to measure the adoption of CA among farmers. This new approach permits us to show that most maize and soybean farmers are partial adopters of CA (77.08%) in Québec and that about 38.89 % are flexible, that is, they adopt the principles of CA while remaining flexible to respond to any stimuli coming out of the market outlet or biophysical conditions [11,12].

2. Materials and Methods

2.1. Data Sources

Data used in this study are primary data coming from two sources: an online survey of maize and soybean producers and a focus group of experts. The survey was carried out in winter 2021 from February to April through a unique questionnaire developed by the first author and tested by a pilot survey carried out in February 2021. Since the response rate of mailing surveys usually tends to be low [16], the invitation was sent to all of Québec's grain producers. Roughly 298 maize and soybean producers participated in the survey, but only 144 maize and soybean producers were retained for the analysis, as other participants failed to properly complete the questionnaire. The questionnaire covers a wide range of information, including farmers' characteristics, farm's characteristics, contingent valuation questions and risk elicitation lotteries, but only the summary descriptive statistic of variables used for this study is presented in Table 1. The questionnaire section used for building the composite index is available upon request.

Table 1. Descriptive statistics of key variables.

Variables	Observation	Mean	Std Dev	Min	Max
Proportion of maize and soybean farm under no or minimum mechanical soil disturbance in 2020	144	72.44	36.34	0	100
Proportion of maize and soybean farm under no or minimum mechanical soil disturbance in 2019	144	72.04	36.19	0	100
Proportion of maize and soybean farm under no or minimum mechanical soil disturbance in 2018	144	68.85	37.50	0	100
Proportion of maize and soybean farm under permanent mulch soil cover in 2020	144	68.49	39.18	0	100
Proportion of maize and soybean farm under permanent mulch soil cover in 2019	144	69.15	37.08	0	100
Proportion of maize and soybean farm under permanent mulch soil cover in 2018	144	64.76	38.66	0	100
Proportion of maize and soybean farm under crop rotation in 2020	144	82.38	28.90	0	100
Proportion of maize and soybean farm under crop rotation in 2019	144	82.46	28.30	0	100
Proportion of maize and soybean farm under crop rotation in 2018	144	80.54	30.60	0	100

Online questionnaires were preferred over the in-person interviews for three main reasons. First, the online survey strongly reduces any interviewer bias. Second, concomitantly, it favours the expression of the participant on sensitive questions [16]. Third, the online survey is also suitable as it respects social distancing advocated during the COVID-19 pandemic.

A focus group was also organised in May 2021 with eight experts for weighting the PCAs. During the focus group, the PCAs were presented to the participants, and they were asked to weight them during a post-focus-group survey organised in May 2021. Although all eight experts attended the focus group, only five experts effectively participated in the weighting process that occurred during the post-focus-group survey. These experts were recruited based on their academic experience in relation to agricultural sustainability. The experts invited for the focus group come mainly from universities and research centres.

2.2. Modelling of Partial Adoption

To consider the complexity of CA and the flexibility in its adoption, we use a composite index to measure the adoption of CA. The composite index is first calculated at parcel level and then aggregated at farm level and averaged over three years. The computation of the composite index is sequential as follows.

Let us assume that the farm of a given maize and soybean producer X is made up of N distinct parcels (n = 1, . . . , N) whose sizes (in hectares) are respectively S_1, S_2, . . . S_N for parcels 1, 2, . . . N. The proportion of parcel n over the overall farm is:

$$P_n = \frac{Sa_n}{\sum_{n=1}^{N} Sa_n} \tag{1}$$

Given that CA is characterized by three principles [1], the composite index of CA at the parcel level can be computed by the formula below:

$$PCIACAI_{nt} = \left(\sum_{j=1}^{3} w_j Y_j\right)_{nt} \tag{2}$$

where $PCIACAI_{nt}$ is the composite index of CA of parcel n at year t, Y_j are three dichotomous variables standing for the three principles of CA and w_j are their corresponding weights hypothesized to depend upon their contributions to agricultural sustainability. Y_j takes the value 1 if the farmer has applied the principles of CA on the parcel and 0 otherwise. Table 2 below provides the description of the three principles of CA.

