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Pioneering Farmers Value Agronomic Performance of Cover Crops and Their Impacts on Soil and Environment

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Abstract: Cover crops (CCs) have aroused a great deal of interest as a multifunctional measure to improve the sustainability of agriculture. Understanding farmers' views are important for future farm-scale implementation. A farmer survey was carried out in Finland in 2021 with the aims to gather farmers' views on agronomic performance of CCs, their environmental impacts and contribution to climate smart agriculture, and understand how farmers' views on CCs differed depending on farm/farmer characteristics. The farmers' sample was conventional and organic farms that had selected CCs as a registered measure in 2020. 6493 farmers were invited to answer a questionnaire with 18 statements (a Likert scale, 5 answer choices), and 1130 responded (17.4%). A Cochran–Mantel–Haenszel test was used to measure the strength of the association between ten characteristics of the respondents and 18 statements. Farmers considered CCs to have wide-ranging benefits for soil conditions. Only 21% of farmers agreed that CCs increase the need for nitrogen fertilizer use. 49% of farmers agreed that CCs reduce weed problems. Farmers mostly agreed (ca. 80%) that CCs reduce nutrient leaching and erosion. They were in general more uncertain about CCs' contribution to climate change mitigation (53% agreed), adaptation (51%), and resilience (58%). In agri-environmental schemes subsidies for use of CCs should aim large-scale implementation with two important target groups: younger farmers (≤50 years) as they were slightly more skeptical than older ones and farmers with less diverse land use as they were more doubtful of benefits provided by CCs.

Keywords: cash crop; climate smart agriculture; competition; cover crop; diversification; farming system; land use; soil health

1. Introduction

Cultivation of cover crops (CCs) is a multifunctional agronomic measure that both benefit from and support ecosystem services [1]. Recent meta-analyses have compiled quantified data on impacts of CCs e.g., on yields [2], carbon sequestration [3–5], soil water [2], weed suppression [6], nutrient dynamics and leaching [2,7,8], and enhancement of soil functionality [9] (see also Table S1). Cover crops include under-sown CCs, autumn-sown CCs, CCs used as catch crops, and CCs used as break-crops. The cultivation of CCs may provide both direct benefits for crop production such as the reduced use of chemical fertilizers and herbicides, and indirect benefits like improvements in soil quality [10]. Despite many benefits, one should not overlook the complexity of CCs as an agronomic measure, as it may limit their adoption. Many site-specific factors such as the climate, soil type, availability of choices of CCs and cash crops, tillage practices and termination methods must be acknowledged when optimizing CCs in a cropping system [10–12]. Used

CCs are in general diverse but vary a lot depending on climatic conditions and regional policy [13–15]. Finnish farmers have used or at least tested quite a large number of CCs despite the limitations for crop choices caused by northern conditions (Figure S1).

In Finland, the area under CCs has been low, only 1% of arable land, but it has significantly increased during the 2010s when a new subsidy program was introduced [13]. During rapid transitions, farmer experience-based views are especially valuable for knowledge sharing [16]. Farms applying CCs form a comprehensive network of field-scale experiments. They represent different regions, farming systems, farm types, farm sizes, choices of cash crops and CCs, land use patterns, and farming practices. Farmers' experiences that cover a wide range of production situations are especially relevant for Finland, where farms are very heterogeneous. Early adopters have accumulated know-how for sharing, as continuous use of CCs associates with a willingness to self-learn and experiment through trial and error [17]. The results originating from existing farming systems might be more credible for other farmers and hence, have high potential to encourage implementation [18].

Surveys to explore farmers' motivations to cultivate CCs, gather experiences and know-how, and enhance collective knowledge have been published in recent years [17–19]. In some cases, motivation for cultivation of CCs has been simply to comply with European regulations or get subsidies [14,20], while in some other cases, to fully exploit the comprehensive benefits provided by CCs [18]. In this study, Finnish farmers were invited to share their views in a survey to collect the accumulated, so far largely hidden understanding on farmers' views and likely motivations for growing CCs in Finland. The specific aims were to: (1) gather farmers' views on the agronomic performance of CCs, their environmental impacts and contribution to climate smart agriculture (CSA), and (2) understand how the region, farm characteristics, land use and demography associated with the farmer's views on CCs. Such novel data and understanding are used for knowledge-sharing with the ultimate motivation to support successful transition towards regenerative agricultural practices.

2. Materials and Methods

The farmer survey was carried out in Finland in spring 2021. In total, requested details of 7025 farms (16% of Finnish farms in 2021) were obtained from the registry of the Finnish Food Authority (FFA) (Figure 1, phase 1). These included farm identification numbers, farm types, locations, and the farmers' email-addresses. The selection of farms included two subsets: organic (1432) and conventional farmers (5593) who had applied for CC payments in 2020. Subsidies were registered on the field parcel scale. The number of parcels with CCs varied on a farm. As the farmers were contacted by email, only those whose email-address was available in the registry of the FAA were invited. Part of the farmers had same email address to two different farms etc. With these definitions the total number of invited farmers decreased to 6493.

The survey started on 16 March 2021 and ended on 11 April 2021 (Figure 1, phase 2). Both official languages, Finnish and Swedish, were available for farmers to choose. One reminder message was sent on 30 March 2021. In addition to this questionnaire with 18 statements on experienced farmers' general views, the survey included other questions. The median of the respondent's answering time was some 15 min and 42 s (lower quartile 11 min and 31 s; upper quartile 24 min and 10 s). The farmers could save the answers and continue answering later. In total 1130 farmers answered the survey, which corresponded to a 17.4% response rate. An additional 362 viewed or started to fill in the survey without completing and returning it before the deadline. The primary question included in this study was "What do you think about the following general statements?" with 18 statements (Table S1). The farmers were informed that in this survey CCs were used as a general term covering under-sown CCs, autumn-sown CCs, CCs as catch crops and break-crops, if not otherwise specified. In Finland, CCs are most commonly used as under-sown CCs inter-seeded with the cash crop in spring. All statements reported here were focused on

CCs concerning their agronomic performance, environmental impacts, and contribution to CSA. Statements were formulated based on findings reported on a high number of recent papers [3,10,13,21–23]. The questionnaire was test run with four farmer-researchers who had long-term experience of CCs in Finland. Based on this dialogue questionnaire was finalized by e.g., improving clarity when needed. The survey respondents were requested to answer all the questions in the survey to be able to return their answers. According to the preliminary examination, the answers of all the 1130 respondents were considered acceptable and were used for statistical analyses.

