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Faculty of Landscape Architecture, Horticulture and Crop Production Science

Care in digital farming

- from *acting on* to *living with*

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Care in digital farming – from *acting on* to *living with*

Abstract

Keywords: precision agriculture, precision livestock farming, digital farming, SMART farming, Activity theory, Distributed Cognition, automated milking systems, CropSAT, relational, systemic

Development of digital technology to handle complex situations in agriculture has for long time mainly been technology driven, resulting in limited adoption. This thesis aims to: 1) Introduce methods and theories from the research field of human-computer interaction in the agricultural domain to improve design and development processes of digital technology. 2) Introduce the concept of care to increase knowledge about farmers' technology use in their socio-technical system (practice), as well as to introduce a relational perspective in agriculture. The two systemically described complex decision situations are fertilization with a decision support system, that uses satellite images and automated milking systems. 3) Evaluate two different theoretical lenses to study the concept of care in practice, Distributed Cognition and Activity Theory. The studies of farmers' socio-technical systems show that farmers develop an *enhanced professional vision* to interpret data from the technology and learn more about the field/crop or the cow. New technology changes the relationship between the farmer and the field/crop or cow, but the experienced farmer supplements what they see through the technology with direct contact with, for example, the cow. The need for a stockperson's eye is thus at least as great after the introduction of robots in milk production. A relational perspective involves an understanding of our mutual dependence with the crop or the cow in these examples, as well as nature and its ecosystem services. Introduction of the concept of care and a relational approach, meaning that farming is to *live with*, not just *act on,* can support the transformation of agriculture that we know is necessary. In this transformational process, technology has an important role to play. However, it must be developed in cooperation and dialog with end-users to fit in their socio-technical-ecological system and thus support their care.

Care in digital farming – from acting on to living with

Abstract

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Utvecklingen av digital teknik för att stödja beslutsfattande i komplexa situationer i lantbruket, har ofta varit teknikdriven och den praktiska användningen har i många fall varit begränsad. Denna avhandling syftar till att: 1) Introducera metoder och teorier från forskningsfältet människa-datorinteraktion för att förbättra design- och utvecklingsprocesser av digital teknik i lantbruket. 2) Introducera begreppet omsorg (*care*) för att öka kunskapen om lantbrukares teknikanvändning i deras socio-tekniska system (praktik) genom att systemiskt beskriva två komplexa beslutssituationer i praktiken, gödsling med ett beslutsstöd baserat på satellitbilder och robotmjölkning, samt introducera ett relationellt perspektiv i lantbruket. 3) Utvärdera två olika teoretiska linser, distribuerad kognition och aktivitetsteorin, för att studera omsorgsbegreppet i praktiken. Studierna av lantbrukares socio-tekniska system visar att lantbrukare utvecklar en vidgad professionell blick (*enhanced professional vision*) för att tolka data från tekniken och lära sig mer om fältet/grödan eller den enskilda kon. Ny teknik ändrar relationen mellan lantbrukaren och fältet/grödan eller kon, men den erfarne lantbrukaren kompletterar det de ser genom tekniken med direktkontakt med exempelvis kon. Behovet av djuröga är därmed minst lika stort efter införande av robotsystem i mjölkproduktionen. Ett relationellt perspektiv innebär en förståelse för vårt ömsesidiga beroende av såväl gröda som kor i dessa exempel, som naturen och dess ekosystemtjänster. Introduktion av omsorgsbegreppet och ett relationellt synsätt, att inte bara bör *agera på* utan *leva med*, kan stödja den omställning av lantbruket som är nödvändig. I denna omställning har digital teknik en viktig roll att fylla. Men den måste utvecklas i dialog och samverkan med användare för att passa in i deras socio-tekniska-ekologiska system, dvs i lantbrukarnas praktik.

‘*Because the world is always bigger than the knowledge of an individual, we must listen to each other, because the world is always bigger than the knowledge of a group, cultures must learn from each other, and because the world is always bigger than the knowledge of a species, humans must listen to other species and on ecosystems*’. Jonna Bornemark, 2022

Contents

List of publications

This thesis is based on the following papers, referred to by Roman numerals in the text:

I. Lundström, C., Lindblom, J., Ljung, M. & Jonsson, A. (2015). Some considerations about the development and implementation process of a new agricultural decision support system for site-specific fertilisation. *Precision Agriculture,* 15, 437-444. https://doi.org/10.3920/978-90-8686-814-8_54

II. Lindblom, J., C. Lundström, M. Ljung, & A. Jonsson, (2017). Promoting sustainable intensification in precision agriculture: a review of decision support systems' development and strategies. *Precision Agriculture*. 18(3). DOI: 10.1007/s11119-016-9491-4.

III. Lundström, C., & Lindblom, J. (2018). Considering farmers' situated knowledge of using agricultural decision support systems (AgriDSS) to Foster farming practices: The case of CropSAT. *Agricultural Systems*, 159, doi.org/10.1016/j.agsy.2017.10.004

IV. Lundström, C., & Lindblom, J. (2018). Motivations and needs for adoption of the agricultural decision support system CropSAT in advisory services. *Agricultural Extension and Education*, 71-82.

V. Lundström, C., & Lindblom, J. (2021). Care in dairy farming with automatic milking systems - using an Activity Theory lens. *Journal of Rural Studies*, 87, doi.org/10.1016/j.jrurstud.2021.09.006

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The contribution of Christina Lundström to the papers included in this thesis was as follows:

I. Lundström, C., Lindblom, J., Ljung, M. & Jonsson, A. (2015). Some considerations about the development and implementation process of a new agricultural decision support system for site-specific fertilisation. *Precision Agriculture,* 15, 437-444. https://doi.org/10.3920/978-90-8686-814-8_54

Lundström was the main author. She developed the idea and wrote the paper together with Lindblom, in consultation with the other co-authors. Christina Lundström presented the results at a conference.

II. Lindblom, J., C. Lundström, M. Ljung, & A. Jonsson, (2017). Promoting sustainable intensification in precision agriculture: a review of decision support systems' development and strategies. *Precision Agriculture*. 18(3). DOI: 10.1007/s11119-016-9491-4

Lundström supported Lindblom in developing the idea and writing the paper in consultation with the other co-authors.

III. Lundström, C., & Lindblom, J. (2018). Considering farmers' situated knowledge of using agricultural decision support systems (AgriDSS) to Foster farming practices: The case of CropSAT. *Agricultural Systems*, 159, doi.org/10.1016/j.agsy.2017.10.004

Lundström was the main author and developer of the idea, planned and performed the fieldwork, selected sequences to be included in the manuscript, analysed the data, presented the results at a conference and wrote the paper together with Lindblom.

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Abbreviations

AgriDSS	Agricultural Decision Support Systems
AKIS	Agricultural Knowledge and Innovation System
AMS	Automated Milking Systems
AT	Activity Theory
DCog	Distributed Cognition
HCI	Human-Computer Interaction
ICT	Information and Communications Technology
PA	Precision Agriculture
PLF	Precision Livestock Farming
POS	The Swedish network of Precision Agriculture
UCD	User-Centred design

1. Introduction

This thesis takes its starting point in the ongoing discussion on agriculture as well as in society concerning an urgent need for increased sustainability to reach global goals and stay within planetary boundaries in parallel with digitalisation. Agriculture is facing challenges and thus extensive, large-scale, far-reaching transition or transformation. Those concepts are related and used for non-linear, structural and radical change in complex systems, but are not interchangeable (Hölscher et al. 2018). Both are normatively used to describe a desired change. Their differences mainly stem from their respective research communities working with change (Hölscher et al. 2018). In this thesis, the concept of transformation is used since it is commonly used '*to refer to fundamental shifts in human and environmental interactions and feedbacks*' (Hölscher et al. 2018:1). In the digital era, many expect digital technology to change our everyday life, and that digital technology will account for a significant part of the solution to challenges regarding environmental issues. The focus in research on digital technology has been on technical aspects for a long time, such as what digital technology could measure and how it could improve agricultural practice and productivity. In recent years, the scientific interest in social issues about the digitalisation of agriculture has increased (Klerkx et al. 2019), and this thesis belongs to this body of research. The work focuses on the micro-level, i.e. the farmer's socio-technical (-ecological) system in his/her practice using digital technology to increase sustainability on the farm. The thesis introduces the concept of care (Mol et al. 2010; Krzywoszynska 2016; Puig de la Bellacasa 2017) to use a holistic, relational perspective of farmer's work practice in a direction of increased sustainability. To reach global goals and keep within planetary boundaries, the individual farmer and his/her practice, including digital technology, are crucial. Accordingly, this thesis starts in three critical areas for future agriculture. Sustainability, digital technology, and the individual farmer's practice that is supposed to benefit from digital technology and result in a local sustainable farming practice or care.

1.1 Increasing sustainability, a central aim for agriculture

Agriculture is facing huge challenges regarding global goals, namely Agenda 2030, for sustainable development and planetary boundaries. Although this is well known in the agricultural domain, it is still difficult to manage. For a long time, productivity enhancement or intensification has been the dominant paradigm in agriculture development, without including sustainability largely, or there has been a focus on efficiency increase and reduction of negative impacts rather than investigating synergies between intensification, on the one hand, and sustainability and transformation, on the other (Pretty et al. 2018). This simplification, homogenisation and intensification of our production ecosystems have resulted in systems that are efficient in delivering food but are characterised by weakened sustainability (Folke et al. 2021; Lieder & Schröter-Schlaack 2021).

There are different narratives concerning sustainability in agriculture (Schreefel et al. 2020; Clapp & Ruder 2020). One production-oriented narrative is the concept of sustainable intensification, with a focus on increased food production on existing farmland, in parallel with a decrease in environmental impact (Garnet et al. 2013; Pretty et al. 2018; Yan et al. 2021). Another narrative is ecological intensification (Brommarco et al. 2013; Kleijn et al. 2019; Kernecker et al. 2021), with the aim to '*design multifunctional agroecosystems that are both sustained by nature and sustainable in their nature*' (Tittonel 2014:53). There has been some focus on the sustainability intensification narrative (Pretty et al. 2018; Folke et al. 2021). However, there seems to be a growing consensus that an iterative development of large-scale intensive agriculture is not enough (Brommarco et al. 2013; Tittonel 2014; Pretty et al. 2018; Kleijn et al. 2019; Folke et al. 2021; Kernecker et al. 2021; Rose et al. 2021). Instead, there is a need for a re-design (Pretty et al. 2018), transformation (EU Commission 2020; Folke et al. 2021) or re-generation (Brommarco et al. 2013). Folke et al. (2010) define transformation as the ability to develop new systems of interactions and feedbacks between humans and the environment, when economic, ecological and social structures in the earlier system have become untenable.

