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From the ground up: exploring European carbon farming through social practice theory

Mariana Debernardini [a,*], Jeroen Candel [b], Rogier P.O. Schulte [a]

[a] Farming Systems Ecology Group, Wageningen University, the Netherlands
[b] Public Administration and Policy Group, Wageningen University, the Netherlands

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ABSTRACT

The IPCC has highlighted the role of Carbon Dioxide Removals (CDR) to limit global warming to 1,5 °C, as hard-to-abate emissions fail to reach target reductions. Many academics, policy makers, private actors and civil society organisations argue that rewarding carbon farming could be a key approach to increasing CDR despite the uncertainty around the potential of carbon farming to contribute to net-zero efforts. The experiences and lived realities of farmers have largely been overlooked in the scientific and policy debates around carbon farming. Nevertheless, the EU is heavily investing in the development of carbon certificates for land managers through policies such as the Carbon Removal and Carbon Farming regulation (CRCF). This study provides a bottom-up perspective to carbon farming, by learning from farmers who have already implemented the ground-level changes sought by policy-makers. We collected data on the practices of 21 front-runners across Europe who are already involved in carbon farming initiatives. We find that carbon farming practices are deeply entangled in complexes across space and time, which leads to unique trade-offs and choices borne by the farmer. We also find that front-runner farmers are in a constant state of adapting practices to fit the context of their farm through experimentation. This leads to alternative entry points worthy of further exploration related to how carbon farming *practicing*, rather than individual practices, could be incentivised and supported.

1. Introduction

The European Green Deal has highlighted the role the agriculture sector must play to reduce its overall impact on the environment by 2050, given the contribution of the sector to biodiversity loss, impact on water quality and quantity, and contribution to climate change (The European Green Deal, 2019). Adding to the extensive policy landscape governing European agriculture, the European Climate Law has set forth the European Union's action plan to meet the Paris Climate Agreement and become climate neutral by 2050 across all sectors, including agriculture (European Union, 2021). Within that context, Carbon Dioxide Removal (CDR) is heralded as a key approach to achieving a climate-neutral European agriculture sector, as laid out in the regulation on a certification framework for carbon removals and carbon farming (here-after referred to as CRCF), which sets rules for voluntary and independent verification of carbon removals through certification schemes (European Union, 2024). Additional frameworks to promote carbon farming across the EU include the Common Agriculture Policy (CAP), and the Land Use, Land Use Change and Forestry (LULUCF) regulations. Additionally, the EU has invested €1 billion in funding for research projects on soil health through the EU Mission Soil, which specifies carbon farming as one of 9 key topics (European Commission, 2020). Under the proposed Soil Monitoring Law, the EU also aim to track progress towards soil health objectives, including carbon storage (European Parliament, 2024).

While the EU is investing heavily in promoting carbon farming, there is an ongoing debate about its definition and its role in contributing to net-zero objectives. Carbon farming is one of many approaches to sustainable agriculture, and is often used interchangeably to refer to farming practices, business models, and/or a means to achieve net-zero GHG emissions. For example, in the Staff Working Document Sustainable Carbon Cycles- Carbon farming, the European Commission has defined Carbon Farming as "*a green business model* that rewards the actors of the land sector for taking up improved land management practices, resulting in carbon sequestration …" On the other hand, according to the CRCF, carbon farming is defined as "*any practice or process*, carried out over an activity period of at least five years, related to terrestrial or coastal management and resulting in capture and temporary storage of

* Corresponding author. Droevendaalsesteeg 1, building 107, 6708 PB, Wageningen, the Netherlands.
E-mail address: Mariana.debernardini@wur.nl (M. Debernardini).

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atmospheric and biogenic carbon into biogenic carbon pools or the reduction of soil emissions" (European Union, 2024). As a farming practice, carbon farming overlaps with other approaches such as regenerative agriculture, climate smart agriculture, and conservation agriculture. A main difference with these other philosophies is that carbon farming practices are often specifically associated with climate change mitigation, either via carbon sequestration alone (Demeyer et al., 2021; Hermann et al., 2017; Oberč and Arroyo Schnell, 2020) or by including the reduction/avoidance of other greenhouse gas (GHG) emissions (COWI et al., 2020; Elliott et al., 2022; McDonald et al., 2021). Quantifying the contribution of farming practices to climate mitigation, however, is a highly contested exercise because of the challenges involved in accurately and reliably measuring soil organic carbon (SOC) sequestration (Don et al., 2024; Garnett and Müller, 2017; Goidts et al., 2009; Leifeld, 2023; Moinet et al., 2023; Wang et al., 2023; Paul et al., 2023).

The European institutions are relying on policies such as the CRCF to move the needle towards climate neutrality by encouraging land managers to increase the adoption of carbon farming practices. Despite a substantial body of literature on the barriers to adopting new farming practices, however, policymakers still find it difficult to trigger farmers to change their farming practices and reach climate targets (European Court of Auditors, 2021). Literature on drivers of farming practices has focused on behaviorist approaches which focus on individuals' motivations, biases, attitudes and beliefs. For example, Braito et al. (2020) interviewed arable farmers to understand their varying views on soil management and to help inform how policy can be designed to target certain 'types' of farmers (e.g. nature participants, profit maximisers). A study by Dumbrell et al. (2016) surveyed farmers on their attitudes towards carbon farming, and which carbon sequestration practices they would be most and least likely to adopt. Topp et al. (2024) conducted a network analysis comparing the mental models that conservation agriculture and conventional farmers have around their understanding of 'good soil management.' There is an emerging argument, however, that there is a need to look beyond behavioral psychology to disentangle the challenges and barriers that farmers face. Bartkowski and Bartke (2018) conducted a systematic literature review of empirical studies investigating factors that influence the decision-making of farmers in European countries and found that most papers focused on behavioural factors, farm characteristics, and economic constraints, but that very few focus on social-institutional environmental factors, and decision characteristics (i.e. 'goodness of fit' of practices within existing management strategies). Additionally, a comprehensive literature review supported by interview data found that economic and structural factors are the most significant drivers of farmer adoption of environmental practices (Brown et al., 2021). The latter study confirms Bartkowski and Bartke's finding that the fitness of new practices with existing practices of a farmer strongly influence the potential for on-farm changes. By relying on behavioural approaches, the experiences of farmers could be dismissed as 'cognitive links' or mental models'', rather than actual trade-offs, or physical and structural issues. Nevertheless, few studies have gone beyond behavioural approaches and used farmers' situated experiences as entry point to understanding the challenges that arise when adopting new farming practices (Huttunen, 2015). While agronomic studies in farming systems research have emphasised the importance of context-specificity when promoting the scaling out of new innovations (Meynard et al., 2023; Sumberg, 2005; Toffolini et al., 2017), studies on carbon farming often assume adoption is based on behavioural or rational choices. As a consequence, there is a limited understanding of the types of – often context-specific – day-to-day tensions borne by farmers when integrating new carbon farming practices.