The weights of the PCAs were determined by a panel of five experts. The weighting was performed through the Analytic Hierarchy Process (AHP). Although the AHP was initially developed as helping tool for complex decision-making [17], it has also been used for weight elicitation of criteria [18,19]. The AHP will be presented in the subsequent section. The weights of the PCAs are then obtained by aggregating the scores of each principle which themselves have been obtained by pairwise comparisons of the PCA. Given that five experts were involved in the weighting process, the geometric mean of the experts' weights were used in this study.

Table 2. Principles of conservation agriculture.

Y_j	Definitions	Principles of CA
Y_1	1 if the farmer has used direct seeding or minimum tillage on the parcel and 0 otherwise.	1—No or minimum mechanical soil disturbance.
Y_2	1 if the farmer has left crop residues or has planted cover crops on the parcel and 0 otherwise.	2—Permanent mulch soil cover/cover crop.
Y_3	1 if the farmer has applied crop rotation on the parcel and 0 otherwise	3—Crop rotation.

The composite index of CA at farm level was obtained by aggregating the composite index of CA at parcel level ($\mathrm{PCIACA_{nt}}$) through the formula below:

$$\mathrm{CIACA_t} = \sum_{n=1}^{N} \mathrm{P_n.PCIACA_{nt}} = \sum_{n=1}^{N} \mathrm{P_n} \left(\sum_{j=1}^{3} \mathrm{w_j Y_j} \right)_{\mathrm{nt}} \tag{3}$$

where $\mathrm{CIACA_t}$ is the composite index of CA at farm level for year t and $\mathrm{P_n}$ is, as previously stated, the proportion of the parcel over the whole farm. The equation can be rewritten as follows:

$$\mathrm{CIACA_t} = \sum_{n=1}^{N} \mathrm{P_n (w_1 Y_1 + w_2 Y_2 + w_3 Y_3)_{nt}} \tag{4}$$

where w_1 w_2 and w_3 are respectively the weights of first, second and third PCA (Y_1 Y_2 and Y_3). By assuming that principles 1, 2 and 3 were applied on L_t, C_t and R_t parcels, respectively (L_t, C_t and R_t stand for the number of parcels where principle 1, 2 and 3 are applied, respectively), in year t and given that Y_i takes the value 1 if the principle was applied on the parcel and 0 otherwise, it can be easily shown that:

$$\mathrm{CIACA_t} = \mathrm{w_1} \sum_{n=1}^{\mathrm{L_t}} \mathrm{P_n} + \mathrm{w_2} \sum_{n=1}^{\mathrm{C_t}} \mathrm{P_n} + \mathrm{w_3} \sum_{n=1}^{\mathrm{R_t}} \mathrm{P_n} \tag{5}$$

The above equation is valid as the values of $\mathbf{w_i}$ are assumed to be constant over years and across parcels. Equation (5) can be rewritten as follows:

$$\mathrm{CIACA_t} = \mathrm{w_1 PL_t + w_2 PC_t + w_3 PR_t} \tag{6}$$

where $\mathrm{PL_t} = \sum_{n=1}^{\mathrm{L_t}} \mathrm{P_n}$, $\mathrm{PC_t} = \sum_{n=1}^{\mathrm{C_t}} \mathrm{P_n}$ and $\mathrm{PR_t} = \sum_{n=1}^{\mathrm{R_t}} \mathrm{P_n}$ are, respectively, the proportions of farms under the principles 1, 2 and 3 in year t. Given that an ideal CA system should imply a rotation of a minimum of three different crops [1], the $\mathrm{CIACA_t}$ was calculated for the last three years, and their average (CIACA) was used as the final measure of adoption of CA.

$$\mathrm{CIACA} = \frac{\sum_{t=1}^{3} \mathrm{(w_1 PL_t + w_2 PC_t + w_3 PR_t)}}{3} \tag{7}$$

