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Carbon farming and nutrient management. Influential factors of Polish farmers' perception of pro-climate measures

Rolnictwo węglowe i zarządzanie składnikami pokarmowymi. Czynniki warunkujące postrzeganie przez polskich rolników działań proklimatycznych

Abstract. Carbon farming and nutrient management, a sustainable pro-environmental and pro-climate approach to enhance soil quality and mitigate carbon losses, faces implementation challenges in the European Union. To explore potentially existing barriers, a survey involved 122 Polish farmers, representing diverse systems and land-use. Utilizing structured questionnaires, in-depth interviews, and Principal Component Analysis, we assessed farmers' perceptions of six pro-environmental and pro-climate measures. The survey highlighted factors influencing farmers' willingness to adopt surveyed practices, revealing that the potential to enhance soil carbon and nitrogen stocks outweighed the impact of subsidies, bureaucracy, age, and farm size. Barriers included technical challenges and machinery limitations, notably hindering manure and slurry incorporation. Conservation tillage was considered least feasible nationally, attributed to machinery needs and a preference for conventional practices. Addressing these challenges, especially in conservation tillage, requires targeted education. Raising awareness about measures' impact on soil carbon stock emerged as a potent means to overcome identified barriers.

Key words: carbon farming, individual in-depth interviews (IDI), structured questionnaire, sustainable agriculture

INTRODUCTION

Environmental and climatic threats related to agricultural production have become pivotal factors in determining the direction of agricultural development and agroecosys-

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tem protection in the European Union (EU) [Walczak et al. 2022]. This has been reflected in the subsequent reforms of the EU's agricultural policy. The recent stage, initiated by the European Green Deal strategy, mandates EU farmers to reduce their carbon footprints and adopt more sustainable practices [European Commission 2021, Faichuk et al. 2022, Wrzaszcz 2023].

These issues played a significant role in the development of the national (Polish) Strategic Plan for the Common Agricultural Policy for 2023–2027 [Dz.U.2023.412], which introduced eco-schemes [Latacz-Lohmann et al. 2022, Runge et al. 2022, Jongeneel and Gonzalez-Martinez 2023). The most extensive and frequently used eco-scheme by Polish farmers is "carbon farming and nutrient management", encompassing both CO_2 sequestration and protecting the soil by increasing its ability to retain nutrients [Styburski et al. 2023]. By engaging farmers in the pursuit of additional environmental and climate objectives, carbon farming and low-emission practices aim to contribute to environmental protection and sustainable agriculture, thereby enhancing agricultural efficiency while mitigating anthropogenic pressures arising from agricultural activities. Consistent with the scenarios evaluated by the Intergovernmental Panel on Climate Change (IPCC), the European Commission, as articulated in the Circular Economy Action Plan 3 released in March 2020, has declared its intention to formulate a robust certification framework [European Commission 2020]. This framework aims to facilitate the certification of carbon removals, serving as a strategic instrument to stimulate the adoption of carbon removal practices and enhance the circularity of carbon cycles [European Commission 2022].

The objectives of the selected carbon farming measures addressed in this study encompass various key pro-environmental and pro-climate actions, including biodiversity protection, soil quality enhancement, reduction of ammonia and greenhouse gases (GHGs) emissions, and water protection. While these actions in Poland are voluntary for farmers, their implementation can yield environmental, economic, and social benefits [Jayaraman et al. 2021, Petsakos et al. 2023]. Through the support of environmentally friendly practices, the European Union aims to foster sustainable agricultural development, achieve environmental protection, and meet climate change objectives [Cuadros-Casanova et al. 2023]. However, barriers to their effective implementation within the EU-27 often vary and the factors affecting its employment often remain obscured [Heyl et al. 2021, Runge et al. 2022, Van Hoof 2023].

Despite extensive research on specific sustainable agri-practices under carbon farming has been widely demonstrating significant benefits such as a mitigation of the soil organic matter (SOM) decomposition, an increase in soil organic carbon (SOC) stock [Han et al. 2018, Wang et al. 2020], reduced volatile carbon and nitrogen losses [Velthof et al. 2020 , Bumbiere et al. 2022], improved soil health [Khangura et al. 2023], and protection water resources [Poláková et al. 2023], there is a knowledge gap regarding potential barriers to their adoption from the farmers' perspective [Sharma et al. 2021]. As far as the authors are concerned, up to date there was a lack of socio-agricultural survey studies conducted in Poland. It is alarming specifically addressing the lower-than-expected implementation levels of carbon farming measures recommended as part of the recently announced subsidized Polish eco-scheme: Carbon Farming and Nutrient Management [Eco-Scheme: Carbon Farming and Nutrient Management].