We aim to bridge this knowledge gap by zooming-in on farmers' lived realities and asking the central question: How do farmers incorporate CF as part of their existing agricultural activities, and what tensions arise as they adopt CF practices? We address this question by applying a Social Practice Theory (SPT) lens to study the practices of farmers and land-managers across Europe. SPT allows for an understanding of farming practices as constituted by elements that need to come together to cause changes on the farm. This shifts the focus away from the individual farmer, towards the available infrastructure and context-specificities of farming practices. We explored the social practices of carbon farming by learning from those who have already been motivated to make changes on-farm, and are therefore already implementing carbon farming practices. These so called "front-runner" farmers are often seen as pivotal in the transition, as they inspire policy makers to think beyond the known solution space, contribute to reimagining alternative future scenarios, and encourage other farmers to adopt sustainable practices (Bennett et al., 2016; Mattila et al., 2022b; Valencia et al., 2022). By adopting a bottom-up perspective of farmers' day to day experiences, we aim to broaden understandings of the challenges that farmers face when implementing carbon farming practices, as such informing policy design endeavours that may better connect with target groups.

2. Theoretical framework

2.1. Social practice theory

Social Practice Theory builds on the work of sociologists Bourdieu (1977), and Giddens (1984), who questioned the role of individual attitudes as drivers of social change, and proposed broader approaches that include the complex social structures which impact individual action. Social Practice Theory, coined as an explicit theoretical lens by (Schatzki, 2002), offers an alternative approach to studying farmers' roles in climate change. It moves away from behavioural approaches, such as the ABC framework of Attitude, Behaviour, Choice, which is largely grounded in psychological literature and theories of planned behaviour. Rather than the individual's choices, SPT focuses on the importance of those routinised behaviours which make up daily practices, and highlights the interconnections between those practices and larger-scale institutional development. In other words, rather than studying farmer behaviour, SPT scholars study farming practices as the main unit of analysis (Huttunen, 2015). More recently, Shove et al. (2012), applied SPT to climate change studies. They raise the argument that traditional approaches to studying changes in society, especially related to climate change, are inflating the role of the individual, taking burden of blame away from governments, which sustain unsustainable economic institutions and ways of life.

We adopt the definition of social practices-as-entities and performances composed of three interlinking elements: meanings, materials and competences (Shove et al., 2012). Practice-as-an-entity exists as an abstracted and connected set of elements, that are relatively stable in shaping social life. For example, Huttunen (2015) identifies land clearing in Finland as a practice which is made up of the meaning of controlling nature, competence of having knowledge of the land, and materials of availability of suitable fields for cultivation and manure spreading, inter alia. Practice-as-performances refer to the actual and routinised doing of a practice. The contextually variable performances of a practice may reinforce a practice or lead to new and adapted configurations of elements over time (Shove et al., 2012).

We conceptualise the three constitutive elements as follows: materials are tangible physical entities such as things, objects, technologies, infrastructure, land, tools, hardware, animals, the body itself. We also include neighbours, contractors, advisors, and their materials following (Huttunen, 2015). Competences are know-how, skills, background knowledge, and understandings. Meanings are associations of importance, reasonings, ideas, and beliefs. An important dimension of studying farming practices has been to pay attention to sources of knowledge and information flows. While some scholars conceptualise information flows as social practices (Naus et al., 2014), in this study they are understood as elements of carbon farming practices, rather than practices themselves (cf. Huttunen, 2015). So, sources of information are material elements (e.g. internet, advisors), while the knowledge or skills specifically mentioned are competences (e.g. livestock management).

Social practice theory emphasizes the importance of the connections between the elements of different practices, and how links must be made, sustained or broken to trigger change. Practices are often connected across space and time by the shared elements between them, such as machinery, tools, infrastructure which can all be used for multiple practices. Understanding the interactions between the elements of multiple practices can be just as important as understanding the individual practices (Maeder et al., 2023). Shove et al. (2012) refer to bundles and complexes of practices, whereby bundles are loose-knit patterns, such as those based on co-location or temporal sequencing. In other words, bundles do not depend on each other. For example, eating and working form a bundle because they take place in the same space (e.g., the office) and may shape each other, but they are not necessarily co-dependent (Castelo et al., 2021). We conceptualise bundles as practices which occur in a similar setting (i.e. a farm or field), but are not reliant on each other for performance.

Sometimes, practices exhibit stickier forms of co-dependence, where they are linked through sequence, synchronisation, proximity, necessary co-existence, or shared elements (Shove et al., 2012). These types of relationships can be described as complexes. Again, consider eating as a practice: in some contexts where grocery stores are distant and mobility is restricted to driving, eating becomes chronologically dependent on other practices such as driving to a store, shopping, and cooking. Complexes may also be traced through shared elements. For instance, the notion of "being healthy" can become integral to the interconnected practices of cooking, exercising, and eating (Castelo et al., 2021).

Beyond identifying and analysing the elements associated with practices, we also study the circulation of practices to understand the tensions associated with adopting a new practice into an existing management strategy. The circulation of elements refers to how elements travel, or in other words, are adopted by new practitioners in new contexts. For materials to circulate, there needs to be sufficient infrastructure, availability, and transportation available. For competences to travel, we focus on the process of re-contextualisation of knowledge, which is a process of adapting knowledge based on unique contexts. Finally, for meanings to travel, we explore de- and re-classification of meanings where "certain connotations have to be shaken off and new connections made" (Shove et al., 2012). Shove relies on the example of Nordic Walking, in which walking with sticks had to be dissociated from meanings of frailty and somehow connected to concepts of vitality and wellbeing for that practice to take hold.