2.3. Weighting of Principles of Conservation Agriculture: Analytical Hierarchy Process

If three farmers adopt only one but distinct PCA (for instance principles 1, 2 and 3 by respectively the first, the second and the third farmer), are they equivalent in terms of adoption of CA? That would only be the case if each principle contributed to the same extent to agricultural sustainability, which is obviously not the case in reality. Agricultural sustainability here stands for "practices that meet present and future societal needs for food and fibre, for ecosystem services and for healthy lives, and that do so by maximizing the net benefit to society when all costs and benefits of the practices are considered" [20]. PCAs perform different functions, including minimization of soil loss in runoff or wind, reduction of labour and fuel energy inputs, reduction of pests and diseases, etc. [21], and by doing so, they contribute differently to the agricultural sustainability of CA. This situation exemplifies the necessity of weight elicitation of the PCAs in accordance with their actual contributions to agricultural sustainability as a condition for classifying farmers in relation to their degree of adoption of CA. This task was performed along with five agricultural sustainability experts invited to carry out the weighting process of the PCAs. Experts' opinion has been extensively used in the literature for weight elicitation [18,19,22]. Although the use of experts' opinion for weight elicitation of the PCAs is subjective, it remains appropriate for rapid evaluation when there is lack of data. Moreover, the validity of experts' opinion as a potential alternative to data-rich methods has been demonstrated in previous studies [23]).

During the focus group, experts performed pairwise comparison judgments of each PCA based on their knowledge. These pairwise comparison judgements were completed by asking the following three questions: "Which pillar between crop rotation and permanent mulch soil cover/cover crop is more important for you to ensure the sustainability of CA? Which pillar between minimum mechanical soil disturbance and crop rotation is more important for you to ensure the sustainability of CA? Which pillar between minimum mechanical soil disturbance and permanent mulch soil cover/cover crop is more important for you to ensure the sustainability of CA?" The Saaty's scale as presented in Table 3 was used for comparison [17]. The value 1 means that two principles are equally important, while the values 3, 5, 7 and 9 mean that one principle is moderately, strongly, very strongly and extremely important over another principle, respectively. The value 2, 4, 6 and 8 are intermediate values. The pairwise comparisons were used to build the pairwise comparison matrix A:

$$\mathrm{A} = (\mathrm{a_{ij}}), \text{ with } \mathrm{a_{ij}} = p \text{ and } \mathrm{a_{ji}} = \frac{1}{p} \tag{8}$$

where p is the relative importance of one principle (i) over another (j), which can take any integer from 1 to 9. As judgement process often suffers from inconsistency [24]; the consistency ratio (CR) (see Equation (9)) was calculated and the 10% bound was used for maximum tolerable inconsistency as recommended by Saaty [17]. Inconsistency in the judgement process occurs when redundant comparisons of some elements lead to multiple comparisons of an element with other elements [24].

$$CR = \frac{\mathrm{CI}}{RI} \tag{9}$$

where $CI = \frac{\lambda_{max} - \blacksquare}{\blacksquare - 1}$ and RI are, respectively, the consistency index and the random index, which is the consistency index obtained from a randomly generated reciprocal matrix of the same order. λ_{max} and $\blacksquare$ are, respectively, the principal eigenvalue of matrix A and the number of criteria (or PCAs). The weights of the PCAs are given by the principal eigenvector of matrix A also obtained by solving the following system equations:

$$Aw = \lambda_{max} w \tag{10}$$

where w is the principal eigenvector or the vector of weights of the PCA. The overall calculation (principal eigenvector, principal eigenvalue and consistency ratio) was performed with the use of the software Expert Choice. Since several experts were involved in the judgement process, the geometric mean of experts' weighting was used in this study. Geometric mean weighting has been used by previous studies [25] and has been shown to be more consistent than arithmetic mean, as it is suitable for aggregating both judgements and priorities in AHP [26].

Table 3. Saaty's scale.

Principles	Extreme Importance		Very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		Very Strong Importance		Extreme Importance	Principles
No or minimum mechanical soil disturbance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Permanent mulch soil cover/cover crop
No or minimum mechanical soil disturbance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Crop rotation
Permanent mulch soil cover/cover crop	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Crop rotation