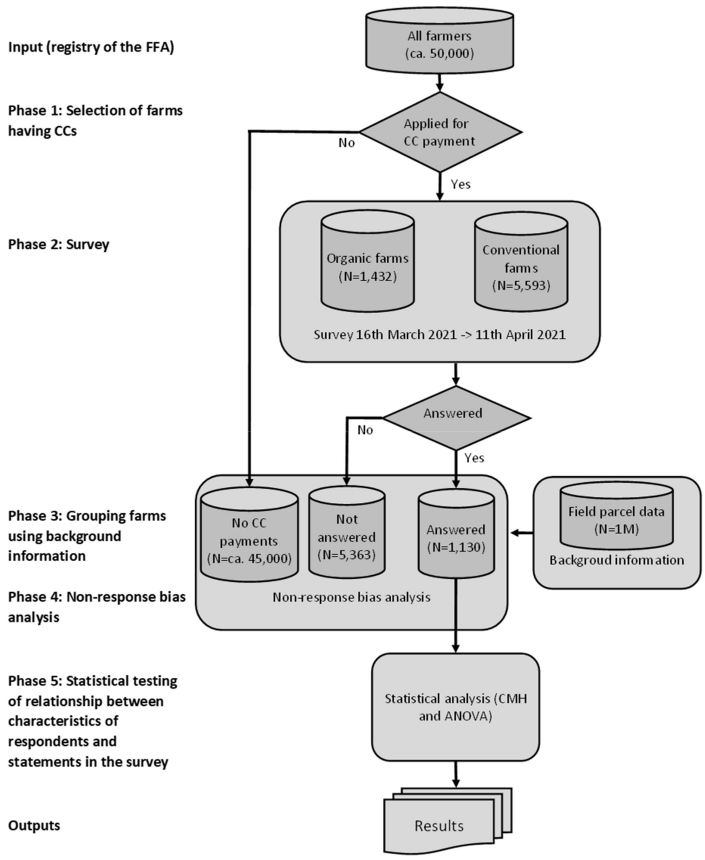

Figure 1. The schematic presentation of the data processing.

The statistical analyses began by grouping the respondents (Figure 1, phase 3). Only the farmers' age (≤30, 31–50, 51–70 and >70 years) and education were requested as background information in the survey. Because the shares of farmers ≤ 30 and >70 years were low within Finnish farmers' population, as was also the case in this survey, these age groups were merged into the adjacent ones to form two age groups of ≤50 years and >50 years. The 2020 farm registry (FFA) was used to collect background information from each farm and merged with survey data. First, for each responding farm the share of land devoted for cereals, grassland, special crops [including peas (*Pisum sativum* L.), faba beans (*Vicia faba* L.), spring and winter oilseed rape (*Brassica napa* L. and turnip rape *B. rapa* L.), caraway (*Carum carvi* L.)] and other diversifying crops [including a high number of species, e.g., potatoes (*Solanum tuberosum* L.) and sugar beets (*Beta vulgaris var. altissima*), strawberries (*Fragaria* sp.), reed canary grass (*Phalaris arundinacea* L.), and carrots (*Daucus carota* L.)] were assembled. The respondents were grouped for statistical analyses according to: (1) the farming system (organic and conventional), (2) farm type (cereal, special crop, horticulture, cattle, pig, poultry and horse/sheep farm), (3) the farm size (<40, 40–79, 80–119 and ≥120 ha), (4) geographical region (South-, West-, East/North-Finland and inland region), (5) farmers' age (≤50 and >50 years), (6) education (basic, vocational, college level and university education), (7) cereal area on a farm (<25%, 25–50% and ≥50%),

(8) grassland area on a farm (<25%, 25–50% and ≥50%), (9) area of other crops on a farm (<25%, 25–50% and ≥50%), and (10) special crop area on a farm (0%, <10% and ≥10%. Finnish farms are very heterogeneous, and hence, the data were used to identify how farmer's background factors associated with views.

Non-response bias (Figure 1, phase 4) was assessed by comparing the characteristics of respondents who returned the survey to those of the non-respondents. The compared characteristics included: the region, farming system, farm type, farm size, farm cereal area, farm grassland area, farm special crop area and other farm crop area. No significant distortions of representativeness were found. The cattle farms and pig farms were slightly, but not alarmingly under-represented (Table S2). The non-response bias was assessed also for organic farmers by comparing organic farmers who responded to those who did not. No alarming bias was found. Large farms with 80–120 ha of agricultural land, farms with ≥50% cereal area or <10% with special crops, and farms located in East- and North-Finland were slightly under-presented. All these were the least common groups for organic farms (Table S2) and hence, two to four more respondents per group would have turned them to be full representative.

A Cochran–Mantel–Haenszel test (CMH) was used to test the relationship between the row and column variables (Figure 1, phase 5). The row variables were formed from ten characteristics of the respondents and column variables were the results of the18 statements asked with a 5-point Likert scale. Typically, both variables were ordinal scales and "the correlation statistic" of the CMH with 1 degree of freedom was used. If a row variable was not an ordinal scale (region and farm type), the ANOVA (Row Mean Scores, RMS) statistic of the CMH was used. ANOVA (RMS) tests were used for all pairwise comparisons, as well as, when testing the interaction between the farming system and other characteristics of the respondents. This study was focused on farmers having experience with CCs and hence, no control group of unexperienced farmers was invited. All CMH tests were performed using SAS/FREQ and SAS/GLM (version 9.4) procedures.

The number of CCs that a farmer experienced was defined as:

$$y_i = \sum_{k=1}^{28} I_{ij} \quad (1)$$

where I_{ij} is 1 if the ith farmer answered "somewhat", "plenty" or "very much" for the experience of the kth crop, otherwise it was 0. For the statistical analysis, the number of CCs that the farmers experienced were classified into three groups (1–5, 6–10 and ≥11 CCs). After that, all statistical analyses were based on the CMH and ANOVA tests.

3. Results

The target group of this study was organic and conventional farmers, who had experience with cultivation of CCs. Respondents were mostly positive about the impacts of the CCs on their production systems: for 17 statements (out of the total of 18) only ≤6% fully disagreed (Figure 2). The only systematic exception was on a statement saying that CCs increased the need for N fertilizer use. This statement correlated negatively with all the other statements and positively only with the statement that under-sown CCs compete with primary crops for soil water reserves (Table S3). The statement on soil water reserves was the second least agreed. When considering environmental impacts, farmers agreed that use of CCs reduced N and phosphorus (P) leaching risks. When CCs were under-sown, they were thought to use effectively residual N for their growth.

Cover crops were considered beneficial for the soil quality, preventing soil compaction, improving the soil structure, diversifying the soil microbiome, and increasing the SOC. Farmers have often selected the soil quality test as a measure of Agri-Environment Scheme in Finland. By making such multistage test on all fields (exceeding 0.5 ha in size) in a farm, they have likely gained plenty of novel understanding and sensory perceptions on soil structure, health, and functionality. Furthermore, most farmers agreed that CCs benefitted the soil even after decades-long continuous use, and that diverse mixtures of CCs improved soil health faster than the use of a single species of CC. Deep root systems were valued with break-CCs more than for catch crops. Although farmers with experience in use of CCs were positive in general about their impacts on production systems, they were less convinced that CCs reduced problems with weeds (Figure 2).