3. Methods

In this study, we follow a qualitative, exploratory approach to examining the practices of front-runner carbon farmers across Europe. We conducted thematic semi-structured interviews based on farmers' experiences when implementing carbon farming practices. Considering that the term "carbon farmer" is not a label many farmers currently associate with (as opposed to regenerative, organic, etc.), we focused on farmers who are already participating in projects or initiatives in Europe that support or encourage the adoption of carbon farming, which includes carbon credit schemes, research and innovation projects, and peer-to-peer learning farmer networks. An overview of the farmer codes used in this study, farm characteristics, and the types of projects they are involved with can be found in Table 1. In order to ensure farmer anonymity, we have omitted references to the specific names of projects in this study. We identified a long-list of potential carbon farming projects through web-scraping, expert consultation, and reviews of carbon farming reports. Projects had to be active in Europe, including the United Kingdom, and explicitly mention either carbon farming or increasing carbon sequestration on farms in their missions or objectives. We excluded projects focusing on peatlands and wetlands, focusing on those in mineral soils instead. We also excluded projects focusing exclusively on afforestation and coastal management, while including agroforestry. We asked the project coordinators to put us in contact with farmers involved. Each project had a distinct approach to rewarding the farmers for implementing carbon farming practices. We categorise three types of projects: i) research and innovation projects with public and public-private funding that support the experimentation, and scaling of carbon farming practices among farmers; ii) carbon credit schemes that provide certificates and financial rewards to farmer for implementing carbon farming practices, and iii) farmer networks which support peer-to-peer learning among farmers experimenting with carbon farming.

For both data collection and analysis we primarily followed the data collection (semi-structured interviews) and analysis (deductive and inductive coding) approach from Maeder et al. (2023). Semi-structured interviews were conducted in person and on-farm, when possible. Where in-person interviews were not feasible due to limited resources and distances, video calls, supplemented by videos and photos (to visualise the farm) were collected. All farmers were already involved for at least one year in implementing carbon farming practices. The interviews were held in the period between March 2023 to March 2024, with 21 interviews conducted across the following European countries, representing a range of pedo-climatic zones: Northern Ireland, The

Table 1
Farmers interviewed with country-based codes, farm size, and sectors.

Code	Gender	Size (ha)	Sector	Type of carbon farming project
F_1_NI	M	90	Livestock, grassland	Research and innovation
F_2_NI	M	78	Livestock, grassland	Research and innovation
F_3_NI	M	56	Livestock, grassland	Research and innovation
F_4_NI	M	110	Livestock, grassland	Research and innovation
F_5_NI	M	485	Arable, livestock, grassland	Research and innovation
F_6_NL	M	60	Livestock, grassland	Carbon credit scheme
F_7_NL	M	45	Arable	Carbon credit scheme
F_8_BE	M	300	Arable, agroforestry	Carbon credit scheme
F_9_BE	M	1000	Arable	Carbon credit scheme
F_10_AT	M	90	Arable, market garden, agroforestry	Research and innovation
F_11_FI	M	110	Arable	Research and innovation
F_12_FI	M	60	Arable	Research and innovation
F_13_NL	M	25	Arable, market garden, agroforestry	Carbon credit scheme
F_14_SK	M	640	Arable	Carbon credit scheme
F_15_SK	M	800	Arable	Carbon credit scheme
F_16_BE	M	50	Arable	Carbon credit scheme
F_17_SI	M	6	Vegetable, agroforestry, livestock	Farmer network
F_18_NL	M	45	Arable	Carbon credit scheme
F_19_FI	F	100	Arable, grassland, agroforestry	Research and innovation
F_20_ES	F	850	Arable, agroforestry, livestock, grassland	Research and innovation
F_21_FI	M	380	Arable	Research and innovation

Table 2
Partial list of EU-relevant carbon farming practices (Martineau et al., 2016).

Group	Mitigation actions from EU
Land Use	Conversion of arable land to grassland to sequester SOC New agroforestry Wetland/peatland conservation/restoration Woodland planting Preventing deforestation and removal of farmland trees Management of existing woodland, hedgerows, woody buffer strips and farmland trees
Cropland management	Zero tillage Reduced and minimum tillage Leaving crop residues on the soil surface Ceasing to burn crop residues and vegetation Use of cover/catch crops
Livestock management	Livestock disease management Use of sexed semen for breeding dairy replacements Feed additives for ruminant diets Breeding lower methane emissions in ruminants Feed additives for ruminant diets
Nutrient & Soil management	Soil and nutrient management plans Use of nitrification inhibitors Improved nitrogen efficiency Biological N fixation in rotations and in grass mixes Improved on-farm energy efficiency

Netherlands, Belgium, Austria, Slovakia, Spain, and Finland.

Themes used to guide the semi-structured interviews:

1. Overview of the farm (ha, labor, products)
2. Types of carbon farming practices (sometimes also referred to as regenerative, soil health, conservation agriculture).
3. For each practice, we asked about the motivations and reasons, materials and infrastructures, and knowledge and skills required.
4. Types of projects they are involved in that have encouraged them to adopt carbon farming

Interviews were transcribed verbatim. For the interviews in a foreign language a native speaker transcribed the interviews and the secure DeepL Pro software was used to translate. Native speakers were consulted in cases of doubt in the translation. We used Atlas.ti to conduct both deductive and inductive coding. The deductive coding was based on the list of carbon farming practices in a report commissioned by the European Commission, summarised in Table 2. We focused on land-management practices. Practices such as "energy efficiency" and "carbon audit tools" were interpreted in this study as material elements (e.g. data, infrastructure, knowledge, financial incentives), rather than as a practice. Inductive coding was conducted to identify the additional practices and the constitutive elements deemed relevant by the farmers. Next, we coded for elements of each practice (material, meanings, competences), as well as indications regarding the circulation of the elements. We analysed the final list of practices based on farmers' interpretations, and the constitutive elements of each practice to develop a farmer-driven list of carbon farming practices. The code co-occurrence function on Atlas.ti was used to identify bundles and complexes of carbon farming practices across all farmers interviewed.

4. Results

In this section, we present the results of the analysis of carbon farming practices. Our analysis yielded 28 carbon farming practices, described in Table 3, as well as 17 competences, 68 materials, and 42 meanings associated these. We provide an overview of co-occurring elements and practices for the most common practices in Appendix A. In general, we found that practices are performed as integrated bundles and complexes across space and time. In this section, we illustrate and reflect on the tensions farmers experience when integrating new practices into existing entanglements of practices on-farm by describing

Table 3
List of carbon farming practices based on inductive and deductive coding across 21 farmers in Europe. Number represents how many farmer have applied each practice.

Practice	#	Description
Managing crop residues	14	Crop residues are left on the soil surface after harvest. Can also include cases if crop residues are used for livestock bedding and ultimately returned to the soil.
Crop selection for rotation	14	This practice involves selecting certain crops based on their traits and characteristics and potential to contribute to soil organic matter. The selection is considered based on the entire rotation on the farm. In some cases it involves excluding a certain crop, including a certain crop, or ensuring there is enough time between crop planting frequencies.
Sowing and managing cover crops	13	A cover crop is any crop grown to provide soil cover, regardless of whether it is later incorporated.
Applying minimum-tillage cultivation	13	Minimum tillage is used to describe all non-plough based cultivation practices. There are many iterations of min-till, but the common factors are that reduced tillage does not completely invert the soil and less energy is required to carry out cultivation.
Ploughing	11	Ploughing is the practice of mechanically turning the soil, usually at 30 cm depth.
Compost application	10	Applying compost to fields. Can be compost purchased or made on farm. With or without manure.
Direct seeding	10	Direct seeding is a technique of sowing crops with minimal soil disturbance. Associated with minimum or no-tillage methods, and can include broadcasting seeds or direct drill.
Grazing animals	10	Livestock management in rotational grazing.
Planting and managing agroforestry	7	Agroforestry is the practice of integrating trees and/or shrubs with the production of food crops
Planting and managing green Manure	7	Green manuring involves the soil incorporation of any field or forage crop while green or soon after flowering, for the purpose of soil improvement. Green manures may also be grazed in the field.
Applying no-tillage cultivation	7	No-tillage is the elimination of all soil tillage. Seed is drilled directly into an uncultivated soil or simply broadcast onto the soil surface. The adoption of zero tillage removes the need for fallow, allowing crops to be grown in every year.
Woodland planting	7	We describe this action more widely than afforestation and reforestation, by including development of new farmland features that include planting of trees (shelterbelts, hedgerows, woody buffer strips and in-field trees).
Compost making	7	Making the compost as part of farming business. Compost may be re-applied to farm, or sold.
Manure application	6	Using manure as fertiliser. Can be imported or on-farm made manure from cow, pig, horse, etc.
pH level management	6	Maintaining soil pH at suitable levels for crop production. Typically involves applying lime.
Planting and managing legumes in grassland	5	Planting and growing legumes, such as closer, in grasslands. Often referred to colloquially as Multi-species swards, herbal lay.
Planting and managing legumes for food	5	Planting and growing legumes for harvest for human consumption, such as peas or lentils.
Woodland management	4	Forest management activities such as thinning, pruning, altering growth, fertilisation.
Managing permanent grassland	4	This is about managing permanent grassland such as re-sowing grass, fertilisation.
Planting and managing legumes for feed	3	Planting and growing legumes for harvest as feed, silage, or hay for livestock.

(*continued on next page*)

Table 3 (*continued*)

Practice	#	Description
Making and using compost tea	2	Making a liquid by either extracting from compost production, or by mixing the organic matter with water. May include purchased inoculants of microbes.
Planting field edges	2	Planting strips of native vegetation or flower strips around edges of fields.
Field shaping and levelling	2	Field shaping and levelling include changing the topography of fields to get rid of slopes or valleys that may capture too much water.
Managing no-dig market garden	2	No-dig gardening is a common practice among market gardeners, where the soil is not disturbed at all. Beds are instead covered and topped with thick layers of compost, thus building up organic matter.
Shaping and maintenance of swales	2	Shaping the fields to have large low or hollow place in key areas on slopes to trap large amounts of rainfall and reduce erosion. Larger indentations than those formed by contour tillage.
Biogas production	1	Incorporating farm residues (manure, plant matter) in bio-digestion for energy production. Can be part or separate from farm business.
Contour tillage and planting	1	A tillage and planting practice of following slope lines horizontally to create small bunds that trap sediment, reduce speed of rainfall, and thereby reduce erosion. Also referred to as key lines.
Feed additives	1	Additives or livestock feed that reduce enteric fermentation.

three examples of complexes. These complexes reveal new and uncommon types of carbon farming practices that often remain unseen. Moreover, we identify limitations to the uptake of carbon farming practices through the lens of the circulation of elements.

4.1. *Carbon farming practices as complexes*

Below, we present three practice complexes which, together, cover the most frequent carbon farming practices that the interviewed farmer engaged in (Table 3). As discussed in section 2.1, practices form into complexes when they are connected by shared elements and sequentially or temporally co-dependent. These complexes differ from the more loosely connected bundles of associated practices, which are listed in Appendix A. The three complexes clearly highlight the types of tensions that may occur when integrating multiple carbon farming practices.

4.1.1. *Planting cover crops – minimum tillage – direct seeding*

Planting cover crops, minimum tillage, and direct seeding are three separate practices that are connected as sequential complexes by their spatial and temporal sequencing and shared meaning of keeping soil covered all year long. The practice of minimum tillage in the autumn prepares the fields for sowing cover crops, which cover the soil until spring time when the farmer can sow their spring crop directly into the cover crop. However, the sequential co-existence can change as farmers reported that, in the face of climate change, the autumn weather in central and northern Europe has become more unpredictable and often too wet to establish cover crops after minimum tillage. The short window of time and lack of minimum tillage machinery leads many farmers to have to choose between minimum-tillage or cover crops. This shows that cover crops and ploughing may, in certain conditions, emerge as a new complex of practices, as cover crops are dependent on ploughing in order to be performed (F_13_NL, F_16_BE, F_9_BE, F_15_SK):

> "*When you use a plough, you have a larger time window. The conditions are more relaxed. With direct seeding, you have to be on the field, the two or three days when the conditions are good. If you don't do the work at that moment you have bad conditions. It's more stressful to do these techniques, the time period is tighter. I think more than in conventional techniques, you have to follow your land more closely.*" - F_9_BE

Ploughing is often associated with poor soil management and loss of carbon. However, farmers experience that the plough forms a complex with many carbon farming practices, such as establishing agroforestry (F_13_NL), planting and managing cover crops (F_13_NL, F_16_BE, F_21_FI, F_9_BE), sowing multi-species in grasslands (F_1_NI, F_6_NL), leaving crop residues in arable fields (F_12_FI, F_11_FI, F_5_NI, F_18_NL), and applying compost (F_5_NI). In some cases, refusing to plough could come at the cost of performing other practices. If a farmer does not manage to sow winter cover crops in time, then the wet soil conditions could mean that ploughing would be the only way to ensure cover crop establishment:

> "*I didn't want to plough, and that meant that I now have 300kg of winter wheat and 300kg of faba bean seed which I've put in my shed and [which will] hopefully will be okay next winter.*" - F_13_NL

In different climates, there is a similar complex formed between minimum-tillage and cover crop planting, depending on the availability of the material element of water. In Spain and Austria, water shortages mean that cover crops begin to compete with the main crops in arable or agroforestry systems. In very dry conditions, it is difficult to perform no-tillage practices as increased weed pressure can exacerbate the limited water supply issue meaning that cover crops are dependent on some form of tillage (F_20_ES, F_10_AT):

> "*Ground cover is the most effective way to build up soil around the trees, but the issue here again, is the competition of ground cover with the tree. So currently we're implementing it in strips, so we strip-till only in the summer. In winter if it's raining enough, it's a full ground cover.*"- F_20_ES

4.1.2. *Planting legumes in grassland – pH management – grazing livestock*

The practice of sowing legumes in grasslands forms a complex with many other practices, which are tied together by a web of elements. The performance of planting clover and other herbs requires first and foremost for a field to be cultivated and prepared. If transitioning from perennial ryegrass or even permanent grassland, then this typically means ploughing or using herbicide, rotovating, and then sowing the new fields (F_1_NI, F_3_NI, F_4_NI, F_6_NI):

> "*A drawback to get an herb-rich grassland is that you have to sow it. So then you plough it and then you have to re-seed it. This is an example of a rule at odds with another. You want biodiversity, but in the context of carbon-farming, you can't.*" - F_6_NL

Achieving a stable pH, particularly in highly acidic soils, is an important practice in this complex, as species such as clover will not establish well otherwise (F_1_NI, F_2_NI, F_3_NI, F_4_NI). Lime ($CACO_3$) is an essential material element in the practice of establishing clover in grasslands, which is associated with the meanings of reducing fertiliser application by introducing legumes, providing better feed for livestock, improving biodiversity such as worm count, and increasing general soil health (F_1_NI, F_2_NI, F_4_NI, F_6_NL). These competences and meanings are spread through farmer networks and front-runner farmers who have already transitioned from perennial ryegrass to diversified swards (F_1_NI, F_2_NI, F_4_NI). The practice of managing pH, through materials such as soil samples, and ultimately, lime, is an essential baseline of other practices (F_9_BE, F_1_NI, F_2_NI, F_4_NI, F_3_NI):

> "*If my soil is not right, it is a complete waste of time putting legumes into it. Yeah, and that's what people don't get, right. They should get the soil right first, then look at your species diversity. I want to see the pH here above 6.5 before I start putting further legumes into.*" - F_3_NI

Swards are always formed as complexes with their eventual end product of livestock. Whether it is the neighbour's animals that perform the practice of grazing, or the owner's, they are linked by the material element of livestock, or the meaning associated with achieving high yield (F_1_NI, F_2_NI, F_4_NI, F_6_NL). This becomes a challenging complex because when farmers start a new practice, such as legumes in grassland, they often prefer to experiment with one field at a time. They test various material elements, such as various seed mixes, and livestock reaction. The issue with testing legumes is that if only one field has been sown within a rotation, the livestock are switching between perennial ryegrass and legumes, this may invoke digestion issues such as bloat. The farmer must therefore either transition the whole grazing area at once (an expensive and risky manoeuvre) or they must divide the field into smaller blocks so that they can rotate a sample of their herd. This is feasible, but becomes expensive when considering that the material elements such as labour, fences, gates, troughs, need to all be added to establish these smaller blocks:

> *"So we're rotationally grazing the animals, and they go on a field for two to three days, and then they move on to the next field. Now, we've only got 2 fields of herbal ley. So they were on on that field, once every three weeks as part of our rotation. But the animals didn't like it when they were only going in there for three days, so we would need to keep them on herbal ley all the time. But that would mean that one field, I would have to split up, and put a wee batch of sheep that would just stay on that field. That would just be quite a lot of work actually."* F_2_NI

4.1.3. Leaving crop residues – selecting crops for rotation – minimum tillage - ploughing

The two practices of selecting crops for rotation and leaving crop residues share certain elements, and are sequentially and iteratively linked into a complex. Some farmers explicitly mention the practice of selecting certain crops based on the relative impact on soil health and structure, and on the amount of potential residues left over (F_16_BE, F_18_NL). These two practices are therefore connected not just by their material elements (e.g. main crop) but by the meaning associated with improving soil organic matter. However, this complex can cause tension with other meanings of crop selection, such as ensuring a reduction in fertiliser and improving biodiversity (F_15_SK, F_16_BE, F_5_NI, F_18_NL):

> *"So I prefer growing wheat and corn for the grain only and then I chop the straw. But, I have to take into account my rotation. I cannot put the same crop every year on the same fields just because of the organic matter they provide*." F_16_BE

The practice of selecting crops is also linked by material elements with the practice of ploughing and minimum tillage. Depending on the soil type and amount of water in the soil, or the available machinery, a farmer may choose to practice ploughing or minimum tillage (F_19_FI, F_15_SK, F_5_NI). For example, F_5_NI, describes how they can avoid ploughing after oil seed rape because it has a different root structure and stubble, which allows them to sow into that residue with minimum tillage cultivator and drill. On the other hand, a few farmers reference needing to plough after leaving (certain) crop residues on the field because they believe it improves the breakdown of residues into soil organic matter (F_11_FI, F_12_FI, F_5_NI, F_18_NL):

> *"When I'm ploughing onions, you don't actually push anything into the ground. When I do cauliflower ploughing, I push quite a lot of organic matter into the soil."* F_18_NL

There are further examples of how the practice of leaving crop residues is interlinked with other practices, such as managing agroforestry through mulching of pruning (F_17_SI); grazing animals by shepherding herds onto grain stubble (F_20_ES), and the trade-off between leaving the residues or selling the straw to buy compost (F_16_BE).

4.2. Invisible carbon farming practices

During the interviews, many other practices emerged that are not typically considered in lists of carbon practices but did prove to bear considerable relevance for farmers. We refer to these as 'invisible' practices. We will zoom in on a few examples to illustrate the diversity of practices and the elements that farmers consider as important to their engagement with carbon farming.