3. Results

3.1. Weighting Process: The AHP Results

Results of AHP analysis are presented in Table 4. The second, third and fourth columns present the weights of the PCAs, whereas the last column presents the inconsistency ratios. The normalized geometric mean weights of the overall experts are presented in the tenth row and are, respectively, 57.68%, 22.95% and 19.37% for no or minimum mechanical soil disturbance, permanent mulch soil cover and crop rotation. Given that the judgements of two experts (experts 2 and 3) were inconsistent as their inconsistency ratios are greater than 10% (0.13 and 0.17), equal weights were assumed for them (33.33, 33.33 and 33.33, respectively, for no or minimum mechanical soil disturbance, permanent mulch soil cover and crop rotation) and the new normalized geometric mean weights of experts were calculated using equivalent weights for no or minimum mechanical soil disturbance, permanent mulch soil cover and crop rotation for both experts 2 and 3 (see last row of Table 4). According to this latter weight computation, the weights of no or minimum mechanical soil disturbance, permanent mulch soil cover and crop rotation are, respectively, 48.03%, 23.93% and 28.04%. Indeed, the results show that the no or minimum mechanical soil disturbance principle contributes more than 48.03% to the sustainability of CA, while permanent mulch soil cover and crop rotation contributions are, respectively, 23.93% and 28.04%. The dominance of no or minimum mechanical soil disturbance could be explained by the different functions performed by no or minimum mechanical soil disturbance. These functions include the reduction of evaporative loss form upper soil layers, minimization of oxidation of soil organic matter, minimization of carbon dioxide loss, reduction of labour requirement and energy use, maximization of rain infiltration, minimization of soil loss, etc., and are summarized in [21]. Despite the dominance of no or minimum mechanical soil disturbance, it is also important to note that permanent mulch soil cover and crop rotation perform important functions contributing to the sustainability of CA. For example, past studies have shown that mulch increases soil moisture, reduces the presence of weeds, increases soil nutriment and yield [27], reduces total soil water evaporation and soil water runoff, reduces soil erosion [28], increases soil water infiltration and increases soil organic carbon and soil fauna abundance, especially arthropod, nematode and earthworm populations [28]. Several other studies have also shown the positive effect of crop rotation on soil quality [29], on soil microbial biodiversity [30] and on crop yield [31]. Crop rotation can be used strategically in intensive systems to control for insect and pathogen infestation, to improve soil nutriment [32] and to maximise profit when the prices of rotational crops are increasing [13].

Table 4. Weights of principles of conservation agriculture.

Expert	Weight			Inconsistency Ratio
	No or Minimum Mechanical Soil Disturbance	Permanent Mulch Soil Cover	Crop Rotation	
Expert 1	71.72	8.81	19.47	0.09
Expert 2	76.62	7.59	15.79	0.13
Expert 3	21.85	71.47	6.68	0.17
Expert 4	33.33	33.33	33.33	0.00
Expert 5	66.67	16.67	16.67	0.00
G-mean *	48.44	19.27	16.27	
G-mean **	44.63	22.24	26.06	
Normalised * weight	57.68	22.95	19.37	
Normalised ** weight	48.03	23.93	28.04	

* Weights with inconsistency. ** Weights corrected from inconsistency.

3.2. Computing Composite Index of Adoption of CA

Following Equations (5) and (6), we computed the composite index of adoption of CA for 144 maize and soybean farmers from Québec. The results are presented in Table 5.

Table 5. Descriptive statistics of CIACA.

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
$CIACA_{2020}$	144	0.74 a	0.28	0	1
$CIACA_{2019}$	144	0.74 a	0.27	0	1
$CIACA_{2018}$	144	0.71	0.29	0	1
CIACA	144	0.73	0.27	0	1

a = Means that the means are statistically equivalent ($p > 0.1$).

$CIACA_{2018}$, $CIACA_{2019}$ and $CIACA_{2020}$ stand, respectively, for the level of adoption of CA in 2018, 2019 and 2020, and CIACA is the average over the three years.

4. Discussions

Our results show that on average, maize and soybean farmers apply about 73% of the PCAs. The results further show an increasing adoption of CA from 71% to 74% between 2018 and 2019, but a constant adoption of CA between 2019 and 2020. This was further confirmed by the mean comparison tests, which show a significant difference of CA adoption between 2018 and 2019 and an insignificant difference of CA adoption between 2019 and 2020. Although the results show a global increase of adoption of CA estimated at 4.2%, farmers globally follow nine trends, represented in Figure 1.

The distribution of farmers according to the types of trends is presented in Table 6.

While 46.53% of farmers have a constant trend, the remaining farmers have either an increasing trend, decreasing trend, semi-increasing trend, semi-decreasing trend or broken line trend. We interpret these trends (except trend 5) as proof of flexibility of farmers in the adoption of PCAs, which was also reported in the previous literature [11,12]. Although most farmers (farmers following trends 2, 3, 6, 7, 8 and 9) could be considered as flexible farmers, farmers following trends 2 or 3 are perfect examples of flexibility in adoption of PCAs as their adoption of PCAs starts increasing (decreasing) and then decreases (increases). Flexibility of farmers can be explained by two likely arguments: the economic and biophysical arguments [11,12].