When considering the contribution of CCs on CSA, the farmers were slightly more uncertain: the share of "neither agree nor disagree" answers tended to be high (33–38%). From four statements farmers agreed most that use of CCs is a means to improve the climate resilience of crop production, followed by the statements that CCs have great potential for C sequestration, their cultivation compensates for GHG emissions in agriculture and CCs are an important means to adapt to climate change (Figure 2).

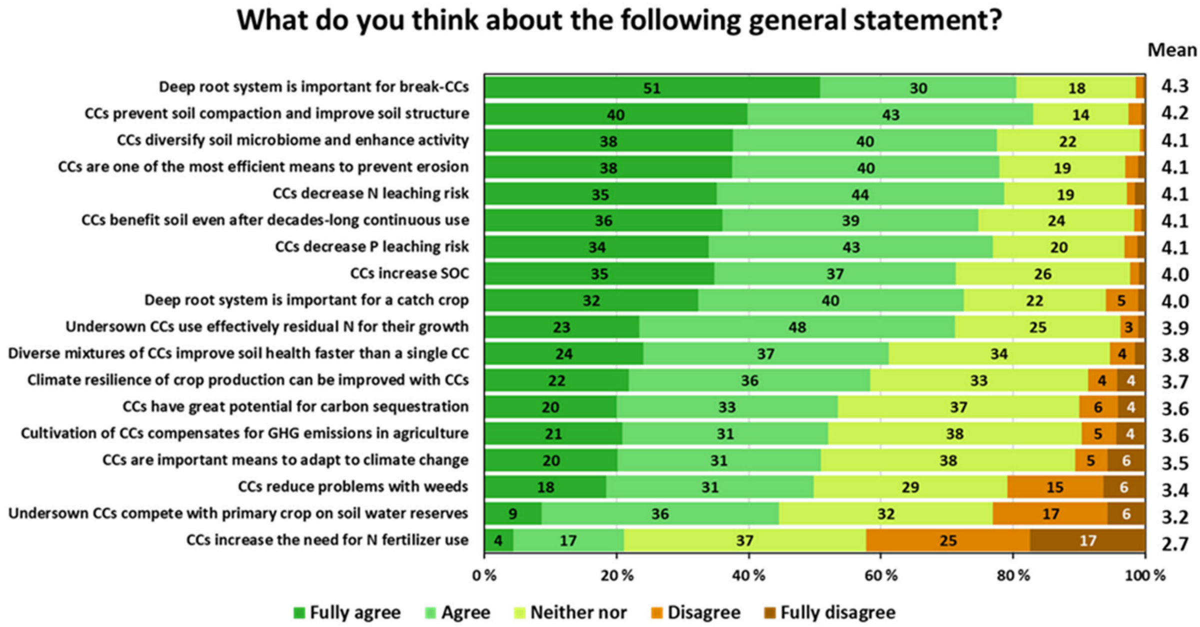

Figure 2. The distribution and mean (in order of decreasing value) of farmers' answers (n = 1130) to the principal question What do you think about the following general statements? The answer choices were: 1 = fully disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = fully agree. The share of each answer choice is shown within each bar except in the case it was <3%.

3.1. Farmers' Responses Depending on Farming System and Farm Type

Organic farmers agreed more frequently than conventional ones on all statements except for two of them highlighting potential drawbacks of CCs: "CCs increase the need for N fertilizer use" and "under-sown CCs compete with primary crops for soil water reserves" (Figure 3). 34% of organic farmers fully disagreed and 27% disagreed on the statement on N fertilizer use. There was, however, significant farming system × region interaction for these two statements (Table S4). The views of conventional farmers did not differ depending on region, while organic farmers in inland, East- and North-Finland agreed more often that under-sown CCs competed for soil water reserves. Furthermore, organic farmers in South-Finland agreed least that CCs increased the need for N fertilizers. The difference between farming systems were most striking (i.e., organic farmers were much more positive than conventional ones) on statements that CCs reduced problems with weeds, but also with those dealings with the contribution of CCs to CSA (Figure 3).

Respondents representing different farm types differed on five statements. Poultry farmers gave only agreed/fully agreed answers to the statements that CCs were one of the most efficient means to prevent soil erosion (Figure S1) and thereby, differed from all the other farmers (Table 1). They tended to be most positive that under-sown CCs use effectively residual N for their growth and together with horticulture farmers that diverse mixtures of CCs improve soil health faster than the use of a single species of CC. Cattle farmers were again the most positive that CCs could reduce problems with weeds contrary to cereal, special crop and poultry farmers (Figure S2, Table 2).

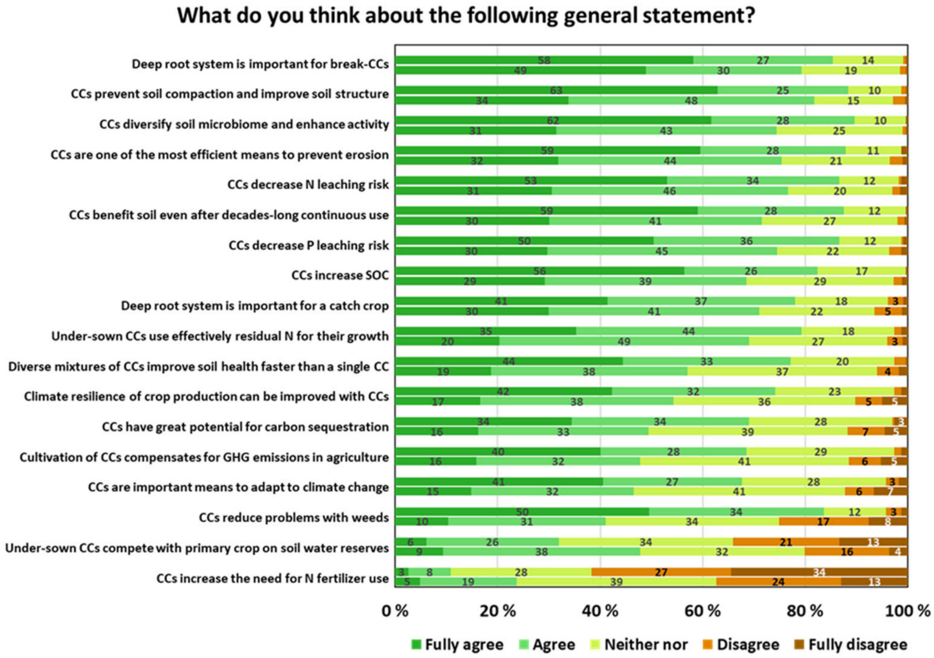

Figure 3. Significant effects of farming system on the distribution of farmers' answers (n = 1130). In each double bar next to the statement the upper one is for organic farmers and the lower one for conventional farmers. The share of each answer choice is shown within each bar except in the case it was <3%.