Crops selection for rotation is a practice described by farmers, which involves the purposeful design of a crop rotation, and the active selection of specific crops for a given purpose (F_13_NL, F_16_BE, F_11_FI, F_12_FI, F_18_NL, F_20_ES). Selecting which crops to plant is an active practice that requires many elements, including the knowledge to design a system, and to actively take into account the existing material elements in a farm. Other relevant elements include soil type (F_6_NL), machinery (F_19_FI), available markets (F_11_FI, F_5_NI, F_21_FI), and, importantly, certificates such as organic or gluten-free. Organic certification is part of this practice (F_8_BE, F_13_NL, F_10_AT, F_21_FI), as organic guidelines may require farmers to change their rotation, e.g., by including more legumes. Additionally, many farmers perceive a premium price opportunity with gluten-free certification, which requires spatial design considerations as there cannot be cross contamination between a wheat field, for example, and oat fields (F_11_FI, F_21_FI). In some cases, carbon farmers are also deciding which crops or varieties to grow based on the crop's potential to produce organic matter through crop residues or below ground root structures, and they are even choosing not to grow some crops based on the negative impact they have on soil structure, an important meaning making up this practice (F_16_BE, F_11_FI, F_12_FI, F_18_NL, F_20_ES):

> "*It hurts me to put those [onions] in because I believe they take a bit of the carbon away of the soil. On the other hand, it brings some money to be able to continue them. I tried to fill in with wheat and corn mostly. Those are really advantageous based on the studies I've read for the carbon content*." - F_16_BE

Other referenced invisible practices include field shaping or creating swales. These practices change the topography of a field to flatten and reduce slopes and pits, thereby reducing erosion and making it easier for the farmer to practice other carbon farming practices, such as using minimum tillage machinery or planting and growing winter cover crops (F_12_FI, F_11_FI):

> *"To ensure wintering of autumn cereals, there should be no depressions with ponds of water in the fields. Therefore, the fields must be shaped with some kind of manure. Autumn cereals in winter cannot withstand water ponding."* - F_12_FI

Finally, planting and managing a no-dig market garden, was an invisible carbon farming practice referenced by one farmer. This involves vegetable gardening to be sold directly to consumers. No-dig market gardens are typically cultivated at small scales with high labour input, as there is no disturbance or cultivation of the soil, but involves high levels of application of compost in a field (F_10_AT, F_13_NL). Although one particular farmer has many carbon farming practices performed on the farm, it was this practice which he believed to deliver the most benefits as a whole, such as improving biodiversity, adapting to climate change, reducing inputs, and improving soil health (F_10_AT).

4.3. Carbon farming practices are limited by the circulation of elements

In order to perform reduced or no tillage, farmers interviewed referenced processes far more complicated than simply "tilling less", as a configuration of multiple elements must come together for the practice to be performed. To illustrate, we zoom in on the circulation of elements that make up reduced tillage and no-tillage practices. To start with, the availability of materials for both practices can be limiting, as machinery, such as tine cultivators, direct drills, harrows, and roller-crimpers can be very expensive to purchase, so farmers may have to rely on contractors. However, the window of time to cultivate the soil can be very short, even as short as a few days. Farmers reported that there are not enough contractors in the region with the machines to begin with, so farmers may struggle to access desired machinery (F_13_NL, F_9_BE). Farmers who can afford to invest in the machines, acknowledge that the size of the farm justifies the large investment (F_8_BE), or that municipal grants supported them (F_18_NL):

"One of the issues we have is the availability of machines. We don't have our own machines, so we use local contractors. Those contractors don't always have the machines to do direct seeding." - F_9_BE

Beyond machinery, time itself was referenced as an important dimension for the performance of these practices, as farmers experience that materials such as soil biology (earthworms and microbes) can take many years to build up before they start to effectively replace the plough and support the function of breaking down soil organic matter into plant-available nutrients (F_7_NL, F_15_SK, F_10_AT, F_9_BE):

"To stop ploughing is only one small step because the soil has to recover for a number of years. Eventually, the biological processes take over from what was previously done mechanically. So, that's why this doesn't work overnight, it takes a long time." - F_7_NL

Beyond these materials, knowing how to use these machines, such as a direct seeder, and being able to time the application around sub-optimal weather conditions, are important competences that farmers develop by re-contextualisation of the theoretical knowledge into their own unique circumstances. Farmers achieve this via repeated performance of this practice, and learning from failures becomes a perennial process. Time, again, emerges as a critical consideration in farming practices, due to the annual or bi-annual nature of many of these practices; farmers may only get one or two chances a year to perform them, and thereby learn from their mistakes. (F_15_SK, F_12_FI, F_10_AT, F_7_NL, F_18_NL, F_6_NL, F_8_BE, F_9_BE, F_14_SK, F_20_ES):

"Minimum tillage doesn't always work on the first attempt. Sometimes the yields are very high, and then the next year they're very low. And you never really know- was it the weather? Was it the crop rotation? Was it too little tillage? Was it too cold in the spring? There are so, so many reasons why things can go wrong." – F_10_AT

Finally, the practice of reduced or no tillage is subject to a variation of meanings such as yields improvements, reducing erosion (F_16_BE, F_12_FI, F_9_BE), improving soil structure and soil organic matter (F_10_AT, F_5_NI, F_7_NL, F_18_NL, F_6_NL, F_21_FI), reducing the need for inputs such as fertiliser and fossil fuels (F_15_SK, F_16_BE, F_10_AT), improving biodiversity (F_15_SK, F_16_BE, F_12_FI, F_10_AT, F_7_NL), and climate change adaptation (F_16_BE, F_12_FI, F_7_NL, F_9_BE). The long-term return on investment of these practices requires a certain belief in these practices (F_15_SK, F_9_BE, F_13_NL, F_16_BE), as it can be easy to abandon the practice. For example, one interviewee explained how they woke up to find their no-tillage fields had been ploughed by part of the cooperative division because the yields were too low in the first year and they panicked (F_15_SK).