Therefore, to address uncertainties regarding contributing factors and potential barriers in the farmers' perspective on carbon farming and low-emission practices, aligning with the Farm to Fork Strategy [Billen et al. 2024] and the European Green Deal [Faichuk

et al. 2022, Sikora 2021] we conducted a comprehensive survey study with 122 Polish farmers. Specifically, this study investigated farmers' viewpoints and knowledge of organic matter management measures facilitated by soil incorporation of manures, slurry and crop residues, conservation tillage, diversified crop structure, and intercropping.

The primary research question addressed in this study was: How do farmers in Poland perceive the six potent low-emission sustainable farming practices endorsed by CAP and carbon farming-related strategies? By exploring this question, the study aimed to contribute valuable insights to inform Polish agricultural policies. The study addressed the following key issues:

– what is the level of farmers' willingness to implement the practices proposed under the surveyed carbon farming measures in Polish agriculture?

– what factors influence farmers' point of view on carbon farming and low-emission agricultural measures in their farming households?

– how does farmers' education align with their perception of practices endorsed by the surveyed pro-environmental and pro-climate practices?

– is there any deriving effect between farmers' age, education, farm size, farming system and implementation of diversified crop structure, conservation tillage, cover crops and intercropping, manure and slurry soil incorporation, and straw return?

– what are the potential barriers to the implementation of surveyed pro-environmental and pro-climate practices in Polish agriculture?

To address these questions comprehensively, a two-fold survey approach was employed, consisting of the standardized questionnaire [Cheung 2020] and individual in-depth interviews – IDI [Eppich and Gormley 2019] executed on a group of 122 Polish farmers encompassing a diverse range of age, agricultural education levels, farming systems, and land-use area.

MATERIALS AND METHODS

Data collection

122 Polish farmers were randomly chosen across Poland encompassing a sample size vast enough to maintain a confidence interval not lower than 95% for the Polish farmers' general population. All regions (voivodeships) were analyzed collectively to ensure a socio-demographic perspective as representative of the entire Polish population as possible. Therefore, no specific regionalization was implemented during the survey process. Additionally, no sociodemographic targeting or other specific criteria were applied in selecting respondents, in order to capture the wide variability within the representative sample group.

The combination of structured questionnaires and IDI were utilized in order to research the farmers' perspective in carbon farming and low-emission measures. A structured questionnaire was prepared to endorse both demographic and factual inquiries structured in the combination of close-ended, open-ended, and rating scale questions regarding the information as follows:

– farmer's age – close-ended question;

– farmer's education – close-ended question;

– farm size – close-ended question;

– farm type – close-ended question;

– farm production focus – open-ended;

– farmer's viewpoint and the willingness to employ the diversified crop structure, conservation tillage, crops and intercropping, manure soil incorporation within 12 h after application, slurry application without surface spreading, and straw return – Likert scale questions;

– farmer's subjective assessment of: soil C stock increase; soil N stock increase; water pollution mitigation; air pollution mitigation; bureaucracy, formalities, controls; financial subsidies importance in employing pro-environmental and pro-climate measures – 10 points rating scale questions.

Utilizing individual in-depth interviews, each respondent was additionally asked six separate questions regarding different pro-environmental and pro-climate measures promoted by the surveyed pro-environmental and pro-climate measures outlined as follows:

Will you utilize, or are you already utilizing:

– diversified crop structure,

– conservation tillage (including no-till cultivation),

– cover crops and intercropping,

– manure soil incorporation within 12 hours after application,

– slurry application using techniques other than surface spreading,

– straw return (soil incorporation),

– in alignment with carbon farming and low-emission agricultural practices?

Subsequently, depending on whether the farmers answered yes or no, they were asked to explain why or why not they are utilizing or would be willing or not willing to employ certain measures.

Data utilization and analysis

Standard grouping approaches were utilized to analyze the responses of surveyed farmers. General farming households were classified based on the Eurostat Farm Typology Glossary [EUROSTAT 2021]. Principal production type groups were established based on the main agricultural products. Groups of farmers' age, farmer's education and farm size were established based on the related answers. Each group had their shares calculated as a percentage of all respondents (n = 122).