This includes agency, practices, behaviours, incentives, institutions, beliefs, values and worldviews and all at multiple levels, from local to global (Moore & Milkoreit 2020). In this thesis, sustainability is not considered as a stable condition that can be achieved once and for all (Folke et al. 2021; Pretty et al. 2018; Darnhoefer 2020). Rather, it is regarded as an ongoing process of transformation, learning, adaptation and change, at different levels, from local to global, and in interaction with humans, non-humans, materials and natural settings, with different roles and at different levels in the system (Folke et al. 2021).

1.2 Digitalisation – a tool for increased sustainability and transformation

A central discourse in agricultural science and politics is the need for and possibilities with the implementation and use of Information and Communications Technology (ICT) or digital technology to increase sustainability (Rose & Chilvers 2018; Trendov et al. 2019; European Commission 2020; Lieder & Schröter-Schlaack 2021; Moysiadis et al. 2021). Some scholars have introduced this kind of digital agriculture as Agriculture 4.0 (Klerkx & Rose 2020). These kinds of digital technology have different names: Digital farming, Data farming, SMART farming, precision agriculture (PA) and precision livestock farming (PLF), among others (Rijswijk et al. 2021). Ingram and Maye (2020) describe three levels of digital technologies: 1) Technologies that provide raw data (for example, weather data), 2) Smart devices that provide farm management advice and 3) Smart systems that perform autonomous actions. In this thesis, the agricultural decision support system (AgriDSS) CropSAT[1] as well as automated milking systems (AMS) in dairy farming are examples of the second kind of technology. In this context, it is also relevant to mention the difference between digitisation and digitalisation. Digitisation can be defined as a process of making physical entities digital (Rijswijk et al. 2020). Digitalisation describes the use of digital technologies in socio-technical processes that affect social contexts, which, in turn, depend on digital technologies (Rijswijk et al. 2020). In agriculture, digitisation often concerns

[1] https://cropsat.com/se/sv-se

digital technology on one farm. Accordingly, PA and PLF are both considered digitisation technologies (Klerkx et al. 2019).

Digital technologies encompass data-driven and data-enabled technologies, such as sensors, robotics, drones and global positioning systems (GPS) (Wolfert et al. 2017). Trendov et al. (2019) describe technological development as a transformation and claim that digital technology thereby will transform agriculture. They claim that '*The desired results of digital agriculture are systems of higher productivity, which are safe, anticipatory and adapted to the consequences of climate change, to offer greater food security, profitability and sustainability*' (Trendov et al. 2019:2). Other authors are more critical (Barret & Rose 2020; Klerkx & Rose 2020; Ingram et al. 2022), and some argue that '*the increasing use of digital technologies is often described as a panacea that enables sustainable agriculture*' (Lieder & Schröter-Schlaack 2021:1). This kind of optimism, characterised by not regarding unintended effects, has been common during the history of agricultural innovations (Sassenrath et al. 2008; Rose & Chilvers 2018), raising some pessimistic concerns about digital development (Sassenrath et al. 2008; Rotz et al. 2019; Basso & Antle 2020; Clapp & Ruder 2020; Eastwood & Renwick 2020; Rijswijk et al. 2021). Some claim that small farmers face disadvantages, the so-called digital divide (Trendov et al. 2019), while others claim that small farmers will be more competitive. Small farmers with agro-ecological orientation could be excluded from food production, and conventional farmers' income crisis will be deepened due to corporate concentrations and market integrations (Rotz et al. 2019). The World Bank (2019:4) argues, on the one hand, that new technologies in the food system have already led to '*better informed and engaged consumers and producers, smarter farms, and improved public services*', but on the other hand, digital technologies should not be considered a panacea. Often, the optimism concerning technological innovations overshadows those who are more hesitant, and there is little discussion concerning potential unintended consequences (Clapp & Ruder 2020; Fielke et al. 2022). The literature is dynamic, but many concepts focus on modelled or assumed efficiency advantages, ignoring technical as well as societal presumptions and barriers (Basso & Antle 2020; Klerkx & Rose 2020; Lieder & Schröter-Schlaack 2021). Media and policy documents present high-tech smart technology in an overwhelmingly positive light, much more positive than do farmers (Barret & Rose 2020). In addition, media and policy documents focus on increased productivity and profitability, while social and environmental benefits are not presented as saliently (Barret & Rose 2020). It is also important to consider low-tech solutions in order to support farmers, people and the planet (Klerkx & Rose 2020). If we focus on hyped high-tech SMART technology, we even risk missing a lot of low-tech solutions and other ideas from coming to the fore (Klerkx & Rose 2020). Klerkx and Rose (2020) claim that there are many doubts concerning advocating and focusing on high-tech agriculture without really considering its negative consequences. They present three concerns: 1) A focus on high-tech farming would risk losing attention on other important issues and ideas. 2) There is a risk that we forget simple solutions and spend a lot of money on high-tech solutions that probably could have an impact later on, instead of using more mundane low-tech solutions with a direct impact. 3) Limited efforts will be made to reconsider already known technologies and practises and combinations thereof in new ways. For instance, combinations of ideas from agro-ecology, permaculture and digital technology, etc. Another concern is that those who advocate new digital technology are deeply enmeshed within the established industrial agricultural system (Clapp & Ruder 2020). This discourse is also mainly focusing on the iterative development of increased productivity and decreased impact within the framework of the current agricultural system. However, the EU's Farm to Fork strategy clarifies that farmers must transform their production methods quickly and from their local perspective make the best of their '*nature-based, technological, digital, and space-based solutions to deliver better climate and environmental results, increase climate resilience and reduce and optimise the use of inputs*' (European Commission 2020:8). Even though the EU Commission uses the concept transition, not transformation, the EU highlights both transformation and local adaptation. However, in this context, Eastwood and Renwicks (2020:1) claim that we need to highlight farmers' struggle with adaptation processes to better understand '*where (and which) technologies can have an actual impact on farm as opposed to technologies that only create greater farmer distrust and uncertainty'*.

Development of digital technologies often aims to contribute to *sustainability through design*, i.e. how ICT can be used to promote more sustainable behaviours (Hanks 2008), and digital technology in agriculture is no exception. Often, the overall ambition is to transfer scientific knowledge embedded in technology (Eastwood et al. 2012). However, human activity is contextual, and variation in people's contexts as well as worldviews, etc. makes the design of digital technology challenging. Digital technologies such as PA and PLF have been developed for more than thirty years, and some technologies have had a wide impact, while others have not (McCown 2002; Eastwood et al. 2012; Rossi et al. 2014; Trendov et al. 2019; Vaintrub et al. 2021; Eastwood et al. 2022). One important milestone for PA was when the USA made the GPS signal available for civilian applications. The aims of PA were to improve input use; increase farm viability, yield amounts as well as quality; and decrease environmental impact. Broad access to GPS made it possible to measure within-field variation in yield or soil, etc. and adapt interventions as well as input applications. Thus, technology development to map yield, steer automatically, and apply inputs adapted to the within-field variation, among others, became possible. However, it was not always as easy as it seemed. In PA, automated steering systems are broadly adopted, while technologies that are more complex to evaluate and test, such as variable rate application technologies, have had a much slower implementation rate (Ingram & Maye 2020).

In animal production, the societal demand for animal products has increased due to changes in diet and demographics (Schillings et al. 2021). The livestock production has doubled worldwide since the 1970s, and the production of pigs and poultry has doubled in the last thirty years (Hartung et al. 2017). In parallel, considerations concerning issues on the environment, animal welfare and human health have increased, and the development of PLF technology is regarded as one way to meet those challenges. PLF technology provides possibilities for earning more money, spending less time at work and a better approach to the genetic potential in livestock species (Berckmans 2017). PLF means technologies that monitor individual animals continuously and automatically, concerning parameters of health, welfare, production/productivity, reproduction and environmental impact (Berckmans 2017). When needed, farmers receive an alarm and can thereby handle the situation. There are also ethical concerns about human-animal relations in the era of PLF (Schillings et al. 2021), especially whether digital technology will replace farmers' ears and eyes (Berckmans 2014). One PLF technology that has revolutionised production and spread around the world is automated milking systems (AMS). The first commercial AMS was installed in the Netherlands in 1992 (de Koning 2010); since then, the adoption has increased steadily, especially in European countries (Salfer et al. 2017), where the Nordic countries and the Netherlands have the highest percentage of AMS herds (Barkema et al. 2015). In 2015, there were more than 25,000 dairy businesses with AMS worldwide (Barkema et al. 2015), and some estimates show that there were over 35,000 units on farms in 2017 (Salfer et al. 2017).

A broad range of other digital technologies are not as widely spread as the AMS and automated steering systems. The European Parliament expressed that *'the full potential of precision agriculture is not yet harvested. We only see the first series of precision farming practices implemented on a small number of farms. These precision farming are- making farming more easy rather than giving crop plants and animals the optimal treatment at the right time and lowest scale possible. For the latter, the adoption rate is still very low'* (European Parliament 2016:132). Many companies develop promising technology as pilots; however, scaling up the production is complicated, and the envisioned benefits of digital farming are still not proven (Trendov et al. 2019; Barret & Rose 2020; Kuch et al. 2020). There are challenges with data usage, data formats, software complexity and unclear return of investment (Trendov et al. 2019), and many farmers still struggle to understand the benefits of farm data produced by digital technology (Eastwood et al. 2022; Ayre et al. 2019; Rotz et al. 2019; Barret & Rose 2020; Trendov et al. 2019; Kuch et al. 2020). Before adoption, the individual farmer considers the relative advantage, compatibility, trial ability, complexity, and observability compared to the technology it might supersede (Rogers 2003). High compatibility, trial ability, and observability normally increase adoption, while high complexity decreases it (Rogers 2003). Technologies that are more complex are still reliant on the farmer to interpret the data and use the rule of thumb. Still, both farmers and advisors have problems managing, interpreting, and making use of the digital data (Ingram & Maye 2020). The Agricultural Knowledge and Innovation System's (AKIS) capability to use digital data has so far not matched the optimistic discourse in agriculture (Ingram & Maye 2020). In precision agriculture, the *problem of implementation* has been discussed (McCown 2002; Rossi et al. 2014), and the reasons for the scaling problem are not well-understood and still under-researched (Trendov et al. 2019). There is a discourse of blaming farmers for a lack of openness or innovativeness to new ideas (Rose et al. 2018; Vaintrub et al. 2021), and *pro-innovation bias* (Rogers 2003) concerning digital technology is common (Rossi et al. 2014;

Rose et al. 2018). There is somehow an assumption, conscious or not, that farmers should adopt digital technology with embedded scientific knowledge, more or less automatically (Rose et al. 2018), which obviously is not the case (Trendov et al. 2019).

1.3 Farmers' practice – where technology is used, and transformation is performed

Farming systems are characterised by complexity, which is important to remember when there is an ambition to improve them through the implementation of digital technology. Poli (2013) describes complexity as: '*Complex problems and systems result from networks of multiple interacting causes that cannot be individually distinguished; must be addressed as entire systems, that is they cannot be addressed in a piecemeal way; they are such that small inputs may result in disproportionate effects; the problems they present cannot be solved once and for ever, but require to be systematically managed and typically any intervention merges into new problems as a result of the interventions dealing with them; and the relevant systems cannot be controlled – the best one can do is to influence them, learn to dance with them*' (Poli 2013:142). That above quote represents what farmers' practice is about. Instead of supposing that digital technology *is good* and farmers *must* understand, we need to study real-life settings and farmers' real practice. Such studies would increase our understanding of how transformation is performed and what kind of technology transformation requires. Farmers' practice within their socio-technical systems where the technology is used should be studied to gain a deeper understanding of how humans actually carry out their work, what kind of technology they would need to increase sustainability in practice, and what impact new technology really has on the same work or practice. There seems to be a mismatch between, on the one hand, technology developers and others who advocate a broad implementation of digital technology and, on the other hand, the farmers who are supposed to realise the digital development. There seems to be a gap between what different actors consider valuable and relevant. Research and development professional who work with digital technology should re-focus and consider what is important for farmers from a deeper and short as well as long-term perspective. How should they develop their practice to transform agriculture in parallel with short-term viability and how can digital technology support that process?

The focus in this thesis is to contribute to rephrasing this conceptual re-focusing by introducing the concept of *care* (Krzywoszynska 2016; Mol et al. 2010; Puig de la Bellacasa 2017) via methods and theories to analyse it in digital farming. *Care* is systemic, relational and a tinkering process, or dance, based on farmers' situated knowledge, attentiveness, responsiveness and engagement. *Care,* in this meaning, is considered '*the result of all practices that make technology and knowledge work*' (Krzywoszynska 2016; 290). Where *work* in this sense, would be, on the one hand, defined by the individual farmer from his/her context and worldview but also in the context of agricultural transformation, related to global goals and planetary boundaries. The first interpretation of care in this thesis is as reflected management, a tinkering process based on care ethics, meaning that we all have a larger responsibility for things in our vicinity. The second interpretation in this thesis is that the one who performs care, is struggling to increase sustainability, could do it from different perspectives and does not follow moral rules. Rather, 1) a reflected management that considers myself as interdependent to humans, non-humans and natural settings in my vicinity and 2) having an ambition to care for those in order to develop relations and increase sustainability based on our interdependence.

At the end of the day, the care of the individual farmer drives local agriculture development. Care in practice, is based on his/her worldviews, ambitions, engagement and driving forces where he or she uses his/her assets, experience and knowledge and makes decisions, manages the practice, and is more or less willing to learn, adopt to new technology and perform the transformation. If the different actors in practice as well as in research and development should be able to perform good care, a changed perspective from *acting on* to *living with* is central, following Puig de la Bellacasa (2017). The traditional productivist perspective of agriculture identifies *care* not as a co-constructed interdependent relation, but rather as control of an object, whether it concerns farmers, animals or crops.

This thesis work started in the domain of PA with a focus on farmers' care in their socio-technical system concerning issues of development, adoption and usage of digital technology in crop production. Later, the area of interest was widened to involve automated milking systems in dairy production. The thesis's starting point was in the tradition of Farming systems research (Darnhofer et al. 2012), having its basis in the three statements by Röling (1988) who criticised the knowledge transfer approach and the lack of a systemic perspective on technology in farming nearly 25 years ago. He argued that:

- Technology is often seen as an isolated phenomenon.
- Technology is not adapted to the needs of farmers.
- The traditional view of knowledge transfer lacks a systemic perspective and does not put the technology in the context to which it belongs.

Since then, a lot of work has been done, but some of the above problems still remain (Eastwood et al. 2022; Rose et al. 2018). In a review from 2019, a broad range of research was presented (Klerkx et al. 2019). However, few studies concerned farmers' real practice when they interact and use digital technology (Rose et al. 2018), but there were exceptions (Schewe & Stuart 2015; Higgins et al. 2017). This thesis aims to contribute to our understanding of the micro-level in farming. The farmer in his/her real-life settings use digital technology from a perspective of transformational change, a *care* perspective. Transformation is sometimes presented in the sense of digitalisation (Trendov et al. 2019). However, this thesis claims that transformational change in agriculture must be more comprehensive than that and should rather be directed to a systemic change in human and environmental interactions and feedback. Accordingly, agriculture needs a new perspective on technology development and use in practice. This thesis suggests the *care* concept as this new perspective, to get a deepened understanding of how farmers 'live with' technology to care for their relations.

1.4 Aim and objectives

This thesis aims to introduce and apply the concept of *care* to gain a deeper understanding of farmers' use of digital technology in their practice and to introduce a relational perspective on farm practice and technology use to increase sustainability and to contribute to facilitation of transformational pathways in agriculture. In order to do this, the following four objectives are formulated:

- Present recommendations concerning digital technology development and design processes, to ensure relevant, usable and credible technology for end-users that support their care practices.

- Investigate and analyse farmers' use of digital technology as an ongoing learning process of *care* in their socio-technical system.

- Introduce and apply theoretical lenses to study farmers' care in practice from a systemic perspective.

- Present implications for advisors in their work with farmers, based on the relational perspective of care.

1.5 Research approach

1.5.1 My point of departure

This thesis builds on my previous licentiate work and follows a tradition of qualitative research. My intention has not been to find statistical, significant proofs, but rather to accomplish a qualitative inquiry, based on ethnographically grounded case studies, to increase our understanding about farmers' practice in their complex socio-technical systems using digital technology, such as PA and PLF. To make farmers' work visible by describing as well as analysing their work practice, I introduce the concept of care and use this concept both as a means and as an aim. *Care* in this meaning is considered '*the result of all practices that make technology and knowledge work*' (Krzywoszynska 2016:290). Care is thus never performed without reflection, not only in every single operation, but as an overall objective of the actions performed.

Coming from a natural scientific background, working in the network of Precision Agriculture Sweden (POS) for many years, the research topic investigated in this thesis started as a reaction to my personal experience of the *problem of implementation* (McCown 2002; Matthews 2008; Mackrell et al. 2009; McCown et al. 2009; Rossi et al. 2014) concerning PA technology in Sweden. However, I soon experienced a need for a changed, wider and more holistic perspective on technology development and use in practice to consider farmers' care in their socio-technical system. My ontology and epistemology have developed during this process from the reductionist paradigm, focusing on *objectivity* and *acting on,* to the interpretative paradigm with a focus on *subjectivity* and *living with*, realising that there are no objective truths, rather socially constructed meanings and a worldview, revealing that everything is related and interdependent. My worldview and the point of departure for this research are captured in the words of Röling (1997:249): '*natural systems are governed by causes, people are guided by reasons – predicting human behaviour based on causes has consistently led to failure*'. Natural science is effective to understand natural systems but says little of human activity (Röling 1997). Human activity is, instead, based on social constructions, relations, learning processes and interactions between a broad range of actors, and is affected by such things as greed, attitudes, values, worldviews, fear, power, knowledge, identity, motivation, culture, etc., depending on the individual and the situation (Röling 1997). People change their behaviour when they have reasons for doing so, as long as they have a choice. An individual does thus not *receive* reality; rather, it is *constructed and enacted* in relations and interactions with others and with the natural world (Röling 1997).

Learning in this thesis is focused on farmers' development of situated knowledge in their socio-technical system and depends on relations with humans, non-humans, material matters and natural settings. Accordingly, this thesis takes the view that knowledge is socially constructed, enacted and dependent on context, following Salner's (1986) definition of higher cognitive development or learning named contextual relativism. All humans have their interpretation of the world, which, on the one hand, means that there is no objective truth; rather that truth is dependent on an interaction between the self and the world. The relevance of knowledge and values is thus contextual. Different individuals create their interpretations of their *world,* and the researcher's task is to reveal different interpretations of an object, task or phenomenon among individuals and groups (Rodela et al. 2012). While knowledge is seen as socially constructed and enacted, the researcher aims to identify and understand different interpretations and determine whether and how they interact with each other and the object of interest. In the age of Big Data, Kitchin (2014) suggests a new paradigm and epistemology that is situated, reflexive and contextually nuanced. Big Data, he argues, is relational and always examined through a particular chosen lens that frames it. It must always be embedded in wider knowledge, since pattern identification is one thing and explaining patterns another. A pattern is thus not an end, rather a starting point for further analysis that certainly will require additional kinds of information and knowledge (Kitchin 2014).

It is widely acknowledged that farming is a complex dynamic system, involving products and impacts that are difficult to measure, let alone predict and control (e.g. Woodward et al. 2008). Accordingly, history has shown that there is no agricultural development model that is generally applicable (Leeuwis 2004). To increase sustainability in agriculture, the strategy will not be a question of adaptation to any global policy or initiative, but it will instead require transformation and a never-ending local decision-making and learning process depending on the fundamental characteristics of the system of interest, as well as its sensitivities and vulnerabilities (Schlindwein et al. 2015), here called *care*. To move agriculture along a more sustainable trajectory, a wide range of approaches, conventional, high-tech, agro-ecological and organic, must be assessed and tested in relation to physical and social contexts (Garnett et al. 2013; Folke et al. 2021). Leeuwis (2004) expresses this as different stakeholders requiring a focus on the development of situated knowledge that is *complex, diverse* and *local.* Agricultural transformation progress will require the integration of different major approaches within research and development to face and consider a wider range of complexity than before, and find more diverse solutions or strategies, more closely adapted to local situations (Jordan & Davis 2015), and thus to farmers, their farms and their *care*.

In PA and PLF research, the focus has long been on technical aspects, i.e. to develop and analyse functions and results of different technologies. Such a technology driven perspective results in a knowledge gap and the implementation problem (McCown 2002; Matthews 2008; Mackrell et al. 2009; McCown et al. 2009; Rossi et al. 2014). Human properties and social aspects in the whole chain from technology development, advisory work, decision-making, learning and usage in practice have been neglected to a great extent, with the PA and PLF fields remaining wedded to the normative perspective of *knowledge transfer* (McCown 2002). By the introduction of the care concept, I want to contribute to a change in this perspective, following Röling's (1997) advice about working with *subjectivity* instead of *objectivity*, using a holistic and systemic approach, which relates to farmers' care in practice.

To support farmers in the agricultural transformation towards increased sustainability, there is a need for a wider approach than focusing to understand and manipulate causalities in the natural world. In so doing, it is important to avoid the style of communication that is common within conventional agriculture (Carolan 2016:15), which is '*more interested in telling than listening, in directing rather than following and in effecting rather than learning to be affected*'. Thus, the purpose should not be to find a so-called objective truth. Rather, the purpose is to increase our understanding of human learning or care, as it is demonstrated in its socio-technical system to avoid the perspectives of technology fix (Black 2000), knowledge transfer, and *acting on*. This would be performed by claiming the perspective of PA and PLF technology as embedded in and dependent on farmers' situated knowledge and care, where care is a concept for farmers' attentive and responsive learning and tinkering process in practice (Mol et al. 2010). The use of technology is no exception. Technology needs a farmer's good care to optimise the result in the socio-technical system of the farm (Mol et al. 2010). From my point of view, sustainability beyond sustainable intensification demands a perspective of care, focusing on relations and thus *living with*, rather than *acting on*.

1.5.2 An interdisciplinary approach

The work performed in this thesis was interdisciplinary, in order to find theories, methodologies and tools to study and analyse farmers' *care* in practice, in their socio-technical system. To do so, I have used a systemic approach, spanning three major fields of study. The adoption of the phrase *field of study* here is deliberate in order to imply that these fields of study are not all claiming the status of a discipline, nor are they equally advanced in their development. These fields of study are: 1) Digital farming, such as precision agriculture (PA) and precision livestock farming (PLF) (Moysiadis et al. 2021; Neethirajan & Kemp 2021; Rijswiik et al. 2021), 2) Activity Theory (AT) and Situated and Distributed Cognition (DCog) (Engeström, 2015; Lindblom 2015; Rogers 2012; Bechtel et al. 1998; Hutchins 1995; Suchman 2007) and 3) Human-computer interaction (HCI) (e.g. Suchman 2007; Hartson & Pyla 2012; Rogers 2012; Issa & Isaias 2015). The starting point for the thesis work was the assumption that digital technology has an important role to play in the agricultural transformation. However, as explained above, we need new theories, methodologies and perspectives to understand farmers' work practice in their socio-technical systems as well as to develop technology in a way that makes it usable, credible and viable for the practitioners. If we gain a deeper understanding of their work practice from a more holistic view, the development of digital technology that is considered credible, relevant and usable among farmers would be better facilitated. To find theories, methodologies and tools to accomplish this endeavour, I looked outside the domain of agriculture towards the research fields of modern approaches of cognitive science and HCI albeit still having my feet anchored in the tradition of farming systems research.

1.5.3 Theoretical framework

Farmers' care in the complex socio-technical system involves technical components as well as cognitive, social and relational components. Therefore, I have chosen to turn to the above-mentioned fields of study to widen the technical, biological and natural scientific approach developed within the field of PA and PLF, to bring systemic, cognitive, relational and human-centred issues to agricultural science and farming practice. Farmers' management has traditionally been studied using theoretical frameworks from economic science, similar to the classical approach within cognitive science, which has resulted in a limited understanding of their situated and naturalistic decision-making and management process that encompasses the whole socio-technical system. To acquire more knowledge of how farmers' care occurs in their socio-technical contexts *in the wild*, I turned to the more modern approaches of cognitive science and technology use, especially the frameworks of DCog (Hutchins 1995) and the AT (Engeström 2015). Both have frequently been successfully applied in HCI (Rogers 2012), especially in studies of computer supported work (Halverson 2002). Although DCog and AT have not been applied in agriculture, they have more in common with and share the ontological and epistemological bases of interactionism and constructivism that are the main pillars of farming systems research (Darnhofer et al. 2012). In so doing, they contribute by widening the unit of analysis to include technology and other artefacts as well as humans and non-humans in the studied agricultural socio-technical system. In addition, there is a need for improved knowledge on convenient strategies for the design and development of ICT systems, where the research area of HCI (Rogers 2012; Issa & Isaias 2015) could contribute significantly. HCI provides established knowledge and processes to design and develop ICT systems that are usable, efficient and credible through the user-centred design (UCD) approach, which would benefit agriculture in general, and PA as well as PLF in particular. It should also be mentioned that both DCog and AT have been successfully applied within HCI (Rogers, 2012).

1.5.4 Methodology

This thesis work is based essentially on a qualitative approach using naturalistic inquiry, which was taken to be interchangeable with the qualitative inquiry. The only exception was a questionnaire linked to the last case study, in which a mixed methods (Creswell & Clark 2017; Patton 2002) approach was used. Naturalistic inquiry is characterised by observations conducted in natural settings (Lincoln & Guba 1985) and focuses on deep and detailed descriptions of actions, practices, conversations, activities and interpersonal interactions from fieldwork (Patton 2002). Moreover, the context is incorporated in the analysis because it is considered important for the interpretation of the meaning of a situation (Patton 2002; Lincoln & Guba 1985). Furthermore, the quality of the data combined with sound conclusions are the most important aspects to achieve scientific rigour (Patton 2002). With such an inquiry, ethnography-inspired data collection techniques are commonly used and combined. The ethnographic approach involves the study of cultural perspectives and patterns in their natural settings over time. A common ethnographic approach for studying work is workplace studies that aim at studying, discovering and describing how people accomplish various tasks while getting work done. Workplace studies have been described as a prominent method for addressing the interactional organisation of a workplace and the ways different tools and technologies are used to support work activities, tasks and collaborations (Heath et al. 2000; Luff et al. 2000). Hence, making work practices visible (Szymanski & Whalen 2011), work place studies offer rich insights about how technology is integrated into the social and cultural worlds of the farmers.

To answer the aim and objectives posed in this thesis (*cf.* section 1.4), four case studies were performed. A case study can use both quantitative and qualitative methods, but in this thesis, essentially qualitative methods were used. The first and the fourth case studies were influenced by the *workplace study* methodology (Luff et al. 2000), with the focus on farmers and their opinions and needs, mostly using participant observation, video-recordings, field notes and ethnographic interviews as data collection techniques. The second case study mostly took a conceptual approach, using design methodology from HCI to investigate the pros and cons in initiating a shift in ICT system design methodology for precision agriculture, where the theoretical part was used as a lens in analysing and discussing the data collected.

The third case study was a qualitative study based on semi-structured interviews with crop advisors to investigate their thoughts and reflections on precision agriculture and the AgriDSS called CropSAT. In the last case study, the context was changed from PA to PLF and dairy production performed with automated milking systems (AMS), i.e. milking robots. This study was also inspired by a *workplace study methodology* (Luff et al. 2000), with data collection performed by ethnographic semi-structured interviews and field visits. In addition, a quantitative questionnaire was used to get quantitative data to confirm the qualitative results. Hence, using a mixed-methods design (Patton 2002).

2. Background

In chapter 2 important aspects of the thesis background are presented. The chapter begins with section 2.1, where a relational perspective on farming is introduced. What does a relational perspective mean and what consequences would a relational perspective on farming have? There are hopes and fears concerning digital and SMART farming. Thus, a reflection regarding human expertise and digital technology is important to have as a bases for the further reading and thus this is reviewed in section 2.2. Applying a systemic perspective on farming, requires a systemic approach on farmers technology use in their socio-technical system. In section 2.3 a short description of the concept of socio-technical system is presented. The focal actor in farming is the farmer. It is he or she that will implement measures and develop a farm in a more sustainable direction. Therefore, section 2.4 reflect on the farmer and what kind of work situation a farmer has. This have implications on what really happens in practice. In section 2.5 the concept of care is introduced and discussed from different perspectives. Finally, in section 2.6 theories to analyse care are described.

2.1 A relational perspective on farming

A relational perspective describes a process that combines different ideas and objects into a meaningful whole, through a dialogue concerning the integration, use and linkages of objects, resources and ideas (Darnhofer et al. 2016). It characterises a new ontology based on what will become, not how things are, '*how ever-present possibilities for different futures are enacted or current arrangements stabilised*' (Darnhofer 2020:521). It has a focus on relations, both social and ecological, which are aspects that could both weaken and strengthen farm sustainability. In this case, a combination of biophysical relations as well as relations based on values, beliefs and meanings can better describe the drivers that have formed a farm in a specific context as well as what will shape a coming change, incremental or transformational, in farming practice over time. This could be specific relations on a farm, or drivers embedded in a wider context, such as relational ties embedded in productivism, which constrain transformation (Darnhofer et al. 2016). This web of relations will continually change, be modified and reinterpreted, due to both human and material agency. Accordingly, the web of relations will simultaneously strengthen and weaken both sustainability and stability. Focusing on relations would improve the ability to describe '*both path dependency and path creation*' (Darnhofer et al. 2016:120) and foster the understanding of what relations do actually encourage and hinder transformational change, based on the farmer's individual drivers and the biophysical conditions on the specific farm. This perspective focuses less on what *a farm has* or *what a farmer is* (Darnhofer et al. 2016). Instead, the focus is on relations (material, social and so forth) in ongoing farming as a process of learning, adaptation and transformation. Hence, the focus is not merely on specific resources, but rather on the relations between them.

From a relational point of view, we are all interdependent, with other humans as well as with non-humans, material things and natural settings. In an era of digitalisation and adoption of digital technology, this affects farmers' work directly in two ways. On the one hand, farmers must develop a relationship with the technology, to customise and insert it into the production system and his/her care. On the other hand, technologies can become mediating artefacts and provide a filter between the farmer and something else (Verbeek 2012). Verbeek (2012) takes a car as an example. A novice driver must focus on the car as a technology to be able to drive it, but an experienced driver instead uses the car to experience the road and things happening outside. '*Technologies can disappear from our experience— like a pair of glasses, which we do not look at but rather through*' (Verbeek 2012:394). The way Verbeek (2012) describes this phenomenon corresponds well with how it is initially described in AT. In the farming context, it could be a cow or a herd in milk production with AMS or the crop or field with satellite images. Thus, technology affects the relation to the "other," and, often, this shift leads to an increase in distance between the farm and the farmer (Herman 2015). Farmers must then find other ways to keep and develop those kinds of relations.

Digital technology certainly does complement human cognitive abilities. It can, for instance, manage big data samples and measure properties that the human senses cannot perceive. Many farmers have concerns regarding the calculation transparency of different technologies and thus question if they can trust the software (Rotz et al. 2019). However, when they trust it, it is up to the farmer to use the provided information in a way that complements and not disturbs the relation to the *thing*. In some animal production, there is a concern regarding PLF and animal welfare (Schillings et al. 2021). How the individual farmer handles this concern is probably a question of worldview, values, engagement, experience and situated knowledge. If the individual considers the relation to the thing important and obvious, he or she will secure that it will not deteriorate when they adopt a new technology.

2.2 Human expertise and digital technology

This thesis argues that digital technology must be embedded in farmers practice to work. In a digital era, where society's trust in digital technology is great, I would like to mention something about expertise and what technology can and cannot support us with. Dreyfus and Dreyfus (2005) developed a five-stage model of the cognitive activities involved in directed skill acquisition in real-life handling of complex situations (Table 1). It ranged from a novice, who followed rules or recipes, to an expert who applied sophisticated heuristics and used his/her experience and intuitive knowledge from earlier, similar situations. Formulating explicit rules from intuitive knowledge is both impossible and a way of simplifying a situation, whereupon it is no longer considered expert knowledge. Computers are faster and more accurate than people to handle big data, calculate and follow rules (Dreyfus & Dreyfus 2005). In complex situations with few true rules, expertise is instead an application of sophisticated heuristics to a broad range of facts (Dreyfus & Dreyfus 2005). This model was published some years ago. Since then, a lot of technology has developed, but also our belief in technology and what it will be able to accomplish. Dreyfus' and Dreyfus' (2005) model for expertise development seems to still be relevant for complex issues and situations, even though they were wrong about, for

Table 1. The Dreyfus and Dreyfus (2005) model of skill acquisition.

Level	Description
Novice	Follows rules, regardless of context
Advanced beginner	On developing some experience, the advanced beginner can recognise meaningful additional aspects of the situation and the experiences, as well as rules used in performance.
Competent	A huge number of potentially relevant elements and procedures are recognised in the situation, and the task seems overwhelming. In this step, the performer learns how to determine which elements and procedures to consider important and which can be ignored. Moreover, each individual must decide for themselves in each situation what plan or perspective will be adopted, without being sure that it will be appropriate.
Proficient	To get to this level, the individual must be engaged. Now the performer's skill, as represented by rules and principles, is gradually replaced by situational discrimination accompanied by associated responses. The individual then sees what should be done rather than using any calculative procedure to select alternatives, still making decisions.
Expert	The individual sees what needs to be done and can also immediately see how to achieve the goal. The expert reacts to a situation with an immediate intuitive situational response

instance, chess playing, where computers now have beaten humans.

Since 2010, deep learning, one kind of machine learning, has become the dominant AI paradigm (Mitchell 2019a). Deep learning means machines '*that "learn" from data or from their own "experiences"*' (Mitchell 2019a:22). Mitchel (2019b:51) concludes: '*Today's AI systems sorely lack the essence of human intelligence: Understanding the situations we experience, being able to grasp their meaning'*. Rule-based AI is difficult to use in complex situations since it easily becomes difficult due to incomplete rules or unintended situations (Mitchel 2019a). In ethical discussions, it is difficult to make certain that AI would value things in the same way that humans do. However, then Mitchel (2019a) questions if there really are any universal values in society, so what should AI be compared with? However, even the best AI system of today lacks human common sense, which some say is a prerequisite for moral reasoning (Mitchel 2019a). AI has difficulties to generalise from learning one game to another. Humans can learn how to play chess and then use that knowledge in other situations. That is not the case for AI. Mitchel (2019a) mentions the *easy things are hard paradox* for AI. What humans learn as babies, such as things move if you push and they are not too heavy, things fall if you drop them, some things can move by themselves, some things are alive and so on. It is very complicated for technology to learn those things that we just know from common sense. AI also does not understand meaning. People, on the contrary, are very competent concerning what we regard as easy things. We see things that are partly hidden in a picture. We are able to anticipate what could happen in a given situation; in addition, we can imagine how a situation can develop if certain things change. We are social beings, with empathy and can put ourselves in another person's situation and imagine and predict people's feelings, goals, beliefs and reactions. '*An integral part of understanding a situation is being able to ... imagine different possible futures*' (Mitchel 2019a:202). People also understand by simulation. Lawrence Barsalou writes: '*As people comprehend a text, they construct simulations to represent its perceptual, motor, and affective content. Simulations appear central… of meaning*' (Mitchel 2019a:202). This kind of cognitive skills require '*two fundamental human capabilities: abstraction and analogy*' (Mitchel 2019a:205). '*Abstraction is the ability to recognize specific concepts and situations as instances of a more general category*' (Mitchel 2019:206). To make abstractions is closely related to making analogies and seeing similarities between things and situations. '*We have core knowledge—some of it innate and some of it learned during development and throughout life… Our concepts, ranging from simple words to complex situations, are formed via abstraction and analogy*' (Mitchel 2019:208). In that way, we are able to predict what is likely to happen in a given situation or what could happen if something changes. Abstraction and analogy making, as humans are capable of, are very complicated or not possible to implement in some kind of programmed technology. The function and results of those systems are difficult to predict. Deep-learning systems have shown to be not as smart as they were supposed to be (Mitchel 2019a). They lack ability to generalise outside their very narrow domain, and they do not "understand" what they are taught. There is an ongoing discussion concerning whether more data or deeper networks help '*or whether something more fundamental is missing*' (Mitchel 2019a:213). Work is ongoing and the future will tell. However, it is not an easy task, and it also builds in a lot of uncertainty in those systems. To reflect and perceive on our own thoughts, metacognition, helps us to move further in complicated situations. AI systems do not manage such and that impairs its possibilities to reconsider a problem or a strategy. Human intelligence is embodied, and our intelligence is developed in interaction with the surrounding world. Michel (2019a) claims that it would be impossible to develop a machine with humane-like intelligence if it is not embodied and active in the world. An interesting reflection on this theme is this post on a blog from the deep-learning and computer-vision expert working with AI technology at Tesla: '*The state of Computer Vision and AI: we are really, really far away*' (karpathy.github.io). Creation of an AI with human intelligence will take very long time! Oren Etzioni, director of the Allen Institute for AI expresses it like this: '*Take your estimate, double it, triple it, quadruple it. That's when' (*Mitchel 2019a:232). '*Several surveys given to AI practitioners, asking when general AI or "super intelligent" AI will arrive, have exposed a wide spectrum of opinion, ranging from "in the next ten years" to "never." In other words, we don't have a clue*' (Mitchel 2019a:233). Some people claim that an explosion of technology intelligence without human weaknesses and shortcomings could happen if certain steps are taken. However, Michel (2019a) instead claims that those human weaknesses and shortcomings are parts of our intelligence, based on our embodiment, emotions and biases that facilitate our function as and in social groups. Our shortcomings in that sense are that prerequisites *'are in fact precisely what enable us to be generally intelligent rather than narrow savants. I can't prove it, but I think it's likely that general intelligence can't be separated from all these apparent shortcomings, in humans or in machines*' (Mitchel 2019a:235). There is an ongoing debate concerning strong and weak AI. For more information read Lindblom (2015). The real worry is thus not that AI, and such technology, would take over the world, rather '*our societies headlong dash to embrace AI technology*' (Mitchel 2019a:236). Accordingly, we should be concerned about ourselves and our beliefs concerning AI and what it can do.

Stupid technology is more to worry about than intelligent ditto. Their specific intelligence is very valuable in the right context and that is true for human general intelligence too. We should embrace our human competence and care, our values, ability to socialize, cooperate and our somewhat deficient intelligence to do what we have to do and start our transformation, supported by relevant, usable and credible technology!

2.3 Socio-technical systems

Relations between and a systemic perspective on humans and technology are important to consider, since, on the one hand, technology is dependent on human practice to function in a workplace and, on the other hand, technology mediates relations between, for instance, farmers and their crops or animals, as noted above. The concept of a socio-technical system was introduced already in the 1950s in research concerning British coal mines (Trist 1978). The researchers found that it was not fruitful to divide the operational work in the mine into two parallel subsystems, one social and one technical/material, since the social and the technical/material were interconnected and dependent on each other to perform local work. Earlier, labour studies concentrated on the adaptation of humans to the organisation or technical framework of the production (Ropohl 1999). Thus, it seems that humans gained increased value because technology depended on and required human interaction. Accordingly, the relations and interdependence between material things and humans is the core interface in a socio-technical system (Trist 1978). Thus, the concept of socio-technical system refers to the interdependencies between humans and technology, including both digital and analogue technologies, like various IT systems, pen and paper, and mechanical tools, such as hammers or ploughs. These technologies come to have meaning only when they are embedded in social work practices (Suchman 2007), which implies that the technology itself does not ‘do’ anything. Instead, the technology is dependent on the social practice in which they are implemented and used, in ways that shape the very nature of the practice itself (Suchman 2007). Orlikowski (2007:1437) uses the term *constitutively entangled* to describe the phenomenon. However, *constitutively entangled* brings it even one-step further. ‘*Humans are constituted through relations of materiality - bodies, clothes, food, devices, tools, which, in turn, are produced through human practices. The distinction of humans and artifacts, on this view, is analytical only; these entities relationally entail or enact each other in practice*’ (Orlikowski 2007:1438). In the context of this thesis, however, this philosophical position is unnecessary to discuss further. However, the main message is clear, technology is not a delimited or individual entity, but a central part of a socio-technical system, thus relational to humans and dependent on social practice and human care. Accordingly, digital technology in agriculture is dependent on the individual farmer and his/her care. In section 2.4 we will continue to reflect on this focal actor. First, the thesis will go deeper into two kinds of digital technologies or systems and the socio-technical systems that embed them.

In this thesis, two kinds of socio-technical systems in farming were studied, PA farmers who used an AgriDSS called CropSAT for fertilisation and dairy farmers who had implemented AMS. The work started in the context of PA. The traditional way of studying PA technology is to focus mainly on the technology and its functions. How well does CropSAT predict the nitrogen requirements of the crop to reach a certain level of yield and crop quality, for instance? In this thesis, we instead used a socio-technical system perspective to study fertilisation events, where the farmers used CropSAT in practice. The study concerned the cognitive processes, which are the results of technology use and the functional relationships between humans and artefacts in the system. This study used the theoretical framework of DCog to analyse the cognitive processes. The other kind of socio-technical system that was studied is AMS in dairy. These AMS were more complex systems that are in a continual development process. Those socio-technical systems also include non-humans (cows) beyond humans and different artefacts. Many studies have been performed on AMS, but as far as we have found in the literature, this chosen approach was new. We used AT to analyse the socio-technical system.

2.4 The farmer – the focal actor in the system

At the very core of the transformation as well as the use of digital technology in farming is the individual decision-maker, making strategic, tactical and operative decisions, bridging theory and practice and balancing the desirable with the feasible (Matthews et al. 2008; Van Meensel et al. 2012). Each farmer has an individual, dynamic and contingent relation to his/her farm based on an everyday, embodied and emotional basis. Use of different technologies change, but do not break this relation (Herman 2015). Feeling the soil by walking on it or driving on it with a tractor gives different results, but the farmer can still tell about the soil, based on his/her experience. There is a broad range of narratives or worldviews that shape farmers' relations to their farms (Herman 2015). However, they are always based on a need to get a sustainable income from the farming practice. The demand for a viable farm means that the farmer always acts in relation to the structural and social features of the economic system, where he/she operates (Falconer 2000). However, there are always non-economic norms and obligations that guide their behaviour, decisions and experiences.

Farmers' daily work is characterised by problem-solving in various areas and of differing severity in a broad range of operations. External factors, e.g. weather, vary continuously, and the impacts on weather-dependent biological systems are difficult to explain and impossible to predict and control. Accordingly, exactly the same situation will never reappear, and it is impossible to repeat an action to investigate different alternatives under exactly the same conditions in a certain field, either on a farm or with a specific animal in a herd. It is also essential to consider that a solution to one part of the farming system could create problems in another part (Leeuwis 2004). As a result, the individual farmer must often balance and make trade-offs between several, sometimes conflicting, environmental as well as production goals, given different time scales. The continuous and ongoing act of comparing formal knowledge with self-experienced results, obtained during earlier years in different places, is made either consciously or unconsciously, creating new knowledge and rules of thumb in current farming practice (Lindblom & Lundström 2014). During this knowledge development process, a broad range of different individual and social learning situations are of major importance in influencing the farmer. Hoffman et al. (2007) claimed that farmers live in a kind of life-long longitudinal case study set-up. They develop operating skills to *know that* action is required, *know what* to do, and *know how* to solve a problem, even if it is clear to them that the actions they perform will probably never be optimal (Baars 2011).

Farmers' experimentation is not a question of solving a clearly defined problem; rather, it is finding a solution that works in a specific situation (Darnhofer et al. 2016), to *care* (Krzywoszynska 2016) or "*dance with them*" (Poli 2013:142). This is a process that changes depending on what is possible, available and seems to work. Hence, farmers' experimentation is not a traditional scientific, laboratory experiment, but rather a way of speculative, experiential knowing and doing, to handle complexity and uncertainty (Darnhofer et al. 2016). Farmers' daily work activities are complex insofar as they require knowledge and consideration of a wide range of biological, technological, practical, political, legal, economic, ethical and social factors and circumstances (e.g. Nitsch 1994; Lindblom et al. 2013). According to Nitsch (1994:30), the very core of farm management lies in '*the ability to coordinate complexity under uncertainty'*. The farmer manages a wide range of competencies to handle complexity, including: 1) Knowledge about the subject (crop production, *etc*.). 2) Skills in formal planning (the ability to keep economic records and make a budget). 3) Practical skills (the ability to organise and to get farm tasks and chores done in time). 4) Orientation about the institutional environment (legislation, market conditions, agricultural policies and other institutional factors). However, this is not enough: '*The crucial element is the ability to apply them in the coordination of the complexities of farming on a specific farm'* (Nitsch 1994:32). '*It is not a matter of doing everything right, rather it is a matter of making sure the right things are done'* (Nitsch 1990:118). This kind of knowledge is personal and cannot be separated from the person who has acquired it.

Thus, it is the individual farmer, with his/her personal and situated knowledge, who must achieve a significant part of the goals for agriculture. The decisions made by every individual farmer will have a positive or negative impact on the local development (Van Mensel et al. 2012; Matthews et al. 2008). Implementation of digital technology in this context is, therefore, not straightforward in understanding the process. Luff et al. (2000) claimed that the lack of understanding of the work practice is a common reason for technology problems. The challenge is not to build the technology; rather, the challenge is to build technology that fits into the workplace where it will be used (Szymanski & Whalen 2011). Research results, even if it is applied research, must always be adapted to the local situation, the practice and the use. Accordingly, farmers' *use* of digital technology must be analysed in their context, their socio-technical system. This *use*, which could be called management (often used in productivist/economic contexts), stewardship (Enqvist et al. 2018; West et al. 2018) (often used in natural scientific environmental studies) or care (Krzywoszynska 2016; Puig de la Bellacasa 2015) (used in agriculture contexts, but originally from feminist science) could be considered differently. This thesis has chosen the concept of care as a systemic, relational and tinkering process of farmers' practice, with its roots in feminist ethics (Gillian 1977; Mol et al. 2010). In some papers, the Stewardship concept has been considered relational (Enqvist et al. 2018) but still with its roots in the natural scientific paradigm (West et al. 2018). The main difference between stewardship and care, as presented in this thesis, is care as relational in its basic meaning. It is not based on moral rules, rather, built on a perspective of interrelatedness and *living with* (Puig de la Bellacasa 2015). It is a tinkering process in practice in a complex world, where perfect care will never be carried out. It is rather an ongoing process of learning based on attentiveness, experience and responsibility for relations, focusing on our near relations and those relations for which we have responsibility. Finally, care has a fundamental perspective of living with, not acting on; in this thesis, this concerns humans, non-humans, material things or natural settings. Thus, the claim from West et al. (2018:36) that it is '*important to develop distinct normative, methodological and ontological roots for relational values*' is not relevant, in relation to the concept of care as manifested in this thesis. Hence, this thesis uses care as the concept for farmers' practice.

The next section discusses and reflects on the value of the care concept and how it can be used to increase our understanding of farmers' practice in their socio-technical systems.

2.5 Care – a systemic concept of relational development

Traditionally, the industrial modern agriculture paradigm considers short-term economic reasons as the dominating driving force for farmers (Ives et al. 2017). Naturally, short-term economic sustainability is always required in order to be able to continue with a business. Considering sustainability, there is no generally applicable and effective tool to either reach or measure, since it always depends. In comparison with short-term economic reasons, sustainability is difficult to define; it requires long-term considerations, and it is never just one specific goal to be reached. Rather, sustainability is an ongoing process of learning and adaptation, based on engagement, values, ethics and a motivation to decrease impact and improve ecological, social and economic conditions (Ives et al. 2017). In this process, several digital technologies and tools are valuable. However, a specific technology or tool can never secure sustainability increase. Rather, the only way to secure sustainability increase is through human incentives, values and tinkering learning practices – human *care*, which does not separate knowledge, values and actions (Krzywoszynska 2016).

As we all know, humanity is dependent on natural resources and many sustainability scientists highlight the need to reconnect people to nature (Ives et al. 2017; West et al. 2018). This reconnection should build on the '*active development of cognitive, emotional and biophysical linkages that positively shape human-nature interactions*' (Ives et al. 2017:106). Others claim that in the era of the Anthropocene, humans are in the environment and the environment is in us. Accordingly, philosophically, there is no more "nature" from a classical point of view (Åsberg & Radomska 2019). We humans are a force of nature, have reached our limit in a sense of planetary limits and have been '*guided by only rational thought (rather than desires) and, so to speak, living on top of things*' (Åsberg & Radomska 2019:1).

The introduction of the care concept aims to highlight a relational approach built on mutual dependence between humans, non-humans and natural settings (Puig de la Bellacasa 2017), in which digital technology has an important role to play in order to support those relations. From now on in this thesis, *more than human relations* include relations to non-humans, natural settings and different material things. Care is situated and place-based, as it concerns developing local solutions to specific local problems (Mol et al. 2010). According to Krzywoszynska (2016), experiential, situated knowledge is central for the delivery of the multiple *care* aspects that society is increasingly expecting and demanding from farmers and agriculture. *Care* in this meaning is not considered an obligation, a principle or an emotion, but '*the result of all practices that make technology and knowledge work*' (Krzywoszynska 2016:290). What work, in this sense, means is socially constructed and locally dependent. The emphasis on *all practices* is important because it expands the area of interest from specific interactions to a broader context (e.g. the whole farm) and could be compared with Nitsch's (1990) concept of coordination skills. Care as a concept highlights farmers' skilled practice, when knowing what and how to act in the heterogeneous, changing and often insecure farming practice (Higgins et al. 2019). Delivery of care is dependent on expert, situated knowledge, which develops from first-hand experience in a practice (Krzywoszynska 2016).

To increase agricultural sustainability, we need to apply a relational perspective on the farming context (Darnhofer et al. 2016). Puig de la Bellacasa (2015:701) asserts that '*care requires thinking from the* *perspective of the maintenance of a web of relations involved in the very possibility of ecosystems rather than only from their possible benefits to humans*'. Accordingly, care is more related to the concept of ecological intensification than sustainable intensification, where the latter is mostly used in a digital farming context. To support a change, we need a shift from a perspective of sustainable intensification, and iterative development with a focus on a traditional rational logic of efficiency, to ecological intensification with a focus on transformation. A relational perspective would also influence how we regard digital technology in the agricultural domain. To do this, agriculture should be regarded as a matter of farmers' *care*, a way of *living with*, instead of the traditional *acting on*, in which technology has an important role to play as a mediating artefact of good care. Thus, this thesis introduces 1) a new logic of efficiency in farming systems, from rational (traditional) to relational in order to change our perspective from *acting on* (rational) to *living with* (relational) and 2) the concept of *care* in digital farming to consider farmers' practice in their socio-technical system as relational, including use of digital technologies as mediating artefacts.

2.5.1 Care as an intellectual concept

Intellectual interest in the care concept started within the nursing theory (Mol et al. 2010). Later, it emerged in relation to farming (Mol 2010), wine production (Krzywoszynska 2016), laboratories (Kerr & Garforth 2016), permaculture (Puig de la Bellacasa 2017), mining (Bekett & Keeling 2019) and soil (Puig de la Bellacasa 2015, 2017; Krzywoszynska 2019; Krzywoszynska 2020). During this transformation, care has expanded from concerning humans to also concern non-humans and natural settings (Krzywoszynska 2019; Puig de la Bellacasa 2017). The care concept builds on the ethics of care (Gillian 1977) and is considered a non-normative proposition and a mix of a vital affective state, an ethical obligation and a tinkering, developing practice (Puig de la Bellacasa 2012). Care is both value and practice and characterised by social relations not on an individual disposition or reduced to an individual state (Held 2006). While justice is based on rights, care is based on needs (Noddings 2015). Care is relational in its nature, and to care for someone or something means to create relations and notice needs (Puig de la Bellacasa 2012). The ontological basis in the ethics of care is relational, and the ethical basis is the caring relation (Nicholson & Kurucz 2019; see Noddings 2013). The value in care ethics is an active relationship where concrete others are cared for – aiming to increase well-being broadly (Nicholson & Kurucz 2019; see Noddings 2013). The ethics of care does not build on roles and moral principles, but rather on contextual relations in practice, in our vicinity, where we have or take responsibility (Puig de la Bellacasa 2017). Instead of rules or moralities, it builds on compassion, sympathy and mutual dependency (Puig de la Bellacasa 2017; Lonkila 2021). In that sense, an ethics of care is not following principles, but rather creating good solutions in practice within a local situation (Mol et al. 2010). '*It does not prescribe what is specifically right or wrong in any concrete situation. Rather, this method allows for an individual to consider several different hypotheses and the implications of each when analysing each moral situation encountered. Building on this, ethics of care does not have absolute principles to guide us. Our efforts are directed at the maintenance of conditions that would allow for caring to flourish*' (Nicholson & Kurucz 2019:28; see Noddings 2013).

Noddings (2015) makes an important distinction between the terms *care for* and *care about*. Care for means paying attention and responding to someone's or something's needs. To care about means to have concerns about someone's or something's needs, but without a guarantee of any intervention due to it. The former follows the care ethics, which is based on an increased responsibility to care for someone or something close to us, as a child-parent relation (Gillian 1977). Similarly, I would claim that a landowner has a responsibility for more than human relations on his/her land. Dialogue, social interaction and co-creation of meaning are the means to develop an interest in caring (Nicholson & Kurucz 2019). Thus, social interactions with peers and others would be an important strategy to develop and broaden farmers' care. Since dialogue in its real sense is impossible in relations to non-humans, material things and natural settings, those needs are instead interpreted as an interaction based on attentiveness, engagement and responsibility. According to Tronto (1998), the four key elements of care are: 1) *Attentiveness*: What care is necessary? What kinds of care are performed? Who has the power to decide what kinds of problems and how those should be cared about? 2) *Responsibility*: Who is responsible to meet existing needs of care? How and why should it be done? 3) *Competence*: Who is giving the care and how well is it done? Are there conflicts between different needs and how could those be solved? What resources do the care providers need? 4)

Responsiveness: How do the care receivers respond? Are there conflicts between different receivers? Who judges and resolves those conflicts?

In a farming context, traditional management is mainly attentive to the requirements of crops and farm animals in order to *act on* them and their context to optimise production. The concept of care in this thesis widens the amount and kind of relations (humans, non-humans, material matters and natural settings) that a farmer based on the ethics of care, should be attentive to, since 1) he/she has a responsibility to be attentive to relations in his/her vicinity and 2) a relational perspective of farming implies an interdependence with humans, non-humans, material matters and natural settings and thus advocates a *living with* perspective in order to promote transformation and increase sustainability. However, to be able to be attentive to more types of relations, the farmer needs competence to recognise them as well as their response. Accordingly, both advisors and technology would have important roles to play in such transformational learning processes. Some type of farm overview or plan and its conditions (digital) would facilitate farmers' attentiveness concerning new relations and their ability to pay attention to and assess their responses.

2.5.2 Good or bad care?

Care is usually performed with a good intention, but it is not always good by definition! Care could also be violent, and it always is a matter of asymmetrical power relations (Martin et al. 2015). Good care is related to thoughts of what is sought to reach, and what is fostered or hoped for (Mol et al. 2010). Bad care is related to what is avoided, resolved or excluded. What is good or bad care is not obvious; it often has to do with complexity and ambivalence (Mol et al. 2010). Caring is thus not a banal activity; on the contrary, it demands competence and judgement (Tronto 1998). There are critiques concerning this ambiguity of what good care is, people's autonomy to decide and a limited regulation concerning the meaning of good care (Nicholson & Kurucz 2019). The solution presented is to establish a continual dialogue with others who are unlike ourselves. To judge a care process, the individual requires an understanding of the complexity. Since caring is complex, perfect care is almost impossible to achieve, but improvement of the process is always possible (Tronto 1998). Care is about tinkering and learning in practice to accomplish a gradual improvement and transformation in work (Mol et al. 2010). As good care in practice depends on experiential knowledge, experience is both the basis of care but also a way of care improvement (Krzywoszynska 2016). Martin et al. (2015:627) noted that care is always '*a selective mode of attention*', focusing on some things or phenomena and excluding others. In practice, care is, on the one hand, ambivalent, contextual and relational and, on the other hand, it requires immediate response without much time for reflection (Martin et al. 2015). However, care is not only a practice, but also a willingness and ability to respond to relations, to humans, non-humans (Martin et al. 2015) and natural settings. Accordingly, due to the care perspective and the ethics of care, farmers have a responsibility to be attentive and respond to requirements concerning related phenomena within their local farming system.

2.5.3 Farmers' care as relational leadership based on a new logic of efficiency

A farmer is a leader with power to impact functions, structures and living creatures within a land area. He or she exercises leadership over employees and the animals that are part of the company. This also comprises the land covered or affected (at least to some extent) by the farm, including wildlife, ecosystem services and soil health for instance. Within a structure of natural and cultural conditions as well as rules, laws and to some extent subsidies, the farmer or the farm leadership decides how to use, develop or discontinue a broad range of relations, including also wildlife, ecosystem services, etc.

To increase sustainability, Nicholson and Kurucz (2019) suggest development of relational leadership (Uhl-Bien 2006) in organisations. The concept of *relational leadership* traditionally places primacy on social processes of co-construction in different organisations (Nicholson & Kurucz 2019). It is explained as an '*ongoing process of meaning making and reflection within a nested system of the biosphere and society that enables this integration (of principles, strategies, and actions) to take place*' (Nicholson & Kurucz, 2019:26). This '*meaning making involves value-laden decisions and questions about 'who wins and who loses' in the process of integrating environmental, social, and economic concerns*' (Nicholson & Kurucz, 2019:26). A relational perspective of leadership changes the focus from the individual to consider it as a collective dynamic process (Uhl-Bien 2006). A farmer who applies relational leadership will become more of *one voice among many* in a collective process involving humans, non-humans, material maters and natural settings on a farm. Of course, we cannot consider a bird responsible for what happens on a farm. However, introduction of a relational leadership provides a perspective of being in a web of relations and interdependency with multiple perspectives of realities. Hence, with a relational leadership, meaning is also negotiated and renegotiated in a process of communication and interaction (Uhl-Bien 2006). Accordingly, relational leadership is not dominance. Rather, '*relational leadership is created by bringing in an increasing number of increasingly responsible people, people to create a development of increasingly involving and complex knowledge principles*' (Uhl-Bien 2006:663). Moving beyond a focus on only human relationships, as this thesis does, this understanding must be a bit modified, since non-humans do not have that possibility to interact. However, their "perspectives" are important and must be regarded in a transformational process to increase sustainability.

Relational leadership is an ongoing process of organising, which is embedded and interdependent on its context – a social system, using communication as a medium to develop the process (Uhl-Bien 2006). Uhl-Bien (2006:668) defines relational leadership '*as a process of social influence through which emergent coordination (i.e. developing social order) and change (i.e. new values, attitudes, approaches, behaviors, ideologies, etc.) are constructed and produced*'. Instead of regarding an effective leadership as an individual pursuit, which is the traditional assumption, leadership should be considered as growth-in-connection (Nicholson & Kurucz 2019). This thesis widens a relational leadership to a process of organising a social-technical-ecological system. Instead of communication, interaction would be the medium for development, based on attentiveness, responsiveness and local knowledge. Thus, a relational leadership could be considered an ongoing process of co-construction, meaning making and reflection within a local-regional (-global) web of relations. In the process of making meaning, reflections and decisions concerning *who wins and who loses* will be more obvious than a traditional leadership focusing on individuals (Uhl-Bien 2006).

To apply a relational approach in farming practice, a new logic of efficiency would be useful. A rational logic of efficiency is what currently drives sustainable intensification as well as the productivist paradigm. A logic of efficiency that instead is based on a relational dimension would help us turn away from the productivist paradigm and support transformation. This thesis follows the ideas expressed by Nicholson and Kurucz (2019) who suggest a new relational leadership in organisations to increase sustainability based on a new logic of efficiency and the ethics of care (sub-section 2.5.3) and applies it in the domain of agriculture. To better fit it into agriculture, this thesis broadens the perspective regarding the various kinds of relationships that are included, to also involve more than human relations, as animals and technology. Nicholson and Kurucz (2019) present four basic dimensions derived from the ethics of care and apply them to two different logics of effectiveness, a rational and a relational. In Table 2, the four dimensions identified by Nicholson and Kurucz (2019) and their interpretations of these two logics of efficiency are depicted. The four dimensions from the ethics of care are: primacy of relationships, complexity in context, mutual well-being focus, and engaging whole person (Nicholson & Kurucz 2019). Beyond that, the table is expanded with a third column that focuses on the desirable relational logic of efficiency demonstrated in the agriculture domain. Nicholson and Kurucz (2019) focus on human relations, but as mentioned above, this is not enough in an agricultural context. A starting point in a relational logic of efficiency in agriculture would significantly change how a place like a farm must be considered, not from its structures, but from its relations. What local (regional and global) relations facilitate and contribute to make farming possible on this farm in short- and long-term perspectives? What relations would the actual farm focus on to meet farmers' interest, support transformation and increase sustainability? Such a relational leadership in agriculture would support a transformational process since more aspects and relations within the local farming system are considered. Environmental aspects, such as water quality, soil health, and biodiversity, among others, could be easier to notice in parallel with efficiency discussions concerning crop yield and animal production, etc. A change from, for instance, soil fertility to soil health as well as from animal welfare to cow comfort, does at least partly incorporate such a change in perspective. Farmers' work would in a more obvious way take its starting point concerning more than human relations in order to secure long-term sustainability as well as short-term viability.

Table 2. Four basic dimensions from the ethics of care and three logics of efficiency; a rational logic, a relational logic and the author's interpretation of a desirable relational logic in farming. Adjusted after Nicholson and Kurucz (2019:30).

Key dimensions related to each ethic of care dimension	**A rational logic of efficiency**	**A relational logic of efficiency**	**A relational logic of efficiency – the farming context**
Primacy of relationships			
View of self	Individual	Self in relation	Self in relation to humans, non-humans, material things and natural settings
Purpose of leadership	Strengthen competitive position	Encourage collaborative capacity	A tinkering transformational process to increase sustainability
Purpose of goals	Setting the course	Co-creation and co-production	Interaction with and attentiveness to humans, non-humans, material things and natural settings
Output emphasised	Marketable goods, services and profit	Social relationship community and collective learning	Development of locally adapted, relational supportive food production that do not exceed planetary boundaries
Complexity in context			
Aim of leadership activities	Enforcing control	Encouraging emergence	A tinkering relational, learning process of local development
Approach to enhancing leadership	Leader development through training: learning outcomes emphasised	Moral development through conversation: ongoing process emphasised	Social interactions with peers and others in AKIS: what does a *good farmer* mean?
Purpose of leadership	Enforcer – task achievement	Catalyst – co-create meaning making	Meaning making, learning and

Key dimensions related to each ethic of care dimension	A rational logic of efficiency	A relational logic of efficiency	A relational logic of efficiency – the farming context
			practice in the local context
Ideal basis of moral judgement	Abstract, generalised principles - simplified	Emphasis on particular circumstances and empathy - complexity embraced	Attentiveness of, engagement in and responsibility for local flourishing relations
Mutual well-being focus			
View of human growth	Self-promotion, individual development	Growth in connection	Growth in relation to humans, non-humans and natural settings
Meaning of achievement	Profit maximisation	An integral view of well-being	Development of locally adapted, relational supportive food production that do not exceed planetary boundaries
Ideal collective outcomes	Efficiency	Caring relation	Caring relations based on mutual dependence
Time frame emphasised	Short-term trade-offs	Long-term integration	Short-term viability as well as long-term process of increasing sustainability
Engaging whole person			
Kind of reasoning emphasised	Cognitive/rational reasoning	Caring/practical reasoning	Caring/practical reasoning from *acting on* to *living with*
Role of emotion	Interferes with judgement: resist	Enables empathetic response: embrace	Important for meaning making, engagement, direction and ambition

Key dimensions related to each ethic of care dimension	A rational logic of efficiency	A relational logic of efficiency	A relational logic of efficiency – the farming context
View of vulnerability	Threatens self: avoid	Opens to others: embrace	Mutual dependency
Role of trust within the relationship	Earned: Naïve to trust without evidence	Assumed: primary assumptions of the best in others	Trust is central for flourishing relationships and thus a central aim to work for

The traditional rational and productivist perspective of agriculture identifies *care* not as a co-constructed interdependent relation but rather as control of an object (Puig de la Bellacasa 2015). This perspective of taking control is not fruitful since we can never fully control a living eco-system. The whole can never be fully understood from its parts and is always more than the parts we can study.

2.5.4 Drivers for care work to increase sustainability

Farmers have, as all individuals, different ambitions, goals and dreams for their business, farm or place (Vanclay 2004). There are multiple and dynamic narratives that shape farmers' relations to their farms (Herman 2015). However, always based on a need to get a viable income from the farming practice. In addition, morality is nowadays an important feature of farming (Burton et al. 2021). Farmers are supposed to produce food for a growing population, support rural communities, consider environmental issues and animal welfare. Finally, society has requirements in exchange for agricultural subsidies (Burton et al. 2020). The demand for a viable farm means that the farmer always acts in relation to the structural and social features of the economic system, where they operate (Falconer 2000). Accordingly, Ahnström et al. (2009) claim that we must look outside the farm, and inside the farmer to understand what external and internal factors that work as drivers in farmers' management and care. However, there are always non-economic norms and obligations that guide people's behaviour, decisions and experiences. So, what a "good farmer" means is not easy to define. Rather, '*being a good farmer is about the prestige given by possession of cultural capital, which is acknowledged as valid by others. It* *is thus about skills and knowing: knowing how to farm well and knowing the legitimate criteria for defining what is well*' (Burton et al. 2020:131). Here farming peers are important to contribute to the legitimacy (Burton et al. 2020), but consumers or others could also provide this kind of legitimacy. Cuncliffe (2009) claims that if we know *who to be*, we know *what to do*. We all want to be good people and accepted as we are. Hence, farmers want to be considered good farmers, but the interpretation of what that means must comply with my own interpretation. A possible way forward would thus be to increase our reflection and discussion concerning a change in care, relations and logic of efficiency.

One example from the summer of 2022 is a farmer who got attention from an ornithologist regarding a bird that had not been seen in the region for almost 60 years, and which now nested on one of his fields. Thanks to the ornithologist, the farmer now has a new relation on his farm. He has learned a new bird species and can perhaps recognise it in appearance or even its song. In addition, the farmer seemed very pleased with what his organic and regenerative cultivation system had achieved and told friends on Facebook. In this case, the farmer did not change his care or production system to benefit the bird. However, nobody knows what measures he would have taken if somebody had drawn his attention to this possibility earlier, and nobody knows what he will do now, but at least he seemed proud.

2.5.5 Care and digital technology

Digital technology could improve farmers' care and visualise, measure and handle different kinds of data needed to better understand new parts of the farming system and important relations. However, technology is not an aim in itself, it is a tool embedded in a care, with an aim to achieve something decided by someone. In the agricultural context, the farming practice is the something and the farmer often is the someone. Farmers will only adopt digital technology and new knowledge if they consider it relevant, credible, usable and sufficiently profitable. Farmers thus must believe there are benefits of technology adoption that make it profitable from economic, learning, time as well as effort aspects and thus be motivated to change their practice.

To date, agricultural research has used digital technology in a prescriptive manner to transfer knowledge from science to practice, aiming to increase farmers' acquisition of scientific knowledge, increase sustainability and facilitate the diffusion of innovation (Nitsch 1994; Leeuwis 2004; McCown et al. 2009; Thornburn et al. 2011; Trendov et al. 2019). For many years, research has produced a large number of digital solutions, but most of them have not been used appropriately in practice (e.g. Rossi et al. 2014; Aubert et al. 2012; Eastwood et al. 2012; Matthews 2008; McCown 2002). Developers of digital technology often come from a knowledge transfer tradition, where they consider one issue at a time, the technology, while the farmer must consider the technology in the whole practice (Rossi et al. 2014; Röling 1988), socio-technical system and care. Aubert et al. (2012) claimed that factors influencing the adoption of innovations are tightly linked to work practices that are more complex than just the perspectives of technology acceptance or diffusion of innovations.

One identified problem is the normative way of developing new technology, without consideration of the actual needs of the end-users (McCown 2009). This often leads to the development of technology that is not perceived as useful, credible and viable enough, thus remaining unadopted (Aubert et al. 2012). Hence, here is an obvious research-practice gap (Mackrell et al. 2009) that McCown et al. (2009) defined as a *gap of relevance* that has to be bridged, or at least decreased, if digital technology should facilitate and support sustainability increase and transformation in agriculture. To bridge, or at least, narrow the gap of relevance, it is important to understand what end-users require, how individuals use technology in practice, and accept that the technology is dependent on farmers' care. However, most existing research on farmers' work practices is based on rationalistic assumptions rather than on empirical data from practice studies in real-life settings, although there are some exceptions (e.g. Bradford 2009; Lindblom & Lundström 2014). Through a more thorough portrayal of farmers' care in their social-technical system, it would be possible to improve the design process in order to make adoption relevant. Adoption is often a kind of substitution process, where the decision maker chooses to substitute one kind of technology with another kind, hopefully better suited for the farmer's intended purposes (Marra et al. 2003). However, taking the view of the end-user as a passive receiver for new technology has resulted in a focus on spreading the knowledge about the innovation, instead of concentrating on the end-user's perspective and requirements. Before adoption, the individual considers the perceived advantage, compatibility, trial ability, complexity and observability compared with the technology it supersedes (Rogers 2003). The perceived relative advantages do not necessarily have much to do with *objective* advantages (Rogers 2003; Matthews 2008; Aubert et al. 2012). High compatibility, trial ability and observability normally increase adoption, while high complexity decreases it.

Two additional important criticisms have been made of the diffusion of research. One is the *pro-innovation bias*, i.e. the normative way of looking at adoption as the correct decision, based on the view that an innovation does not need to be re-invented or rejected (Rogers 2003). This leads to individuals being blamed for not adopting, i.e. the *individual blame bias* (Rogers 2003). Both are related to the *knowledge transfer* and *technology push* perspective. They both assert that somebody other than the end-user knows what is usable and credible. In addition, success in technology transfer or dissemination tends to focus on the number of adopters, not the long-term, cross-domain and cross-scale consequences (Wigboldus et al. 2016).

However, well-designed digital technology could be a useful tool for farmers. Technology that is easy to use and make cost-benefit evaluations can be adopted broadly in a short time. One such successful example is auto-steering systems. More complex technology needs to be better embedded in practice to be adopted. Parker and Sinclair (2001) claimed that the single unifying predictor of success or failure of an AgriDSS is the extent to which users are involved and participate in the design and development process. Accordingly, participatory approaches in the development processes of technology have proven to be a key success factor (Parker & Sinclare 2001; McCown 2002; Matthews et al. 2008; Reed 2008; Woodward et al. 2008; Jakku & Thornburn 2010; Hochman & Carberry 2011; Thorburn et al. 2011; Prost et al. 2012; Van Meensel et al. 2012). Moreover, Van Meensel et al. (2012) and Jakku and Thornburn (2010) stressed the importance of participatory approaches for the successful development of technology, as well as the role and relevance of social learning by the stakeholders involved in the participatory development process. