Exploring transitions towards sustainable farming practices through participatory research

The case of Danish farmers' use of species mixtures

Aare, Ane Kirstine; Lund, Søren; Hauggaard-Nielsen, Henrik

Published in:
Agricultural Systems

DOI:
10.1016/j.agsy.2021.103053

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Aare, A. K., Lund, S., & Hauggaard-Nielsen, H. (2021). Exploring transitions towards sustainable farming practices through participatory research: The case of Danish farmers' use of species mixtures. *Agricultural Systems*, *189*, Article 103053. https://doi.org/10.1016/j.agsy.2021.103053

Agricultural Systems 189 (2021) 103053

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Exploring transitions towards sustainable farming practices through participatory research – The case of Danish farmers' use of species mixtures

Ane Kirstine Aare *, Søren Lund, Henrik Hauggaard-Nielsen

Department of People and Technology, Roskilde University, Universitetsvej 1, DK4000 Roskilde, Denmark

A R T I C L E I N F O

Editor: Guillaume Martin

Keywords:
Participatory research
Sustainable transition
Species mixtures
Intercropping
Crop diversification
Cropping systems

A B S T R A C T

CONTEXT: There is a widespread acknowledgement that research should be supporting farmers'' transition processes towards more sustainable farming systems by applying participatory research approaches. However, scientific papers dealing with participatory research on farming systems seldom include a reflection on the outcome of these processes or the methodological implications of such an aim.

OBJECTIVE: The aim of the research process presented in this paper was together with a group of Danish farmers to explore the potential use of species mixtures in their own farming contexts by following several participatory research principles.

METHODS: 16 farmers volunteered to participate in the joint research process initiated by on-farm experimentation with a diverse catch crop mixture. The paper presents seven activities of the research process carried out using a variety of quantitative and qualitative methods such as an applied game, farm visits, on-farm experimentation, common evaluations and discussions. The authors have analysed the process as a case study using three levels of empirical observations and descriptive narratives.

RESULTS AND CONCLUSIONS: The authors found that the farmers were involved throughout the two-and-a-half-year study period and experimented with species mixtures using different strategies. With the researchers, they identified and challenged structural, agronomic, technical and social barriers, and investigated the potential of species mixtures adapted to local conditions. The case study revealed that both farmers and researchers need to take on new roles, with farmers needing to invest their resources and time to come up with valuable data and knowledge. Similarly, researchers need to facilitate the explorative research process by meeting farmers'' needs while being able to draw valuable scientific conclusions. This requires new skills that have not traditionally been valued in agricultural sciences.

SIGNIFICANCE: This study demonstrates that the barriers to changing farmers'' cropping practices are not necessarily due solely to technical challenges or a lack of knowledge. Instead, researchers need to look beyond the farm gate and involve other actors in unlocking the potential of an increased use of species mixtures.

1. Introduction

In the last few decades, several researchers, including the authors of this article, have been increasingly engaged in addressing the urgent need for knowledge, innovations and actions in order to assist sustainable transitions. Against this backdrop, the traditional principle of mixing crop species is perceived by many researchers (Altieri, 1999; Gliessman et al., 2019; Malézieux et al., 2009) to be a sustainable cropping strategy.

The use of two or more species in proximity and with a certain overlap in time allows for complementarity, competition and facilitation between plants (Horwith, 1985; Jensen et al., 2015; Vandermeer, 1989; Willey, 1979). Such interactions can have several benefits, including yield stability (Bedoussac et al., 2015; Raseduzzaman and Jensen, 2017), increased control of weed, pests and diseases (Hauggaard-Nielsen and Jensen, 2001), reduced need for inputs (fertilisers, pesticides) and resource use efficiency (water, nutrients, space and labour) (Brooker et al., 2015; Jensen et al., 2020). Species mixtures also allow farmers to introduce legumes into crop rotations that are substantially dominated by cereals, creating opportunities for locally produced plant proteins and reducing the need for nitrogen fertilisers and pesticides (Hauggaard-Nielsen et al., 2008). Thus farmers' increased use of species mixtures

* Corresponding author.
E-mail address: akaare@ruc.dk (A.K. Aare).

https://doi.org/10.1016/j.agsy.2021.103053
Received 31 July 2020; Received in revised form 4 January 2021; Accepted 7 January 2021
Available online 22 January 2021

might offer a partial solution to the challenges of modern industrialised agricultural production and markets (Frison and IPES-Food, 2016). Given the current challenges that farmers and society are facing and the potential benefits of species mixture practices, the question arises as to why Danish farmers are not employing these practices to engage in a sustainable transition.

New farming practices involve agronomic and technical changes as well as social and structural ones (Gliessman et al., 2019; Wezel et al., 2018). Researchers therefore need to apply a holistic understanding of farming if they are to understand whether farmers will engage in sustainable transitions. This involves moving away from pure field-level activities, and taking the farm level and even sectoral level into consideration (Francis et al., 2003; Gibbon, 2012; Meynard et al., 2017). This challenges the *engineering approach* paradigm that dominates agricultural sciences (Darnhofer et al., 2009) of controlled single-purpose (e.g. yield optimisation) and single-factor (e.g. N application) experiments deconstructing a farming system's complexity (Catalogna et al., 2018; Kroma, 2006). The engineering approach is linked to the *transfer of technology* paradigm, which assumes that scientists are able to design solutions for agricultural production that can be transferred to farmers, such as through advisory services (Roling and Wagemakers, 1998).

Researchers' contributions to more sustainable farming systems using the engineering approach are definitely of value in a transition process. However, the limitations of generic knowledge are often evident when confronted with the complex reality of local variabilities (geographical, cultural, social and economic) and changing conditions (climate change, fluctuating market prices etc.) (FAO, 2014; Frison and IPES-Food, 2016). Understanding the conditions for a transition towards more sustainable practices among farmers therefore involves acknowledging that farmers manage their farming systems with variability in time and space (Orlando et al., 2020) and in a way that suits their personalities, skills, motivations, values, traditions etc. (Darnhofer et al., 2009; Šūmane et al., 2018; Vanclay, 2004). The diversity of stakeholders, the multiplicity of possible futures and local differences means that research should not only deliver generic solutions, but also help farmers and other stakeholders build their own systems and increase their adaptive capacities (Folke et al., 2002; Hazard et al., 2018; Meynard et al., 2012). A task of this kind requires researcher skills and interdisciplinary methodologies that have not traditionally been valued in agricultural sciences.

Since learning allows for a new perspective on challenges and for perceiving new possibilities (Darnhofer et al., 2009), farmers' ability to adopt and adapt new practices requires continuous learning (Roling and Wagemakers, 1998). Advisory services support farmers' learning, but research shows that farmers are often encouraged to learn more through on-farm experimentation and learning and sharing their experiences with peers (Darnhofer et al., 2009; Kilpatrick and Johns, 2003; Kroma, 2006; Lankester, 2013; Oreszczyn et al., 2010; Rogers, 1995). Experimentation enables farmers to innovate, monitor and learn in their own local conditions, while generating ideas that can inspire and be adopted by other farmers, for example through efficient peer learning (Catalogna et al., 2018; Darnhofer et al., 2009; Ingram et al., 2018). Finally, trust and acknowledgement are identified as important enablers of efficient learning and knowledge sharing (Koole, 2020; Méndez et al., 2017). Consequently, these learning conditions are acknowledged to be efficient and crucial ways of triggering the creation and adaptation of sustainable farming practices (Aare et al., 2020a; Feder et al., 2004; Ingram et al., 2018; Lankester, 2013; Vanclay, 2004; Woodhill and Roling, 1998).

However, supporting farmers' abilities and capabilities to adopt sustainable farming practices does not on its own result in actual engagement. Farmers' willingness to participate is a fundamental condition, influenced too by a range of situational factors, such as farmer identities, the perceived meaningfulness of the practice, economic feasibility, social relations, institutional conditions and political context (Lund, 1998; Lund and Lønholdt, 2005). The ability of farmers to assess, share and discuss with others within such situational conditions is therefore an essential feature in initiatives aiming to make new sustainable practices attractive and desired by the individual farmer.

Partially stimulated by the EU requiring the involvement of multiple actors in projects funded by the Horizon 2020 programme (EIP-Agri, 2017), there has been a participatory shift in farming research. In order to resolve the complex task of supporting the sustainable transition of farming systems, researchers today are increasingly called upon to combine scientifically grounded information (Klerkx et al., 2012) with farmers' contextual and holistic knowledge, as well as specific experimentations (Šūmane et al., 2018).

Participatory research is an overarching term for research that is carried out in collaboration with actors involved in the research field being investigated (Bradbury, 2015). However, the aim of including practitioners in farming research can vary from optimising designs or technical solutions to supporting farmers undergoing a process of transition (Lacombe et al., 2018; Menconi et al., 2017; Méndez et al., 2017; Roling and Wagemakers, 1998). A range of participatory approaches in farming research focuses on co-designing or prototyping new strategies or innovations, and often the actual design is the main outcome of the research process (Klerkx et al., 2012; Meynard et al., 2012; Vereijken, 1997). Other approaches articulate more explicitly an emancipatory aim where farmers and researcher engage in a common reflexive learning process about conditions and possibilities for change (Bos et al., 2009; Vaarst et al., 2007). Therefore, any participatory research project needs to explicitly articulate the rationale behind the participation, as well as select an appropriate methodology that corresponds with this aim.

Examining a range of participatory research processes, Lacombe et al. (2018) investigated the role of farmers and other stakeholders in research and how the process affected their learning and engagement in a local transition of farming systems. Despite the aim of supporting farmers in a learning or transition process, they found that most papers on participatory design processes seldom include a reflection on the outcome of the process for farmers or the possible implications of such an aim for the methodology. However, the authors suggest that farmers' learning and commitment to change depends on whether the research process: i) allows researchers and farmers to share both the design work and the leadership, ii) takes into account the singularity of farmers' situations, iii) bridges thinking and doing, and iv) fosters collective reflexivity to learn from the research process (Lacombe et al., 2018). It is therefore necessary to acquire more experience and reflect on ways of conducting research for sustainable transitions that simultaneously fulfil criteria of relevance to both farmers and researchers. The long tradition of participatory research in other research fields shows that researchers are required to play new roles and develop other ways of drawing scientifically sound conclusions (Bradbury, 2015).

This paper presents an in-depth case study of a participatory research process over a period of two and a half years, involving 16 farmers and two researchers, with the aim of exploring farmers' possibilities of adopting species mixture practices in their individual farming system. The objective of the present research process was to give farmers the opportunity to choose to initiate a transition towards increased use of species mixtures and, if this was not attractive, to identify the conditions needed to make it relevant for them to implement. From the outset, the researchers were faced with a dilemma concerning the rationale and choice of the specific participatory approach to be followed. The researchers wanted to ensure learning and engagement among the participating farmers, but were also bound by the obligation to deliver scientifically relevant knowledge for the funding research project (see Acknowledgements). The present paper outlines how the researchers handled the need to balance these aims throughout the process, and what it yielded.

2. Materials and methods

2.1. The participatory and explorative approach

As outlined in the introduction, making the claim that a participatory research process is being followed is by no means an unequivocal statement. In fact, the term is a social construct, a discourse, which is selected or developed by the researchers of each research project according to the aim of the research process and actual situation (Lund, 1998). As mentioned above, the research project evolved around an inherent dilemma of wanting to support criteria relevant to farmers and their learning process, while also satisfying given research agendas. This resulted in the adoption of an explorative research design (De Graaf and Huberts, 2008; Yin, 1989) where the choice of particular issues to be studied are left open in order to accommodate the interests and needs of the participants. In the present study, the researchers' assumption was that farmers' local on-farm experimentation with new practices was the best way of establishing whether the adoption of an increased use of species mixtures is possible (Falconnier et al., 2017; Hagmann et al., 1997; Hazard et al., 2018; Vaarst et al., 2007). Another assumption was that such contextualised experiments not only generate site-specific conclusions, but also offer valuable insight about general conditions and possibilities for transition (Flyvbjerg and Sampson, 2001). Therefore, the researchers believed that using on-farm experimentation as the starting point for collaboration would fulfil criteria that were relevant to both the farmers and the researchers.

Inspired by the preconditions for farmer engagement and learning identified by (Lacombe et al., 2018) and supported by other sources, the researchers judged it beneficial to follow four principles to facilitate on-farm experimentation. These were as follows:

1. The process is guided by the needs of the people implementing the change (Bos et al., 2009; Salembier et al., 2016) and therefore the activities comprised within the research process are decided in dialogue between researchers and farmers (Westlander, 2006). Creation of trust between researchers and farmers is aimed for to stimulate farmers' commitment (Méndez et al., 2017).
2. Acknowledgement and understanding of the individual farmers' complex situation and possibilities to engage in transitions is promoted, thus there is a focus on inter-subjective validity as well as practical and local knowledge (Šūmane et al., 2018).
3. The research process includes learning by doing (Waks, 2017) through specific on-farm experimentation, which is designed and managed by farmers using local knowledge and contextual conditions to stimulate practical experiences and relevance (Catalogna et al., 2018).
4. The research process is organised within a group of farmers, rather than researchers working with individual farmers, as the creation of common awareness and reflexivity about their collective framework conditions (despite their individual situation) can increase the learning, empowerment and opportunities required for change to take place (Nielsen and Nielsen, 2016; Vaarst et al., 2007).

To operationalise principle #1 while maintaining consistency throughout the process, the researchers developed a simple logic for the progression of the research process, as illustrated in Fig. 1. Each activity focuses on farmers' critical question(s) concerning their transition towards the use of species mixtures. By exploring the question(s) further, this leads to other questions, providing inspiration for the theme of the next (or future) activity. The questions to be explored are determined in the course of a dialogue between researchers and farmers at the end of each activity, prioritising the most critical questions while being pragmatic about possible hosts, seasonal opportunities etc. After a certain period, the researchers ensure that there is a follow-up on the overall situation before moving on to a second iterative cycle (Activity VII).