To explore deriving factors between farmers' age, education, farm size and the factors affecting their willingness to employ surveyed pro-environmental and pro-climate measures, Principal component analysis (PCA) [Abdi and Williams 2010] was performed using the R environment with FactomineR package [Lê et al. 2008].

To achieve variables comparability requitement [Abdi and Williams 2010], PCA was computed after standardizing the data with the formula:

$$x_{sc} = \frac{x_i - mean\ (x)}{sd(x)},$$

where x_{sc} is the scaled variable, x_i is the individual variable, *mean* (x) is the mean of x values, and $sd(x)$ is the standard deviation of x values. As for the descriptive responses, each answer got assigned an individual value based on the standard scaling system in e.g. education level from primary, secondary, and higher education got changed into values 1, 2, and 3 respectively, where the higher number corresponded to higher scale value. Likert answers were scaled in the same manner attributing more convincing answers to the higher

numbers. Surveyed factors affecting farmers' willingness to employ certain measures were scaled in alignment to the 10-point rating scale in which respondents gave their answers.

RESULTS

Surveyed farming households' characteristic

The survey conducted with 122 Polish farmers revealed a substantial diversity in the farming systems employed in Poland (Tab. 1). Utilizing the classification proposed by the Eurostat Farm Typology Glossary, over 40% of the analyzed farming households can be classified as crop-specialist holdings, while livestock-specialist holdings and mixed-farming holdings each constituted approximately 30%. The majority of the surveyed specialist

Table 1. Distribution of surveyed farming holdings key characteristics (n = 122)

Characteristics	Category	Percentage (%)	n
General type[1]	livestock-specialist holding	27.84	34
	crop-specialist holding	42.62	52
	mixed-farming holding	29.51	36
Principal production type	pig	4.92	6
	dairy cattle	7.38	9
	beef cattle	9.02	11
	poultry	2.46	3
	sheep and goats	0.82	1
	horses	3.28	4
	horticulture	10.66	13
	cereals and oilseeds	16.39	20
	root crops	7.38	9
	orchards	8.20	10
	crops and livestock combined	29.51	36
Farm size	<10 ha	18.85	23
	10–25 ha	32.79	40
	26–50 ha	23.77	29
	51–100 ha	18.03	22
	>100 ha	6.56	8
Farmer's age	<20 y/o	9.02	11
	25–35 y/o	40.98	50
	36–50 y/o	32.79	40
	51/65 y/o	14.75	18
	>65 y/o	2.46	3
Farmer's education	primary education	46.72	57
	secondary education	27.05	33
	higher education	26.23	32

[1] Eurostat Farm Typology Glossary [EUROSTAT 2021]