Under the economic argument, farmers will adopt or abandon certain principles of CA in response to market conditions. For example, under intensive systems, crop rotation is often used as a strategic measure by farmers to maximise crop income when a crop used for rotation faces a rising price [13].

Under the biophysical argument, farmers will adopt or abandon certain principles of CA in response to the biophysical condition of the farm. Indeed, in a no-till system, farmers can use tillage for controlling a weed infestation that has become resistant to weed killer or to reduce soil compaction and facilitate the mineralisation [13,14]. Kirkegaard et al. [13] have also reported the use of crop rotation by farmers as a strategic measure for raising soil nitrogen levels and for controlling for plant disease cycles.

Moreover, trend 1 could be interpreted as a sign of a long-term transition of farmers from conventional tillage to CA, while trend 4 could be interpreted as a sign of abandonment of CA in favor of conventional tillage. However, these two latter interpretations should be taken cautiously, as the time frame was relatively short to draw a definitive conclusion. It is also important to note that out of the 67 farmers having constant trend (trend 5), about half (50.74%) are partial adopters of CA, 46.27% are full adopters of CA and 2.99% are non-adopters of CA. Full adopters of CA are farmers that have applied all the PCAs in all their parcels (here maize and soybean parcels) over the three years (CIACA = 1), and non-adopters of CA are farmers that did not apply any PCA in their parcels over the three years (CIACA = 0). The partial adopters of CA are any farmers between the two previous situations (CIACA can take any value between 0 and 1, with 0 and 1 excluded).

