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Factors explaining the differences in the adoption of circular economy measures among farms in Southwest Finland

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Transitioning to a circular economy is essential for addressing the inefficiencies and environmental impacts of traditional agricultural practices that rely on synthetic fertilizers and fossil resources. These conventional methods degrade soil, increase greenhouse gas emissions, and pollute waterways through nutrient runoff. A circular economy enhances sustainability by minimizing waste, optimizing resource use, and recycling nutrients. This study analyzes the adoption of circular economy practices among farms in Southwest Finland and identifies influencing factors. A survey distributed to farmers measured the extent of circular practices and the challenges faced. Cross-tabulations and logistic regression analyses evaluated how farm characteristics and farmer attitudes impact implementation. Results show a slow and variable transition among farms. About 50% of respondents have reduced mineral fertilizer use, although trading in byproducts and especially on-farm energy production from byproducts remain uncommon. Many farmers highlight insufficient policy support. The study concludes that policy interventions, training, and education are essential to accelerate adoption and stresses the importance of tailored, regional decision-making for effective policy development.

Key words: agriculture, byproducts, fertilization, nutrient management, statistical analysis

Introduction: agriculture and circular economy

Modern food production faces significant sustainability challenges. Agriculture relies heavily on non-renewable resources, such as fossil fuels and mineral fertilizers, which have altered the global nutrient cycles of nitrogen and phosphorus. This has led to nutrient buildup on land, runoff into waterways, and greenhouse gas emissions (Vitousek et al. 1997, Rockström et al. 2009, Elser and Bennett 2011). Additionally, food systems are often inefficient, assuming that natural resources are infinite and that the environment can indefinitely absorb waste (Marín-Beltrán et al. 2022).

Soil quality degradation is another global issue, exacerbated by industrial farming practices and climate change (Sofo et al. 2022). Heavy use of synthetic fertilizers reduces soil organic matter and carbon content, while monoculture farming decreases biodiversity and microbial life. Water management practices, such as excessive irrigation and poor drainage, often result in either water scarcity or surplus, both of which can harm crops and soil health (Magdoff and Van Es 2021). Climate change further complicates agriculture, making weather patterns unpredictable and increasing the frequency of extreme weather events (Masson-Delmotte et al. 2021).

In Finland, despite high food self-sufficiency – where only 20% of food relies on imports (Huan-Niemi et al. 2021) – agriculture is still heavily dependent on imported fertilizers, feed, and energy. Recent geopolitical conflicts and the COVID-19 pandemic have highlighted the vulnerability of this dependency (OSF 2022b, OSF 2023b, Rimhanen et al. 2023). Moreover, the reliance on inorganic fertilizers and fossil fuels has led to agriculture contributing about 12% of Finland's total greenhouse gas emissions (OSF 2022a). Thus, Finnish agriculture is both influenced by external factors and a significant contributor to the climate crisis.

A proposed solution to these sustainability challenges is transitioning to a circular economy (CE). Traditional linear economic models – characterized by a take-make-dispose approach – are prevalent in food production. This model disrupts the natural cycles of critical nutrients like nitrogen and phosphorus, primarily due to the use of inorganic fertilizers (Rockström et al. 2009, Richardson et al. 2023). CE in agriculture offers opportunities to conserve resources and reduce emissions (Rodias et al. 2021). For instance, farms can use processed animal and human waste as fertilizers, facilitating the transfer of nutrients from surplus to deficit areas (Spiegal et al. 2020). Effective

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nutrient management can also be achieved through diverse crop rotations, maintaining continuous vegetation cover, enhancing soil health, and managing water efficiently (McDaniel et al. 2014, Magdoff and Van Es 2021). Additionally, farm machinery can be powered by biogas, produced from food production byproducts (Metson et al. 2022).

To address the pressing sustainability challenges in agriculture, our research on implementing CE practices provides essential insights that bridge theoretical frameworks with practical applications. By focusing on how CE measures can be effectively adopted at the farm level, particularly in Southwest Finland, this study offers an evidence-based approach to transforming the circular economy from concept to practice in the agricultural sector. The findings contribute data for policymakers, farmers, and stakeholders to scale CE practices regionally, reinforcing the pathway toward a more resilient, low-waste agricultural system aligned with global sustainability goals.

Our research focuses on the practical application of CE measures within agriculture. It critically examines these measures, acknowledging that CE is not a panacea for all sustainability challenges (Åkerman et al. 2020). Furthermore, the study considers how agricultural policies influence the adoption of CE practices and the development of closed-loop systems at various scales.

The study investigates the adoption of CE practices among farms in Southwest Finland. It aims to analyze the differences in conditions that affect CE practice adoption among these farms. Initially, the study evaluates the current level of CE adoption in the region (RQ1). Subsequently, it explores the factors related to farmers and farm characteristics that predict CE adoption (RQ2).

To address these questions, we present results from a survey conducted among farmers in Southwest Finland. By focusing on a specific region, we can analyze CE and agriculture on a scale often overlooked in research (Koppelmäki et al. 2021). This includes presenting the frequencies of responses to survey questions about barriers to CE adoption.

The study further uses cross-tabulations and logistic regressions to understand why some farms are more equipped to implement CE practices than others. This statistical analysis helps identify the reasons behind the differences in farming conditions and readiness to adopt CE operations.

Materials and methods

Survey

We conducted an online survey targeting primary agricultural entrepreneurs in Southwest Finland, who formed the population of the study. Southwest Finland, the country's third most populous province, is a crucial area for food production, contributing significantly to the national grain harvest and housing many pig and poultry farms (OSF 2023a, OSF 2023c). The region benefits from an extended growing season, consistent rainfall, and nutrient-rich soils, favourable for diverse crop cultivation (Kersalo and Pirinen 2009, Peltonen-Sainio et al. 2019).

Located along the Baltic Sea, the region's rural landscape includes a long coastline and the extensive Turku Archipelago, with approximately 20 000 islands (Fig. 1). Agricultural runoff can quickly reach the marine environment, impacting the Baltic Sea, a shallow inland sea particularly susceptible to such disturbances. The Archipelago Sea, a pollution hotspot mainly due to agricultural runoff, is a focus for Finland's commitment to remove it from HELCOM's (2020) list by 2027 (Laurila et al. 2022).

Before the actual collection of survey responses, we piloted the questionnaire with five test respondents who at that time were agricultural entrepreneurs in Southwest Finland. We received their contact information from the Central Union of Agricultural Producers and Forest Owners. Based on their comments, we further improved the questionnaire. The contact information of the actual survey respondents was provided to us by the Finnish Food Authority. We limited the sample to those farmers in Southwest Finland who had applied for agricultural subsidies in 2022.

We conducted the survey using the Webropol survey system and sent a link to the survey by email. The survey was available from November 30 to December 14, 2022, which we estimated – based on our previous experience – would be long enough for participants to respond and short enough so that time would not become a determining factor in response. We sent a reminder email two days before the questionnaire closed to improve the survey response rate.

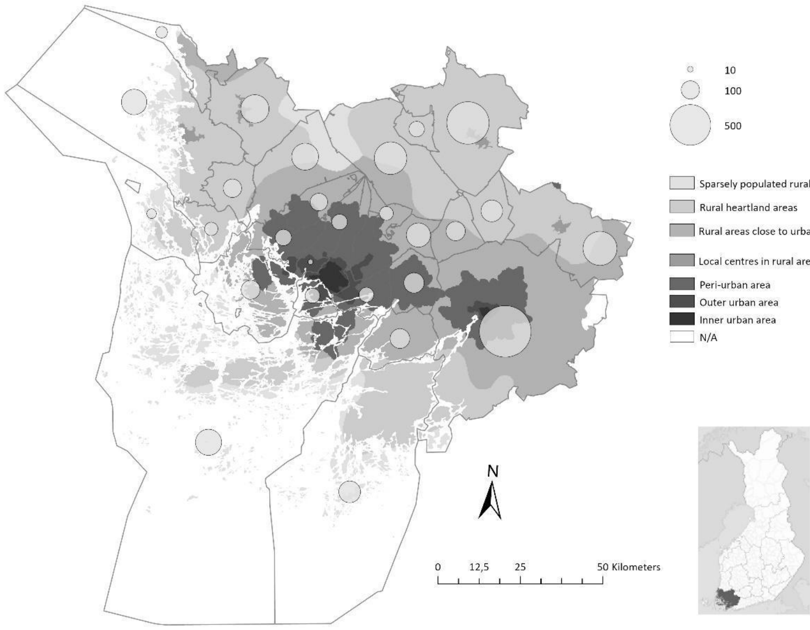

Fig. 1. The province of Southwest Finland divided by the 2018 urban-rural classification and showing the total number of farms by municipality in 2022 (circles). Index map source: Fenn-O-Manic/ Wikimedia Commons.