The researchers are responsible for facilitating the process by suggesting different methods for answering the questions that arise. Each specific choice of method is made from available options familiar to the researcher, assessed against practical criteria as to what would be an appropriate tool for addressing the questions raised. The ambition is to have farmers actively participating, conducting on-farm experiments, and sharing their knowledge, questions and experiences.

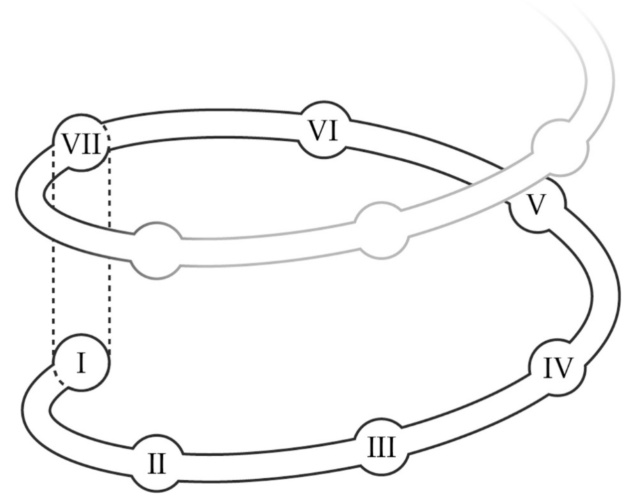

Fig. 1. Illustration of the logic behind the research approach developed by the researchers before initiating the research process to operationalise methodological principle #1. Each meeting explores a critical question. New questions arise in the exploration, providing inspiration for the theme of the next (or future) activity. A status review is carried out after a while to compare the starting point with the current situation, and thereby create awareness about the progression of the research among all participants.

2.2. Establishment and presentation of the group of farmers

Participant selection is an important step in any participatory research process (Méndez et al., 2017). In the current study, an invitation to participate in the project was extended to attendees of a conservation agriculture (CA) farm demonstration in 2017, a farmers' network with whom this study's researchers were already working. The researchers expected that this group might be interested in species mixtures owing to CA principles about diverse crop rotation and soil cover (FAO, 2017). Ten farmers enlisted to participate in exploring the potential use of species mixtures in their own farming context, starting with on-farm experimentation with a diverse catch crop mixture.

The farmer sampling strategy aimed to engage farmers to play an active role in the research process (Halwart and Settle, 2008). No offer of payment was made to cover farmer's working hours or other expenses because: i) farmers were being sought who had an actual interest in the topic and ii) the intention was to facilitate a research process that, despite their busy everyday working lives, was sufficiently relevant for them to want to be engaged. More limited financial support for specific material to enable the farmers' experimentation was offered where needed (e.g. seeds for smaller experiments, riddles for separation equipment etc.). The researchers found it relevant to work with these CA farmers who had voluntarily enlisted because: i) innovative farmers are important sources of inspiration for exploring possible sustainable transitions (Salembier et al., 2016) and ii) interest and engagement is a prerequisite for successful participative research (Méndez et al., 2017).

The farms are located throughout Denmark (Fig. 2), with the majority in the eastern part of the country. The participating farmers varied in age and experience with species mixtures. The individual farms also differed greatly in size (ha), soil type, management traditions and production (Table 1). During the research period, some farmers (F5, F10, F13) left the group due to a lack of resources, changing working

Fig. 2. Geographical location of the farms of farmers participating in the research process.

Table 1
Selected features of the farmers, with some joining the group after the first selection of volunteers (in bold) and others leaving (in italics).

Farmer ID	Production	Management	Soil type	Size (ha)	Age	Previous experience with species mixtures
F1	Pigs, arable	Conv, RT	CSC-C	420	57	Catch
F2	Pigs, arable, biogas	Conv, RT	FS – HC	800	56	Catch
F3	Arable	Conv, RT	CSC - C	25	39	Catch, Comp
F4	Pigs, arable	Conv, RT	FSC - C	80	38	–
F5	*Arable*	*Org, RT*	*CSC-C*	*80*	*60*	*Catch, Comp*
F6	Pigs, arable	Conv, RT	FCS - HC	550	63	–
F7	Arable, horses	Conv, RT	FSC-C	5	26	Catch
F8	Arable, forestry	RT, CA	CSC-FSC	300	52	Catch
F9	Arable	RT, CA	FS-C	400	54	Catch, Comp, MC
F10	*Pigs, arable*	*Conv*	*FCS-C*	*600*	*23*	–
F11	**Arable**	**RT, CA**	**HC-C**	**250**	**55 + 24**	**Catch, Comp**
F12	**Arable**	**RT, CA**	**FS-AS**	**300**	**39**	**Catch, Comp**
F13	***Livestock, arable***	***Org***	***N/A***	***78***	***N/A***	***Catch, MC***
F14	**Pigs, arable**	**Conv, RT**	**CSC-C**	**90**	**25**	**Catch**
F15	**Arable**	**Conv, Org, CA**	**C**	**12**	**26**	**Catch**
F16	**Arable, pigs**	**Conv, RT**	**FSC-HC**	**300**	**26**	**–**

Legend: CONV = conventional, RT = reduced tillage, CA = conservation agriculture, ORG = organic, CSC = coarse sandy clay, C = clay, FS = fine sand, HC = heavy clay, FSC = fine sandy clay, FCS = fine clayey sand, AS = atypical soils, Catch = catch/cover crops, Comp = companion crops, MC = main crops.

conditions etc., but new farmers (F11-16) were invited by the farmers and researchers to join the group due to their interest and potential contributions. F11 and F12 already had some experience of species mixtures, e.g. undersowing and mixed catch crops, and F13 had previously experimented with species mixtures in organic farming and for livestock fodder (Table 1). F14-F16 are younger farmers preparing for generational handover and thus very keen on exploring the potential integration of new sustainable practices in the farming systems that they would be taking over.

Most farmers were engaged in arable farming practices, primarily producing feed either for their own use or to sell, with some crops for human consumption such as bread wheat and malting barley. Common to all the farmers was that they practise or intend to practise some degree of reduced tillage or conservation agriculture.

2.3. The research process and empirical material

The participatory research process presented in this paper consisted of seven activities. The first step of the process was for researchers to establish personal relationships with each of the participants and to agree on the overall idea and purpose of the research (principle #1). The first visit (Activity I) to the individual farms was made by the first author of this manuscript who explained the researchers' motivation for exploring sustainable transitions towards increased use of species mixtures in Denmark and thus the need to include farmers' perceptions (principle #2). The researcher asked the farmers about their experiences with species mixtures, their motivations for entering the research process and the perceived barriers to them using species mixtures. To encourage the farmers' active involvement in experimenting and generating local knowledge about species mixtures, the researchers provided all the farmers with a bag of mixed catch crops (six species, 25 kg, approx. 1 ha) (principle #3). The researchers suggested that the farmers started the experiment with catch crops to reduce their risk of losing cash crop yields. The researchers chose the specific mixture because it was the most diverse catch crop mixture available from a national retailer. The second visit (Activity II) to the individual farms was conducted by the same researcher during the crop stage of maximum catch crop aboveground biomass production (late October to mid-November) to evaluate the outcome of the individual catch crop mixture with the farmer (principle #2). The time-consuming hand harvest was used to stimulate a quantitative and systematic evaluation of the farmers' own experimentation as a supplement to their typical visual judgement. Some months later, the researchers invited all the farmers to a workshop at the university (Activity III) where all the farmers met for the first time to share and discuss their results and plan possible new experiments (principle #4). During the initial dialogue, the researchers found that the farmers were mentioning a wide range of barriers to the use of species mixtures. The researchers therefore compiled the barriers into a common list to reflect how this specific group of farmers together *perceived* their situation at this specific time (principles #2 and 4). Inspired by the socio-technical system perspective (Geels, 2004), the researchers sorted the barriers using categories such as technical, social, institutional etc. to create a better overview and awareness of the diversity of the barriers. The researchers' aim was to make the farmers' collective experience visible, thereby creating awareness about the collective starting point for a transition process (principle #4).

Acknowledging the manifold barriers perceived by the farmers, the researchers developed an applied game (inspired by e.g. Martin et al., 2011) to invite the farmers to focus on the potential benefits of species mixtures without being hampered by the perceived barriers or limited opportunities within their own current farming system. The researchers divided the farmers into three groups and asked them to design the most diverse rotation possible to increase the benefits of species mixture functionality by bringing their local and practical knowledge into play (principle #2). Each group were given a game board consisting of four "fields" and a pile of cards with different species (including cash crops, companion crops and catch crops). On each card the researchers had written the potential functionality of each species based on scientific knowledge. After the design of the rotations, there was a group discussion about the mixtures (principle #4) and the farmers' concrete plans for new on-farm experimentation (principle #3).

After the first group meeting at the university, the farmers were increasingly involved in planning the research process (principle #1, following the logic of Fig. 1). A decision was taken with the farmers to hold theoretical meetings in the winter (Activities III and VII) and undertake joint visits to farms during the growing season (Activities IV and V), i.e. two to three meetings a year in total. At the end of each meeting, there was a discussion and decisions were taken about the topic and place of the next activity, as well as other tasks to be carried out between meetings (e.g. Activity VI). The researchers were responsible for planning, issuing invitations and facilitating the activities. They also wrote and issued minutes after each meeting and every meeting started with the researchers going over the main conclusions from the previous activity and giving an update of the actions carried out in between. All the farmers were also invited to present and share with the group what they had learned or what questions they had at the start of the meetings. Between meetings, the researchers and farmers communicated with one another using a closed WhatsApp group.

After identifying and presenting the barriers for farmers in Activity III, the researchers observed that these barriers became a recurring reference for researchers and farmers in the collective discussions. Inspired by this, the researchers actively used the barriers as part of the facilitation to ask new questions (based on the farmers' initial perceptions) and track the progression of the learning process (identifying whether the group had found answers to overcome some of the barriers through the explorative research process). After a period of two and a half years (Activity VII), the researchers decided to revise the barriers to using species mixtures as a way of tracking the progression of the research (cf. Fig. 1).

The seven main activities in the research process are presented in chronological order in Table 2.

The on-farm experimentation (running throughout the period) was monitored and evaluated using templates completed by farmers before the experiment was established to identify the objectives, history of the field, expected management and expected use (e.g. sale or internal fodder use). The experiments were monitored again after harvest to document the actual management, use and success (in accordance with the farmers' objectives) and this was used to develop suggestions for improvements to the experiment's design (e.g. sowing density, species variety, management) (principle #3).

The manifold activities were documented by researchers using: i) recorded interviews transcribed in Nvivo (QSR International Pty Ltd. Version 12, 2018), ii) pictures, written material (Post-its etc.), audio recordings, minutes and researchers' notes from meetings, iii) plans and evaluations of on-farm experimentation, pictures and other communication via WhatsApp, email or telephone between meetings. This comprehensive information provided the empirical material analysed in this paper.

2.4. The empirical analysis of the participatory research process

In order to balance the two distinct aims mentioned in the introduction of supporting learning and engagement among the participating farmers, as well as delivering scientifically relevant knowledge, the authors decided to consider the empirical data in this study from three levels of observations. The *substantial level* refers to data about the specific species mixtures, the cultivating practices and observations about weather conditions, plant diseases, weeds etc. The substantial level is reflecting the fundamental material reality of the farming systems studies and was considered to be of common interest to the individual farmers as well as the agronomic scientific community. The *agency level* includes data on the participants' motivations and situational analyses at each step, their knowledge and skills, their perceptions of barriers, their assessments of outcomes etc. The agency level is reflecting the need to link the observed substantial reality to the perceived situational reality of the farmers. The authors considered this level to be a fundamental prerequisite for practicing and documenting the type of participatory research presented in this paper. Finally, the *methodological level* considers researchers' accounts of the contextual choice and application of, for example, specific methods of meeting facilitation, methods for joint situational analysis and tools for evaluating outcomes to constitute empirical data. The methodological level is reflecting the wish among authors to transparently monitor and reflect on such contextual choices.

The research process itself was driven by an ongoing joint empirical analysis by the farmers and researchers of the observations and outcomes obtained step by step, thus linking one activity to the next (cf. Fig. 1). This joint empirical analysis contains both exemplary insights about the performance of specific farmer-driven combinations of species mixtures and cultivating techniques at farm level *(substance)* and their implications for farmers' potential use of species mixtures and needs for further knowledge and skills *(agency)*, as well as *methodological* learnings about the benefits of the research methodologies applied at each step to fulfil farmers' and researchers' needs.

2.4.1. Narratives as a communicative tool to account for the participatory research process

For this paper, the three level aspects of each activity are summed up in the form of a densified illustrative narrative description. Case studies often contain narrative elements because "thick" descriptions allow inclusion of "the complexities and contradictions of real life"(Flyvbjerg and Sampson, 2001). A narrative is a researcher's retrospective analysis of a process (van Bommel and van der Zouwen, 2012) allowing the authors of this papers to illustrate and evaluate the two-and-a-half-year research process. The authors found narratives to be a valuable way of presenting the "rich" empirical material and its inherent joint analysis in a scientific paper, while still illustrating the explorative character of the research process (Materials and Methods, 2.1). Extracting valuable knowledge is an essential task for the researchers in a participatory research process (Lacombe et al., 2018). The authors therefore used the narrative descriptions to discuss the research objective structured around four themes (Discussion).

3. Results

The results section presents a broad range of outcomes of the research process. It is structured chronologically following the seven steps (activities) of the research process and using a narrative description combining the analyses of the three empirical levels (Materials and Methods, 2.4). Each subsection first presents the aim of the activity, including the specific research method(s) used, before presenting the outcomes and the progression of the activity, and finally outlining the implications of the outcomes of this activity for a decision on what to include in the next activity.

The research questions and the outcomes of each activity are first summarised in Table 3 and afterwards reviewed individually.

3.1. Activity I: getting to know each other and defining the point of departure

During the initial and individual in-depth interviews, all the farmers expressed an interest in species mixtures as a practice to improve the ecological and/or economic performance of their farming system. Entering into dialogue and creating solutions with the researchers was new to some of the farmers, while others had previously been involved in other research projects. The interviews primarily took place in farmers' kitchens or offices in an informal atmosphere, with interruptions by family members, co-workers or telephone calls, which gave the researchers a sense of the farmers' daily routines.