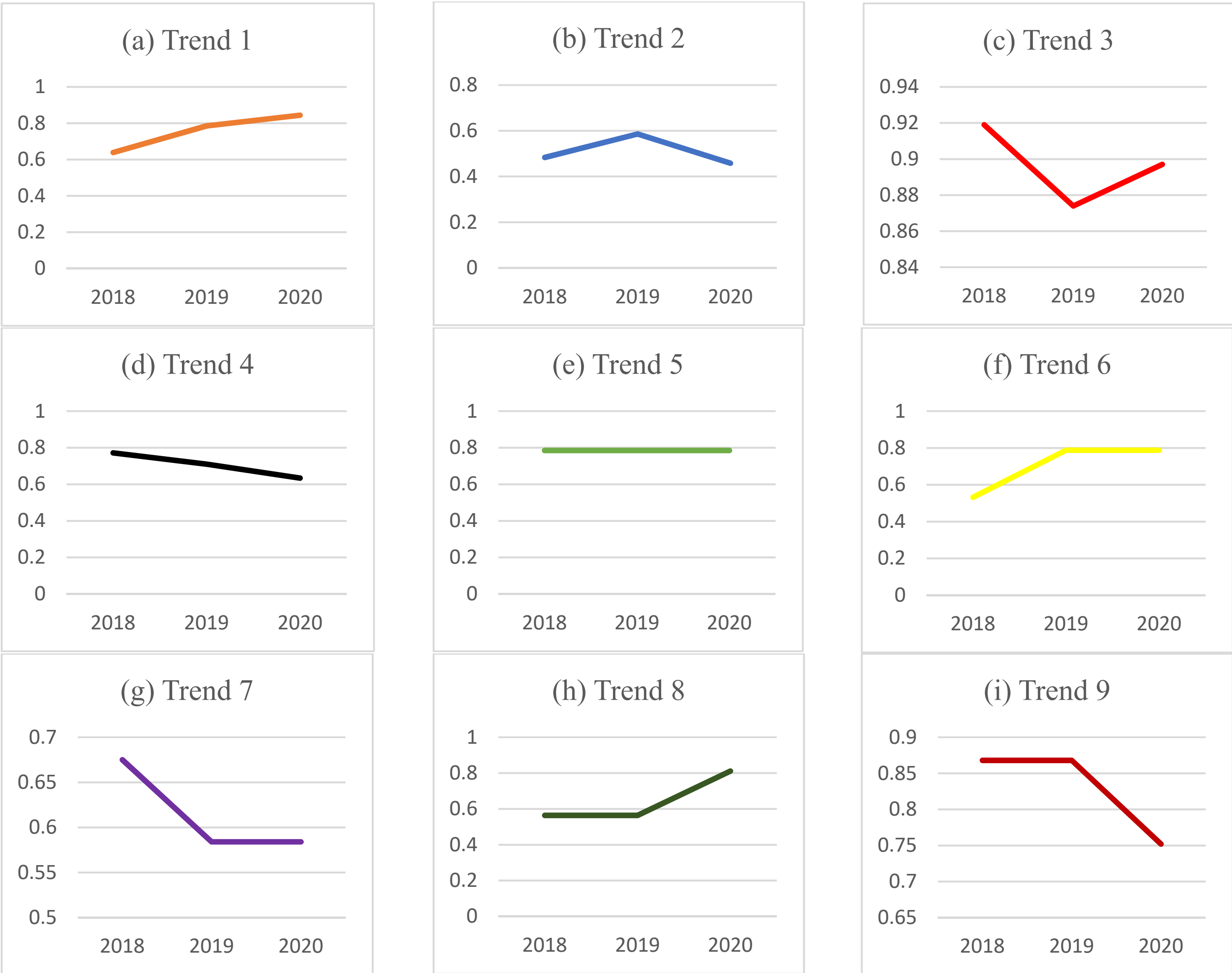

Figure 1. Trends in adoption of CA.

Table 6. Distribution of farmers according to trends.

Type	Relative Frequencies	Definitions
Trend 1	8.33	Increasing trend
Trend 2	10.42	Broken line trend
Trend 3	4.17	Broken line trend
Trend 4	6.25	Decreasing trend
Trend 5	46.53	Constant trend
Trend 6	6.94	Semi-increasing trend
Trend 7	4.17	Semi-decreasing trend
Trend 8	7.64	Semi-increasing trend
Trend 9	5.56	Semi-decreasing trend
Total	100	

Farmers were also grouped into the three above defined categories as shown in Table 7. Table 7 shows that most farmers are partial adopters of CA (77.08%), and only 21.53% are full adopters of CA. To compare our composite index of adoption of CA with the traditional binary indicator of adoption of CA, we have also asked farmers if they practiced CA. We noticed that 83.33% declared they practice CA against 16.67% that did not practice CA. This latter classification hides the reality where partial adoption of CA is dominant (77.08%). Most socioeconomic studies focusing on the analysis of adoption and performance of CA use a binary indicator of adoption of CA [4], whereas farmers are often partial adopters of CA [4,10]. The present study has shown that more than 75% of farmers are partial adopters of CA, and then invalidates the use of binary indicators for measuring the adoption of CA. An example of partial adoption was also shown by [33] in the United States (USA), where the authors showed that only 17% and 25% of corn and soybean farmers, respectively, reported to continuously apply no-till in four successive years against 30% that alternated between no-till and tillage for both corn and soybean farmers. Although partial adoption of CA can be explained not only by environmental conditions and the farmers' judgement based on their practical experiences, but also by their ability to practice CA [12]; the literature broadly identifies factors such as farmers' perceptions, education, agricultural training, group membership, household size, farm size, etc., as key factors of agricultural innovation adoption in general [6,8,34,35].

Table 7. Distribution of farmers according to the category of adopters.

Category	Number of Farmers	Relative Frequencies
Full adopters of CA	31	21.53
Non-adopters of CA	2	1.39
Partial adopters of CA	111	77.08
Total	144	100