We aimed the survey to identify barriers and factors affecting the adoption of CE practices at the farm level. CE practices here include replacing mineral fertilizers with organic ones, utilizing production side streams, and improving nutrient management. We also asked respondents to define CE and assess how current agricultural policies support CE transitions. We formulated the questions to be accessible and non-leading. This study focuses on the quantitative results, while qualitative aspects are explored in another study.

The survey initially began with ten background questions providing insights into farmers' engagement with CE practices and allowing a comparison between the farms. We categorized respondents by age and the farms by the total arable area. Farms were also grouped into locational categories based on their postal code and by using the urban-rural classification (Fig. 1) from the Finnish Environment Institute (2020). All closed-ended questions in the survey were mandatory.

Conducted during a time of heightened geopolitical tensions and fluctuating energy markets due to the conflict in Ukraine, the survey addressed changes in the use of mineral fertilizers over five-year periods. We also acknowledged that specific examples in the nutrient management section might have influenced responses. See Appendix 7 for the complete survey questionnaire.

Statistical analyses

Cross-tabulation

We analyzed the survey data using IBM® SPSS® software, starting with cross-tabulation to explore pairwise associations between variables. Cross-tabulation provides chi-square (χ^2) values which tell us if there is a statistically significant association between the two variables and how strong it is.

To interpret the chi-square value, it is essential to examine the *p*-value, which indicates whether the observed relationship is likely attributable to chance or is statistically significant. A smaller *p*-value (typically less than 0.05) suggests that the relationship between the variables is unlikely to result from random variation, providing greater confidence in the existence of a genuine association. In other words, a low p-value supports the conclusion that a meaningful link exists between the variables under investigation.

We constructed a total of 74 cross-tabulations based on seven response variables and eleven explanatory variables (Appendix 2). Investment in enhancing nutrient management and view on the current state of agricultural policy serve as both response variables and explanatory variables. Based on the cross-tabulations, we can claim whether the characteristics of farmers and their farms have a statistically significant association with whether they implement circular economy practices or not and whether they see current agricultural policy as supporting the circular economy transition or not. Following the examination of these associations individually, their combined effects can be analyzed through logistic regression.

Logistic regression

Following cross-tabulations, we applied logistic regression analysis. This technique extends linear regression to explain the occurrence of events through variations in multiple explanatory variables (Domínguez-Almendros et al. 2011, James et al. 2021). In our analysis, response variables represented CE practices, while explanatory variables described farm or respondent characteristics. This method helps identify whether individual background factors influence the adoption of CE practices. Logistic regression is suitable for categorical variables, estimating the probability of a specific outcome relative to all other outcomes. This probability is described by the regression coefficient B, which tells us how much a one-unit change in the value of the explanatory variable changes the value of the response variable.

More interesting than coefficients in terms of interpretation is the odds ratio (OR), which is obtained by raising the regression coefficient B to the power of *e* (Napier's constant; Burgess 2013). An OR compares the odds of an outcome happening with and without a specific factor. If an OR is greater than 1, it suggests that the factor increases the likelihood of the outcome, and, conversely, an OR below 1 suggests the factor decreases the likelihood of the outcome. An OR of exactly 1 means the factor has no effect on the likelihood of the outcome.

We conducted logistic regression for seven response variables (Appendix 2). Binary logistic regression was used for variables with two possible outcomes (Domínguez-Almendros et al. 2011, James et al. 2021). For the analyses, a No response was coded as 0 and a Yes response as 1. In this way, we were able to model the probability that a survey respondent would not implement a circular economy practice based on their own or their farm's characteristics.

Multinomial logistic regression was applied to variables with three or more outcomes (Domínguez-Almendros et al. 2011, James et al. 2021). For analyses, outcomes were coded as numerals. Using multinomial logistic regression, we modelled the probability that a respondent would not implement a circular economy practice relative to all forms of practice implementation based on the background characteristics.

Ordinal logistic regression was used for Likert scale variables (O'Connell 2006). It is possible to analyze the variation of a Likert-scale variable using logistic regression analysis if the response options are coded as numerals in numerical order (1–5). Thus, the probability of a respondent choosing a certain answer option is modelled based on background variables. In the case of our research, we structured the Likert-scale questions so that they measured the direction and degree of the respondent's action: is the farm moving closer to or further away from circular economy operations, and if so, to what extent?

Each analysis included all nine explanatory variables (entry method; Appendix 2). Models with high *p*-values were not automatically rejected; individual variable *p*-values were also considered. Generally, high *p*-values weaken the model's explanatory power.

Key indicators in logistic regression include the *p*-value, ORs, and the Pseudo R-squared value (R^2). R^2 is a coefficient of determination that estimates how much of the observed variation in a variable a logistic regression model is able to explain (Hemmert et al. 2018). It is very commonly used in empirical studies to assess the overall acceptability of the model. In simplified terms, higher R^2 values indicate a better fit to the data. We reported Cox & Snell R^2, Nagelkerke R^2, and McFadden R^2 values to enhance model credibility, except for binary models where McFadden R^2 is not output in SPSS®.

We also report the regression coefficients and 95% confidence intervals for each model. The confidence intervals better capture the degree of uncertainty related to the regression models and their interpretation than the *p*-values alone.

Again, in our analysis, the response variables represent CE practices and the explanatory variables represent farmer and farm characteristics, but unlike cross-tabulations, we entered all explanatory variables into each model simultaneously. This allowed us to identify situations where two or more explanatory variables together contributed to the values obtained by the response variable.

Use of artificial intelligence

To refine this article, we used OpenAI's ChatGPT model to enhance clarity and conciseness, particularly in summarizing the main findings and core content. The output was reviewed and edited to ensure accuracy and alignment with the research objectives. As authors, we take full responsibility for the content of this article.

Results

Representativeness of the sample

We distributed the survey to 4 167 agricultural entrepreneurs in Southwest Finland, receiving 389 valid responses – a 9.3% response rate. Despite the moderate response rate, the sample represents the population excellently across all key variables, as shown by the Tables 1–2. Respondents included a diverse range of agricultural professionals and activities spanning all 27 municipalities in the province (Fig. 2; see also Appendix 1 for the municipality-specific comparisons). This distribution ensures that the sample captures the regional variation and structural diversity of farming in Southwest Finland, meeting the criteria for reliable analysis even with lower response rates (Fosnacht et al. 2017).

Table 1. The group of survey respondents (sample) compared to all farmers in Southwest Finland (population). Sources for all farms: OSF 2020b, OSF 2022c, OSF 2022d. 1 Information for all farms from 2022. 2 Including oilseeds 3 E.g., potato, sugar beet. 4 Sheep and goat farms only. 5 Information for all farms from 2020.