Table 1. Significant differences in farmers answers (n = 1130) to statements about environmental impacts of cover crops depending on land use on a farm. Means with the same letter do not differ significantly from each other (at $p \leq 0.05$).

Land Use on a Farm	Prevent Erosion	Decrease N Leaching	Decrease P Leaching	Improve Climate Resilience	Potential for Carbon Sequestration	Compensate for GHG Emissions	Support Adaptation to Climate Change
Cereal area:							
<25%	4.31 a	4.27 a	4.25 a	3.95 a	3.81 a	3.82 a	3.87 a
25–50%	4.20 a	4.13 a	4.11 a	3.75 b	3.69 a	3.66 a	3.60 b
>50%	4.00 b	4.02 b	3.98 b	3.53 c	3.46 b	3.47 b	3.41 c
Grassland area:							
<25%	4.00 b	4.03 b	3.98 b	3.55 b	3.48 b	3.47 b	3.41 b
25–50%	4.30 a	4.26 a	4.26 a	3.89 a	3.79 a	3.78 a	3.77 a
>50%	4.20 a	4.09 b	4.09 b	3.75 a	3.67 a	3.70 a	3.65 a
Area under other crops:							
<25%	4.09 b	4.06 b	4.03 b	3.63 b	3.55 b	3.55 b	3.49 b
25–50%	4.16 ab	4.20 a	4.16 a	3.78 a	3.71 a	3.65 ab	3.68 a
>50%	4.37 a	4.31 a	4.29 a	4.00 a	3.80 ab	3.92 a	3.90 a
Region:							
South	4.23 a	4.19 a	4.16 a	3.81 a	3.62 a	3.65 a	3.68 a
West	4.03 b	4.06 a	4.02 a	3.59 b	3.56 a	3.57 a	3.49 b
Inland	4.12 ab	4.06 a	4.05 a	3.68 ab	3.65 a	3.59 a	3.52 ab
East-North	4.19 ab	4.12 a	4.11 a	3.71 ab	3.53 a	3.49 a	3.53 ab

Poultry farms (mean 4.71) differed from other farms (4.06–4.19) on statement that CCs are one of the most efficient means to prevent erosion, and poultry farms (4.07) also differed from cereal production farms (3.54) and pig farms (3.52) on statement that CCs have great potential for carbon sequestration.

Table 2. Significant differences in farmers answers (n = 1130) to statements about impacts of cover crops (CCs) on cultivation depending on farm characteristics. Means with the same letter do not differ significantly from each other (at $p \leq 0.05$).

Farm Characteristic	Deep Root System Is Important for Break-CCs	Diverse CCs Mixtures Improve Soil Heath Faster than Use of a Single Species of CC	CCs Reduce Problems with Weeds	CCs Increase the Need for N Fertilizer Use
Cereal area:				
<25%	4.33 a	4.00 a	3.95 a	2.60 b
25–50%	4.30 a	3.84 b	3.59 b	2.47 b
>50%	4.28 a	3.68 c	3.12 c	2.79 a
Grassland area:				
<25%	4.31 a	3.70 b	3.12 b	2.77 a
25–50%	4.39 a	3.87 a	3.76 a	2.44 b
>50%	4.16 b	3.91 a	3.79 a	2.59 b
Special crop area:				
0%	4.25 b	3.77 a	3.47 a	2.67 a
<10%	4.45 a	3.76 a	3.41 ab	2.74 a
≥10%	4.35 a	3.83 a	3.27 b	2.59 a
Area under other crops:				
<25%	4.27 b	3.75 b	3.35 b	2.66 a
25–50%	4.34 ab	3.83 b	3.59 a	2.69 a
>50%	4.53 a	4.10 a	3.71 a	2.39 a
Farm size:				
<40 ha	4.18 b	3.84 a	3.58 a	2.56 b
40–79 ha	4.32 a	3.75 a	3.40 b	2.63 b
80–119 ha	4.28 ab	3.81 a	3.28 b	2.68 ab
≥120 ha	4.42 a	3.74 a	3.31 b	2.81 a
Farm type:				
Cereal	4.31 a	3.76 b	3.36 b	2.66 a
Special crop	4.32 a	3.85 b	3.35 b	2.71 a
Horticulture	4.56 a	4.28 a	3.39 ab	2.44 a
Cattle	4.21 a	3.74 b	3.68 a	2.65 a
Pig	4.39 a	3.61 b	3.00 ab	2.67 a
Poultry	4.29 a	4.43 a	3.21 b	2.64 a
Horse/sheep	4.19 a	3.81 ab	3.50 ab	2.50 a

Farmers in South-Finland (mean 3.25) differed from those in East- and North-Finland (3.66) on statement that CCs reduce problems with weeds as did farmers with basic (mean 3.56) and vocational education (3.50) from those with college level education (3.23). Pairwise comparisons did not reveal any differences between farmer's education for statement that deep root system is important for break-CCs.

3.2. Farmers' Responses Depending on Farm Size and Region

Farmers' answers were not often dependent on farm size. They differed only on four statements which all concerned agronomic performance of CCs (Figure S3). In general farmers valued a deep root system for break-CCs but least in the case they had small farms (<40 ha) (Table 2). Farmers with very large farms agreed more frequently than those with a farm <80 ha in size on the statement that CCs increased SOC (Table 3). Farmers with small farms (<40 ha) agreed more frequently than those with larger farms that CCs reduce problems with weeds. Farmers with small and medium sized farms agreed less often than those with very large farms that CCs increased the need for N fertilizer use (Table 2).

Table 3. Significant differences in farmers answers (n = 1130) to statements about impacts of cover crops (CCs) on soil conditions depending on farm characteristics. Means with the same letter do not differ significantly from each other (at $p \leq 0.05$).