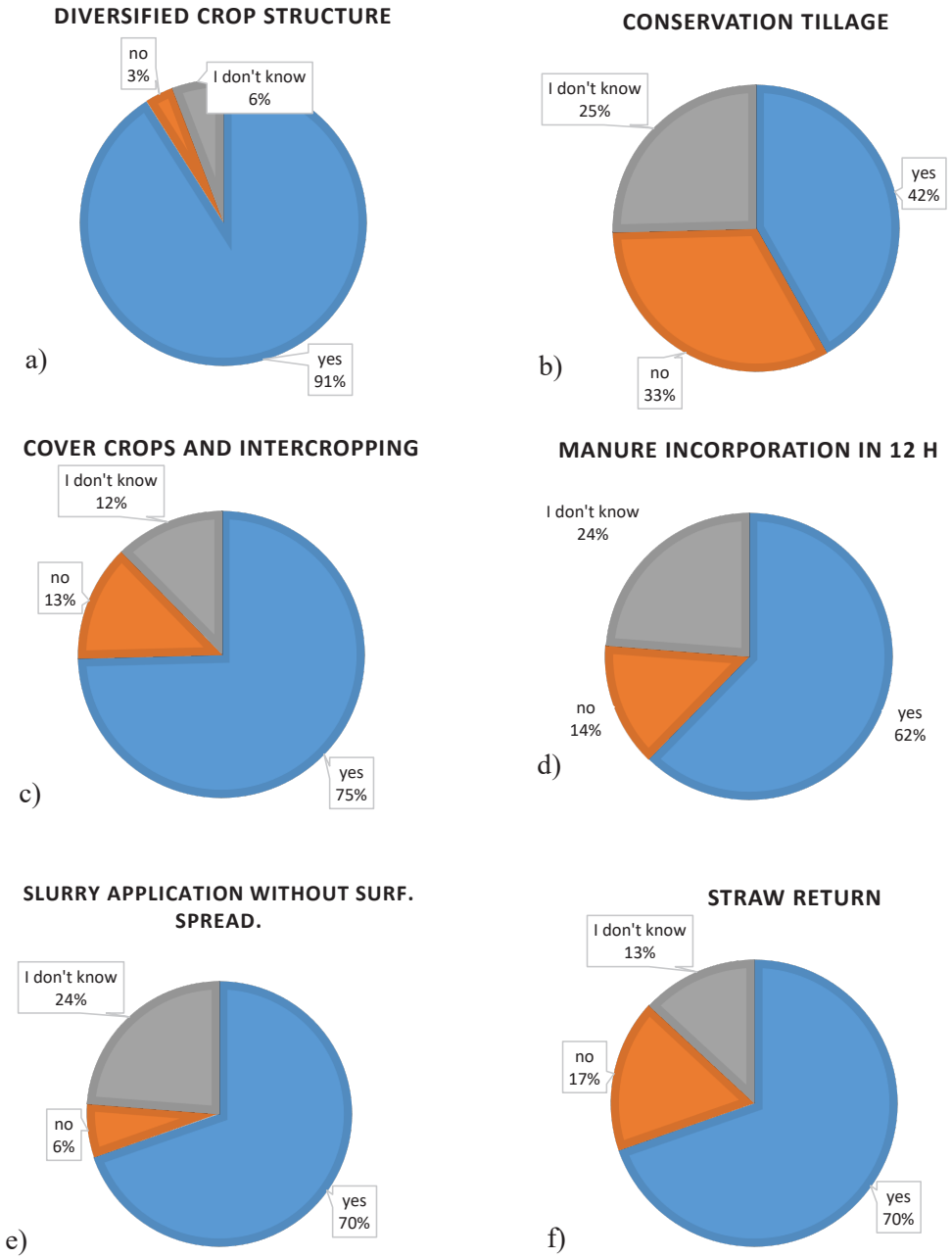

Fig. 1. Pie charts of the distribution of surveyed farmers' willingness to utilize: a) diversified crop structure; b) conservation tillage; c) cover crops and intercropping; d) manure soil incorporation within 12 h after application; e) slurry application employing techniques other than surface spreading; f) straw return

farming holdings indicated a focus on cereal and oilseed production (16.39% of respondents), with horticulture as the second most prevalent focus (10.66% of respondents). Regarding livestock specialist holdings, beef production was found to be the most prevalent (9.02% of respondents), followed by cattle dairy production (7.38% of respondents).

The farm size distribution within the tested group revealed that the majority of respondents engage in farming on land areas ranging from 10 to 25 ha (32.79% of respondents), making this the most prevalent category. The second most common farm size falls within the range of 26 ha to 50 ha, accounting for 23.77% of respondents. Farms smaller than 10 hectares constituted the third most prevalent group (18.85% of respondents), while those exceeding 100 hectares were the least common (6.56% of respondents).

The majority of respondents fell within the age range of 25–35 years old, constituting 40.98% of the total respondents. The second-largest age group comprised farmers between 36-50 years old, accounting for 32.79% of respondents, while the smallest group consisted of farmers over 65 years old, making up only 2.46%. Regarding education, nearly half of the surveyed farmers (46.72% of respondents) reported having obtained only primary education. Secondary education was attained by 27.05% of respondents, while 26.23% indicated having acquired higher education.

Farmers willingness to employ surveyed carbon farming and low-emission measures

Subsequent analysis of IDI responses revealed that the motivations behind farmers' interest in employing the surveyed carbon farming measures vary significantly. For diversified crop structure, over half of the respondents mentioned the potential to increase SOC content in the longer perspective as the main reason (50.82% of respondents). The second most common response emphasized the pivotal role of financial subsidies (22.95% of respondents). In contrast, less than 20% of respondents indicated biodiversity reasons as the primary motivation for utilizing this measure. Conversely, the barriers identified in the implementation of diversified crop measures include a uniform production profile and the land use area, which pose technical difficulties. Additionally, only less than 2% of the respondents mentioned that they do not perceive any benefits from employing these measures.

Conservation tillage emerged as the most contentious measure in the perception of surveyed farmers. The predominant arguments in favor of this measure included its positive impact on soil microbial activity (19.67% of respondents) and its effectiveness in mitigating SOM decomposition (14.75% of respondents). However, positive responses were less frequent than arguments against the measure, or the reasons why farmers might hesitate to adopt it. The most commonly mentioned argument against conservation tillage was farmers' attachment to traditional, standard cultivation practices involving regular tillage (24.59% of respondents). The second most frequently mentioned barrier was the lack of machinery for conservation tillage (21.31% of respondents), followed by the lack of perceived visible economic and environmental advantages (12.3% of respondents).