	Sample (n=389) %	Population (4 554 in total) %
Share *of agricultural and horticultural enterprises*[1]		
Cereal farming	64.0[2]	54.9
Horticulture	4.9	7.3
Other plant farming[3]	13.6	20.0
Dairy cattle farming	2.6	2.6
Other cattle farming	3.6	3.1
Pig farming	3.8	2.0
Poultry farming	3.6	3.1
Other livestock farming	3.8	1.4[4]
Mixed farming	14.7	6.2
Organic farming	14.7	10.6
Share *of agricultural and horticultural enterprises by farm size category*[1]		
0–50 ha	43.4	56.0
50–100 ha	27.8	23.8
Over 100 ha	28.8	20.2
Share *of farmers on privately owned farms by age group*[1]		
under 40	12.1	13.3
40–55	38.0	35.3
Over 55	49.9	51.4
The average age of farmers	53.6	54
Share *of multi-sector agricultural and horticultural enterprises*[5]	36.2	31.6
Farms with land in cultivation[1]	100.0	97.0

Table 2. Descriptive statistics for survey variables. SD = Standard Deviation

Variable	Mean	SD	Frequency	Percentage
Age	53.64	11.974		
Gender				
Male			330	84.8
Female			57	14.7
Other			2	0.5
Farm location				
Sparsely populated rural areas			5	1.3
Rural heartland areas			198	50.9
Rural areas close to urban areas			115	29.6
Peri-urban area			65	16.7
Outer urban area			4	1.0
Inner urban area			1	0.3
Education				
Primary school			28	7.2
Vocational school			116	29.8
Upper secondary school			38	9.8
University of applied sciences			129	33.2
University			78	20.1
Share of agricultural income in total income (1=0–24%,..., 4=76–100%)	2.54	1.263		
Arable area (in hectares)	81.41	90.699		
The main form of production				
Cereal and oilseed farming			249	64.0
Horticulture			19	4.9
Other plant production			53	13.6
Cattle farming			24	6.2
Pig and poultry farming			29	7.5
Other livestock production			15	3.9
Mixed farm				
Yes			332	85.3
No			57	14.7
Method of production				
Conventional farming			332	85.3
Organic farming			51	13.1
Combination of organic and conventional farming			6	1.5
Change in the amount of mineral fertilizers used 2018–2022 (1=Significantly increased,..., 5=Significantly decreased)	3.63	0.809		
Intention to change the amount of mineral fertilizers used 2023–2027 (1=Significantly increase,..., 5=Significantly decrease)	3.60	0.796		
Use of manure/recycled fertilizers				
Yes, both			38	9.8
Manure			134	34.4
Recycled fertilizers			20	5.1
Neither			197	50.6

On-farm energy production from side streams				
Yes			11	2.8
No			378	97.2
Off-farm utilization of side streams				
Yes			138	35.5
No			251	64.5
Investment in enhancing nutrient management (1=Very little or none,..., 5=Very much)	3.20	1.017		
View on the state of agricultural policy (1=Very poorly,..., 5=Very well)	2.39	0.973		

Note: Mean and SD are not applicable for categorical variables. Mean and SD are reported for Likert scale as an approximation of central tendency.

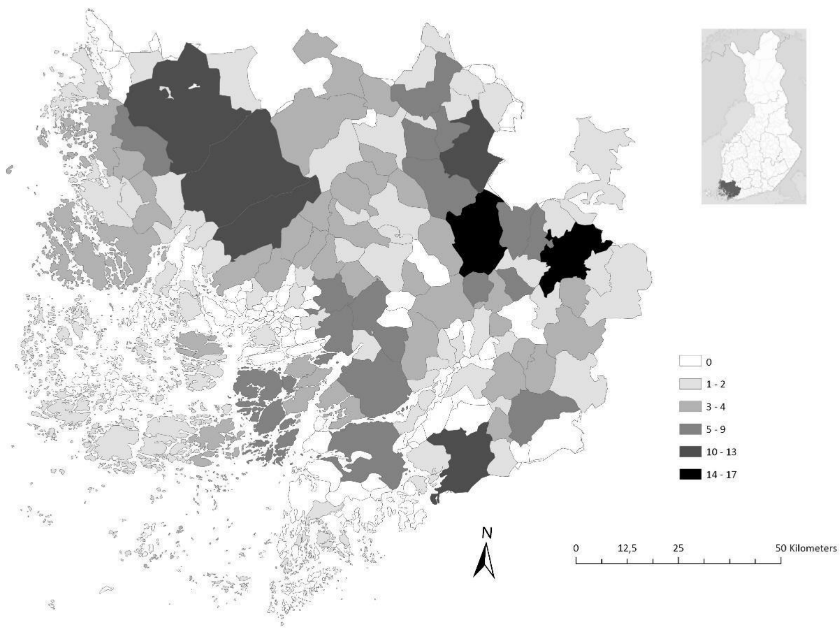

Fig. 2. Number of farms that responded to the survey (389 in total) per postal code area in the province of Southwest Finland. Index map source: Fenn-O-Manic/Wikimedia Commons.

Adoption of circular economy practices in Southwest Finland agriculture

The survey revealed diverse practices and trends in production forms and methods among the respondents. 15% of the farms managed mixed operations involving both plant and animal production, while 13% engaged in organic farming, and an additional 1.5% were in the process of transitioning to organic practices.

Mineral fertilizer usage showed notable changes between 2018 and 2022, with 50% of respondents reporting a decrease and only 3.1% indicating an increase in usage. These trends are expected to persist, as half of the respondents planned to further reduce mineral fertilizer use between 2023 and 2027, and 47% intended to maintain current usage levels.

At the time of the survey, 49% of respondents' farms used organic fertilizers, with manure being the predominant choice (44%), followed by processed recycled fertilizers (15%). The application of organic fertilizers varied significantly by farm type, with 96% of animal farms using them compared to 40% of plant farms.

Only a small proportion (2.8%) of farms reported producing energy from byproducts generated in their operations. However, 35% of respondents indicated that they distributed, exchanged, or sold their byproducts externally, primarily for use as bedding, fertilizer, or feed. Additional uses included soil conditioning, growing mediums, and ground cover.

In terms of nutrient management, 38% of respondents reported making significant or substantial investments in this area, while 21% indicated little to no investment. Finally, perspectives on agricultural policy support for transitioning to a CE varied. Just over half of the respondents (51%) believed that current policies poorly support the CE transition, while 27% viewed them as neutral. Only 1.0% felt that agricultural policies support the transition very well.

Factors influencing the adoption of circular economy practices

Results of cross-tabulations

We used cross-tabulation to examine how background factors were associated with adoption of CE practices (Table 3). Only the statistically significant analysis results are covered in the following text.

Table 3. Pairwise associations between background factors and circular economy practices: chi-square (χ^2) values and *p*-values for cross-tabulations

Dependent variable	Independent variable	χ^2	*p*-value
Change in the amount of mineral fertilizers used 2018–2022	Age	6.562	0.585
	Gender	2.839	0.585
	Farm location	1.809	0.986
	Education	21.844	0.148
	Share of agricultural income in total income	10.376	0.583
	Arable area	15.676	0.476
	The main form of production	13.352	0.053
	Mixed farm	2.689	0.611
	Method of production	29.098	**<0.001**
	Investment in enhancing nutrient management	16.875	0.394
	View on the state of agricultural policy	32.519	**0.038**
Intention to change the amount of mineral fertilizers used 2023–2027	Age	16.611	**0.034**
	Gender	4.314	0.365
	Farm location	16.867	0.661
	Education	19.733	0.232
	Share of agricultural income in total income	11.883	0.455
	Arable area	19.727	0.233
	The main form of production	24.301	0.229
	Mixed farm	2.847	0.584
	Method of production	29.962	**<0.001**
	Investment in enhancing nutrient management	26.860	**0.043**
	View on the state of agricultural policy	39.683	**0.005**
Use of manure/recycled fertilizers	Age	24.468	**<0.001**
	Gender	9.087	0.028
	Farm location	17.238	0.305
	Education	29.344	**0.004**
	Share of agricultural income in total income	28.654	**<0.001**
	Arable area	56.525	**<0.001**
	The main form of production	100.302	<0.001
	Mixed farm	70.443	**<0.001**
	Method of production	25.434	**<0.001**
	Investment in enhancing nutrient management	53.275	**<0.001**
	View on the state of agricultural policy	10.126	0.812