Farm Characteristic	Prevent Soil Compaction and Improve Soil Structure	Diversify Soil Microbiome and Enhance Its Activity	Benefit Soil Even after Decades-Long Continuous Use	Increase SOC	Under-Sown CCs Compete with Primary Crop on Soil Water Reserves
Cereal area:					
<25%	4.31 a	4.30 a	4.27 a	4.18 a	3.08 b
25–50%	4.28 a	4.19 a	4.13 b	4.06 ab	3.13 b
>50%	4.11 b	4.06 b	3.99 c	3.96 b	3.37 a
Grassland area:					
<25%	4.13 b	4.07 b	4.01 b	3.98 b	3.38 a
25–50%	4.37 a	4.31 a	4.25 a	4.16 a	3.12 b
>50%	4.19 b	4.14 b	4.10 b	4.00 b	3.03 b
Special crop area:					
0%	4.19 a	4.10 b	4.04 b	3.97 b	3.24 a
<10%	4.20 a	4.13 ab	4.24 a	4.11 ab	3.20 a
≥10%	4.22 a	4.22 a	4.12 ab	4.13 a	3.27 a
Area under other crops:					
<25%	4.17 b	4.12 b	4.07 b	4.00 b	3.26 a
25–50%	4.23 b	4.18 ab	4.06 b	4.04 b	3.26 a
>50%	4.55 a	4.35 a	4.39 a	4.39 a	3.00 a
Region:					
South	4.23 a	4.24 a	4.18 a	4.16 a	3.19 b
West	4.18 a	4.08 b	4.04 b	3.97 b	3.19 b
Inland	4.21 a	4.11 b	4.06 ab	4.04 ab	3.38 a
East-North	4.18 a	4.22 ab	4.10 ab	3.93 b	3.34 ab

Farms < 80 ha in size (mean 3.94 for farms < 40 ha and 3.99 for those with 40–79 ha) differed from those ≥120 ha (4.16) on statement that CCs increase SOC. Farmers with university education (4.12) differed from those is basic (3.82) and vocational education (3.98) as well as farmers with college level education (4.09) from those with basic education on statement that CCs increase SOC. Pairwise comparisons did not reveal any differences between farmer's education for statement that CCs diversify soil microbiome.

Farmers' answers differed depending on region mainly on statements concerning impacts of CCs on soil conditions. Farmers valued CCs as a means to diversify soil microbiome (Figure S4) more in South-Finland than in western and inland regions (Table 3). Farmers in the most drought prone regions (South- and West-Finland) agreed less often than those in inland regions that under-sown CCs competed with primary crop for soil water reserves. Farmers in South-Finland agreed more frequently than those in West-Finland that CCs were the most efficient means to prevent erosion, their benefits for soil were available even after decades-long continuous use, and that CCs were a means to adapt to climate change and that they improve resilience (Tables 1 and 3). Farmers in South-Finland were also more positive towards the statement that CCs increased the SOC content when compared to those in West, East- and North-Finland but they valued CCs less for the reduction of weed infestations (Table 2).

3.3. Farmers' Answers to Statements on the Agronomic Performance of CCs Depending on Areas under Different Crop Types

Farmers having <50% area under cereals were more positive that CCs prevented soil compaction, improved the soil structure, diversified the microbiome, enhanced microbe activity, increased the SOC content, competed less for soil water reserves, provided benefits for soil even after decades-long use, reduced problems with weeds, and, that diverse mixtures of CCs improved soil health faster than a single species of CC (Tables 2 and 3, Figure S5). Farmers who had low cereal areas agreed less frequently that CCs increased the need for N fertilizer use. There was, however, significant farming system × cereal area interaction for statements on CCs competing for soil water reserves and reducing problems with weeds (Table 4). The views of organic farmers did not differ depending on the cereal area, while conventional farmers with a higher share of the area under cereals agreed more that CCs competed for water reserves and less that they reduced problems with weeds. Land use on a farm was dependent on farm type and location. High dependency on grasslands for cattle, horse and sheep farms means low shares of land areas available for other crops. Hence, views of farmers who had plenty of grassland were often even opposite (Table 3, Figure S6) to those of farmers with high share of cereal area (Tables 2 and 3, Figure S5).

Table 4. Statements with significant farming systems × farm cereal area interaction. CCs, cover crops; CON, conventional farm; ORG, organic farm; s.e., the standard error of the mean.

Farming System × Farm Cereal Area	Under-Sown CCs Compete with Primary Crop on Soil Water Reserves	CCs Are One of the Most Efficient Means to Prevent Erosion	CCs Are Important Means to Adapt to Climate Change	CCs Reduce Problems with Weeds
p-value (interaction)	0.019	0.045	0.015	0.047
Estimate (s.e.):				
CON/<25%	3.12 (0.102)	4.17 (0.084)	3.67 (0.102)	3.57 (0.104)
CON/25–50%	3.25 (0.064)	4.12 (0.053)	3.48 (0.064)	3.33 (0.065)
CON/>50%	3.41 (0.043)	3.96 (0.035)	3.36 (0.043)	3.05 (0.044)
ORG/<25%	3.04 (0.105)	4.45 (0.087)	4.09 (0.105)	4.35 (0.108)
ORG/25–50%	2.85 (0.096)	4.39 (0.079)	3.87 (0.096)	4.18 (0.098)
ORG/>50%	2.67 (0.183)	4.67 (0.152)	4.37 (0.185)	4.40 (0.189)
p-value cereal area (CON only)	0.011	0.010	0.010	<0.0001
p-value cereal area (ORG only)	0.157	0.275	0.044	0.409

The share of the area under special crops (i.e., grain legumes, oilseed crops and caraway) was lower than in other studied crop groups (Figure S7). Farmers with a higher share of their field areas used to cultivate special crops tended to be more positive about the beneficial impacts of CCs on the soil microbiome and SOC (Table 3), but they were less positive about the ability of CCs to reduce problems with weeds (Table 2). Farmers who did not grow special crops tended to be more doubtful of their benefits even after decades-long continuous use (Table 3) and they agreed less often that deep root systems are important for break-CCs (Table 2). There was, however, significant farming system × special crop area interaction in the data for statements that under-sown CCs competed with primary crops for soil water reserves and that they increase the need for N fertilizers (Table S5). The views of conventional farmers did not differ depending on the share of special crop areas on their farms, contrary to those of organic farmers. Organic farmers who cultivated special crops in areas of <10% agreed less with these two statements

The respondents also had variable, but high shares of other crops such as potatoes and sugar beets that were not included in any other crop group. In the case that the share of the area under other crops was >50%, farmers agreed more frequently that CCs prevented soil compaction, improved the soil structure, increased the SOC and that the benefits provided by CCs were available even after decades-long use (Table 3, Figure S8), and that diverse mixtures of CCs were more effective than single species of CCs (Table 2). Farmers with <25% of other crops were less positive than those with >50% that CCs diversified the soil microbiome and enhanced its activity (Table 3) and that a deep root system was important for break-CCs (Table 2). They also agreed less frequently that CCs reduced weed problems. Farming system × other crop area interaction in the data was significant ($p = 0.032$) only for the statement that under-sown CCs competed with primary crops for soil water reserves. The views of conventional farmers did not differ depending on the other crop area ($p = 0.419$), but organic farmers ($p = 0.043$) with a 25–50% area on their farms dedicated to other crops agreed most with this statement on competition for soil water (data not shown).