Given that our composite index of adoption of CA is subjective as the weights of the PCAs were obtained from experts' judgement, we also computed the composite index of adoption of CA using similar weights (33.33%) for all PCAs. This latter index that we labeled uniform composite index of adoption of CA (UCIACA) was calculated for 2018, 2019 and 2020; the average was used as the final composite index of adoption of CA. Despite the difference of weights of PCAs between UCIACA and CIACA, the results presented in Table A1 show an increasing adoption of CA between 2018 and 2019 and a constant adoption of CA between 2019 and 2020 just as with CIACA. UCIACA also identified 77.08%, 21.53% and 1.39% of maize and soybean farmers just as with CIACA as partial adopters, full adopters and non-adopters of CA, respectively. The CIACA and UCIACA were also highly correlated, and the coefficient of correlation $r = 0.99$ was statistically significant at 1%. Despite the high correlation between UCIACA and CIACA, the ranking of farmers obtained by the two composite indexes was slightly different, as presented in Table A2 Even if the two composite indexes give to the first 34 farmers the same position, all the remaining farmers except farmers A41 and A57, have received different ranks with the two composite indexes. This difference mainly results from the difference in the weights of the PCA used by the two approaches. While CIACA uses weights of 48.03%, 23.93% and 28.04% for no or minimum mechanical soil disturbance, permanent mulch soil cover and crop rotation, respectively, UCIACA uses similar weights for all PCAs. The fundamental question here is this: which weighting best represents the contribution of PCAs to the sustainability of CA? Using similar weights would mean that the three PCAs contribute equally to the sustainability of CA. We think that PCAs contribute unequally to the sustainability of CA, as they perform different functions in the cropping system. We rather rely on experts' judgement for weighting PCAs as empirical evaluations of the contribution of PCA to sustainability are lacking in the literature. Nevertheless, whatever weighting is used, the present study has shown the inappropriateness of a traditional binary indicator for measuring the adoption of CA.

5. Conclusions

The objective of the study was to propose a new composite index for measuring the adoption of CA. A model of partial adoption of CA both at parcel and farm levels was then developed to build the new composite index. Experts' judgements and the Analytical Hierarchy Process were also used for weight elicitation of principles of CA. The results showed that the most important principle of CA is the no or minimum mechanical soil disturbance principle, followed by crop rotation and permanent mulch soil cover with, respectively, weights of 48.03%, 28.04% and 23.93%. Using data from 144 Québec maize and soybean farmers, the new composite index showed that 77.08%, 21.53% and 1.39% of maize and soybean farmers were respectively partial adopters of CA, full adopters of CA and non-adopters of CA whereas the traditional binary indicator wrongly indicated that 83.33% and 16.67% of maize and soybean farmers were, respectively, adopters of CA and non-adopters of CA.

Although the new composite index constitutes a net improvement on the measure of adoption of CA as compared to traditional binary indicator, the use of experts 'judgement for weight elicitation of principles of CA is an important limit of the study that needs to be acknowledged. Even though experts' judgement is particularly recommended for quick evaluation in the presence of lack of data, it is important for future studies to derive the weights of principles of CA from actual data instead from experts' judgement.

Despite the above limit, the new composite index presented under this study could be a useful tool in the hands of land conservation programme managers that would like to promote the adoption of CA by subsidising farmers in function of their levels of adoption of PCA.

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Appendix A

Table A1. Descriptive statistic of UCIACA.

Variable	Observation	Mean	Standard Deviation	Minimum	Maximum
UCIACA 2020	144	0.74 [a]	0.27	0	1
UCIACA 2019	144	0.75 [a]	0.26	0	1
UCIACA 2018	144	0.71	0.28	0	1
UCIACA	144	0.73	0.25	0	1

a = Means that the means are statistically equivalent ($p > 0.1$).

Table A2. Rank of farmers according to CIACA and UCIACA.

Farmers	CIACA	Rank	UCIACA	Rank
A1	1	1	1	1
A2	1	1	1	1
A3	1	1	1	1
A4	1	1	1	1
A5	1	1	1	1
A6	1	1	1	1
A7	1	1	1	1
A8	1	1	1	1
A9	1	1	1	1
A10	1	1	1	1
A11	1	1	1	1
A12	1	1	1	1
A13	1	1	1	1
A14	1	1	1	1
A15	1	1	1	1
A16	1	1	1	1
A17	1	1	1	1
A18	1	1	1	1
A19	1	1	1	1
A20	1	1	1	1
A21	1	1	1	1
A22	1	1	1	1
A23	1	1	1	1
A24	1	1	1	1
A25	1	1	1	1
A26	1	1	1	1
A27	1	1	1	1
A28	1	1	1	1
A29	1	1	1	1
A30	1	1	1	1
A31	1	1	1	1
A32	0.999	2	0.998	2
A33	0.998	3	0.997	3
A34	0.985	4	0.978	4
A35	0.982	5	0.978	4
A36	0.977	6	0.967	5
A37	0.977	6	0.967	5
A38	0.977	6	0.967	5
A39	0.966	7	0.959	6
A40	0.963	8	0.956	7
A41	0.961	9	0.945	9
A42	0.958	10	0.95	8
A43	0.958	10	0.95	8
A44	0.953	11	0.934	10
A45	0.953	11	0.934	10
A46	0.951	12	0.934	10
A47	0.941	13	0.917	12
A48	0.93	14	0.917	12
A49	0.93	14	0.917	12
A50	0.922	15	0.923	11
A51	0.921	16	0.889	15
A52	0.919	17	0.887	16
A53	0.906	18	0.912	13
A54	0.9	19	0.9	14
A55	0.898	20	0.885	17
A56	0.889	21	0.867	18
A57	0.884	22	0.838	22