Based on the first round of interviews with the farmers, the

Table 2
The seven research activities (I-VII) carried out from 2017 to 2020, including practical information, aims and methodological inspiration (Materials and Methods, 2.1), as well as experiments and communication carried out between activities. The participating farmers in each activity are referred to by their farmer ID (F1-16) (Table 1). The aims defined mainly by the researchers are given in italics.

Activity ID	I	II	III	IV	V	VI	VII
Activity title	Getting to know each other and defining the point of departure	Experimenting and evaluating individually	Sharing experiences and inspiration	Evaluating jointly in the field	Investigating management possibilities	Discussing market possibilities	Taking stock and planning future work
Date	March-August 2018	28 October - 9 November 2018	24 January 2019	17 June 2019	10 October 2019	16 January and 5 February 2020	14 February 2020
Duration	1–2 h	2–3 h	5 h	5 h	5 h	2 × 2 hours	5 h
Place	Individual farms	Individual farms	University	F11's farm	F2's farm	University and retailer	University
Participants	F1-F11, (F12-16)[a] 1 researcher (1st author)	F1-4, F6-F14[b] 1 researcher (1st author)	F1-4, F6, F11 (father and son), F12, F15 2 researchers (1st and 3rd author) 1 junior researcher	F2-4, F6, F9, F11 (father and son), F15, 2 researchers (1st and 3rd author) 1 junior researcher	F1-4, F6, F8, F11 (father and son), F15, F16 4 guests[c] 2 researchers (1st and 3rd author)	DAKOFO, Viking Malt 2 researchers (1st and 3rd author)	F1, F3, F4, F8, F9, F11 (father and son) 2 researchers (1st and 3rd author)
Aims	*Establish personal relationships and agree the overall purpose of the research* *Identify experiences, motivation and barriers for the use of species mixtures* *Initiate on-farm experiments*	*Evaluate the outcome of the individual catch crop mixture together with the farmer in the field*	Meet each other to share and discuss results of catch crop mixtures experiments and plan possible new experiments *Share farmers' compiled list of perceived barriers to the use of species mixtures* *Stimulate farmers' creativity and knowledge by designing fictive crop rotations* *Encourage on-farm experimentation*	Jointly evaluate and learn from farmers' experimentation in the field	Discuss machinery and techniques supporting species mixtures *Discuss the sales possibilities for species mixtures*	Discuss opportunities for retailers to support species mixture practices	*Revise barriers towards use of species mixtures to track the progression of the research* Discuss the future of the group beyond the research project
Methodological inspiration	Semi-structured interviews (Kvale and Brinkmann, 2009) System analysis with stakeholders (Bos et al., 2009; Dogliotti et al., 2014)	Go-along interview (Carpiano, 2009; Kusenbach, 2003) Quantitative evaluation through participatory 5x1m^2 biomass cut in transect.	Applied game (Martin et al., 2011), Working with attractive futures/ utopian scenarios (Bos et al., 2009; Nielsen and Nielsen, 2016) Common evaluation (Vaarst et al., 2007)	Quantitative evaluation through participatory 3 × 0.75 m^2 biomass cut in transect. Qualitative evaluation of farmer's objective (Vaarst et al., 2007; Verret et al., 2020)	Farmers' discussion of possibilities for implementation of practice (Hagmann et al., 1997)	Semi-structured interviews (Kvale and Brinkmann, 2009) Value-chain dialogue (Bos et al., 2009)	Revision of barriers (Hagmann et al., 1997)
On-farm experiments		X	X	X	X	X	X
WhatsApp communication			X	X	X	X	X

[a] The farmers (F11-F16) entering the research process after the initial interviews were interviewed later. F15-16 entered the process after Activity II and therefore did not establish the catch crop experiment.
[b] F5 was not able to establish the experiment and withdrew from the project at around the time of Activity II.
[c] The owner and two employees at the host farm and a relative of one of the farmers.

Table 3
Research questions of and outcomes from the seven activities of the research process. For further description of the seven activities see Table 2.

Activity ID	I	II	III	IV	V	VI	VII
Research question (s)	What are the participating farmers' experiences, motivation and barriers for the use of species mixtures? Do the participating farmers agree with the overall aim of the research?	How did the experimentation go and how do farmers individually evaluate their experiments in the field?	How do farmers jointly evaluate the results of the catch crop experiments? Can farmers make use of and learn about potential benefits of species mixtures by designing diverse fictive rotations? What mixtures do farmers wish to use for on-farm experiments?	How do the participating farmers jointly evaluate the on-farm experiments of F11 in the field?	What machinery is suitable for species mixtures? How can farmers sell species mixtures?	Can retailers support the use of species mixtures?	How do the participating farmers respond to retailers' openness to species mixtures? Do the participating farmers still agree on the barriers initially identified? What is the farmer group's potential for continued activities after the research project?
Outcomes	Some farmers are new to species mixtures and others are familiar. Farmers are motivated to use species mixtures to improve the ecological and/or economic performance of their farming system. Farmers identify a long list of different barriers to the use of species mixtures. On-farm experience with species mixtures is critical in order to initiate the research process. Farmers agreed on the overall purpose of the research including on-farm experiment with mixed catch crops selected by researchers.	Farmers evaluate the performance of the catch crop mixture using different parameters including: i) price, ii) effect on soil structure, iii) soil cover, iv) provision of N and v) N capture. Farmers use catch crops for different purposes, including grazing, biogas and less fertiliser next year. Farmers find Danish environmental regulations discouraging for experimentation with mixed catch crops. Biomass cuts showed very different catch crop mixture yields between farms.	Farmers and researchers agreed that the differences in biomass production of catch crop mixture were due to variations in: i) precipitation, ii) sowing date, iii) local availability of nutrients and iv) previous use of pesticides. Farmers designed very diverse rotations using different intercropping principles through researcher-developed gaming activity, however still taking many factors into account (logistics, market etc.). Selected mixtures for farmers' own on-farm testing differed from those in the game fitting into their current rotation. However, not all farmers managed to carry out these on-farm experiments.	Some of F11's objectives were met and others were not (e.g. LER values). Farmers suggested a test of fertiliser strategies in plots next year. F15's lack of success due to pesticide strategy problems. Experiments triggered discussion about machinery.	New machinery might help farmers use species mixtures. F2 inspired other farmers to modify their own equipment to meet the challenges of species mixture cropping. Farmers with pigs can easily use species mixtures on their farms. Plant producers still need to find ways of e.g. sorting and selling. Farmers are dependent on cash crop market prices, defining the level of rotation crop diversity. More self-sufficiency and processing is attractive to some of the farmers, but many are specialised in specific cropping strategies and have single crop high-price contracts.	Retailers were not as reluctant about receiving mixed fractions as farmers had experienced. However, retailers require large volumes of mixed grains.	Farmers are still sceptical about high volumes for retailers. Most of the farmers are not ready to take the risk of growing large areas of species mixtures without specific contracts. Supplying retailers with species mixtures will require local cooperation, which is not well established. Farmers are not keen on establishing pilot projects with local retailers. Many perceived barriers remained the same but some were reformulated or nuanced. Farmers ranked the barriers in order of importance: 1) market-related, 2) technical/agronomic, 3) knowledge-related and political/institutional, 4) logistical, 5) cultural/social and financial. The participating farmers find it difficult to be innovative. The establishment of the group is felt as a support and safe space for exploring innovations and farmers want to continue the group with some kind of facilitation.

researchers compiled a list of barriers to the use of species mixtures as *perceived* by farmers at the time of the first interview (Materials and Methods, 2.3). The list of barriers (Table 4) was presented to the farmers at the first collective meeting (Activity III), and was subsequently revisited and revised after two growing seasons (Activity VII) to evaluate the progress of the research process (cf. Fig. 1).

Some of the barriers (B1-6) were related to management in the field that farmers had either already experienced or could imagine. However, apart from the more technical challenges, the lack of knowledge (B30) and advice (B31) as well as difficulties in selling mixed fractions on the market (B13) were also mentioned by most farmers. Some of the barriers, such as B10, B12, B19 and B21, revealed to the researchers the difficulties of introducing new practices due to limited time or financial leeway for experimentation, thus presenting a general challenge to farmers when entering a transition process. B22-28 and discussions with farmers (Activity VII) also indicated that most farmers were affected by scepticism from their colleagues and co-workers.

By compiling the list (B29-30) and talking to farmers about their motivations and experiences with species mixtures (Table 1), the researchers were able to confirm that for many of the farmers concrete and local experience was a critical initial step in a transition process. The relevance of on-farm experimentation with catch crop mixtures (Materials and Methods, 2.3) was therefore confirmed as a relevant way of initiating the research process. To boost the social relationship between the researchers and farmers and to discuss and document the individual experiences of using catch crop mixtures (principle #2), the researchers decided to re-visit each farm.

3.2. Activity II: experimenting and evaluating individually

All the farmers except F5 managed to establish the catch crop mixture experiment. F5 explained that he did not establish the catch crop due to a lack of time and available machinery during the busy sowing period (B7). The follow-up individual interviews were conducted in the field while the farmer and researcher were hand-harvesting the mixed catch crops together, giving the researchers a chance to learn about the farmers' ways of evaluating their own crops. Despite having made appointments for the interviews, a few farmers (F1, F6, F8, F13) were unable to attend a full interview owing to urgent farm management tasks. The lack of ability to attend interviews confirmed to the researchers that farmers generally operate under busy and unpredictable working conditions (B7).

The use of mixed catch crops was new to some of the farmers, including some of the species sown, while others had used the same mixture before (Table 1). Several farmers (e.g. F1, F2, F4, F8) had chosen to use other single or mixed catch crops in neighbouring fields for comparison purposes. The farmers explained to the researchers the criteria they used to judge the value of the catch crop mixture. The criteria varied and included the mixture's performance in terms of: i) price, ii) effect on soil structure, iii) soil cover (living roots and competition with weeds), iv) leguminous atmospheric N_2 fixation and additional soil N dynamics (primarily arable farmers, cf. B6), and v) N capture to avoid the risk of autumn-winter nitrate leaching.

F2 used the biomass of the catch crop for his own biogas plant and F13 used it for livestock grazing. The researchers regarded such practices as being beyond the average farmer practice in Denmark of merely following the regulatory aims of catching surplus nutrients to avoid leaching. Most of the farmers left the mixture to die from frost during the winter or terminated the sward with pesticides before spring seeding. A few farmers (e.g. F2) seeded the next spring crop directly into the catch crop using specialised direct drilling machinery. Some farmers (e.g. F9) reduced the amount of fertiliser applied in the next growing season due to the preceding crop effects gained from the catch crop mixture. This idea was later discussed in Activity III.

In the evaluation of the catch crops, several farmers (F2, F3, F4, F7, F8, F9, F11, F12) mentioned that strict Danish environmental

Table 4
List of barriers to the use of species mixtures in Denmark, as perceived by the farmers at the start of the research process (Activity I) and later revised by farmers in Activity VII. The barriers were categorised by the researchers before being presented to the farmers in Activity III. The revisions made in Activity VII are in italics (elaborations or additions) or strikethrough (no longer relevant).

Theme	ID	Barriers
Technical/ agronomic	B1	Different species require different harvesting methods ~~and different harvesting times~~
	B2	Interspecific competition *can* be difficult to control
	B3	Spraying in species mixtures is challenging e.g. *due to the combination of plant families*
	B4	Unpredictable weather makes it hard to establish multiple crops
	B5	Using multiple species at the same time increases the proximity of plant families in rotation, increasing the risk of disease
	B6	Some functionalities of species mixtures might not be needed, e.g. N fixing at a livestock farm with surplus N
Logistical	B7	Lack of capacity on the farm (silo, machinery, labour) or possibilities for drying to obtain the correct storable seed quality
	B8	Need for self-supply of cereals for fodder *due to exchange rate on the market reducing room in the rotation for other species*
	B9	Sorting difficulties (lack of equipment)
Financial	B10	Lack of financial flexibility for experimenting (small scale), due to high investment in seeds ~~and machinery~~, *being time-consuming* etc.
	B11	Time-consuming (and expensive) at full scale due to different treatments, sorting etc.
	B12	~~Not profitable~~*Large volumes needed for species mixtures to be profitable*
Market-related	B13	Difficult to sell mixtures on the current market (sorting is needed *for plant producers*)
	B14	Limited sales promotion and offer of seeds *specifically*
	B15	Not many cash crops on the market, limiting the possible variety of mixtures
	B16	~~Veterinarian recommendation (e.g. correct composition between species)~~*Soy is so cheap that the cost price of home-grown protein cannot compete,* which limits livestock farmers' use of local protein crops
	B17	Grains/seeds for breeding contracts need to comply with high purity standards that are difficult to achieve in sorted mixtures
Political/ institutional	B18	Strict regulations reduce the possibility of managing fields according to local needs
	B19	No political support or reward for working with species mixtures
	B20	Template for reporting fertiliser application for EU does not allow for registration of more than one species
	B21	Lack of focus on species mixtures in extension service and national on-farm experiments
Cultural/social	B22	Judged harshly by colleagues if you differ from the norm
	B23	Average age of farm owners hinders innovation in the sector
	B24	Actors in the sector require evidence before implementing/supporting new innovations
	B25	Species mixtures require farmers to have a new mindset
	B26	Lack of interest among farmers (incl. attitudes, ideology, conservatism and habits)
	B27	Conservative education system and advisory service (both agricultural schools and universities place a great focus on productivity alone)
	B28	Catch crops' reputation among farmers as "harassment crops"
Knowledge-related	B29	Uncertainty about the impacts/effects of species mixtures
	B30	Lack of experience of and knowledge about mixtures (e.g. *what mixtures work for what purpose, what varieties work in mixtures*)
	B31	Lack of concrete advice and guidance
	B32	Lack of inspiration and ideas (e.g. *in Danish farmers' experience)*

regulations discourage farmers from experimenting with catch crop mixtures (B18-19; cf. Activity I). The regulations require 10–14% of farmers' fields to be covered with catch crops in the winter season (September-March), linked to a number of other regulations associated with fertiliser application. Currently, farmers can only use mixtures of brassica and grass species. The farmers stated that the limited amount of permitted species in the obligatory catch crops prevents them from using ecosystem functions and services, such as the atmospheric N_2-fixation ability of leguminous species (B28), due to arguments of increasing leaching risks of nitrate (water framework approach). However, it is possible to apply for a voluntarily scheme to decrease N loads through mixed catch crops with legumes (e.g. F8, F11). However, the obligatory catch crops are always established first, which creates time pressures on voluntary catch crop establishment in what can be wet autumn months (B7).