On-farm energy production from side streams	Age	1.308	0.520
	Gender	0.287	0.592
	Farm location	4.627	0.463
	Education	5.293	0.259
	Share of agricultural income in total income	2.211	0.530
	Arable area	6.458	0.167
	The main form of production	2.386	0.794
	Mixed farm	0.280	0.597
	Method of production	1.442	0.230
	Investment in enhancing nutrient management	2.066	0.724
	View on the state of agricultural policy	9.189	0.146
Off-farm utilization of side streams	Age	2.665	0.264
	Gender	0.085	0.771
	Farm location	4.916	0.426
	Education	6.935	0.139
	Share of agricultural income in total income	4.974	0.174
	Arable area	6.792	0.147
	The main form of production	15.822	**0.007**
	Mixed farm	4.127	**0.042**
	Method of production	1.282	0.257
	Investment in enhancing nutrient management	10.271	0.036
	View on the state of agricultural policy	2.462	0.782
Investment in enhancing nutrient management	Age	13.680	0.090
	Gender	0.548	0.969
	Farm location	22.741	0.302
	Education	28.626	0.027
	Share of agricultural income in total income	30.552	**0.002**
	Arable area	34.732	**<0.001**
	The main form of production	29.556	0.077
	Mixed farm	7.107	0.130
	Method of production	7.254	0.123
	Investment in enhancing nutrient management	28.124	0.107
View on the state of agricultural policy	Age	20.438	**0.025**
	Gender	4.706	0.453
	Farm location	14.615	0.950
	Education	13.703	0.845
	Share of agricultural income in total income	5.270	0.990
	Arable area	22.554	0.311
	The main form of production	20.229	0.735
	Mixed farm	1.572	0.905
	Method of production	1.593	0.902

Note: statistically significant (<0.05) *p*-values are in bold.

The type of farm production significantly affected the change in mineral fertilizer use from 2018 to 2022. Organic farms and those combining organic and conventional methods were more likely to reduce usage. Farmers satisfied with current policies also tended to reduce mineral fertilizer use.

Future plans to adjust the amount of mineral fertilizers used from 2023 to 2027 were influenced by the farmer's age and the farm's production method. Younger farmers and those on organic farms were more open to adjusting the amounts. Farmers who invested heavily in nutrient management were less likely to plan adjustments but were more satisfied with current policies.

The use of manure and recycled fertilizers was more prevalent among younger farmers, female farmers, and those with higher education or larger farms. Organic and mixed farms were more likely to use both manure and recycled fertilizers, and farms with significant agricultural income invested more in nutrient management and used these fertilizers more frequently.

No significant background factors explained energy production from byproducts. However, external utilization of byproducts was more common on animal and mixed farms compared to plant farms. Farms investing in nutrient management were more likely to utilize byproducts externally.

Investment in nutrient management varied by education level, farm income structure, and size. Farmers with lower education and smaller farms invested less, while those with a higher agricultural income percentage invested more. Older farmers were generally more critical of current agricultural policies than younger ones.

Results of logistic regressions

Logistic regression was used to analyze changes in mineral fertilizer use and other CE practices (Tables 4–7), in terms of the most important indicators for each seven regression models. Below we present the results of statistically significant models and the statistically significant results of individual variables from statistically non-significant models. The full results of the logistic regression models can be found in Appendices 3–6.

Farms in sparsely populated rural areas were more likely to reduce fertilizer usage from 2018 to 2022 compared to those in rural heartlands. For future fertilizer use plans (2023–2027), the model suggested that farms in sparsely populated areas and those with mixed production methods were inclined to plan reductions. Livestock farms were less likely to plan decreases compared to cereal and oilseed farms.

The regression model for the use of manure and recycled fertilizers was significant. It indicated that animal farms, younger farmers, and those with higher education were more likely to use manure. Farms in rural heartlands and involved in organic farming preferred recycled fertilizers. Larger farms and those with substantial agricultural income were more likely to use both manure and recycled fertilizers.

Although statistically non-significant (p= 0.425), farms that combine organic and conventional production methods might be more likely to produce energy from byproducts compared to farms that are entirely in conventional production.

In another statistically non-significant model (p= 0.123) related to external utilization of byproducts, farms focused on other plant production were more likely to utilize byproducts externally compared to cereal and oilseed farms.

Model related to investment in nutrient management was statistically significant. Older farmers invested less, while those with a higher percentage of income from agriculture invested more. On the other hand, no specific background factors significantly explained respondents’ views on agricultural policy from a CE perspective.

Table 4. Which variables predict adherence to reduce the amount of mineral fertilizer used: statistically significant results of the first two logistic regression models

Response variable: Change in the amount of mineral fertilizers used 2018-2022 (Significantly decreased/ Somewhat decreased/Remained the same/Somewhat increased/Significantly increased)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Significantly increased	0.040	0.041	0.100	0.089
Independent variables				OR (B)	[95% CI]
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas				0.061 (-2.803)*	-0.006, 0.618
Rural areas close to urban areas				0.012 (4.413)*	0.000, 1.749

Response variable: Intention to change the amount of mineral fertilizers used 2023–2027 (Significantly decrease/Somewhat decrease/Keep the same/Somewhat increase/ Significantly increase)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Significantly increase	0.072	0.039	0.093	0.083
Independent variables		OR (B)		[95% CI]	
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas		15.271 (2.726)**		1.976, 118.002	
The main form of production (reference category: Cereal and oilseed farming)					
Other livestock production		0.280 (-1.274)*		0.088, 0.894	
Method of production (reference category: Conventional farming)					
Combination of conventional and organic farming		6.922 (1.935)**		1.422, 33.706	

R^2 = R-Squared, OR = Odds ratio, B = regression coefficient, CI = Confidence interval for odds ratio. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Table 5. Which variables predict adherence to use manure and recycled fertilizers: statistically significant results of the third logistic regression model

Response variable: Use of manure/recycled fertilizers (Yes, both/Manure/Recycled fertilizers/Neither)						
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2	
Multinomial	Neither	<0.001	0.275	0.508	0.450	
Independent variables	Manure		Recycled fertilizers		Yes, both	
	OR (B)	[95% CI]	OR (B)	[95% CI]	OR (B)	[95% CI]
Age	0.953 (-0.048)***	0.929, 0.979				
Farm location (reference category: Rural heartland areas)						
Peri-urban area			0.107 (-2.232)*	0.012, 0.947	0.124 (-2.084)*	0.024, 0.632
Education (reference category (Primary school)						
Higher education degree (applied sciences)	7.230 (1.978)*	1.381, 37.855				
% of agricultural income in total income (reference category: 0–25)						
25–50					4.349 (1.470)	1.213, 15.587
The main form of production (reference category: Cereal and oilseed cultivation)						
Cattle farming	24.867 (3.214)**	2.842, 217.579			10.880 (2.387)*	1.055, 112.256
Pig and poultry farming	17.718 (2.875)*	1.803, 174.105				
Other livestock production	40.936 (3.712)**	4.190, 399.903				
Mixed farm (reference category: No)						
Yes	10.245 (2.327)*	2.769, 37.905				
Method of production (reference category: Conventional farming)	3.177 (1.156)*	1.281, 7.878				
Organic farming			7.376 (1.998)**	2.002, 27.172	8.105 (2.092)***	2.591, 25.349

R^2 = R-Squared, OR = Odds ratio, B = regression coefficient, CI = Confidence interval for odds ratio. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Table 6. Which variables predict adherence to utilize byproducts: statistically significant results of the fourth and fifth logistic regression model

Response variable: On-farm energy production from side streams (Yes/No)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Binary	No	0.425	N/A	0.260	0.059
Independent variables			OR (B)	[95% CI]	
Method of production (reference category: Conventional farming)					
Combination of conventional and organic farming			29.429 (3.382)*	1.224, 707.501	

Response variable: Off-farm utilization of side streams (Yes/No)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Binary	No	0.123	N/A	0.106	0.077
Independent variables			OR (B)	[95% CI]	
The main form of production (reference category: Cereal and oilseed farming)					
Other plant production			2.080 (0.732)*	1.089, 3.975	

R^2 = R-Squared, OR = Odds ratio, B = regression coefficient, CI = Confidence interval for odds ratio. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Table 7. Which variables predict adherence to invest in nutrient management and attitude towards prevailing agricultural policy: statistically significant results of the sixth and seventh logistic regression model

Response variable: Investment in enhancing nutrient management (Very much/Quite much/Somewhat/ Rather little/Very little or none)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Very little or none	<0.001	0.048	0.133	0.125
Independent variables			OR (B)	[95% CI]	
Age			1.018 (0.018)*	1.001, 1.036	
% of agricultural income in total income (reference category: 0–25)					
75–100			0.478 (-0.737)**	0.273, 0.839	

Response variable: View on the state of agricultural policy (Very well/Quite well/Neither well nor poorly/Rather poorly/Very poorly)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Very poorly	0.859	0.017	0.047	0.044
Independent variables				OR (B)	[95% CI]
(No statistically significant results in this model)					

R^2 = R-Squared, OR = Odds ratio, B = regression coefficient, CI = Confidence interval for odds ratio. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Discussion

The results of this study can be summarized in three main arguments: 1) Farms are moving towards organic fertilizers at a markedly different pace, 2) The production method and the main form of production may explain the degree of byproduct utilization, and 3) Young and full-time farmers are the most willing to invest in nutrient management – despite few political incentives. We have structured the Discussion chapter according to these three arguments. At the end of the chapter, we provide recommendations on which topics it would be important for decision-makers and researchers to focus on to promote the transition to a circular economy in agriculture.