For many of the carbon farming practices identified in this study, sources of inspiration, ideas, and understandings of practices were largely facilitated through farmer networks and by learning from front-runners who had already experimented with these practices (F_15_SK, F_8_BE, F_9_BE, F_13_NL, F_14_SK, F_11_FI, F_17_SI, F_1_NI, F_4_NI, F_18_NL). These networks supported the spread of competences such as knowing which types of cover crops work (F_15_SK), how to avoid compaction with no-tillage (F_8_BE), and how to graze in multi-species swards (F_1_NI). These networks also helped build a sense of community around practices and enabled farmers to attach new meanings, such as regenerative agriculture or conservation agriculture, to their evolving sets of practices.

"When you have lived like all of your life in the same place, the farming practices that your parents have done are quite deeply in your mind. It's hard to change something- you need other experiences, and you need to see it with your own eyes. But then I found regenerative farming, and I was part of this carbon action platform, which was educating farmers about regenerative farming or carbon farming. There I realised that I can do things completely differently."
- F_19_FI

5. Discussion

Our results provide a bottom-up perspective on how farmers integrate carbon farming practices into their existing practices. We apply a social practice lens to complement the existing body of literature on carbon farming behavioural studies. We started by asking the question: how do farmers incorporate carbon farming as part of their existing agricultural practices, and what tensions arise as they adopt CF practices? By interviewing farmers across Europe, we found three main lessons on how carbon farming is situated in practice. First, we established that practices are tightly interlinked in complexes. These existing complexes, in particular, have implications for how we understand current approaches to incentivising approaches of carbon farming practices, which we discuss in this section. Based on the results, we suggest an alternative approach to scaling out carbon farming practices by focusing on *practicing* rather than practices. By studying front-runner carbon farmers through a social practice theory lens, we widened the scope beyond the motivations and behaviours constraining the adoption of carbon farming. Because of the diversity of farming systems across Europe, the variance in farmer types interviewed allowed us to cast a wide net across various European pedo-climatic regions, farming businesses and production types. A consistent coding guiding table was followed across all interviews to derive a comparable set of practices. This study does not intend to provide an exhaustive description of each practice, nor does it provide a detailed analysis of how practices are situated within specific geographic or other types of communities. SPT studies with homogenous types of farmers (i.e. regions, sectors) may provide for more place-based analysis of how collective understandings of practices are shaped by communities (Huttunen, 2015; Maeder et al., 2023; Nettle et al., 2025). The heterogenous nature of the farmers we interviewed provided breadth in understanding carbon farming across Europe, but was relatively superficial approach to understand how each practice is spread and shared across connected communities in specific institutional contexts. Rather, we provide valuable and generalisable insights into the practical constraints farmers experience when embedding carbon farming into their existing practices.

5.1. Complexes of carbon farming practices

Understanding the interlinking of practices has particular implications for the study of carbon farming, which currently focuses on assessing the carbon sequestration impact of individual practices rather than the impacts of groups of practices (Jordon et al., 2022; Kätterer et al., 2012; Laporta et al., 2021; Piscitelli et al., 2023; Spotorno et al., 2024). We elaborated on three different types of complexes to illustrate how elements tie together practices, and found that there is a fluidity with how strongly linked the elements are. Although many practices are bundled through temporal or spatial proximity, our results primarily illustrate *complexes*, which more clearly highlight trade-offs and tensions. We show how complexes can break down and reconfigure; for example, when heavy rainfall disrupts the interlinkages between planting cover crops and practicing minimum tillage. Under such conditions, these practices can become mutually exclusive, requiring ploughing to meet a shortened sowing window. This complexity is often overlooked in the scientific literature, or it's been understood as the mental models of farmers that link practices together, rather than their actual experiences (Topp et al., 2024). By acknowledging the web of practices which farmers describe, we argue that there are tangible tensions that exist in practice, rather than mere cognitive links. Some practices that are required to perform carbon farming may thereby be considered counterintuitive. The SPT lens highlights how farmers grapple with practices that are understood as 'not good for carbon,' but that they experience as critical to their complex of practices. For example, while occasional ploughing may lead to disturbances in soil microbial communities, it can also be used as a tool to prevent compaction, and manage wet soil conditions which allows for planting cover crops. These 'counterintuitive' practices should not be immediately dismissed, as they may have a role to play in easing farmers' transition to new management strategies. Cavalaris et al.'s (2023) paper on reduced tillage practices arrives at similar conclusions and argues for thinking beyond singular practices and towards "… hybrid systems that intermittently combine intensive and less intensive tillage practices to provide a practical solution for soil compaction, easing the farmers' apprehensions and facilitating a smoother transition toward regenerative soil management systems." Policy makers could incorporate the bottom-up perspective offered in this study to design more effective and fit-for-purpose incentives and policies.

5.2. Implications for results-based and practice-based incentives

Many public incentives and market-based instruments aimed at promoting new practices rely on single-practice approaches. Examples include practice-based payments under the CAP and results-based carbon farming models that use IPCC emissions factors linked to individual practices (Hillier et al., 2011). However, it is worth exploring how both types of incentives could better account for the *complexes of practices* and the *invisible practices* that farmers manage, especially during transitional phases.

Practice-based payments for ecosystem services have long been criticised for failing to deliver on desired outcomes, and for being too rigid in implementation requirements (Cord et al., 2025; Šumrada et al., 2022). Indeed, practice-based payments may discourage or penalise invisible or counter-intuitive practices and material elements even though farmers may find them important within their complexes of practices. For example, the complex involving legumes in grassland and pH management through liming introduces a layer of complexity in achieving net-zero targets. Liming, while important for maintaining soil conditions, is considered an emissions source due to the CO_2 it releases upon dissolution. For this reason, soil pH management was ultimately excluded from the list of effective climate mitigation tools in agriculture in the EU-commissioned report by Martineau et al. (2016).

These examples underscore the need to move beyond prescriptive measures that contain simplified indicators and advice. Governing the transition to carbon farming will – in addition to more sophisticated regulations and incentives – require more holistic support systems, including strong advisory services, peer-to-peer learning, user-friendly data tools for farmers, and sufficient space and time for experimentation (Braito et al., 2020; Brown et al., 2021; Dumbrell et al., 2016). Many carbon credit schemes which are based on results-based incentives theoretically provide more room for experimentation as they allow more flexibility for farmers to choose practices. However, many carbon credit schemes are not designed with accompanying on-farm advisory services. Instead, they prioritise resources and funding on monitoring, reporting and verification (MRV) rather than supporting and advising farmers at field-level. Additionally, part of experimenting is also about failing, and learning from failures. Results-based incentives, however, are not designed to learn from failures or accept failures, even if they are due to force majeure such as extreme weather events.