The time-consuming hand-harvest of the catch crops encouraged the farmers to articulate their judgements about species mixture performance and responses to field-specific temporal and spatial variability in growth resources, as shown for example by single species dominance (e.g. F12, F13, F14), species complementarity (e.g. F1, F7), interspecific competitive interactions with grass soil N uptake and legume atmospheric N_2-fixation ability (e.g. F2, F11) etc. At the same time, the second individual interview raised topics such as financial constraints (e.g. F6, F12), decreasing prices for traditional cereal crops (e.g. F6), the environmental cost of inputs (e.g. F9), and other social and economic factors influencing the overall farm household system.

During the second visit, farmers expressed great interest in continuing the research collaboration as well as meeting other farmers and learning from their experiences. Thus, experiencing rather different catch crop mixture yields in farmers' fields encouraged the researchers to focus on the differences between farms to stimulate a discussion about contextual conditions.

3.3. Activity III: sharing experiences and inspiration

At the first collective meeting, the researchers presented the list of barriers (Table 4) that had been compiled for the farmers (Materials and Methods, 2.3). The farmers accepted the categories, but were taken aback by the length of the list, as not all the farmers recognised all of the barriers from their own experience.

The results of the individual catch crop mixture harvested were analysed before the meeting by the researchers comparing average dry matter production on each farm (Fig. 3), indicating distinct local variations in precipitation and biophysical conditions in such a small country as Denmark (Table 2). However, linking the differences in dry matter production with issues raised by the farmers during the second interviews (see 3.2) also indicated the potential impact of farmers' management skills, such as timely seeding at a busy time of the year, as well as the impact of soil quality and access to appropriate machinery.

At the meeting, the farmers were asked to share their analysis and they agreed that the differences in biomass production were due to variations in: i) precipitation, ii) sowing date (Fig. 3), iii) local availability of nutrients (due to a drought in the summer of 2018, farmers assumed a high concentration of available nitrate for the catch crop), and iv) previous use of pesticides possibly reducing the growth of some species. The researchers supported the farmers' analysis with explanations about species mixture functionalities. Lacy phacelia dominated the mixture on all farms except F10, where the catch crop mixture was erroneously mixed with oilseed radish, thus exemplifying interspecific competition. The farmers emphasised how the mixture responded to their specific annual spatial and temporal conditions, discussing the possibilities of achieving the same biomass production in other years by taking advantage of the abilities of other species (emphasising the potential of species mixtures to compensate for unpredictable weather (B4)). The farmers also mentioned the fact that the distribution of species varied during the growing season, questioning the researchers' proposal to evaluate the mixture with just one biomass cut. The sowing dates varied from 29 July (F14) to 23 August (F4) (Fig. 3), suggesting a clear effect on biomass production (F14 = 489 g DM m^{-2} and F4 = 182 g DM m^{-2}). However, some farmers (e.g. F8) indicated that they did not have machinery or labour available at the optimum time for sowing (B7), which was as early as possible after harvesting the main crop. F2 suggested machinery for easy harvesting in order to be able to sow catch crops earlier (see Activity V).

During the initial interview, F15 explained to the researchers that he systematically used species functionalities, such as leguminous atmospheric N_2- fixation, deep rooting, slowly degradable root and stubble material, diversity promotions etc., to design the functions and services of his catch crop mixtures. Inspired by this approach, the researchers designed an applied game (Materials and Methods, 2.3). In groups of

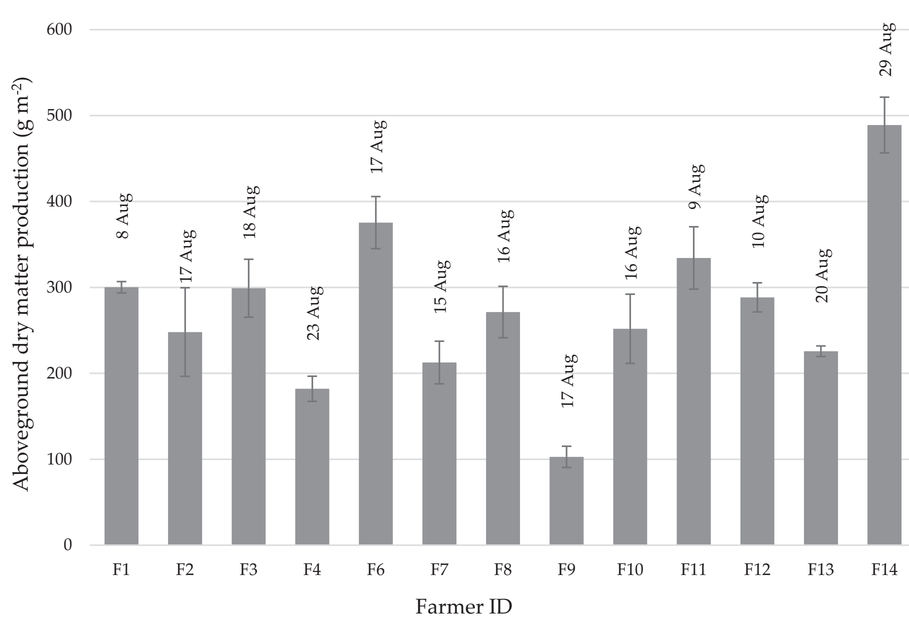

Fig. 3. Aboveground catch crop species mixture (6 species) dry matter production (g m^{-2}) on 13 farms (F5 was unable to establish the catch crop mixture) (for additional farmer information, see Table 2). Sowing dates above the columns.

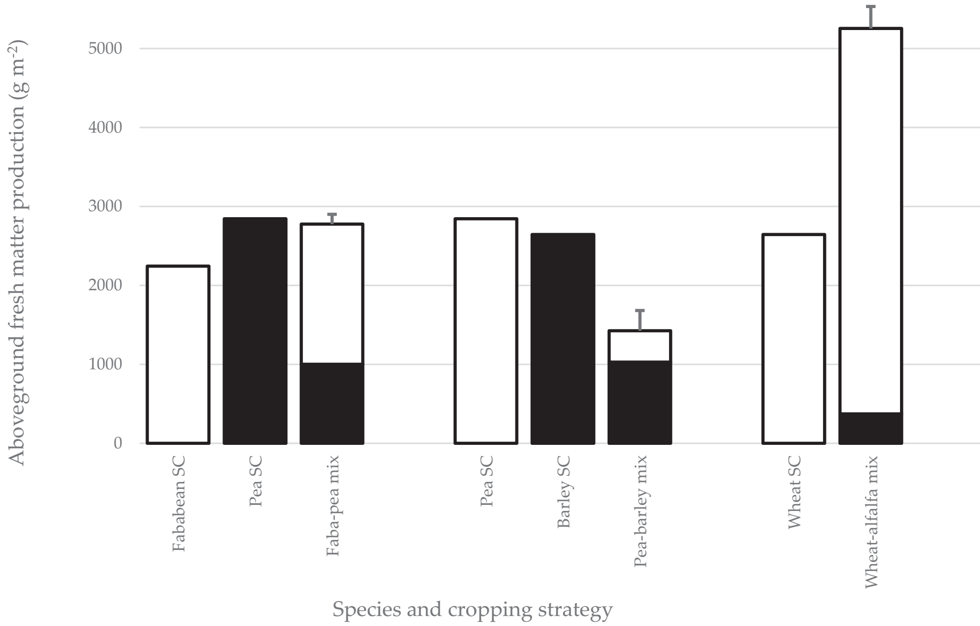

Fig. 4. Aboveground fresh biomass production (g m^{-2}) in the three F11 species mixture (MIX) experiments (see Table 7; for further about F11 see Table 1) compared with sole crop (SC). Alfalfa SC is missing from the figure as F11 did not establish this on the farm. The species and cropping strategies are illustrated by open columns equivalent to one species and closed columns equivalent to the other. The species mix are illustrated as stacked columns including the respective SC colours. Error bars (S.E., $N = 3$) are missing for SC as limited time only allowed for one biomass cut of each SC.

three or four, the farmers designed diverse four-year rotations of mixed cash and catch crops using species functionalities to reduce the risk of disease, secure plant cover and improve soil quality and yield stability etc. (Table 5).

Table 5 shows the fictive rotations designed by the farmers. In a plenary session, each group explained the arguments for the rotations they designed, with clearly different starting points. Group 1 used the existing rotation of one of the farmers, adding diversity through companion and catch crops; in Group 2 each farmer chose one cash crop following the joint development of the rotation, adding catch crops and companion crops; finally Group 3 wanted to include high-value crops with optimised diversity in the rotation (Table 5). Common to all the groups was the use of cash crops as the starting point for the design process. All the groups also took the required machinery, spraying, selling, costs (time, money), risks (diseases, pests), sorting etc. into consideration when discussing species functionalities and interspecific competitive interactions. Weaknesses, ideas for improvements and potential risks, including the risk of snails in constant plant cover (Group 1) (later discussed in Activity V), were raised, as well as the drawbacks of late seeding of wheat (Group 2) (as experienced in mixed catch crops, see Activity III), difficulties in separating lentils and spinach (B9), and the risk of transferring disease between rapeseed and spinach (Group 3) (B5).

At the end of the meeting, the researchers asked the farmers to select one or more new or already known mixtures that they would like to try out on their own farm the next season (Table 6). Some farmers were using mixtures they had tried before (e.g. pea and barley), but added one more species (e.g. F7). The researchers noticed that the mixtures that farmers chose for their own on-farm experimentation deviated from those designed in the applied game, but also that novel ideas were adopted, such as undersowing catch crop mixtures in the main crop (e.g. F2) and dual cash crop mixtures (e.g. F4).

Five out of eight farmers (F2, F4, F7, F11, F15) managed to establish one or more experiments of mixed cash crops and cash crops with

Table 5
Four-year rotations designed by the farmers to offer the greatest possible diversity and enhance the use of species mixture functionalities. The result of the farmers' group work in the applied game developed by the researchers.

Group	1st year	Catch crops	2nd year	Catch crops	3rd year	Catch crops	4th year	Catch crops
1	Rapeseed (*Brassica napus*)	Winter vetch (*Vicia villosa*); common bird's-foot trefoil (*Lotus corniculatus*)	Wheat (*Triticum aestivum*); white clover (*Trifolium repens*)	White clover; pea (*Pisum sativum*); serradella (*Ornithopus sativus*); summer vetch (*Vicia sativa*); Egyptian clover (*Trifolium alexandrinum*); lacy phacelia (*Phacelia tanacetifolia*); rye (*Secale cereal*); oilseed radish (*Raphanus sativus* var. oleiformis); buckwheat (*Fagopyrum esculentum*)	Spring barley (*Hordeum vulgare*); field pea; crimson clover (*Trifolium incarnatum*)	Crimson clover	Winter barley; common bird's-foot trefoil; crimson clover	Common bird's-foot trefoil; crimson clover
2	Barley; field pea	Crimson clover; serradella	Rapeseed; white clover; lacy phacelia	White clover; lacy phacelia; oilseed radish; buckwheat; vetch	Spring wheat	Vetch; buckwheat; lacy phacelia; oilseed radish; sunflower; crimson clover	Barley; tall fescue (*Festuca arundinacea*)	Tall fescue
3	Spinach (*Spinacia oleracea*); lentil (*Lens culinaris*)	Vetch; lacy phacelia; buckwheat; oilseed radish	Wheat; field pea	Red clover	Rapeseed; red clover (*Trifolium pratense*)	Red clover; buckwheat	Ryegrass (*Lolium perenne*)	Field pea; vetch

Table 6
Farmers' choice of on-farm species mixture experiments in 2019 for the next spring season, decided during Activity III. Experiments ultimately not established are in italics.

Farmer ID	Species mixtures for on-farm experiments 2019
F1	*Spring barley (Hordeum vulgare) + field pea (Pisum sativum)*
F2	*Spring barley + field pea + undersowing red fescue (Festuca rubra)*
	Spring wheat (*Triticum aestivum*) + undersown clover (*Trifolium*)
	Oat (Avena sativa) + lacy phacelia (Phacelia tanacetifolia) + oilseed radish (Raphanus sativus var. oleiformis)
F3	*Spring barley + crimson clover (Trifolium incarnatum)*
	Winter rapeseed (Brassica napus) + vetch (Vicia sativa) + crimson clover
F4	Spring wheat + fababean (*Vicia faba*)
F7	Spring barley + field pea + crimson clover
F11	Spring barley + field pea
	Spring wheat + fababean
	Fababean + field pea
	Fababean + undersowing tall fescue (Festuca arundinacea)
F12	*Spring barley + field pea*
	Spring barley + serradelle (Ornithopus sativus)
	Field pea + blue grass (Poa pratensis)
F15	Spring barley + field pea
	Spring wheat + fababean
	Spring rapeseed + spring barley
	Quinoa (*Chenopodium quinoa*) + crimson clover

companion crops. During follow-up telephone calls, the farmers who did not establish their intended experiment(s) (F1, F3, F12) explained that this was due to unforeseen constraints regarding, for example, available time, the availability of seeds (delivery delays) and prioritisation (even a small plot takes time) in a busy sowing period with very limited and unpredictable time slots due to variable weather conditions (B4, B7). Furthermore, some farmers adjusted their original plans (F2, F4, F11, F15) because new ideas and possibilities emerged in the period between Activity III and sowing.