Farms are moving towards organic fertilizers at a markedly different pace

The survey reveals a gradual decrease in mineral fertilizer use among farmers in Southwest Finland. While many farms maintained their usage levels several years before reducing them, younger farmers show a greater propensity to adjust fertilizer use over five years. This aligns with similar trends observed in Swedish (Lima et al. 2024) and Danish (Case et al. 2017) agriculture.

Unexpectedly, reductions are more prevalent in sparsely populated rural areas. This may be due to larger livestock farms in these areas utilizing manure from their animals, providing a natural alternative to mineral fertilizers.

50% of the farms in Southwest Finland use organic fertilizers, predominantly manure. This is lower compared to Sweden and Denmark, where the usage is 80% and 72%, respectively (Case et al. 2017, Lima et al. 2024). The continued preference for mineral fertilizers on plant farms in Southwest Finland could be due to logistical constraints. For comparison, in Denmark, 65% of farmers engaged in plant production in 2014 (Case et al. 2017), compared to 82% in Southwest Finland in 2022. "Around 50%" of Danish farms had a manure exchange agreement in 2011 (Asai et al. 2014), while in Southwest Finland, 6.6% of farms exported manure and 14.7% imported manure in 2020 (OSF 2020a). This suggests that in Denmark, the separation of animal and plant production from each other has not been as great as in Finland, and that Danish plant farms have more manure-producing animal farms near them than plant farms in Southwest Finland do.

Manure and recycled fertilizers are more commonly used on larger farms and those engaged in organic or mixed farming. This mirrors trends in Denmark but is limited by the separation of plant and animal production regions. Organic farms, bound by EU certification standards, favour entirely organic fertilizers (EC 2018).

Gender influences fertilizer use, with women managing farms that utilize manure and men more likely to use recycled fertilizers. This partly contrasts with Central European trends where male farmers predominantly adopt all kinds of sustainable practices (Herrera et al. 2023). Older farmers tend to avoid both manure and recycled fertilizers, differing from findings that link longer tenure with higher adoption of emission reduction practices.

Higher education and deriving significant income from agriculture correlate with a greater likelihood of using organic fertilizers, reinforcing the connection between education, primary agricultural reliance, and sustainable farming (Nordin et al. 2022, Herrera et al. 2023).

The production method and the main form of production may explain the degree of byproduct utilization

On-farm energy production from byproducts remains rare. The analysis of survey responses concerning energy production yielded a single statistically significant result: organic farms in Southwest Finland may be more involved in energy production from byproducts. According to Rizzo et al.'s (2024) systematic literature review, environmental awareness is prioritized over immediate economic benefits more frequently on organic farms than on conventional ones. This suggests that the observed connection might indeed be valid.

Conversely, the sale, exchange, or transfer of byproducts for off-farm use is moderately common, with one-third of farms in Southwest Finland participating. According to Kämäräinen et al. (2014), the restructuring of Finnish agriculture has decreased the proportion of farms involved in these practices due to the decline in farm numbers, increased farm sizes, greater distances between farms, and specialization.

The type of production significantly affects whether farms utilize byproducts externally, although the specific nature of this relationship varies, making it difficult to draw definitive conclusions.

Young and full-time farmers are the most willing to invest in nutrient management – despite few political incentives

Investment in nutrient management is modest across most farms, likely influenced by the requirement to meet minimum environmental subsidy standards (Finnish Food Authority 2023). Younger farmers, however, are more inclined to invest in nutrient management compared to older farmers. This contrasts with findings from Central Europe, where older farmers are more likely to adopt emission-reduction practices (Herrera et al. 2023), but it aligns with Serebrennikov et al.'s (2020) literature review, which indicates that younger farmers are more willing to switch to organic production than those nearing retirement.

Farmers with elementary education tend to invest less in nutrient management, while those with a higher proportion of income from agriculture and larger farms show a greater willingness to invest. This trend supports the link between education, income dependence on agriculture, and sustainable practices (Serebrennikov et al. 2020, Nordin et al. 2022).

There is a general sentiment among farmers in Southwest Finland that current agricultural policies do not adequately support the transition to sustainable food production. This criticism is more pronounced among older farmers.

Limitations of the study

While the survey sample and population are largely consistent, certain discrepancies should be noted. Cereal farms were overrepresented in the survey relative to the population. However, this discrepancy narrows to 2.7 percentage points when cereal farming is combined with other crop production, reflecting differences in how these categories are classified in the Official Statistics of Finland (OSF 2022d).

The survey respondents were geographically more concentrated than farmers in Southwest Finland in general. 52.6% of respondents came from the four largest respondent municipalities (see Appendix 1). Therefore, some degree of bias can be assumed in the analyses based on farm locations.

Another bias arises from the definition of mixed farms. In this study, mixed farms were defined as those with at least one plant production form and one livestock production form, based on farmers' self-reports. In contrast, the Official Statistics of Finland define mixed farms more stringently, as those where at least two-thirds of total output comes from a single product. This definitional difference likely accounts for the observed disparity between the sample and the population in this category.

Furthermore, livestock and organic farmers were slightly overrepresented in the sample. This may be attributed to livestock farmers' heightened interest in nutrient recycling due to their reliance on animal manure, and organic farmers' greater awareness of environmental impacts, which may make them more inclined to participate in studies of this nature. These biases should be taken into account when interpreting the results and generalizing findings to the wider farming population.

Overall, analyzing the quantitative results of a single survey is only scratching the surface of the realities of farmers ahead of the sustainability transition in agriculture. Further research is warranted for a deeper understanding of the impact of both the relative and absolute locations of farms, as well as the influence of national policies and regulations, on farmers' readiness to adopt circular economy practices.

Recommendations and conclusions

The transition to a circular economy in Southwest Finland's agriculture is progressing slowly, driven mainly by a few adopted practices. To accelerate this shift, policy interventions are crucial, particularly in promoting energy production. Decision-making, tailored to the diverse needs of different farm types, is essential. Policies should focus on paying attention to small farms managed by part-time farmers, integrating agricultural viability with broader livelihood options. Additionally, there seems to be a need for targeted training on circular economy principles, especially for farmers lacking formal agricultural education.

Our research indicates that farms in Southwest Finland differ significantly in their extent of adopting circular economy measures. This diversity can be attributed to various factors, including the type of circular economy measures being considered, the farmer's age, educational background, the balance of income derived from agriculture versus other sources, the farm's production method, and geographical location. Notably, the combined influence of these factors is most apparent in the willingness to use organic fertilizers, with farm size and the farmer's gender also playing critical roles. These insights underscore the need to recognize the unique profiles of farms, ensuring that the transition to a circular economy is inclusive, feasible, and impactful across all sectors of agriculture.

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Appendices

Appendix 1. Share of agricultural and horticultural enterprises by municipality in Southwest Finland

	Sample (n=389) %	Population (4 554 in total) %
Salo	8.9	17.7
Loimaa	8.8	12.0
Somero	11.1	7.7
Pöytyä	7.5	7.0
Parainen	10.2	4.5
Uusikaupunki	8.6	4.3
Koski Tl	11.3	3.1
Mynämäki	7.3	4.8
Laitila	5.7	5.4
Lieto	7.4	3.9
Turku	18.2	1.4
Paimio	9.8	2.7
Nousiainen	12.0	2.0
Sauvo	8.5	2.6
Others (<10 respondents)	6.8	20.8

Appendix 2. The response variables and explanatory variables used in cross-tabulations and logistic regression analyses

Response variable	Response variable description	Explanatory variable	Explanatory variable description
Change in the amount of mineral fertilizers used 2018–2022	The respondent's own assessment of how much and in which direction the amount of mineral fertilizer used on their farm has changed between 2018 and 2022	Age	Respondent's age in years
Intention to change the amount of mineral fertilizers used 2023–2027	The respondent's own assessment of how much and in which direction the amount of mineral fertilizer used on their farm will change between 2023 and 2027	Gender	Respondent's gender
Use of manure/recycled fertilizers	Does the respondent's farm utilize manure, processed recycled fertilizers, both, or neither?	Farm location	The location of the respondent's farm according to the Urban-rural classification
On-farm energy production from side streams	Are side streams generated on the respondent's farm utilized for energy within the farm?	Education	Respondent's highest completed degree
Off-farm utilization of side streams	Does the respondent's farm sell, exchange, or transfer side streams generated in its production for off-farm use?	Share of agricultural income in total income	What percentage of the respondent's total income comes directly from agriculture?
Investment in enhancing nutrient management	Respondent's own assessment of how much effort is being invested in improving nutrient management on their farm?	Arable area	Total area of the respondent's own and leased arable land on the farm
View on the state of agricultural policy	Respondent's assessment of how well current agricultural policy supports farms' transition to a circular economy	The main form of production	From which form of agricultural production does the respondent's enterprise receive the most sales revenue?
		Mixed farm	Does the respondent's farm involve both plant production and animal husbandry?
		Method of production	Is the respondent's farm in conventional production, organic production, or in transition to organic production?

Appendix 3. Full results of the first two logistic regression models

Response variable: Change in the amount of mineral fertilizers used 2018–2022 (Significantly decreased/Somewhat decreased/Remained the same/Somewhat increased/Significantly increased)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Significantly increased	0.040	0.041	0.100	0.089
Independent variables			OR (B)	[95% CI]	
Age			1.014 (0.014)	0.996, 1.033	
Gender (reference category: Male)					
Female			0.944 (-0.058)	0.521, 1.710	
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas			0.061 (-2.803)*	0.006, 0.618	
Rural areas close to urban areas			0.012 (-4.413)*	0.000, 1.749	
Peri-urban area			0.100 (-2.298)	0.005, 1.879	
Outer urban area			0.082 (-2.503)	0.008, 0.853	
Inner urban area			0.060 (-2.813)	0.006, 0.609	
Education (reference category: Primary school)					
Vocational school			1.021 (0.021)	0.586, 1.779	
Upper secondary school			0.462 (-0.771)	0.208, 1.028	
Higher education degree (applied sciences)			0.660 (-0.416)	0.360, 1.207	
Higher education degree (university)			1.219 (0.198)	0.505, 2.939	
% of agricultural income in total income (reference category: 0–25)					
25–50			0.736 (-0.307)	0.412, 1.315	
50–75			0.658 (-0.419)	0.360, 1.200	
75–100			1.327 (-0.307)	0.697, 2.526	
Arable area			0.998 (-0.002)	0.995, 1.000	
The main form of production (reference category: Cereal and oilseed farming)					
Horticulture			0.758 (-0.277)	0.190, 3.025	
Other plant production			1.389 (0.329)	0.365, 5.289	
Cattle farming			0.632 (-0.459)	0.194, 2.064	
Pig and poultry farming			0.697 (-0.360)	0.180, 2.701	
Other livestock production			0.617 (-0.483)	0.209, 1.825	
Mixed farm (reference category: No)					
Yes			0.874 (-0.135)	0.412, 1.854	
Method of production (reference category: Conventional farming)					
Organic farming			0.218 (-1.524)	0.043, 1.092	
Combination of conventional and organic farming			0.286 (-1.252)	0.062, 1.328	

Response variable: Intention to change the amount of mineral fertilizers used 2023–2027 (Significantly decrease/Somewhat decrease/Keep the same/Somewhat increase/Significantly increase)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Significantly increase	0.072	0.039	0.093	0.083
Independent variables			OR (B)	[95% CI]	
Age			1.000 (0.000)	0.982, 1.018	
Gender (reference category: Male)					
Female			0.676 (-0.391)	0.374, 1.224	
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas			15.271 (2.726)**	1.976, 118.002	
Rural areas close to urban areas			0.988 (-0.012)	0.623, 1.566	
Peri-urban area			1.083 (0.079)	0.625, 1.876	
Outer urban area			1.479 (0.391)	0.205, 10.644	
Inner urban area			0.237 (-1.440)	0.003, 18.644	
Education (reference category: Primary school)					
Vocational school			0.443 (-0.815)	0.194, 1.008	
Upper secondary school			0.633 (-0.458)	0.240, 1.665	
Higher education degree (applied sciences)			0.548 (-0.602)	0.242, 1.241	
Higher education degree (university)			0.445 (-0.810)	0.183, 1.084	
% of agricultural income in total income (reference category: 0-25)					
25–50			1.138 (-0.129)	0.497, 1.557	
50–75			0.836 (-0.179)	0.427, 1.637	
75–100			0.773 (-0.258)	0.432, 1.381	
Arable area			0.999 (-0.001)	0.997, 1.002	
The main form of production (reference category: Cereal and oilseed farming)					
Horticulture			1.242 (0.217)	0.485, 3.180	
Other plant production			0.848 (-0.165)	0.470, 1.530	
Cattle farming			0.366 (-1.005)	0.134, 0.998	
Pig and poultry farming			0.984 (-0.016)	0.361, 2.687	
Other livestock production			0.280 (-1.274)*	0.088, 0.894	
Mixed farm (reference category: No)					
Yes			0.792 (-0.233)	0.368, 1.706	
Method of production (reference category: Conventional farming)					
Organic farming			0.872 (-0.137)	0.476, 1.599	
Combination of conventional and organic farming			6.922 (1.935)**	1.422, 33.706	

R2 = R-Squared, OR = Odds ratio, B = regression coefficient, CI = Confidence interval for odds ratio. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Appendix 4. Full results of the third logistic regression model

Response variable: Use of manure/recycled fertilizers (Yes, both/Manure/Recycled fertilizers/Neither)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Multinomial	Neither	<0.001	0.275	0.508	0.450