For the cover crops and intercropping measures, a substantial number of respondents highlighted the increase in SOC as the primary factor convincing them to adopt these measures (47.54% of respondents). However, respondents frequently mentioned drawbacks, with increased production costs being a common concern. Additionally, more than 25% of respondents collectively expressed reservations due to the perceived lack of economic and environmental benefits associated with these measures.

In the context of incorporating manures within 12 h from application, the aspects of reducing ammonia and GHG emissions played a pivotal role. Over 50% of respondents reported a cumulative acknowledgment of these benefits, with a stronger emphasis on soil sorption of ammoniacal nitrogen (38.52% of respondents). The primary argument against the adoption of this measure centered around farm-size issues and the inability to incorporate manure in a timely manner (18.85% of respondents). Approximately 7.4% of respondents mentioned that they do not apply manure or other natural fertilizers due to the absence of livestock production and the financial constraints prohibiting purchase.

In parallel with the timely incorporation of manure, the utilization of techniques other than surface spreading for slurry application is primarily justified by its positive impact on reducing ammonia losses. The key emphasis is on maximizing ammoniacal nitrogen sorption in the soil (38.52% of respondents) and mitigating gaseous losses (21.32% of respondents). The most frequently mentioned obstacle in implementing this measure is the absence of the requisite equipment for soil injection or other applicable techniques (13.11% of respondents).

Approximately 40% of respondents expressed their willingness to implement complete straw return as a means to enhance SOC stock, which was identified as the primary rationale for employing this measure. The second most prevalent convincing argument was the anticipated increase in soil microbial activity, as indicated by 23.77% of respondents. In contrast, 18.85% of surveyed farmers mentioned the inability to incorporate straw due to its necessity in livestock husbandry. Additionally, 4.92% of respondents pointed out that the utilization of straw in energy production hindered them from adopting straw return. Furthermore, 6.58% of respondents did not perceive any discernible economic or environmental benefits resulting from complete straw soil incorporation. Detailed IDI responses both in favor of and against specific measures are outlined in Table 2.

Deriving effects between the Polish farming households' characteristics and farmers' willingness to employ surveyed pro-environmental and pro-climate measures

Principal Component Analysis revealed substantial interrelations among farmer's age, education, farm size, and the factors influencing their willingness to adopt specific measures (Fig. 2). Farmer's education, coupled with the inclination to enhance soil N and C stocks, as well as to mitigate water and atmosphere pollution, were most prominently represented in PC1 (eigenvalue = 50.8%) and PC2 (eigenvalue = 28.9%). This underscores that these factors exerted the most substantial influence on the variability of farmers' responses.

The education level and farm size exhibited a strong positive correlation with farmers' willingness to employ conservation tillage and a diversified crop structure. Notably, both of these measures contradicted the farmer's age, which displayed a negative effect. Farmer's age demonstrated a positive correlation with their willingness to implement complete straw return. No discernible effects of farmer's age, education, or farm size were identified concerning the impacts of financial subsidies. However, bureaucracy, and to a lesser extent, atmosphere protection, tended to influence the decisions of older farmers more strongly than those of younger farmers.

Table 2. In-depth interview (IDI) answers obtained from surveyed farmers (n = 122)