In order to supplement the researcher-designed activities with more hands-on activities and observation of species mixtures in the field (Materials and Methods, 2.3), the farmers and researchers decided to visit F11 to see the results of his experiments (Table 6).

3.4. Activity IV: evaluating jointly in the field

F11 (father and son) have a strong tradition of smaller plot experimentations. For this activity, they experimented with pea + spring barley, fababean + pea and winter wheat + perennial alfalfa (*Medicago sativa*) as a permanent living mulch in a cereal cash crop rotation (Table 7). The researchers decided that farmers should evaluate the experiments based on F11's own objectives. F11 introduced the objectives of the experiments and the farmers were randomly divided into groups to evaluate each of the experiments using $3x1m^2$ biomass cuts, as in their own catch crop experiments (Activity II). F11's objective was, among others, to achieve a land equivalent ratio (LER) value above 1 in the mixtures[1] (Table 7). LER calculations (sum of the fractions of the intercropped yields divided by the respective sole-crop yields) were used by the researchers to determine the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level (Willey, 1979). Furthermore, the farmers were asked to undertake a qualitative evaluation as to whether the mixtures met F11's more qualitative objectives (Table 7).

After hand-harvesting in the field, the group gathered in the farmyard to weigh the samples so as to be able to perform the LER calculations. Plenary discussions were initiated based on the farmer group's

[1] F11's son studied agronomy and therefore was familiar with LER as a way of evaluating the performance of species mixtures. LER is defined as the relative land area under sole crops that is required to produce the yields achieved when the same species are used in a species mixture.

Table 7
Presentation of the species mixtures strategy, objectives and establishment for the three experiments presented at F11.

Strategy (researcher description)	Objective(s) (formulated by F11)	Establishment (decided and managed by F11)
Pea + barley *A classic mixture in Denmark for fodder*	LER-value >1 To achieve complementarity between peas and barley. To test if it is possible to sort the mixture in a purity that allows barley to be sold as malt.	60% of normal sowing density of spring barley and 60% of normal sowing density of pea in a pure stand. Problems with germination so the experiment was re-established. Different sowing dates between mixture and sole crop hindered LER calculation.
Fababean + pea *Strategy to maximise protein production/ha*	LER-value >1 To achieve complementarity between peas and beans.	60–65% faba bean and 60–65% pea of pure stand. The mixture was established successfully.
Wheat + alfalfa *Strategy to secure permanent plant cover and use all possible sunlight*	To achieve a normal yield for wheat with a strong alfalfa mulch ready to function as a catch crop when wheat is harvested and before the next cash crop.	125% wheat of a pure stand sown in living mulch. Alfalfa was not established in a pure stand, so no LER calculation. Low dose of herbicide application (130 g/ha instead of 220 g/ha) to control alfalfa competition with the wheat.

evaluations where farmers found it difficult to achieve the pea + barley objectives (Table 7) due to a late sowing date, possibly even making combine harvesting impossible. They also found that the limited barley tillering observed due to late sowing would influence the yield, without compensation from pea due to the sowing density being too low. In contrast, the fababean + pea mixture was judged to be very successful and as meeting F11's objectives. The pesticide strategy to secure wheat growth in a permanent alfalfa sward appeared to work, securing a competitive wheat yield compared with the average pure stand. Some farmers suggested a test of fertiliser strategies in plots the next year to find out more about interspecific wheat-alfalfa competitive interactions, and how they affect the final wheat yield and quality. F11 informed the group that a decision had been made to advance the experiments the following year using a mixture of four wheat cultivars to increase spatial and temporal diversity in the field and thus yield stability (Fig. 4).

The visit showed the farmers and researchers that the pesticide strategy in the wheat + alfalfa mixture was an innovative solution to control interspecific competition (B2). F7 adopted the strategy of controlling mixtures with herbicides the following season (perennial clover in pea + barley).

At the meeting, F15 shared his experience (see experiments in Table 6) using herbicides to control heavy weed infestation levels in cereal-legume species mixtures. This resulted in more or less cereal sole cropping, in contrast to his pre-season strategy. Despite the fact that the experiment had not succeeded as planned, F15 reported that he observed that the cereal sole crops were able to fill the space left by weeds and legumes, thus producing a similar yield to other sole cropped cereal fields, possibly also supported by a very successful preceding mixed catch crop. The pesticide strategy was a matter of great concern to several of the farmers (B3) and therefore the researchers suggested, and the farmers agreed, that this should be one of the themes of the summer 2020 meeting (which was due to take place after this paper was written) hosted by F15. The reason for visiting F15 was that farmers were keen to see his renovated on-farm sorting equipment for species mixtures (B9).

F11's different experiments triggered a number of discussions about technical issues with machinery (B1, B7) and trading (B11-17) throughout the day. A decision was taken at the end of the meeting to focus on more logistical issues at the next meeting hosted by F2. F2 was considering investing in new machinery to ease the seeding of several species using the same sowing equipment, as well as harvesting to secure the undersown crop mixture.

3.5. Activity V: investigating management possibilities

F2 is one of the older and most experienced arable farmers in the group and manages a large farm (Table 1). He played a central role in encouraging a constructive dialogue within the group, both supporting and correcting younger members (e.g. F15 and F11's son). F2 produces seeds and other high-value main crops on contracts, limiting the possibilities of including species mixtures in his rotation (B17). Instead he is experimenting with early sowing of catch crops within the main crop to improve soil cover and ensure living roots to feed the soil microbial biomass all year round.

One of the aims of the visit was to see the results of a new stripper header for the combine harvester that is able just to remove the grains, leaving the stem standing, to speed up combine harvester capacity while giving space to a higher-growing catch crop. However, F2 was not satisfied with the stripper header because it was losing too much grain on the field. After harvesting 5–10 ha, he reverted to the normal combine harvester strategies on the farm. Nevertheless, F2 expected other stripper headers on the market to perform better, and indicated to the other farmers that the catch crop in the fields with high stubble performed best. This field was not visited because of its distance from the farm. The farmers were eager to discuss more about how to set their header or invest in a new stripper header in line with F2's ambition. The farmers also found the solution attractive for species with different heights ripening at different times (B1). This would solve logistical and economic constraints regarding sorting (B9, B13), but would also involve harvesting twice, with the ensuing high costs of machinery and labour (B10). In addition, the farmers emphasised that the varieties of species mixtures needed other qualities than when they were used as sole crops, such as stem height and standing ability. F4 explained to the others that he was already mixing different varieties of barley with pea to gain more knowledge and understanding of barley's ability to support pea climbing without lodging.

The group inspected a new sowing machine that is able to seed more than one species to different depths. F2 explained that he found the speed of seeding and the accurate seed positioning at specific depths impressive. F2's specific sowing machine was too expensive for many of the farmers, but the principles behind it inspired them to modify their own equipment (e.g. F4, F12).

Apart from machinery, the researchers suggested discussing the sales possibilities of species mixtures. The researchers saw an opportunity to discuss the barriers related to selling as the farm is divided into separate branches of arable farming, pig production and a biogas plant (Table 1). The combination of farm activities allows F2 to sell fodder directly to the pig production branch, avoiding requirements for separation (B13). With this option available, F2 explained that his colleagues preferred the composition of amino acids in fababean protein over imported soy for piglet feed, allowing the typical cereal-dominated rotation to be improved with grain legumes. However, soy is sometimes so cheap that even the cost price of home-grown protein cannot compete and therefore F2 often sell peas or fababeans to retailers. F4 had the same experience. In contrast to farmers' experience of veterinarians' feed advice (B16), F2 has not had a problem using unsorted mixtures for fodder, which was also confirmed by F4. However, both F2 and F4 explained that protein crops are typically more profitable to buy than home-produced cereals (B8). These observations highlight the farmers' dependency on the market prices of cash crops, thus limiting the opportunity to design rotations based on ecosystem functions and services (as intended in the applied game, Activity III).

The researchers suggested to the farmers that a more self-sufficient farming system (e.g. their own fodder production (F2, F4), a biogas plant to make energy and alternative fertilisers (anaerobic digestate) (F2) and sorting equipment (F8, F2, F15)) might reduce the risk and increase their willingness and opportunities to experiment with more diverse crop rotation, including the use of species mixtures. Compared with the younger farmers in the group, the researchers observed a greater reluctance among the older farmers to challenge the current structure of their farming system, possibly influenced by specialisation training throughout their carrier with typical single crop high-price retailer contracts. This is combined with a general experience articulated by the farmers of very few support functions around input supply (B14), financial services (B19), promotion (B15) and advisory services about species mixtures (B21, B27, B29-32). Nevertheless, in a discussion about the theme of the following activity, the farmers stated that some of the main barriers remained around collection, processing, wholesaling and retailing (B7, B9, B11-17). The farmers were critical of how to link species mixture practices, especially for mixed cash crops, with the current specialised market structures and traditions. The researchers suggested inviting other actors in the value chain to meet and discuss with the group. However, the farmers wanted the researchers to contact retailers to understand more about their expected reluctance to receive species mixtures (B13) and discuss opportunities for retailers to support species mixture practices.

3.6. Activity VI: discussing market possibilities

To address the challenging economic barriers farmers faced in producing species mixtures connected to their sale, including possible separation (and purification) requirements, the farmers suggested specific retailers for the researchers to contact, two of whom responded positively. Two meetings were held between the researchers and i) the association of Danish food and feed retailers (DAKOFO, www.dakofo.dk) and ii) a key high-end cereal buyer on the Danish market (Viking Malt, www.vikingmalt.com) to confront them with the farmers' perceptions as well as discuss possible ways to overcome the current barriers for farmers' use of species mixtures.

DAKOFO explained that they do not see a problem with retailers receiving mixed fractions. However, the supply quantities are currently too small and geographically spread out, making it less attractive in a sector heavily determined by logistics in which large volumes are expected (B12). Despite acknowledged lock-ins with some retailers, DAKOFO suggested that receiving mixed fractions might become relevant for their members as a way of increasing the sustainability and local production of legumes, which are currently important political issues that their members will probably have to address in the near future. It could be voluntarily or in the form of regulatory incentives in the longer term (challenging B19). It was suggested that pilot projects be run with local retailers and farmers to explore the opportunities of this.

Viking Malt is a company representing the food service and potential future markets. They find species mixture attractive from the perspective of corporate social responsibility, including food safety, product quality and sustainability in the supply chain possibly fulfilled by ecosystem functions and service requirements provided by species mixtures. They anticipate that they will need to be able to maintain protein accounting comparable to the CO_2 accounting that is now imposed on companies in view of the need to reduce meat intake to feed a growing world population. Such accounting will make receiving barley for malt mixed with legumes an attractive proposition. Furthermore, as beer is a luxury, they are considering producing new ingredients for food. Plant protein might also be of interest here and is already being considered by the R&D department as a profitable food ingredient.

At the meetings, it appeared to researchers that the retailers were not expressing the same reluctance about receiving mixed fractions that the farmers were experiencing in their local social and economic contexts (B13). The researchers therefore invited the farmers to meet at the university to discuss the retailer's perceptions and review the status of the research process.

3.7. Activity VII: taking stock and planning future work

The starting point for the meeting was a report from the researchers to the farmers about the open attitudes of value-chain players with regard to both the logistics and sustainability parameters of receiving species mixtures from farmers. The farmers were interested in their open attitude, but sceptical about the circumstances (price, flexibility etc.) including, for example, the high price of sorting. F12 related his conversation with a local retailer who requires at least 50 t in order to offer a good price on sorting, a quantity he is unable to deliver on his own (B12). This means that farmers need to coordinate with other local farmers. Several of the farmers highlighted the history of Danish farmers' ability to create new cooperative structures and capacities through multiple and locally embedded stakeholders. However, the group agreed that specialised farms and a more independent and competitive environment make a potential collaboration of this kind challenging (B25-26). None of the farmers were particularly keen on initiating a pilot project by themselves, indicating to the researchers that they are still experimenting to make it work at field scale.

Triggered by the update between the researchers and farmers (Materials and Methods, 2.3), the group had a lengthy discussion about co-workers questioning their innovative ideas, as had been the experience of F9. Some found it inspiring, while others found it difficult. Several farmers said that it was hard to be innovative due to social pressure from both co-workers and colleagues (B22-28). The farmers explained that one of the main benefits of the group was their mutual understanding (of being different/innovative), creating a space for an exchange of ideas and acknowledgement.

After confronting several of the barriers that had initially been identified, including knowledge and experience (III and IV) and machinery and selling (V and VI), and as the research process was drawing to a close, the researchers suggested taking stock of the research process to clarify how it had led to a revised diagnosis of the barriers and how the group can progress (Fig. 1; Materials and Methods, 2.3). Looking at the original list of barriers, the farmers found some of them were less relevant and others were reformulated or nuanced (Table 4). For example, some of the farmers perceived different ripening times between species in mixtures (B1) as a barrier at the start of the research process. However, after gaining personal experience through on-farm testing, demonstrations (Activity IV) and discussing management possibilities (Activity V), the farmers no longer perceived this to be a major barrier to the use of species mixtures. Initially, the farmers also perceived it to be difficult to sell species mixtures on the market (B13). The farmers still perceived this as a barrier, but acknowledged the specific market opportunities among pig producers (Activity V) and the potential openness among retailers (Activity VI). The farmers were also asked to prioritise what category of barriers the group could and should work on in the future. They prioritised (with two votes each) the categories in the following order

1. *Market-related* (6 votes)
2. *Technical/agronomic* (5 votes)
3. *Knowledge-related* (4 votes) and *political/institutional* (4 votes)
4. *Logistical* (1 vote)
5. *Cultural/social* (0 votes) and *financial* (0 votes)

The researchers did not anticipate the revision of barriers to be as time-consuming as it turned out due to the farmers' discussions and reflections. Due to the limited time available, the farmers and researchers did not manage to discuss in greater depth which specific barriers under each category to address first and how. However, the list of barriers could be used as guideline for future work with the group. The farmers expressed their willingness to continue when the researcher facilitation ended. However, they expressed a need for someone to facilitate the group.