Independent variables	Manure		Recycled fertilizers		Yes, both	
	OR (B)	[95% CI]	OR (B)	[95% CI]	OR (B)	[95% CI]
Age	0.953 (-0.048)***	0.929, 0.979	0.980 (-0.020)	0.935, 1.027	0.984 (-0.016)	0.947, 1.022
Gender (reference category: Male)						
Female	0.654 (-0.424)	0.250, 1.714	0.250 (-1.387)	0.025, 2.474	0.384 (-0.957)	0.085, 1.730
Farm location (reference category: Rural heartland areas)						
Sparsely populated rural areas	4.168 (1.427)	0.347, 50.031	0.519 (-14.095)	0.000, #	0.468 (-14.103)	0.179, 1.222
Rural areas close to urban areas	1.000 (0.000)	0.518, 1.928	7.561x10^{-7} (-0.657)	0.164, 1.644	7.503x10^{-7} (-0.760)	0.000, #
Peri-urban area	0.544 (-0.609)	0.241, 1.228	0.107 (-2.232)*	0.012, 0.947	0.124 (-2.084)*	0.024, 0.632
Outer urban area	2.356 (0.857)	0.065, 86.042	1.504x10^{-8} (-13.407)	0.000, #	22.192 (3.100)	0.784, 627.971
Inner urban area	6.912x10^{-8} (-16.487)	0.000, #	1.213x10^{-8} (-18.227)	1.213x10^{-8}, 1.213x10^{-8}	1.169x10^{-8} (-18.264)	0.000, #
Education (reference category: Primary school)						
Vocational school	3.973 (1.380)	0.749, 21.067	1.201 (0.183)	0.336, 47.061	3.162 (1.151)	0.298, 33.522
Upper secondary school	4.461 (1.495)	0.708, 28.107	1.073x10^{-6} (-13.745)	0.276, 33.752	1.332 (0.287)	0.087, 20.516
Higher education degree (applied sciences)	7.230 (1.978)*	1.381, 37.855	3.055 (1.117)	0.000, #	5.185 (1.646)	0.491, 54.714
Higher education degree (university)	2.647 (0.973)	0.456, 15.368	3.974 (1.380)	0.100, 14.367	6.049 (1.800)	0.544, 67.245
% of agricultural income in total income (reference category: 0-25)						
25–50	1.017 (0.017)	0.458, 2.259	2.376 (0.865)	0.517, 10.917	4.349 (1.470)*	1.213, 15.587
50–75	1.756 (0.563)	0.687, 4.488	3.389 (1.220)	0.664, 17.307	3.928 (1.368)	0.951, 16.228
75–100	0.831 (-0.185)	0.341, 2.023	0.995 (-0.005)	0.210, 4.723	1.334 (0.288)	0.312, 5.704
Arable area	1.002 (0.002)	0.998, 1.006	1.000 (0.000)	0.991, 1.010	1.005 (0.004)	1.000, 1.009
The main form of production (reference category: Cereal and oilseed cultivation)						
Horticulture	1.842 (0.611)	0.512, 6.628	0.826 (-0.191)	0.079, 8.649	1.128 (0.120)	0.195, 6.513
Other plant production	1.640 (0.494)	0.735, 3.655	0.988 (-0.012)	0.256, 3.817	0.691 (-0.369)	0.209, 2.281
Cattle farming	24.867 (3.214)**	2.842, 217.579	1.712x10^{-6} (-13.278)	0.000, #	10.880 (2.387)*	1.055, 112.256
Pig and poultry farming	17.718 (2.875)*	1.803, 174.105	1.064x10^{-5} (-11.451)	0.000, #	4.098 (1.410)	0.285, 59.006
Other livestock production	40.936 (3.712)**	4.190, 399.903	7.812x10^{-6} (-11.760)	0.000, #	12.153 (2.498)	0.454, 325.432
Mixed farm (reference category: No)						
Yes	10.245 (2.327)*	2.769, 37.905	3.637x10^{-6} (-12.524)	0.000, #	4.705 (1.549)	0.868, 25.494
Method of production (reference category: Conventional farming)						
Organic farming	3.177 (1.156)*	1.281, 7.878	7.376 (1.998)**	2.002, 27.172	8.105 (2.092)***	2.591, 25.349
Combination of conventional and organic farming	3.160 (1.151)	0.204, 48.908	8.468 (2.136)	0.346, 206.947	14.333 (2.663)	0.825, 249.101

R2 = R-Squared, OR = Odds ratio, B = Regression coefficient, CI = Confidence interval for coefficient, # = number is too large to display. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Appendix 5. Full results of the fourth and fifth logistic regression model

Response variable: On-farm energy production from side streams (Yes/No)						Response variable: Off-farm utilization of side streams (Yes/No)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2	Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Binary	No	0.425	N/A	0.260	0.059	Binary	No	0.123	N/A	0.106	0.077

Independent variables	OR (B)	[95% CI]	Independent variables	OR (B)	[95% CI]
Age	0.972 (-0.028)	0.913, 1.036	Age	0.992 (-0.008)	0.972, 1.012
Gender (reference category: Male)			Gender (reference category: Male)		
Female	0.448 (-0.802)	0.041, 4.864	Female	0.911 (-0.094)	0.456, 1.820
Farm location (reference category: Rural heartland areas)			Farm location (reference category: Rural heartland areas)		
Sparsely populated rural areas	0.000 (-17.972)	0.000, #	Sparsely populated rural areas	9.957 (-0.044)	0.124, 7.387
Rural areas close to urban areas	2.157 (0.769)	0.540, 8.611	Rural areas close to urban areas	0.713 (-0.338)	0.420, 1.210
Peri-urban area	0.000 (-18.040)	0.000, #	Peri-urban area	0.601 (-0.509)	0.313,1.157
Outer urban area	0.000 (-18.154)	0.000, #	Outer urban area	1.698 (0.530)	0.203, 14.221
Inner urban area	0.000 (-18.325)	0.000, #	Inner urban area	0.000 (-20.550)	0.000, #
Education (reference category: Primary school)			Education (reference category: Primary school)		
Vocational school	0.170 (-1.770)	0.008, 3.568	Vocational school	1.195 (0.178)	0.436, 3.277
Upper secondary school	4.239 (1.444)	0.319, 56.320	Upper secondary school	1.945 (0.665)	0.616, 6.135
Higher education degree (applied sciences)	0.636 (-0.452)	0.054, 7.519	Higher education degree (applied sciences)	1.890 (0.637)	0.697, 5.128
Higher education degree (university)	0.354 (-1.038)	0.017, 7.358	Higher education degree (university)	0.980 (-0.020)	0.330, 2.912
% of agricultural income in total income (reference category: 0-25)			% of agricultural income in total income (reference category: 0-25)		
25–50	0.312 (-1.165)	0.025, 3.855	25–50	1.487 (0.397)	0.766, 2.886
50–75	1.453 (0.374)	0.216, 9.757	50–75	1.599 (0.470)	0.751, 3.407
75–100	0.687 (-0.375)	0.077, 6.123	75–100	1.460 (0.378)	0.749, 2.843
Arable area	1.002 (0.002)	0.993, 1.011	Arable area	1.000 (0.000)	0.998, 1.003
The main form of production (reference category: Cereal and oilseed farming)			The main form of production (reference category: Cereal and oilseed farming)		
Horticulture	3.823 (1.341)	0.298, 48.966	Horticulture	0.999 (-0.001)	0.341, 2.925
Other plant production	0.340 (-1.080)	0.029, 3.916	Other plant production	2.080 (0.732)*	1.089, 3.975
Cattle farming	1.897 (0.640)	0.092, 39.090	Cattle farming	0.880 (-0.128)	0.305, 2.539
Pig and poultry farming	0.000 (-17.773)	0.000, #	Pig and poultry farming	2.225 (0.800)	0.743, 6.665
Other livestock production	2.991 (1.096)	0.231, 38.730	Other livestock production	2.704 (0.995)	0.826, 8.852
Mixed farm (reference category: No)			Mixed farm (reference category: No)		
Yes	0.340 (-1.078)	0.017, 6.994	Yes	1.019 (0.019)	0.439, 2.367
Method of production (reference category: Conventional farming)			Method of production (reference category: Conventional farming)		
Organic farming	1.441 (0.365)	0.224, 9.271	Organic farming	1.523 (0.420)	0.778, 2.980
Combination of conventional and organic farming	29.429 (3.382)*	1.224, 707.501	Combination of conventional and organic farming	1.805 (0.590)	0.332, 9.812

R2 = R-Squared, OR = Odds ratio, B = Regression coefficient, CI = Confidence interval for coefficient, # = number is too large to display. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Appendix 6. Full results of the sixth and seventh logistic regression model

Response variable: Investment in enhancing nutrient management (Very much/Quite much/Somewhat/Rather little/ Very little or none)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Very little or none	<0.001	0.048	0.133	0.125
Independent variables			OR (B)		[95% CI]
Age			1.018 (0.018)*		1.001, 1.036
Gender (reference category: Male)					
Female			1.312 (0.272)		0.738, 2.333
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas			1.336 (0.289)		0.239, 7.467
Rural areas close to urban areas			1.117 (0.111)		0.716, 1.742
Peri-urban area			1.140 (0.131)		0.669, 1.943
Outer urban area			4.194 (1.434)		0.619, 28.433
Inner urban area			6.367 (1.851)		0.156, 259.914
Education (reference category: Primary school)					
Vocational school			0.774 (-0.257)		0.349, 1.715
Upper secondary school			0.827 (-0.190)		0.323, 2.116
Higher education degree (applied sciences)			0.714 (-0.337)		0.323, 1.579
Higher education degree (university)			0.421 (-0.865)		0.178, 0.999
% of agricultural income in tot. income (reference category: 0-25)					
25–50			1.058 (0.056)		0.609, 1. 836
50–75			0.659 (-0.416)		0.345, 1.259
75–100			0.478 (-0.737)**		0.273, 0.839
Arable area			0.998 (-0.002)		0.995, 1.000
The main form of production (reference category: Cereal and oilseed farming)					
Horticulture			0.743 (-0.297)		0.300, 1.840
Other plant production			0.834 (-0.181)		0.472, 1.473
Cattle farming			0.911 (-0.093)		0.369, 2.250
Pig and poultry farming			1.581 (0.458)		0.600, 4.167
Other livestock production			1.199 (0.182)		0.423, 3.403
Mixed farm (reference category: No)					
Yes			0.680 (-0.386)		0.327, 1.413
Method of production (reference category: Conventional farming)					
Organic farming			0.822 (-0.196)		0.461, 1.467
Combination of conventional and organic farming			2.510 (0.920)		0.554, 11.362