Measure	IDI answers after categorization	Percentage (%)	n
Diversified crop structure	Yes, to increase biodiversity.	17.21	21
	Yes, to increase SOC stock in a longer perspective.	50.82	62
	Yes, mainly to receive additional subsidies.	22.95	28
	No, due to the uniform production profile.	3.28	4
	No, due to the size of the area and technical difficulties.	4.10	5
	No, due to the lack of visible economic and environmental benefits.	1.64	2
Conservation tillage	Yes, to reduce the decomposition of soil organic matter.	14.75	18
	Yes, to increase the soil microbiological activity.	19.67	24
	Yes, mainly to receive additional subsidies.	7.38	9
	No, due to the lack of appropriate machines for conservation tillage.	21.31	26
	No, due to being attached to the traditional form of soil cultivation.	24.59	30
	No, due to the lack of visible economic and environmental benefits.	12.30	15
Cover crops and intercropping	Yes, to reduce the risk of nitrates leaching into groundwater.	11.48	14
	Yes, to increase the soil carbon stock.	47.54	58
	Yes, mainly to receive additional subsidies.	15.57	19
	No, due to the increase in cultivation costs.	18.03	22
	No, due to the lack of visible economic and environmental benefits.	7.38	9
Manure soil incorporation within 12 h after application	Yes, to reduce ammonia and greenhouse gas emissions.	14.75	18
	Yes, to maximize the sorption of ammoniacal nitrogen in the soil.	38.52	47
	Yes, mainly to receive additional subsidies.	9.02	11
	No, due to the too-vast area and technical difficulties.	18.85	23
	No, due to the lack of visible economic and environmental benefits.	11.48	14
	No, due to the inability to produce/obtain manure.	7.38	9
Slurry application without surface spreading	Yes, to reduce ammonia and greenhouse gas emissions.	21.31	26
	Yes, to maximize the sorption of ammonium nitrogen in the soil.	36.07	44
	Yes, mainly to receive additional subsidies.	12.30	15
	No, due to the too-vast area and technical difficulties.	3.28	4
	No, due to the lack of appropriate machines.	13.11	16
	No, due to the lack of visible economic and environmental benefits.	6.56	8
	No, due to the inability to produce/obtain slurry.	7.38	9
Straw return	Yes, to increase the soil carbon stock.	39.34	48
	Yes, to increase the soil microbiological activity.	23.77	29
	Yes, mainly to receive additional subsidies.	6.56	8
	No, due to the need to use straw in litter farming.	18.85	23
	No, due to the use of crop residues for energy production purposes.	4.92	6
	No, due to the lack of visible economic and environmental benefits.	6.56	8

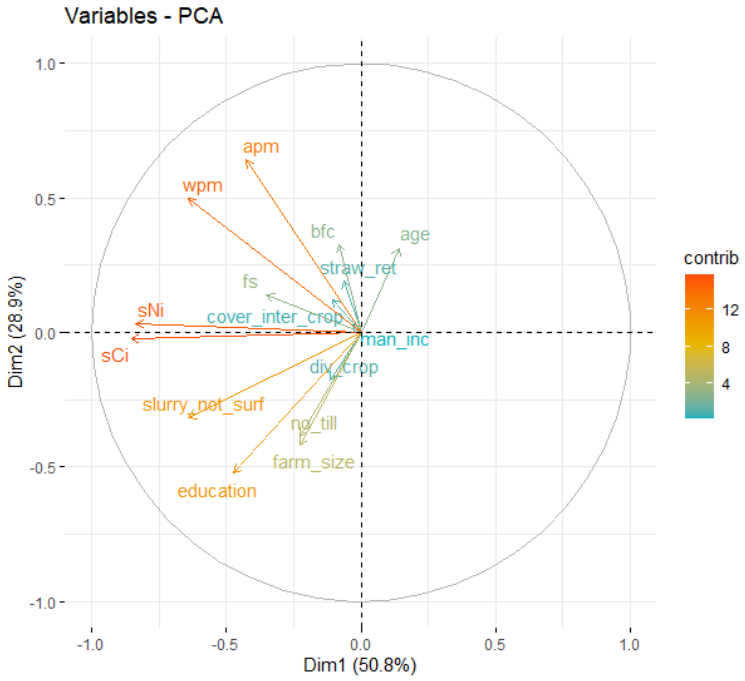

Fig. 2. Principal component analysis correlation circle. Each vector's length shows the quality of the variables on the factor map. The angle between the vectors indicates the correlation between the given variables: close to 0 degrees for strong positive correlation, close to 180 degrees for strong negative correlation, and close to 90 degrees for weak or near-zero correlation

Abbreviations: sCi – soil C stock increase; sNi – soil N stock increase; wpm – water pollution mitigation; apm – air pollution mitigation; bfc – bureaucracy, formalities, controls; fs – financial subsidies; div_crop – diversified crop structure; no_till – conservation tillage; cover_inter_crop - cover crops and intercropping; man_inc – manure soil incorporation within 12 h after application; slurry_not_surf – slurry application without surface spreading; straw_ret – straw return

The factor importance analysis revealed that aspects related to bureaucracy, formalities, and administrative controls played the least influential role in shaping farmers' willingness to implement the surveyed pro-environmental and pro-climate measures. Notably, the potential of certain measures to increase carbon and nitrogen stocks was identified as having the most substantial impact on farmers' perceptions. Although financial subsidies were indicated by a relatively low number of respondents as an essential factor (Tab. 2), they were found to have a considerable influence on farmers' willingness to utilize the measures as promoted with direct payments. This influence was stronger in decision-making than considerations related to water and air pollution mitigation, as depicted in Figure 3.