4. Discussion

This section comprises a discussion of the insights the researchers gained into the farmers' possible use of species mixtures, the key features considered useful in the methodological approach, and the new roles that the participatory approach requires of both participants and researchers. Finally, there is a reflection on whether such participatory research process can encourage transitions towards new sustainable farming practices.

4.1. Farmers' possible use of species mixtures

During the individual interviews (Activity I and II) and plenary discussions (e.g. applied game Activity III), the farmers' concerns about future sustainable farming practices became apparent. They were embedded in issues such as how to design cropping strategies to improve soil health (e.g. water percolation holding capacity), nutrient dynamics to meet crop demands in time and space, as well as restrictions on pesticide use demanding increased use of nature's own regulatory mechanisms (Brooker et al., 2015; Hauggaard-Nielsen et al., 2008; Jensen et al., 2020). The discussions indicated to the researchers that the farmers were interested in the potential beneficial ecosystem functions and services of species mixtures (Altieri, 1999) exerting a greater effect than sole crops due to complementary interspecific interactions (Malézieux et al., 2009). The farmers' focus on soil functions etc. might be related to their common interest in CA (Table 1), but underlines an acknowledgement of a general decline in natural soil fertility and the urgent need to change practices (Taghizadeh-Toosi et al., 2014). One of the more experienced farmers (F9) said from the outset (Activity I) that significant change lies ahead and that current cropping strategies cannot continue as they are, thus acknowledging the need for farmers to increasingly integrate stewardship of land and natural resource management in their farming systems.

Jointly and individually, the farmers identified different strategies to adopt principles of species mixtures. The group concluded that farmers with pig production in particular can use species mixtures for their own fodder production while benefitting from improved soil health and other ecosystem services in the field (Activity V). This strategy was adopted by F4, for example, experimenting with different mixtures of cereals and legumes (e.g. Table 6) and sharing his experiences through the WhatsApp group. For farmers with arable farming, selling, separation and purification were articulated as issues still to be resolved (Activity V). Nevertheless, several arable farmers conducted experiments on species combinations and relative proportion optimisation (e.g. F11 Activity IV) as well as testing (and buying) equipment for separation (e.g. F15, Activity V). Other farmers were more interested in the services provided through companion crops, e.g. undersowing to improve the quality of the main crop and support soil functions and services (e.g. F2, Activity V) as well as finding new ways to adopt equipment (Activity V) to implement new farming practices in their individual farming systems (Salembier et al., 2020). The different strategies exemplify the inevitable translation into the farmers' own context depending on local possibilities, personalities, economy, ambitions etc. (Darnhofer et al., 2009).

Despite the farmers' interest, the research process also showed that species mixtures clearly present challenges to farmers across their different farm structures, experiences and opportunities for progression (Table 1). The barriers articulated by farmers (Table 4) are not just agronomic but cover structural, cultural and social constraints as well as. The demand for large production volumes in the value chain (Activity VI and VII) is an example of how the structure of the agricultural sector presents a challenge to individual farmers' gradual transition towards new practices. Likewise, the fact that legumes may not be used as an obligatory catch crop makes diverse catch crop mixtures less attractive to the farmers, indicating the adverse effects of national and European regulation (B28). The stated importance of safe spaces to discuss experiences and questions about alternative practices (Activity

VII) also highlights the social aspects of a transition process.

The research process confirmed already known challenges presented by the implementation of species mixtures, such as “availability of improved varieties and methods of plant protection” (Activity V; B3 and B5), “complexity of the knowledge to be acquired by farmers” (B29-32), “logistical constraints to harvest collection” (B1, B7 and B9; Activity V) and “difficulties of coordination within the emerging value chains” (B13-17, Activity VI and VII) (Meynard et al., 2018). The researchers also learned that understanding and using nature’s own regulatory mechanisms to increase yield stability (Raseduzzaman and Jensen, 2017) is a new concept for the majority of the participating farmers. Despite their engagement and interest in the potential of species mixtures, these farmers are, as expected, engaged in cereal-rich rotations that are currently dominant and embedded in a mechanised, intensified and specialised agricultural paradigm driven by both (post-war) policy objectives and advancing technology (Matson, 1997; Robinson and Sutherland, 2002). For example, the research revealed the difficult leap from the conventional paradigm and method of “fixing” problems with pesticides to a completely different system approach using species complementary and competitive regulatory mechanisms to reduce weeds as well as pest and disease challenges (F15; Activity IV). Several farmers were concerned about remediation of the soil weed seed pools if herbicides were not used, underlining the fact that changing to a system with a new management logic includes risk assessments. Being able to make such assessments requires several years of adaptation and experience, including the associated challenges, learnings and failures (B10). Thus this study confirms the need (for researchers, politicians, society, farmers etc.) to understand that changing agricultural practices is a complex task and might require changes in many parts of society simultaneously in order to achieve sustainable farming systems (Gliessman et al., 2019).

4.2. Key features of the participatory approach

This subsection evaluates the methodological principles used (Materials and Methods, 2.1) and other key conditions identified to ensure farmers’ learning and engagement in exploring the opportunities for the use of species mixtures.

Firstly, the dynamic organisation of activities in response to upcoming considerations among participants (principle #1) was successfully implemented in the sense that farmers were actively engaged in planning the research activities by taking decisions, raising questions to be explored and hosting the activities (F2, F11 and F15). The farmers’ engagement in the research process, as well as their interest in continuing after the research project ended (Activity VII), indicated that the activities were relevant for the individual farmer and provided rich and valid information about possible implementations (e.g. Activity IV). As put forward by (Millar and Curtis, 1997), the gradual transition from passive to active learning stimulated by involvement in the facilitation of a peer environment gave the farmers the ability to recognise the range of knowledge, experience and skills within the group (e.g. Activity III and IV) and confirmed the group’s potential to hold field days, meetings and the like without necessarily being strictly managed by outside experts (e.g. Activity IV and V). Furthermore, the work with barriers (Activity III and VII) proved useful as a way of challenging the current lock-ins of farmers’ practices. According to Bos et al. (2009), “deliberation requires that institutionally and technologically embedded assumptions, norms, knowledge claims, distinctions, roles and identities that are normally taken for granted must now be critically scrutinized”. It is hard to tell whether the experiences of overcoming some of the perceived barriers (Table 4) fostered such deliberation. Some farmers demonstrated difficulties in challenging the overall structure of current farm practices and markets (e.g. Activity V), while the younger farmers in particular showed continuous or increased engagement in finding new ways of farming (e.g. F4’s local protein production, Activity V, and F15’s renovated on-farm sorting equipment, Activity IV).

Secondly, the researchers aimed to create acknowledgement and stimulation of the individual farmer’s knowledge, experiences and ideas (principle #2), for example by letting the farmers decide individually about management of the experiments (Activity II, IV and V, F15 in Activity IV) and to use the barriers identified by farmers as a guideline for the research process (Materials and Methods, 2.3). Unlike the farmers’ experiences with their colleagues (B22), the group functioned to acknowledge the innovations and alternative practices through on-farm meetings (Activities IV and V) and ongoing communication via WhatsApp for example. The farmers themselves articulated the importance of acknowledgement and mutual understanding within the group (Activity VII) as a contributory factor in creating trust. The creation of trust, e.g. through the two individual visits (principle #1), was also experienced by the researchers as being very beneficial for the participatory process (Koole, 2020; Méndez et al., 2017; Reed et al., 2014). The second farm visit (Activity II) in particular created an informal environment and an invitation to open a dialogue about the farmer’s evaluation and potential increased utilisation of species mixtures (e.g. Danish regulation on obligatory catch crops). The researchers experienced reciprocated trust and acknowledgement as the farmers engaged very actively in all the activities despite the use of what could be assumed to be unfamiliar elements, e.g. discussion of collective barriers and devising fictive rotations (Activity III), which indicated an acceptance of the researchers’ facilitation. The safe space provided allowed farmers to give each other feedback and improve their evaluation skills (Activity IV) and valuable discussions (Activity V) (Reed et al., 2014). Furthermore, the farmers were willing to share their vulnerability, for example by asking questions or sharing doubts, successes and failures with peers and researchers (Kral, 2014; Reed et al., 2014). For example, the group shared the results of their more or less successful catch crop mixture, as well as their individual expertise in the applied game exercise with a group of people they had not previously met (Activity III). The farmers also shared their lack of successful experiments (e.g. F15 in Activity IV) or concerns about social pressure from colleagues and others (e.g. F9 in Activity VII). Their willingness to share their experiences and doubts within the group increased over time, which manifested itself through increased activity in the WhatsApp group, for example. However, despite its importance, too much trust or conformity in a group can also hinder development or lead to “group-think or uncritical environments” resulting in “an adverse effect on learning outcomes”(Koole, 2020). An example of such adverse effects was observed by the researchers, e.g. in the farmers’ reluctance to challenge the overall structure of current farm practices (Activity IV) as well as their lack of interest in meeting retailers for an open dialogue (Activity V).

Thirdly, the research process aimed to bridge thinking and doing through on-farm experimentation and in-field evaluation (principle #3). The relevance of this principle was confirmed when the farmers suggested combining meetings at university with on-farm meetings (Materials and Methods, 2.3). The farmers’ ability to establish on-farm experiments to test different species mixture objectives (e.g. Activities II, III, IV and V; Fig. 3) indicated how farmers can play an active role in the development of cultivation principles (Gliessman et al., 2019) using both technical and social evaluation parameters (Altieri, 2004; Wezel et al., 2018). Several farmers had little or no experience of species mixtures (Table 1), but through the process they either conducted or saw several on-farm experiments of species mixtures, encouraging more qualified decisions on further experimentation, adaptation or rejection of such practices in their own farming systems. This is because, as shown in Fig. 3, farming is real-time management in local conditions (e.g. soil, climate, management), with species mixture practices introduced according to the situated local socio-economic contexts (Activity II). The comprehensive catch crop yield variabilities between the individual farmers (Activity III) demonstrated the need to take farmers’ individual conditions into consideration (principle #2), and illustrated how a comparison of farmers’ experiments (despite not following the same protocol) allowed a constructive dialogue about species mixtures’ functionalities as well as the effect of farm management and local variabilities.

Fourthly, the discussions (e.g. catch crop experiments, Activity III) confirmed the potential of farmer-to-farmer and farmer-researcher knowledge-sharing (principle #4) as a very valuable supplement to *transfer of technology* (Morgan and Murdoch, 2000). As proposed by Vaarst et al. (2007), collective learning can provide ideas for new experiments and farming strategies. For example, the farmers' design of fictive rotations and mixtures that they had never tried before (Activity III) confirmed the potential of the applied game to facilitate thinking outside the box (Materials and Methods, 2.3). A complex holistic pool of knowledge (based on existing experience, knowledge, logics etc.) was activated to create the puzzle, demonstrating that farmer knowledge can be activated and combined by developing novel diverse rotations (Table 5). Based on the evaluation of F11's experiments (Activity IV), some farmers suggested additional experiments for the next year in order to acquire an even better understanding of the interactions of species and possible benefits (e.g. resulting in less need for fertilisation). At the same meeting, F7 was inspired to adopt the strategy of controlling mixtures with herbicides. Finally, in Activity V several farmers were inspired to modify their own equipment based on F2's experiences.

Through this process, the researchers acknowledged that the composition of the group was important for the peer environment created. Most of the farmers actively involved in the group are considered by the researchers to be more innovative (e.g. engaged in CA practices, able to design innovative species mixtures, Tables 5-7) and to have a greater capacity and willingness to change (Activity I) than the average Danish farmer. As mentioned above, the farmers and researchers (Materials and Methods, 2.2) found this shared characteristic to be one of the qualities of the farmer group. However, as noticed by Mendez et al. (2017), differences in age and experience can stimulate peer-learning. Jointly, the farmers identified the high average age of farmers in the sector as possibly hindering innovation (B23). Having little faith in the dominant sole cropping and input-demanding cropping strategies (e.g. F4, F6, F15 and son of F11), the younger farmers in the group were looking for new strategies. In contrast, some of the older farmers (e.g. F2, F8 and F11) were being sceptical about solving the challenges of the sector by introducing species mixtures. Some of these farmers expressed pessimism about institutional pressure on future farming practices, a lack of influence in value chain development, and the often doubtful opinion of business partners (e.g. traders) and neighbours (e.g. Table 4; Activity III). However, the enthusiasm and ideas among the younger farmers stimulated a qualified encouragement of the less experienced farmers in the group (Table 1). For example, F1 was eventually persuaded to try the pea+barley mixture in 2020, inspired by the younger farmers' suggestions (e.g. F4).

A balance between similarities (e.g. innovative and CA farmers) and diversity (e.g. in age and experience) within the group was therefore important to ensure a trustful and stimulating environment while avoiding conformity and uncritical group thinking.

4.3. Playing new roles and managing other ways of knowing

In applying this research approach, it was evident that both the farmers and the researchers needed to participate in the research process in ways that differ from those known from the transfer of technology paradigm. Hazard et al. (2018) claim that both researchers and farmers involved in these processes must leave their comfort zones, indicating an epistemic shift in research.

In the present study, the methodological principles (Materials and Methods, 2.1) invited and allowed farmers to participate actively in the research process, for example by conducting experiments, taking decisions and sharing ideas, knowledge and experiences. The farmers were particularly engaged in the initial experiment (Activity I-II) and in the meetings (Activity III, IV, V and VII), while fewer farmers carried out on-farm experiments after the initial catch crop experiment (Table 6). As on-farm experiments were being targeted (Materials and Methods, 2.1), the effectiveness of self-administrated experiments (principle #3) could be questioned or it could be considered whether the researchers could have supported farmers better, for example by structuring the experiments more like in Activity I. However, the researchers felt that respecting the farmers' resources and needs to initiate on-farm experimentation was an important part of following principles #1 and #2. Furthermore, learning from their peers' experiments might be just as relevant for some farmers (principle #4).