Table A2. *Cont.*

Farmers	CIACA	Rank	UCIACA	Rank
A58	0.883	23	0.85	20
A59	0.881	24	0.834	23
A60	0.881	24	0.834	23
A61	0.877	25	0.867	18
A62	0.865	26	0.812	25
A63	0.863	27	0.856	19
A64	0.862	28	0.867	18
A65	0.86	29	0.867	18
A66	0.854	30	0.834	23
A67	0.851	31	0.823	24
A68	0.849	32	0.789	27
A69	0.843	33	0.795	26
A70	0.841	34	0.834	23
A71	0.829	35	0.784	29
A72	0.817	36	0.823	24
A73	0.814	37	0.778	30
A74	0.813	38	0.777	31
A75	0.81	39	0.789	27
A76	0.789	40	0.728	36
A77	0.788	41	0.839	21
A78	0.775	42	0.789	28
A79	0.769	43	0.695	40
A80	0.761	44	0.778	30
A81	0.76	45	0.834	23
A82	0.756	46	0.767	33
A83	0.75	47	0.773	32
A84	0.744	48	0.823	24
A85	0.708	49	0.684	42
A86	0.704	50	0.727	37
A87	0.701	51	0.712	39
A88	0.699	52	0.745	35
A89	0.695	53	0.756	34
A90	0.694	54	0.684	42
A91	0.689	55	0.684	42
A92	0.689	55	0.6	49
A93	0.685	56	0.639	45
A94	0.681	57	0.723	38
A95	0.673	58	0.689	41
A96	0.664	59	0.617	47
A97	0.661	60	0.6	50
A98	0.648	61	0.667	43
A99	0.645	62	0.65	44
A100	0.641	63	0.667	43
A101	0.628	64	0.599	51
A102	0.603	65	0.557	55
A103	0.577	66	0.623	46
A104	0.566	67	0.567	53
A105	0.565	68	0.562	54
A106	0.565	68	0.562	54
A107	0.561	69	0.556	56
A108	0.537	70	0.512	58
A109	0.521	71	0.5	60
A110	0.52	72	0.667	43
A111	0.504	73	0.612	48
A112	0.5	74	0.5	60
A113	0.478	75	0.524	57
A114	0.475	76	0.35	71

Table A2. *Cont.*

Farmers	CIACA	Rank	UCIACA	Rank
A115	0.473	77	0.506	59
A116	0.461	78	0.445	63
A117	0.457	79	0.456	61
A118	0.45	80	0.584	52
A119	0.449	81	0.45	62
A120	0.427	82	0.445	63
A121	0.427	82	0.434	64
A122	0.401	83	0.5	60
A123	0.383	84	0.367	69
A124	0.372	85	0.395	66
A125	0.361	86	0.389	67
A126	0.361	86	0.423	65
A127	0.36	87	0.334	73
A128	0.334	88	0.334	73
A129	0.333	89	0.289	75
A130	0.331	90	0.334	73
A131	0.313	91	0.356	70
A132	0.307	92	0.384	68
A133	0.293	93	0.35	71
A134	0.281	94	0.334	73
A135	0.281	94	0.334	73
A136	0.281	94	0.334	73
A137	0.266	95	0.339	72
A138	0.257	96	0.317	74
A139	0.186	97	0.22	77
A140	0.18	98	0.25	76
A141	0.141	99	0.167	78
A142	0.094	100	0.112	79
A143	0	101	0	80
A144	0	101	0	80

Red colour is used for farmers that have got the same rank in the two approaches.

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