DISCUSSION

The results of the conducted survey indicate that the utilization of the analyzed carbon farming measures and low-emission is generally well-regarded in Poland. Of the six

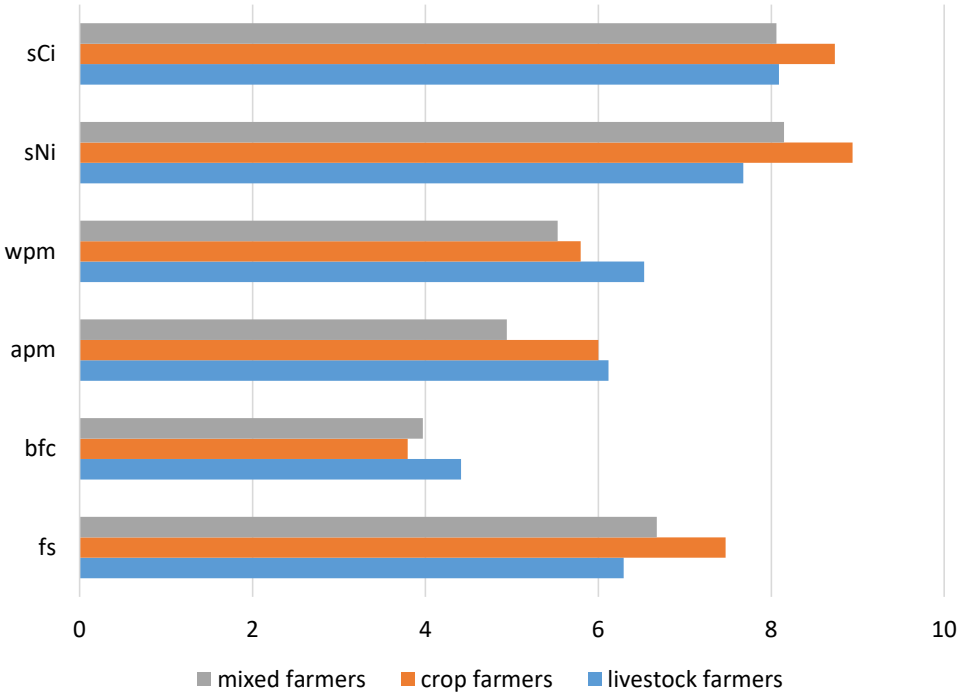

Fig. 3. Importance of the factors affecting the farmers' willingness to employ surveyed pro-environmental and pro-climate measures. The higher is depicted value the stronger the impact of the given factor

Abbreviations: sCi – soil C stock increase; sNi – soil N stock increase; wpm – water pollution mitigation; apm – air pollution mitigation; bfc – bureaucracy, formalities, controls; fs – financial subsidies

surveyed measures, five received positive assessments from over 60% of the respondents, demonstrating their willingness to adopt these measures (Fig. 1, Tab. 2). Notably, conservation tillage cultivation was negatively or hesitantly judged by over 50% of the respondents, suggesting that its implementation may be more challenging compared to the other measures. Interestingly, the analysis of IDI responses revealed that the primary reason for not adopting conservation tillage was the farmers' preference for traditional cultivation methods (Tab. 2). This preference persisted despite their awareness of the potential carbon offsets associated with conservation tillage [Manley et al. 2005]. Additionally, less than 35% of surveyed farmers expressed a willingness to adopt conservation tillage for reasons other than financial subsidies, suggesting a need for further efforts to shift Polish farmers' perceptions of this practice. A similar study conducted among farmers in Tennessee, United States [Lo et al. 2021] indicated a preference for adopting conservation tillage over planting cover crops, contrasting with the perceptions of Polish farmers (Fig. 1). This contrast may suggest that Eastern Europe, including Poland, is still lagging in the adoption of conservation farming practices [Kertész and Madarász 2014]. Notably, the positive correlation between the education level of Polish farmers and their willingness to adopt conservation tillage (Fig. 2) implies that additional education could enhance farmers' positive perceptions of this measure.