Despite the fact that the farmer group was demonstrating promising autonomous qualities, they articulated a need for facilitation (Activity VII) to keep track of the experiences, for example through evaluation and monitoring, follow-up on WhatsApp communication and facilitation of collective and individual evaluation (Activity II, III, IV and V). For example, the farmers stated that they had issues documenting the experiments (Materials and Methods, 2.3) due to difficulties with remembering the details of the experiments at the end of the season. This merely reinforces the need of both the farmers and the researchers to document the experiments so as to be able to learn from them. The researchers also observed a need to structure the discussions and the progression of the meetings in order to stick to the planned agenda. For example, the revision of the initial barriers (Activity VII) led to multiple discussions that did not necessarily achieve the goal of the revision.

The researchers also observed a divergence between, for example, the mixtures designed in the applied game (Table 5), the individually designed mixtures, and the actual implementation of experiments (Table 6). The difference between farmers' visions, their plans and their actual performance in the field emphasises farmers' ongoing prioritisation of resources, thus highlighting to the researchers the circumstances for the selected research approach. Participatory research is time-consuming and the extent to which people involve themselves in the work is unpredictable (Orlando et al., 2020). In the present case, most of the farmers had involved themselves, but continued engagement is not a given. For example, it was clear that some of the farmers had the intention of participating but either left the group (F5, F10, F13) or became inactive (F6, F14). Most of them explained to the researchers that they did not after all have the resources they had expected during the period in question. The dependency on farmers' active participation in the research process (as opposed to traditional research, e.g. with researcher-defined aims or farmers receiving direct payment for experimental management) challenge the ability to structure a consistent collection of farmer-provided empirical material. This results in a heterogenic pool of empirical materials that are not necessarily ready to be analysed through a predefined analytical framework (Orlando et al., 2020). Moreover, as demonstrated in this paper, extracting findings is also a concurrent participatory process between the researchers and farmers (Materials and Methods, 2.4), challenging the use of a predetermined analytical and conceptual framework (Egmose, 2015).

The researchers' role in these participatory research processes is therefore one of both facilitation and validation e.g. considering scientific documentation and thereby the robustness of the findings (Eikeland, 2006). The researchers need to find a constructive balance between researcher-dominated and jointly managed processes (Westlander, 2006) to follow farmers' needs while challenging farmers' practice and knowledge through researcher interventions and delivering robust conclusions (Lacombe et al., 2018). This requires an explorative approach (Materials and Methods, 2.1) making use of *intuition* because no generic methodological protocol can be used and *reflexivity* to ensure that researchers continue to reflect on the consequences of the choices to draw valuable conclusions as well as methodological experiences (Bradbury, 2015; Davydd and Levin, 2007). Furthermore, the researchers need to be *patient,* accepting farmers' limitations to participate and the complexity of transitions (Méndez et al., 2017) as well as be willing and able to *take risks* because one consequence of the explorative and jointly planned research process is that the outcome cannot be predicted. These are all skills that are not as tangible (and trained in academia) as traditional scientific ones. Insisting on expanding the levels of analysis in the agricultural sciences and exploring sustainable transitions with practitioners (Gibbon, 2012) requires more experience on how to work scientifically using such skills. Valuable inspiration might be drawn from other fields of research in which these skills have a longer tradition.

4.4. What about transitioning?

For farmers who have the resources to participate in a research process of this kind, their involvement might lead to a commitment to adopt novel practices (Lacombe et al., 2018). However, initiating collaboration that *can* lead to change takes time (Méndez et al., 2017) and research projects are not usually funded for a sufficiently long period to observe a real change in farmers' practices (Lacombe et al., 2018). The two-and-a-half-year timespan of the present study is a clear example of that. In the current study, the farmers increased their engagement with species mixtures, but the unanswered question is whether the farmers will adopt the new practice at full scale as integrated management of their cropping system(s).

Swapping green revolution logics (agrochemicals, loss of beneficial biodiversity, reduced soil fertility) for species mixture self-regulation and self-sufficiency (Hauggaard-Nielsen et al., 2008; Willey, 1979) requires multidimensional, interrelated transformations over time (Geels and Kemp, 2007; Vandermeer, 1989). Raising awareness of biological interactions, exchanges of expertise and identification of management strategies by visiting farmer colleagues and being asked questions by researchers from a theoretical perspective are regarded by the authors of this paper as a powerful way of questioning existing strategies and exploring new ones (e.g. Activity III) and as a crucial first step in a robust transition process. Working through properly facilitated farmers' groups (instead of single farmers) might be one way of challenging existing institutional set-ups and actually paving the way for new and innovative ways of farming (Bos et al., 2009; Klerkx et al., 2010). The revision of barriers (Activity VII) might help actors identify power asymmetries in the sector (Vaarst et al., 2007). Inequalities, as well as a lack of trust and transparency between farmers and large agribusinesses, might limit transitions to species mixture cropping despite a possible convergence of interests (Activity VI). Acknowledging these power asymmetries can allow the actors to challenge them, e.g. by becoming more independent (self-sufficiency as discussed in Activity V) or entering into dialogue or negotiation (Activity VI) (Gliessman et al., 2019). The manifold barriers and current lack of collaboration also stress the need for a partnership across the value chain to unlock the potential of an increased use of species mixtures (Meynard et al., 2018).

Apart from supporting farmers in their adoption of more sustainable practices, the current research process has provided valuable insight to research the many reasons why farmers may not have a real commitment to species mixtures (Vanclay, 2004). Many of the barriers (Table 4) need to be addressed outside the farm gate (Aare et al., 2020b), conferring on researchers and other stakeholders an important role in introducing other perspectives and investigating opportunities for increased use of more sustainable farming practices.

5. Conclusions

This paper has presented an in-depth case study of a two-and-a-half-year participatory research process involving 16 farmers and two researchers with the aim of exploring farmers' opportunities to adopt species mixture practices in their individual farming system. Despite differences between the participating farmers, they shared an interest in adopting species mixture practices to improve the ecological and/or economic performance of their farming system. Jointly and individually, the farmers identified different strategies to adopt principles of species mixtures depending on their individual farming strategies and interests, while clearly facing the challenges of integrating new logics and practices into current management strategies dominated by optimisation of inputs and mechanisation according to market demands. The farmers and researchers jointly identified and challenged structural, agronomic and technical barriers, and through on-farm experimentation recognised the potential and limitations of species mixtures adapted to the social and economic context in which the individual farmers operate.

The methodological principles applied by the researchers succeeded in creating engagement among the participating farmers. Acknowledgement and trust created a safe space in which to share successes and failures. On-farm experimentation and group visits to each other's farms were valuable ways for the farmers to discuss species mixture functionalities as well as the effect of on-farm management on local variabilities. Collective learnings stimulated new ideas for experiments and strategies, and farmers' knowledge was activated during the applied game exercise. Based on the experiences from the study, the authors suggest that balancing the similarities and differences between farmers in the group can ensure a trustful and stimulating environment while avoiding conformity and uncritical group thinking. The study found that for the explorative research process to be meaningful and valuable to both the farmers and the researchers, both need to assume new roles. It requires the farmers to be able and willing to invest resources in challenging themselves and documenting their experimentation. Likewise, the researchers need to balance being a facilitator stimulating farmers to move forward in a transition process while at the same time ensuring valuable knowledge production. This requires numerous skills including new ones not traditionally valued in agricultural sciences.

From this study, it is hard to determine whether participation in a research process of this kind will lead to permanent change in farming practices. However, the authors believe that it can be an important first step in a robust transition process, for example by challenging power asymmetries in the sector and other barriers. The study shows that a change in farmers' cropping practices is not hampered solely by technical issues or a lack of knowledge, but rather requires changes in many parts of society, indicating that researchers need to look beyond the farm gate and involve other actors to unlock the potential of an increased use of species mixtures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the farmers participating in ReMIX for being involved in the project and for being so willing to share their insights, thoughts and experiences. Thanks also to the other actors participating in the research. The authors are grateful to Agrovi/GMSR for establishing the contacts with farmers, arranging demonstrations etc. and to FRDK for collaborating on communication with farmers and sharing ideas. Thanks to Niklas Buhl for illustration of Figures and Graphical Abstract. The study was funded by the EU Horizon 2020 programme (H2020-EU.3.2.1.1.), grant #727217. The opinions expressed in this paper are not necessarily those of the EU.

References

Aare, A.K., Cooreman, H., Garayoa, C.V., Arrieta, E.S., Bellostas, N., Marchand, F., Hauggaard-Nielsen, H., 2020a. Methodological reflections on monitoring interactive knowledge creation during farming demonstrations by means of surveys and observations. Appl. Sci. 12, 1–26. https://doi.org/10.3390/su12145739.

Aare, A.K., Egmose, J., Lund, S., Hauggaard-Nielsen, H., 2020b. Opportunities and barriers in diversified farming and the use of agroecological principles in the global north–the experiences of Danish biodynamic farmers. Agroecol. Sustain. Food Syst. 00, 1–27. https://doi.org/10.1080/21683565.2020.1822980.

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19–31. https://doi.org/10.1016/S0167-8809(99)00028-6.

Altieri, M.A., 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. Front. Ecol. Environ. 2, 35–42. https://doi.org/10.1890/1540-9295(2004)002[0035,LEATFI]2.0.CO;2.

Bedoussac, L., Journet, E.P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E.S., Prieur, L., Justes, E., 2015. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agron. Sustain. Dev. 35, 911–935. https://doi.org/10.1007/s13593-014-0277-7.

van Bommel, S., van der Zouwen, M., 2012. Creating Scientific Narratives: Experiences in Constructing and Interweaving Empirical and Theoretical Plots 217–239. https://doi.org/10.1007/978-94-007-5113-2_11.

Bos, A.P., Groot Koerkamp, P.W.G., Gosselink, J.M.J., Bokma, S., 2009. Reflexive interactive design and its application in a project on sustainable dairy husbandry systems. Outlook Agric. 38, 137–145. https://doi.org/10.5367/000000009788632386.

Bradbury, H., 2015. How to situate and define action research. In: SAGE Handb. Action Res., pp. 1–10.

Brooker, R.W., Bennett, A.E., Cong, W., Daniell, T.J., George, T.S., Hallett, P.D., Hawes, C., Iannetta, P.P.M., Jones, H.G., Karley, A.J., Li, L., McKenzie, B.M., Pakeman, R.J., Paterson, E., Schöb, C., Shen, J., Squire, G., Watson, C.A., Zhang, C., Zhang, F., Zhang, J., White, P.J., 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytol. 206, 107–117. https://doi.org/10.1111/nph.13132.

Carpiano, R.M., 2009. Come take a walk with me: the "go-along" interview as a novel method for studying the implications of place for health and well-being. Heal. Place 15, 263–272. https://doi.org/10.1016/j.healthplace.2008.05.003.

Catalogna, M., Dubois, M., Navarrete, M., 2018. Diversity of experimentation by farmers engaged in agroecology. Agron. Sustain. Dev. 38 https://doi.org/10.1007/s13593-018-0526-2.

Darnhofer, I., Bellon, S., Dedieu, B., Milestad, R., 2009. Adaptiveness to enhance the sustainability of farming systems. Sustain. Agric. 2, 45–58. https://doi.org/10.1007/978-94-007-0394-0_4.

Davydd, C., Levin, J.G., 2007. The friendly outsider: from AR as a research strategy to the skills needed to become an action researcher. In: Introduction to Action Research, pp. 116–130. https://doi.org/10.4135/9781412984614.

De Graaf, G., Huberts, L.W.J.C., 2008. Portraying the nature of corruption using an explorative case study design. Public Adm. Rev. 68, 640–653. https://doi.org/10.1111/j.1540-6210.2008.00904.x.

Dogliotti, S., García, M.C., Peluffo, S., Dieste, J.P., Pedemonte, A.J., Bacigalupe, G.F., Scarlato, M., Alliaume, F., Alvarez, J., Chiappe, M., Rossing, W.A.H., 2014. Co-innovation of family farm systems: a systems approach to sustainable agriculture. Agric. Syst. 126, 76–86. https://doi.org/10.1016/j.agsy.2013.02.009.

Egmose, J., 2015. Chapter 4 - Methodology. In: Action Research for Sustainability. Social Imagination between Citizens and Scientists. Ashgate, Farnham & Burlington.

Eikeland, O., 2006. The validity of action research - validity in action research. In: Nielsen, K.A., Svensson, L.G. (Eds.), Action Research and Interactive Research: Beyond Practice and Theory. Shaker Publishing.

EIP-Agri, 2017. Horizon 2020 Multi-actor Projects [WWW Document]. https://ec.europa.eu/eip/agriculture/sites/agri-eip/files/eip-agri_brochure_multi-actor_projects_2017_en_web.pdf (accessed 4.30.20).

Falconnier, G.N., Descheemaeker, K., Van Mourik, T.A., Adam, M., Sogoba, B., Giller, K.E., 2017. Co-learning cycles to support the design of innovative farm systems in southern Mali. Eur. J. Agron. 89, 61–74. https://doi.org/10.1016/j.eja.2017.06.008.

FAO, 2014. Building a Common Vision for Sustainable Food and Agriculture: Principles and Approaches (Rome, Italy).

FAO, 2017. Conservation Agriculture.

Feder, G., Murgai, R., Quizon, J.B., 2004. The acquisition and diffusion of knowledge: the case of Pest management training in farmer field schools, Indonesia. J. Agric. Econ. 55, 221–243.

Flyvbjerg, B., Sampson, S., 2001. Making Social Science Matter. Why Social Inquiry Fails and how it Can Succeed Again. Cambridge University Press, Cambridge.

Folke, C., Carpenter, S.R., Elmqvist, T., Gunderson, L.H., Holling, C.S., Walker, B., Bengtsson, J., Berkes, F., Colding, J., Danell, K., Falkenmark, M., Gorden, L., Kasperson, R., Kautsky, N., Kinzig, A., Levin, S., Maler, K.-G., Moberg, F., Ohlsson, L., Olsson, P., Ostrom, E., Reid, W., Rockstrom, J., Savenije, H., Svedin, U., 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. ICSU Ser. Sci. Sustain. Dev. No. 3, 37.