Another argument to look beyond both results and practice-based payments linked to carbon credits can be found in the meanings which farmers associate with their carbon farming practices. Our study indicates that changing practices for a farmer has very little to do with reaching the Paris climate agreement, or contributing to net zero emissions. Further, farmers already involved in carbon credit programs did not cite financial rewards as the primary reason for adopting a practice. In fact, many of the farmers mentioned carbon payments were far too low to cover the costs incurred, and they had even begun experimenting with carbon farming before joining a carbon credit scheme (This does raise concerns of additionality which is beyond the scope of this study). Instead, most farmers were motivated by soil health, erosion prevention, improving yield and profit, and even improving animal wellbeing. This finding is in line with research on Midwest farmers' motivations for adopting carbon centric practices (Braito et al., 2020; Wander and Ugarte, 2023) and with the review of Bartkowski and Bartke (2018) who find that climate change adaptation, rather than mitigation, deserves more attention from decision-makers aiming to trigger transitions in the agricultural sector.

5.3. 'Practicing' to scale out carbon farming

The challenges associated with the scaling out of carbon farming practices can be partially explained by the unique context-specificity of each farming system. Many of the farmers we spoke to associated certain practices with umbrella labels such as regenerative, conservation agriculture, or carbon farming. We conceptualise these labels as competences because they were often referred to as such (e.g. "knowledge of regenerative practices"). In general, the diverse nature of the farmers interviewed meant we did not capture a detailed synopsis of how these labels and associated communities are understood vis-à-vis practices, and how they contribute to the circulation of elements. One exception would be for the group of farmers we interviewed in Northern Ireland, we could trace how front-runner farmers and a farmer network working on carbon farming played a strong role in ultimately convincing other farmers to invest in soil health and associating this meaning with certain practices such as planting legumes in grassland and improving pH balance. We learned that consistently across practices farmers may first learn about a new practice from a book or farmer network, but then need to actually apply it to their unique context before figuring out how to make it work successfully. In other words, we find that the process of re-contextualising knowledge is fundamental for introducing permanent on-farm changes. Trial and error allows farmers to discover how certain practices should be performed on their unique context. Many of the competences referenced by the farmers were very contextual and specific to their particular soil type, machine availability, and weather conditions. They mentioned the differences between one year and the next, and how knowledge gained one year may not be relevant the next, because of the changing weather conditions. This process, also described as experimenting or *practicing*, is in line with findings in the literature on learning (Slijper et al., 2022) and on-farm experimentation (Catalogna et al., 2018; Toffolini and Jeuffroy, 2022), where the importance of *continuous* experimentation as part of the knowledge and skill development of farmers has been studied in detail. Experimenting, however, is highly dependent on one of the most precious dimensions of all, time. When designing incentivisation schemes, the element of capital finance is often addressed, but time is a key element in farming that is too often neglected. Both in policy and academia, time is often overlooked. SPT scholars have so far relegated time as an abstract dimension or consideration outside of the integral elements that make up social practices. Time, and the scarcity of it, is often referenced indirectly through other elements such as amount of labour, availability of contractors, or working hours of farmers (Massfeller et al., 2022; McLoughlin et al., 2020; Šumrada et al., 2022). By inductively defining the elements based on farmers' experiences, we see the opportunity to include time more explicitly as an element of a practice, potentially as a 'material' element. This would expand the conceptualisation beyond 'tangible items' to highlight the importance of the more 'intangible,' and would be worth exploring by further SPT studies. Highlighting the role of time reflects the reality of farming, and both its time-sensitivity as well as the long-term periods in which change occurs. While it has been well established that an abundant and efficient microflora is needed to decompose organic material into soil organic matter, the role of soil biology and the time it takes to build up organic matter must be acknowledged as integral elements of carbon farming practices.

Many agronomists have called for contextualised knowledge production, and greater acknowledgement of the existing infrastructures within farming systems (Darnhofer et al., 2019; Meynard et al., 2023; Sumberg, 2005; Toffolini et al., 2017). Our study echoes these calls by advocating for situated and dynamic approaches to designing farming systems (Meynard et al., 2023). While the agronomic literature recognises that practices need to be tailored to specific contexts, the SPT lens advances this understanding by offering a focused framework to analyse interactions within complexes of practices and their unique elements over time. Through focusing on the circulation of elements of complexes of practices, we can find patterns that re-shape the understanding of how farming systems are performed in clusters of stickier and more co-dependent forms. It is by repetition and experimentation that farmers experience these forms of interlinkages, and learn how and when to break or make them.

6. Conclusion

Through an exploratory SPT study, we aimed to identify how farmers implement carbon farming practices within their existing webs of practices. This study contributes to a body of literature that calls for looking beyond behavioural psychology, which has been the primary focus of studies on carbon farming. Shifting towards practices and their constitutive elements accentuates the systemic and institutional challenges borne even by the most sustainably oriented 'front-runner' farmers. The tensions farmers face can be found in the day-to-day performance of new practices, wherein limits in available machinery, time, and contextualised knowledge presents practical challenges. We found that carbon farming practices are performed in complexes and bundles situated across space and time, meaning that there is no single carbon farming practice, but instead, there exist webs of practices that are unique to each farmer and which change over time. By taking a bottom-up approach and acknowledging these complexes, we identified 'invisible' carbon farming practices which are traditionally overlooked, or deemed contradictory to carbon farming objectives. This calls for more holistic and contextualised understandings of how farmers practice carbon farming as there is a dissonance between policy objectives and farmer motivations. We found that improvements in soil health and climate adaptation are stronger motivators for change than contributing to climate change mitigation, but policies such as the Carbon Removal and Carbon Farming regulation are interested first and foremost with climate change mitigation and see adaptation as a co-benefit. Finally, supporting multi-year on-farm experimentation is key to circulating competences across farming communities. This leads to alternative entry points worthy of further exploration related to how carbon farming *practicing,* rather than practices, could be rewarded.

CRediT authorship contribution statement

Mariana Debernardini: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Jeroen Candel:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Rogier P.O. Schulte:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition.

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Declaration of competing interest

Mariana Debernardini and Rogier Schulte do not declare any competing interests. Jeroen Candel is a member of the Dutch council of animal affairs.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2025.103850.

Data availability

The data that has been used is confidential.

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