Cover crops and intercropping have been identified as the second most frequently chosen pro-environmental and pro-climate measures in Poland, following diversified crop structure (Fig. 1). Farmers expressing a willingness to adopt these two measures have highlighted carbon stock increase as the most significant reason influencing their decision-making (Tab. 2). This suggests that Polish farmers may possess knowledge of the well-documented interactive effects of cover crops, intercropping, and diversified crop structure on SOM turnover, as extensively researched [Pagano et al. 2017, Schaefer et al. 2020, Firth et al. 2022, Ilakiya et al. 2023]. Notably, the carbon stock aspects emerged as among the most influential factors shaping farmers' perspectives in general (Figs 2 and 3). This finding supports the idea that emphasizing carbon stock considerations in farmers' education, particularly in the context of conservation farming [Jayaraman et al. 2022] could further enhance the willingness of Polish farmers to adopt no-till or minimal tillage cultivation techniques.

Manure incorporation within 12 h of application and slurry application using techniques other than surface spreading are two carbon farming measures where Poland lags behind many EU countries [Emmerling et al. 2020]. For instance, all farmers in the Netherlands are obligated to adopt these measures according to national regulations [Leenstra et al. 2019]. The conducted survey has proven that Polish farmers are aware of their positive impact on ammoniacal nitrogen stabilization in the soil (Tab. 2) and having a considerable impact on reducing volatile nitrogen losses [Velthof et al. 2003, Velthof and Mosquera 2011, Hou et al. 2015]. Only approx. 11% of respondents indicated that they do not see any visible and economic and environmental benefits for manure immediate incorporation, and less than 7% expressed similar sentiments regarding slurry injection or other relevant techniques. This suggests a crucial need for educating farmers on the potential advantages of reducing ammonia losses. Additionally, approximately 13% of respondents pointed to barriers in implementation, mentioning the lack of specialized machinery for slurry injection. Almost 19% of respondents mentioned other technical difficulties associated, often, with the vast agricultural areas, particularly regarding timely soil incorporation of manure (Tab. 2).

Such barriers were found to be minor regarding the complete straw return where the main argument against its utilization was the necessity to use straw in livestock production or litter farming in general (Tab. 2) This practice can also be perceived as a means of returning straw, particularly if the natural fertilizers produced in this manner contribute to closing the loop in even more favorable way, as suggested by Liu et al. [2017]. Conversely, various studies have demonstrated the enhancing effect of raw straw return on soil parameters [Su et al. 2020, Chen et al. 2022], aligning with the key reasons why some of the Polish farmers have been choosing to adopt this pro-environmental and pro-climate measure. These reasons emphasize its positive impact on soil carbon stock and soil microbial activity, as outlined in Table 2. Interestingly, straw return was the only measure in which willingness to utilize was strongly positively correlated with farmer's age (Fig. 2), which may indicate the need to focus the efforts to encourage the younger generations to consider complete straw return.

The factor importance analysis (Fig. 3) revealed that the bureaucracy, formalities, and administrative controls aspects play the least important role in shaping farmers' willingness to employ the surveyed pro-environmental and pro-climate measures. This suggests that formalities regarding the eco-schemes and other policy controls are not a substantial

barrier to the implementation of carbon farming in Poland. Specific challenges were identified for certain measures, aligning with the perspective of assessed Polish farmers and highlighting potential barriers in the further utilization of the surveyed measures. These findings resonate with the challenges discussed by Cuadros-Casanova et al. [2023] regarding the implementation of CAP reform, indicating that overcoming identified barriers may not only support the implementation of carbon farming in Poland but also contribute to achieving the goals of the European Green Deal in broader perspective [Sikora 2021, Cuadros-Casanova et al. 2023].

CONCLUSIONS

The conducted survey shed light on the interrelation among various factors influencing farmers' willingness to adopt pro-environmental and pro-climate measures within carbon farming and low-emission practices. The most influential factor in farmers' decision-making was the potential of certain measures to enhance soil carbon and nitrogen stocks, surpassing the impact of financial subsidies, bureaucratic aspects, and farm-specific characteristics, including the farmer's age and farm size. Several barriers were pinpointed, with technical difficulties and a lack of specialized machinery emerging as notable hindrances for practices related to manure and slurry soil incorporation in a way of the surveyed practices. The conservation tillage was deemed the least plausible to implement on a national scale. This reluctance was attributed not only to the need for specialized machinery but also to a preference for the standard conventional tillage practices in Poland. Addressing these challenges, particularly in the context of conservation tillage, requires targeted educational activities related to the provision of advisory services in agriculture in this area. Raising awareness about the impact of surveyed measures on soil carbon stocks has been identified as the most potent mean to overcome the barriers identified in the survey.

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