Francis, C., Lieblein, G., Gliessman, S., Breland, T.A., Creamer, N., Harwood, R., Salomonsson, L., Helenius, J., Rickerl, D., Salvador, R., Wiedenhoeft, M., Simmons, S., Allen, P., Altieri, M., Flora, C., Poincelot, R., 2003. Agroecology : the ecology of food systems. J. Sustain. Agric. 22, 99–118. https://doi.org/10.1300/J064v22n03.

Frison, E.A., IPES-Food, 2016. From Uniformity to Diversity: A Paradigm Shift from Industrial Agriculture to Diversified Agroecological Systems. IPES, Louvain-la-Neuve (Belgium).

Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res. Policy 33, 897–920. https://doi.org/10.1016/j.respol.2004.01.015.

Geels, F.W., Kemp, R., 2007. Dynamics in socio-technical systems: typology of change processes and contrasting case studies. Technol. Soc. 29, 441–455. https://doi.org/10.1016/j.techsoc.2007.08.009.

Gibbon, D., 2012. Methodological themes in Farming Systems Research and implications for learning in higher education. In: Farming Systems Research into the 21st Century: The New Dynamic, SpringerLink : Bücher. Springer, Dordrecht New York, pp. 95–115. https://doi.org/10.1007/978-94-007-4503-2.

Gliessman, S., Friedmann, H., Howard, P.H., 2019. Agroecology and food sovereignty. IDS Bull. 50, 684–685. https://doi.org/10.19088/1968-2019.120.

Hagmann, J., Chuma, E., Murwira, K., 1997. Kuturaya: participatory research, innovation and extension. In: van Veldhuizen, L., Waters-Bayer, A., Ramírez, R., Johnson, D.A., Thompson, J. (Eds.), Farmers' Research in Practice – Lessons from the Field. Intermediate Technology Publications.

Halwart, M., Settle, W., 2008. Participatory Training and Curriculum Development for Farmer Field Schools in Guyana and Suriname. A Field Guide on Integrated Pest Management and Aquaculture in Rice. FAO, p. 123.

Hauggaard-Nielsen, H., Jensen, E.S., 2001. Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. ID - 20013139599. F. Crop. Res. 72, 185–196.

Hauggaard-Nielsen, H., Jørnsgaard, B., Kinane, J., Jensen, E.S., 2008. Grain legume - cereal intercropping: the practical application of diversity, competition and facilitation in arable and organic cropping systems. Renew. Agric. Food Syst. 23, 3–12. https://doi.org/10.1017/S1742170507002025.

Hazard, L., Steyaert, P., Martin, G., Couix, N., Navas, M.L., Duru, M., Lauvie, A., Labatut, J., 2018. Mutual learning between researchers and farmers during implementation of scientific principles for sustainable development: the case of biodiversity-based agriculture. Sustain. Sci. 13, 517–530. https://doi.org/10.1007/s11625-017-0440-6.

Horwith, B., 1985. A role for intercropping in modern agriculture. Bioscience 35, 286–291. https://doi.org/10.2307/1309927.

Ingram, J., Chiswell, H., Mills, J., Debruyne, L., Cooreman, H., Koutsouris, A., Pappa, E., Marchand, F., 2018. Enabling learning in demonstration farms: a literature review. Int. J. Agric. Ext. 29–42.

Jensen, E.S., Bedoussac, L., Carlsson, G., Journet, E.-P., Justes, E., Hauggaard-Nielsen, H., 2015. Enhancing yields in organic crop production by eco-functional intensification. Sustain. Agric. Res. 4, 42. https://doi.org/10.5539/sar.v4n3p42.

Jensen, E.S., Carlsson, G., Hauggaard-Nielsen, H., 2020. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: a global-scale analysis. Agron. Sustain. Dev. 40 https://doi.org/10.1007/s13593-020-0607-x.

Kilpatrick, S., Johns, S., 2003. How farmers learn: different approaches to change. J. Agric. Educ. Ext. 9, 151–164. https://doi.org/10.1080/13892240385300231.

Klerkx, L., Aarts, N., Leeuwis, C., 2010. Adaptive management in agricultural innovation systems: the interactions between innovation networks and their environment. Agric. Syst. 103, 390–400. https://doi.org/10.1016/j.agsy.2010.03.012.

Klerkx, L., van Bommel, S., Bos, B., Holster, H., Zwartkruis, J.V., Aarts, N., 2012. Design process outputs as boundary objects in agricultural innovation projects: functions and limitations. Agric. Syst. 113, 39–49. https://doi.org/10.1016/j.agsy.2012.07.006.

Koole, B., 2020. Trusting to learn and learning to trust. A framework for analyzing the interactions of trust and learning in arrangements dedicated to instigating social change. Technol. Forecast. Soc. Change 161, 120260. https://doi.org/10.1016/j.techfore.2020.120260.

Kral, M.J., 2014. The relational motif in participatory qualitative research. Qual. Inq. 20, 144–150. https://doi.org/10.1177/1077800413510871.

Kroma, M.M., 2006. Organic farmer networks: facilitating learning and innovation for sustainable agriculture. J. Sustain. Agric. 28, 5–28. https://doi.org/10.1300/J064v28n04_03.

Kusenbach, M., 2003. Street phenomenology - the go-along as ethnographic research tool. Ethnography 4, 455–485. https://doi.org/10.1177/146613810343007.

Kvale, S., Brinkmann, S., 2009. Interviews, Learning the Craft of Qualitative Research Interviewing, 2nd edition. Sage Publications, Thousand Oaks, Calif.

Lacombe, C., Couix, N., Hazard, L., 2018. Designing agroecological farming systems with farmers: a review. Agric. Syst. 165, 208–220. https://doi.org/10.1016/j.agsy.2018.06.014.

Lankester, A.J., 2013. Conceptual and operational understanding of learning for sustainability: a case study of the beef industry in North-Eastern Australia. J. Environ. Manag. 119, 182–193. https://doi.org/10.1016/j.jenvman.2013.02.002.

Lund, Søren, 1998. Participation?: A Question of Praxis : a Discussion of the "theories" of Participatory Development Based on Experiences from a Sand Dune Fixation Project in Mauritania, 1982-1990. International Development Studies, Roskilde University (Dissertation paper).

Lund, S, Lønholdt, J, 2005. Project Identification and Formulation. In: Lønholdt, J (Ed.), Water and Wastewater Management in the Tropics. IWA Publishing, London, UK, pp. 5–26.

Malézieux, E., Crozat, Y., Dupraz, C., Laurans, M., Makowski, D., Ozier-Lafontaine, H., Rapidel, B., de Tourdonnet, S., Valantin-Morison, M., 2009. Review article Mixing plant species in cropping systems : concepts, tools and models. A review. Agron. Sustain. Dev. 29, 43–62. https://doi.org/10.1051/agro.

Martin, G., Felten, B., Duru, M., 2011. Forage rummy: a game to support the participatory design of adapted livestock systems. Environ. Model. Softw. 26, 1442–1453. https://doi.org/10.1016/j.envsoft.2011.08.013.

Matson, P.A., 1997. Agricultural intensification and ecosystem properties. Science (80-.) 277, 504–509. https://doi.org/10.1126/science.277.5325.504.

Menconi, M.E., Grohmann, D., Mancinelli, C., 2017. European farmers and participatory rural appraisal: a systematic literature review on experiences to optimize rural development. Land Use Policy 60, 1–11. https://doi.org/10.1016/j.landusepol.2016.10.007.

Méndez, V.E., Caswell, M., Gliessman, S.R., Cohen, R., 2017. Integrating agroecology and participatory action research (PAR): lessons from Central America. Sustainability 9, 1–19. https://doi.org/10.3390/su9050705.

Meynard, J.J.-M., Dedieu, B., Bos, A.P.B., 2012. Re-design and co-design of farming systems. An overview of methods and practices. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Syst. Res. into 21st Century New Dyn. SpringerLink, Bücher, pp. 407–432. https://doi.org/10.1007/978-94-007-4503-2.

Meynard, J.M., Jeuffroy, M.H., Le Bail, M., Lefèvre, A., Magrini, M.B., Michon, C., 2017. Designing coupled innovations for the sustainability transition of agrifood systems. Agric. Syst. 157, 330–339. https://doi.org/10.1016/j.agsy.2016.08.002.

Meynard, J.M., Charrier, F., Fares, M., Le Bail, M., Magrini, M.B., Charlier, A., Messéan, A., 2018. Socio-technical lock-in hinders crop diversification in France. Agron. Sustain. Dev. 38 https://doi.org/10.1007/s13593-018-0535-1.

Millar, J, Curtis, A, 1997. Moving farmer knowledge beyond the farm gate: An Australian study of farmer knowledge in group learning. European Journal of Agricultural Education and Extension 4 (2), 133–142. https://doi.org/10.1080/13892249785300241.

Morgan, K., Murdoch, J., 2000. Organic vs conventional agriculture: knowledge, power and innovatoin in the food chain. Geoforum 31, 159–173.

Nielsen, B.S., Nielsen, K.A., 2016. Critical utopian action research: the potentials of action research in the democratization of society. In: Hansen, H.P., Nielsen, B.S., Sriskandarajah, N., Gunnarsson, E. (Eds.), Commons, Sustainability, Democratization : Action Research and the Basic Renewal of Society. Routledge, New York and London, pp. 74–106.

Oreszczyn, S., Lane, A., Carr, S., 2010. The role of networks of practice and webs of influencers on farmers' engagement with and learning about agricultural innovations. J. Rural. Stud. 26, 404–417. https://doi.org/10.1016/j.jrurstud.2010.03.003.

Orlando, F., Alali, S., Vaglia, V., Pagliarino, E., Bacenetti, J., Bocchi, S., 2020. Participatory approach for developing knowledge on organic rice farming: management strategies and productive performance. Agric. Syst. 178, 102739. https://doi.org/10.1016/j.agsy.2019.102739.

Raseduzzaman, M., Jensen, E.S., 2017. Does intercropping enhance yield stability in arable crop production? A meta-analysis. Eur. J. Agron. 91, 25–33. https://doi.org/10.1016/j.eja.2017.09.009.

Reed, M.S., Stringer, L.C., Fazey, I., Evely, A.C., Kruijsen, J.H.J., 2014. Five principles for the practice of knowledge exchange in environmental management. J. Environ. Manag. 146, 337–345. https://doi.org/10.1016/j.jenvman.2014.07.021.

Robinson, R.A., Sutherland, W.J., 2002. Post-war changes in arable farming and biodiversity in Great Britain. J. Appl. Ecol. 39, 157–176. https://doi.org/10.1046/j.1365-2664.2002.00695.x.

Rogers, E.M., 1995. Diffusion of Innovations, 4th edition. Free, New York.

Roling, N.G., Wagemakers, A., 1998. A new practice: facilitating sustainable agriculture. In: Roeling, N.G., Wagemakers, M.A.E. (Eds.), Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty, vol. 597. Cambridge University Press, pp. 3–22. Communicatiewetenschap.

Salembier, C., Elverdin, J.H., Meynard, J.M., 2016. Tracking on-farm innovations to unearth alternatives to the dominant soybean-based system in the Argentinean Pampa. Agron. Sustain. Dev. 36, 1–10. https://doi.org/10.1007/s13593-015-0343-9.

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., des Rios, I, Rivera, M., Chebach, T., Ashkenazy, A., 2018. Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. J. Rural Stud. 59, 232–241. https://doi.org/10.1016/j.jrurstud.2017.01.020.

Taghizadeh-Toosi, A., Olesen, J.E., Kristensen, K., Elsgaard, L., Østergaard, H.S., Lægdsmand, M., Greve, M.H., Christensen, B.T., 2014. Changes in carbon stocks of Danish agricultural mineral soils between 1986 and 2009. Eur. J. Soil Sci. 65, 730–740. https://doi.org/10.1111/ejss.12169.

Vaarst, M., Nissen, T.B., Østergaard, S., Klaas, I.C., Bennedsgaard, T.W., Christensen, J., 2007. Danish stable schools for experiential common learning in groups of organic dairy farmers. J. Dairy Sci. 90, 2543–2554. https://doi.org/10.3168/jds.2006-607.

Vanclay, F., 2004. Social principles for agricultural extension to assist in the promotion of natural resource management. Aust. J. Exp. Agric. 44, 213–222. https://doi.org/10.1071/EA02139.

Vandermeer, J., 1989. The Ecology of Intercropping. Cambridge University Press, Cambridge.

Vereijken, P., 1997. A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. Eur. J. Agron. 7, 235–250. https://doi.org/10.1016/0308-521X(96)86787-4.

Verret, V., Pelzer, E., Bedoussac, L., Jeuffroy, M.H., 2020. Tracking on-farm innovative practices to support crop mixture design: the case of annual mixtures including a legume crop. Eur. J. Agron. 115 https://doi.org/10.1016/j.eja.2020.126018.

Waks, L., 2017. Learning by doing and communicating. In: John Dewey's Democr. Educ. A Centen. Handb, pp. 15–22.

Westlander, G., 2006. Researchers roles in action research. In: Nielsen, K.A., Svensson, L. (Eds.), Action and Interactive Research: Beyond Practice and Theory. Shaker Publishing, Maastricht, pp. 45–63.

Wezel, A., Goris, M., Bruil, J., Félix, G.F., Peeters, A., Bàrberi, P., Bellon, S., Migliorini, P., 2018. Challenges and action points to amplify agroecology in Europe. Sustainability 10, 1–12. https://doi.org/10.3390/su10051598.

Willey, R.W., 1979. Intercropping: its importance and research needs. F. Crop Abstr. 32.

Woodhill, A.J., Roling, N.G., 1998. The second wing of the eagle: the human dimension in learning our way to more sustainable futures. In: Roling, N.G., Wagemakers, M.A.E. (Eds.), Facilitating Sustainable Agriculture: Participatory Learning and Adaptive Management in Times of Environmental Uncertainty, vol. 597. Cambridge University Press, pp. 46–71. Communicatiewetenschap.

Yin, R.K., 1989. Case study research: design and methods. In: Applied social research methods series, 5th ed., vol. 5. Sage Publications, Los Angeles.