3.4. Farmers' Answers to Climate and Environment Issues Depending on Areas under Different Crop Types

The shares of cereal, grassland, and other crop areas on a farm, but not those of special crops, contributed to the farmer responses to statements on the impacts of CCs on erosion and nutrient leaching (Figures S9–S11). Farmers with a >50% share of cereals and/or <25% grassland areas on their farms were less positive about the impacts of CCs and their ability to prevent erosion (Table 1). Farmers with a >50% share of cereals and/or a <25% share of other crops agreed less with the statement that CCs reduce the N and P leaching risks, while farmers with 25–50% of grassland were most positive. Farmers with a <25% share of land under other crops were more pessimistic than those with >50% concerning the capacity of CCs to prevent erosion. Farming system × grassland area interaction was significant ($p = 0.044$) concerning the statement that CCs are one of the most efficient means to prevent erosion, as was farming system × cereal area interaction (Table 4). Views of conventional farmers on erosion did not differ depending on the grassland area ($p = 0.092$) they had, but organic farmers ($p = 0.011$) with 25–50% grassland area agreed most with this statement (data not shown). Contrary to this, only views of conventional farmers differed depending on the share of the cereal area on their farms: farmers with higher shares agreed least with this statement concerning the prevention of erosion (Table 4).

Farmers' views on the potential of CCs to contribute to CSA differed depending on land use (Figures S9–S11). Farmers who had <25% grassland were least positive about all statements concerning mitigation, adaptation, and resilience (Table 1). Farmers with a land area for other crops of ≥25% agreed more often than those with <25% that CCs improved the resilience of crop production and that they were important for adaptation to climate change, while farmers with lower shares of cereal areas were more positive towards these statements. In the case that the cereal area was >50% and/or grassland area < 25%, farmers were less positive about the contribution of CCs to C sequestration and their capacity to compensate for GHG emissions in agriculture. This tended to be also the case for those farmers having low areas under other crops (Table 1). The farming system × cereal area interaction in the data was significant concerning the statement that CCs are important for adaptation to climate change. Only the views of conventional farmers differed: farmers with a higher share of cereals on their land agreed less often on this statement (Table 4). The farming system × special crop area interaction in the data was significant concerning the statement about mitigation and resilience (Table S5): only the views of organic farmers differed and farmers growing special crops with areas < 10% were most positive.

3.5. Farmers' Responses Depending on Farmers' Age and Education

When the farmers were grouped into those ≤50 or >50 years of age, they differed concerning their responses to four statements (Figure 4). Older farmers were more positive and agreed more often than younger ones that CCs reduced N and P leaching risks, that the deep root system was important for a catch crop and cultivation of CCs compensates for GHG emissions in agriculture. Another four statements differed depending on the farmers' education (Figure S12). Farmers tended to consider that CCs increased SOC more frequently the higher their education (Table 3), while less educated farmers agreed more frequently that CCs reduced problems with weeds (Table 2).

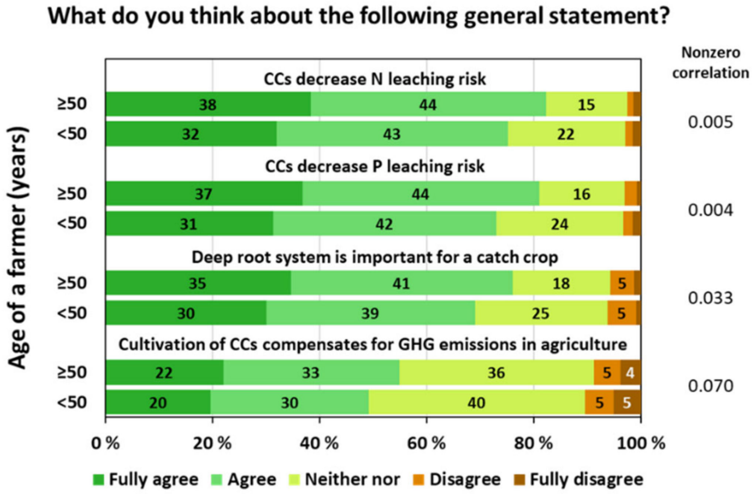

Figure 4. Significant effects of farmer's age on the distribution of farmers' answers (n = 1130). The share of each answer choice is shown within each bar except in the case it was <3%.

4. Discussion

4.1. Competition for N, Soil Water Reserves and with Weeds?

The impact of CCs on the N fertilizer need in conventional cropping systems is context dependent and often a whole set of management practices needs to be considered when specifying the N need for a primary crop grown with CCs [24]. In the case of leguminous CCs, N fertilizer rates can be reduced without compromising the yield [24] or higher yields can be reached with a similar N fertilizer rate [25]. Fertilizer application rates are low in Finland and some conventional farmers might be concerned that under-sown CCs use N fertilizer intended for a primary crop. Cover crops may also compete on water resources [23], which is another possible concern of Finnish farmers, because early summer drought is common [26]. Potential drawbacks may prevent risk-aware farmer from adopting CCs [18]. Therefore, these potential concerns were asked in this survey, and it was found that statements that CCs competed with primary crops for N and water resources were least agreed by respondents (Figure 2). Organic farmers, who often favor N-fixing leguminous species in their cropping systems, disagreed (61%) more frequently than conventional producers (37%) on increased need for N fertilizer use (Figure 3). The target group of farmers for future communication on the N fertilizer issue was identified as those with large, conventional farms and cereal-based production systems (Table 2). Considering the statement that under-sown CCs competed for soil water reserves with the primary crop (Figure 2), farmers in the most drought prone regions (South- and West-Finland) agreed less often than those in inland regions (Table 3). This implies that farmers who frequently face drought problems [26,27] have not experienced the risk of competition for water resources. This may be because of cover cropping practices: CCs are inter-seeded into an existing spring cereal crop, and in the case of drought, the CCs lose the competition with the already established cash crop. A recent meta-analysis revealed that overwintering CCs do a disservice for the water balance due to higher evapotranspiration compared to bare soil, which can be considered a trade-off for reducing the N leaching risks [23,28] especially in arid regions [1]. However, in Finland, the fields are usually saturated in spring, and sowing starts as soon as a field has reached the field capacity. Thereby, CCs may even allow earlier sowing. Conventional farmers agreed more frequently than organic farmers that under-sown crops competed with primary crop for soil water reserves, especially the higher the share of land allocated for cereals (Table 4). This may be attributable to soil and crop management driven differences between organic and conventional farms in the soil condition, structure, and fertility as, e.g., fields with higher SOC and/or less compaction are likely to be more functional and capable of retaining water [29].

Although farmers were in general positive about the impacts of CCs on production systems, they were less convinced that CCs reduced problems with weeds (Figure 2). In general CCs have potential to suppress weeds by competing for light, water, and nutrients [30]. Thereby, CCs form a multiple action component of integrated crop production [1,24,31]. Organic farmers were much more positive than conventional farmers (84% and 41% agreed, respectively) concerning this statement (Figure 3), which is attributable to the fact that CCs are a measure available in the organic toolkit to control weeds [32] while conventional farmers compare the efficacy of CCs against weeds to that of chemical control. The views of organic farmers did not differ depending on the share of land allocated to cereals on their farms (Table 4), even though experiments in South-Finland showed only limited weed suppression capacity on organic cereal farms that used reduced tillage [33].

In this study, conventional farmers with a higher share of cereal areas agreed less frequently that CCs reduced problems with weeds, as did farmers with a higher share of special crops such as grain legumes, rapeseed and caraway or a lower share of areas under grassland or other crops, potatoes and/or sugar beets (Tables 2 and 4). Hence, these findings did not fully support the hypothesis that farmers with more diverse cropping systems would tend to be more positive about the role of CCs in coping with weeds. Setting any specific target group for communication is challenging in the case of impacts on weeds as views varied depending on land use. However, not only land use but also land management may increase or decrease weed infestation [34]. In addition to CCs, weeds per se may enhance multifunctionality on arable lands [35] because of their contribution to biodiversity, for example, by delivering services for pollinators and birds [36]. Optimizing the replacement of weeds with a tailored selection of CC species is however a means to avoid uncontrollable competition and an increase of the weed seed bank in the soil, which may again force the use of more herbicides in the future contrary to the possible reduction in their use in the case of CCs [30].

4.2. Soil Carbon and Structure

Without hardly any opposition, CCs were considered beneficial for soil quality, by preventing soil compaction, improving the soil structure, diversifying the soil microbiome, and enhancing microbe activity as well as increasing SOC (Figure 2). Maintaining and improving soil quality is indeed one of the most indisputable advantages of CCs [1,10,37]. In addition, most respondents of this survey agreed that CCs improve the soil even after decades-long continuous use [3] and that diverse mixtures of CCs improve soil functions faster than use of a single species of CC [38]. The farmers' views differed depending on land use on how CCs affect the soil conditions. For example, in the case of having ≤50% area under cereals or 25–50% under grasslands, farmers were slightly more positive that CCs would prevent soil compaction, improve the soil structure, diversify the microbiome, and enhance its activity (Table 3). The positive impacts of CCs have been demonstrated for soil microbial abundance, activity, and diversity especially when supported with other agricultural practices [9]. Farmers who had larger areas on cereals were slightly less positive that CCs would provide benefits for the soil even after decades-long use (Table 3), and that diverse mixtures of CCs would improve the soil health faster than a single species of CC (Table 2). Hence, one can conclude that Finnish farmers with more diverse cropping systems tend to value more ecosystem services that CCs provide for soil and hence, farmers with monotonous land use are the target group for knowledge sharing about impacts of CCs on soil.

Increasing the SOC content is essential for improving the soil quality and health [29]. However, in Finland the topsoil SOC has declined [39]. Finnish farmers tended to be positive that CCs would increase SOC: especially in the case of a higher education (Figure S12), very large farm (≥120 ha) in South-Finland, and diverse land use (Table 3). However, CCs increase SOC stocks depending on their biomass production capacity [1] and may even offset the effects of crop residue removal [37]. Swiss agri-environmental schemes have been encouraging: support to diversified land use including multi-species CCs have together with other conservation methods contributed to a significant linear increase in SOC [40].

According to another survey, Finnish farmers indicated concern for the soil quality and highlighted the need for improvements [41]. The cultivation of soil improving break-crops has been a measure of agri-environmental schemes in Finland with a high degree of implementation by farmers. In this survey, the deep root system was a valued characteristic for break-CCs, more than for catch crops (Figure 2). Break-CCs with taproots penetrating into deep soil layers and/or substantial root systems contribute to rebuilding the soil porosity in a biological manner [42]. Choosing appropriate plants and supporting their root growth with soil management are key strategies to help soil recover from compaction [43]. The absence of tilling and high input of root biomass also helps to build earthworm numbers [44]. Farmers with ≤50 ha grassland valued such a deep root system in break-CCs more often than those with >50 ha, likely because perennial grasslands per se maintain the soil structure and functionality [45]. Farmers that did not grow special crops or had <25% other diversifying crops valued less the importance of deep root systems for break-CCs (Table 2). Restoring soil conditions is a more novel application for CCs than preventing nutrient leaching with deep-rooted species [21,46]. Hence, it may call for special attention in future communication between early adopters and farmers who lack experience with CCs.

4.3. Water Quality: Erosion and Nutrient Leaching Risks

The vast majority of farmers agreed (71–79% depending on the statement) and only ≤4% disagreed that CCs have the potential to reduce environmental risks related erosion and nutrient leaching—also by effectively using residual N for the CCs' growth (Figure 2). These statements agreed with findings of many recent studies in Finland [13] and elsewhere [30,47], although the impacts are obviously dependent on the CCs and conditions. It is likely that farmers positive answers reflected awareness of research results, but also own estimations of N balances and visual examination of sediment loads (P in soil particles) from the heads of the subsurface drainage pipes. In addition to taking up residual N, CCs also trigger noteworthy N uptake by soil micro-organisms [48], which is then either assimilated into the soil organic matter or released for the next crop. However, more information is needed on role of CCs in preventing P losses in Nordic countries [13]. In some cases, CCs have increased the dissolved reactive P losses [49].

In Finland, the area under CC cultivation increased dramatically in the 2010s [13] and CCs are included in the current agri-environmental scheme, where it is available as an option for field parcel-scale diversification measures (https://www.ruokavirasto.fi/en/, accessed on 22 May 2022). Our findings show that farmers appreciate this subsidized measure—possibly because CCs have multifunctional impacts on farming systems beyond services to the environment. Budget to support cultivation of CCs has been limited compared to farmers' interests. Hence, in future schemes such a valued measure should not be restricted for a limited subsidized field area.

The role of CCs in reducing leaching and erosion risks differed depending on the farm characteristics. Monotonous and diverse land use patterns seemed to be the opposing parties (Table 1). This was further supported by the finding that farmers having experience with a higher number of CCs had more positive views about their impacts (Figure S13). Differences in the farmer's attitudes and behavior arise from their values, which are heterogeneous in the Finnish farmer community [50]. This may also imply that implementing these types of multifunctional diversification actions (among other alternatives) into monoculture-dominated farms may be challenging, even though such farms may have the most acute need for diversifying measures. The farm type, region and the farmer's age had a minor contribution. Surprisingly younger farmers (≤50 years) were slightly more doubtful of the impacts of CCs on nutrient leaching than farmers > 50 years (Figure 4).

4.4. Mixed Opinions on Climate Smart Agriculture

Farmers were in general more uncertain, i.e., they often neither agreed nor disagreed on statements regarding the contribution of CCs to CSA when compared to many of the impacts of CCs on farming per se (Figure 2). Hence, when the statement was more generic in nature like in the case of CSA, farmers were less ready to express their exact view. Nonetheless, the farmers agreed most frequently that the use of CCs is a means to improve the climate resilience of crop production. Finnish farmers are used to cope with highly variable weather conditions as these are typical for the high-latitude conditions [51]. Possibly therefore respondents were more confident about the opportunity to improve resilience. This was followed by the statements (downward trend) that CCs have great potential for C sequestration, their cultivation compensates for GHG emissions in agriculture and CCs are important means to adapt to climate change (Figure 2). Organic farmers were far more convinced than conventional ones concerning all the CSA related statements (Figure 3).

From all the CSA related statements, farmers least valued CCs as a means to adapt to climate change (Figure 2). Despite this, half of the farmers agreed and only 11% disagreed with CCs' role as an important adaptation measure. From the adaptation point of view, the most important contribution of CCs is likely to be the protection of soil conditions [22] from various harmful impacts (e.g., nutrient leaching, erosion and soil compaction) that warming autumns and winters may bring in the future with projected increases in precipitation in Finland [52]. Farmers strongly agreed with virtually all statements that dealt with the positive impacts of CCs on soil quality, structure, and functionality, but also in preventing nutrient leaching (Figure 2). South-Finland is a region with a high share of clay soils and there are high probabilities of snowless, bare soils in future winters [53]. The farmers in this region valued CCs as a means to adapt to climate change (Table 1). The expansion of CCs with some emerging overwintering capacity in future winters may, however, have some trade-offs. When compared to the currently dominating winter fallow practice (bare soils with cereal stubble if any soil cover at all), CCs may become a green bridge carrying pests and diseases through the winter and enabling their migration in the next season [54]. The cultivation of CCs is, however, only one adaptation measure in a diverse assortment of potential measures that farmers may need to implement when adapting to climate change at high latitude conditions [26,41].

Improving resilience in the future climate will be essential to reduce production uncertainties that are in principle typical for high-latitude agriculture [51]. Farmers with higher share of their field area under other crops and lower share under cereals agreed more often that CCs improved resilience. These findings imply that farmers who have diverse land use instead of cereal dominated systems may have personally witnessed how diverse land use buffers the harm caused by weather constraints and variability. Organic farmers with low special crop areas valued CCs as a means to improve resilience (Table S5), possibly because they lack diversity as such in their land use to enhance system resilience.

The majority of the farmers agreed that CCs have potential in terms of mitigating climate change. This has been demonstrated in earlier studies with some uncertainties caused by altered N2O emissions due to CCs [3,22]. However, farmers representing the current mainstream of cereal-based cropping systems in Finland were least positive about the contribution of CCs to C sequestration and the capacity to compensate for GHG emissions in agriculture (Table 1). Interestingly, older farmers (>50 years), i.e., those considered to hold onto old traditions, agreed more frequently than younger ones that cultivation of CCs would compensate for GHG emissions (Figure 4). These findings emphasize that younger farmer generations and farmers with cereal dominated systems should be approached as a target group when contemplating alternative means to compensate for GHG emissions in agriculture.

5. Conclusions

The respondents of this study were farmers who had experience in the cultivation of CCs, and they were in general very positive about the contribution of CCs to their cropping systems. They also valued CCs as a means to reduce the environmental impacts of agriculture and to enhance the climate smartness of crop production systems. Organic farmers were more positive than conventional ones on several benefits provided by CCs. Furthermore, diversity-oriented farmers valued CCs more as an additional means to enhance farm-scale heterogenization when compared to farmers using monotonous cereal sequencing. The respondents' views towards CCs highlight the potentiality to encourage other farmers to try out CCs and/or to further expand their cultivation through the exchange of experiences and transfer of gained know-how in a "from one farmer to another" manner. This study offers further support for the farmers' transition towards regenerative climate-smart systems by identifying critical target groups of farmers—younger farmers and especially those with less diverse land use—for communication.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14138067/s1, Figure S1: The mean (in order of decreasing value) of Finnish farmers' answers (n = 1130) to the question on cover crops (CCs) they have personal experience with. The answer choices were: 1 = none, 2 = little, 3 = somewhat, 4 = plenty and 5 = very much (unpublished data); Figure S2: Significant effects of farm type on the distribution of farmers' answers (n = 1130); Figure S3: Significant effects of farm size on the distribution of farmers' answers (n = 1130); Figure S4: Significant effects of region on the distribution of farmers' answers (n = 1130); Figure S5: Significant effects of the share of cereal area in a farm on the distribution of farmers' answers (n = 1130) on issues related to management when cover crops are used; Figure S6: Significant effects of the share of grassland area in a farm on the distribution of farmers' answers (n = 1130) on issues related to management when cover crops are used; Figure S7: Significant effects of the share of area under special crops in a farm on the distribution of farmers' answers (n = 1130) on issues related to management when cover crops are used; Figure S8: Significant effects of the share of area under other crops in a farm on the distribution of farmers' answers (n = 1130) on issues related to management when cover crops are used; Figure S9: Significant effects of the share of cereal area in a farm on the distribution of farmers' answers (n = 1130) on climate and environmental issues related to use of cover crops; Figure S10: Significant effects of the share of grassland area in a farm on the distribution of farmers' answers (n = 1130) on climate and environmental issues related to use of cover crops; Figure S11: Significant effects of the share of area under other crops in a farm on the distribution of farmers' answers (n = 1130) on climate and environmental issues related to use of cover crops; Figure S12: Significant effects of farmer's education on the distribution of farmers' answers (n = 1130); Figure S13: Significant effects of number of CCs that farmer had experience on the distribution of farmers' answers (n = 1130); Table S1: Statements of the farmer survey on cover crops (CCs) with 1130 respondents under the principal question What do you think about the following general statements? The answer choices were: 1 = fully disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = fully agree. Examples of some indicated quantitative impacts of CCs are shown. More information available on references (e.g., on cash crops and CCs combinations, experimental arrangements, crop management, and growing conditions). n/a = not applicable to show quantitatively the impact; Table S2: Results of sampling bias analysis comparing respondents to non-respondents of the survey with total of 6493 invited farmers with 17.4% response rate; Table S3: Correlations in answer means between statements (n = 898 for conventional and n = 232 for organic producers). The darkest green color indicates that for organic farmers $p < 0.0001$ followed by $p \leq 0.01$ and $p \leq 0.05$ with fading colors. p-values are shown correspondingly with orange colors for conventional farmers. For both farming systems grey color indicates that p-value > 0.05; Table S4: Statements with significant farming systems × region interaction. CCs, cover crops; CON, conventional farm; ORG, organic farm; s.e., the standard error of the mean; Table S5: Statements with significant farming systems × farm special crop area interaction. SC, special crop; CCs, cover crops; GHG, greenhouse gas; CON, conventional farm; ORG, organic farm; s.e., the standard error of the mean. References [55,56] are cited in the supplementary materials.

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