Response variable: View on the state of agricultural policy (Very well/Quite well/Neither well nor poorly/Rather poorly/Very poorly)					
Method	Reference category	*p*-value	McFadden R^2	Nagelkerke R^2	Cox & Snell R^2
Ordinal	Very poorly	0.859	0.017	0.047	0.044
Independent variables			OR (B)	[95% CI]	
Age			1.016 (0.016)	0.998, 1.034	
Gender (reference category: Male)					
Female			0.823 (-0.195)	0.451, 1.501	
Farm location (reference category: Rural heartland areas)					
Sparsely populated rural areas			0.413 (-0.885)	0.060, 2.831	
Rural areas close to urban areas			0.799 (-0.225)	0.502, 1.271	
Peri-urban area			1.271 (0.240)	0.730, 2.213	
Outer urban area			0.561 (-0.578)	0.084, 3.741	
Inner urban area			0.299 (-1.206)	0.008, 11.711	
Education (reference category: Primary school)					
Vocational school			1.070 (0.068)	0.463, 2.478	
Upper secondary school			0.465 (-0.766)	0.174, 1.241	
Higher education degree (applied sciences)			0.812 (-0.208)	0.352, 1.877	
Higher education degree (university)			0.924 (-0.079)	0.373, 2.289	
% of agricultural income in tot. income (reference category: 0–25)					
25–50			1.067 (0.065)	0.603, 1.887	
50–75			1.362 (0.309)	0.691, 2.688	
75–100			0.908 (-0.096)	0.507, 1.629	
Arable area			1.000 (0.000)	0.997, 1.002	
The main form of production (reference category: Cereal and oilseed farming)					
Horticulture			0.566 (-0.569)	0.209, 1.532	
Other plant production			1.027 (0.027)	0.566, 1.864	
Cattle farming			1.923 (0.654)	0.748, 4.948	
Pig and poultry farming			1.171 (0.158)	0.437, 3.142	
Other livestock production			0.975 (-0.025)	0.342, 2.780	
Mixed farm (reference category: No)					
Yes			0.947 (-0.054)	0.453, 1.984	
Method of production (reference category: Conventional farming)					
Organic farming			1.092 (0.088)	0.598, 1.992	
Combination of conventional and organic farming			1.022 (0.022)	0.228, 4.577	

R^2 = R-Squared, OR = Odds ratio, B = Regression coefficient, CI = Confidence interval for coefficient. *** $p< 0.001$ ** $p< 0.01$ * $p< 0.05$

Appendix 7. Original questionnaire

Barriers to the transition to a Circular Economy in agriculture in Southwest Finland

Mandatory questions are marked with a star (*)

Dear Respondent,

Our methods of producing and consuming food are experiencing unprecedented changes. We should feed our population in a way that ensures farmers earn a fair living, the environment's carrying capacity is maintained, and consumers become more integrated into the food systems.

One proposed method to manage this food revolution is the transition to a circular economy. Ideally, activities based on the circular economy model enhance the well-being of both people and the environment. This survey seeks to understand the perspectives of the agricultural entrepreneurs in Southwest Finland on transitioning to a circular economy and the challenges involved in this transition. Unless specified otherwise, please answer the questions from the perspective of your own business.

You can save your answers using the "Save and continue later" button if you need more time and return to complete the survey later. The information you provide will be used solely for this research and will be deleted once the research is complete. You may request the deletion of your data at any time by contacting us, such as by replying to this email.

Thank you for deciding to respond to the survey. Your response is vital to us and contributes significantly to our research, which aims to generate actionable insights for the sustainable development of the Finnish food system. The survey will take approximately 10–15 minutes to complete.

Antti Hynni
PhD researcher
Department of Geography and Geology
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Jukka Käyhkö
Professor
Department of Geography and Geology
University of Turku

Tuomas Kuhmonen
Research director
Finland Futures Research Centre
University of Turku

1. I have read the privacy notice of the survey (attached to the email) and I accept its terms *

Yes / No

PART 1: Respondent's background information

2. Age in years *

3. Gender *

Female / Male / Other / Prefer not to answer

4. Postal code of your farm *

5. Highest completed education *

Primary school / Vocational school / Upper secondary school / University of applied sciences / University

6. Share of income from agriculture in your total personal income (%)

Farmer *

Spouse

under 25 / 25–50 / 51–75 / over 75

7. Cultivated arable area in your farm (ha) *

Total area

of which leased

8. Main production form of your farm which generates you the most sales income *

Dairy farming / Other cattle farming / Pig farming / Poultry farming / Other animal farming / Cereal or oilseed cultivation / Specialized cultivation (potato, sugar beet, other seeds, etc.) / Horticulture / Other plant farming

9. Possible other production forms, select all that apply *

Dairy farming / Other cattle farming / Pig farming / Poultry farming / Other animal farming / Cereal or oilseed cultivation / Specialized cultivation (potato, sugar beet, other seeds, etc.) / Horticulture / Other plant farming / No other forms

10. Is there any other business activity on your farm? *

Yes, what? / No

11. Production method of your farm *

Conventional / Organic / Combination of conventional and organic

PART 2: Circular economy and agriculture

12. Questions 13–26 deal with circular economy measures in agriculture. Before answering those questions, we ask you to define the concept of circular economy in your own words. What do you think the circular economy means? *

13. Has the amount of mineral fertilizers used on your farm changed between 2018 and 2022? *

Significantly decreased / Somewhat decreased / Remained the same / Somewhat increased / Significantly increased

14. Do you intend to change the amount of mineral fertilizers used between 2023 and 2027? *

Significantly decrease / Somewhat decrease / Keep the same / Somewhat increase / Significantly increase

15. What barriers do you see to the realization of your intention?

16. Does your farm use manure or processed recycled fertilizers? *

Yes, both / Manure / Recycled fertilizers / Neither

17. What barriers do you see to the introduction/use of manure and/or recycled fertilizers?

18. Do you process side streams or residues (manure, straw, peeling waste, etc.) generated on your farm into energy, for example, biogas? *

Yes / No

19. What barriers do you see for processing energy from side streams, residues, etc.?

20. Are side streams or residues generated on your farm (manure, straw, peeling waste, etc.) used outside your farm? Select all that apply *

Energy production / Fertilizer / Fodder / Bedding / Other, what? / No

21. What obstacles do you see to the sale, exchange, or transfer of side streams, residues, etc. for off-farm utilization?

22. How much is invested in improving the nutrient management on your farm? *

Very little or none / Rather little / Somewhat / Quite much / Very much

23. Describe what means of enhancing nutrient management you use (e.g. crop rotation, winter vegetation cover of fields, gypsum treatment)

24. What barriers do you see to improving nutrient management?

25. How well do you think the prevailing agricultural policy supports the transition of agricultural enterprises to the circular economy? *

Very poorly / Rather poorly / Neither well nor poorly / Quite well / Very well / Do not know

26. How would you develop agricultural policy so that it would better support the transition to a circular economy as part of sustainable food production?

PART 3: Contact information

27. Leave your contact information here if you want to register to be interviewed. We will interview some of those who left their contact information later. Leaving contact information is not binding. Contact information is only used to communicate with the interviewees and is not combined with survey responses. We handle your contact information confidentially as stated in the privacy notice (attached to the e-mail).

First Name

Last Name

Cell phone

E-mail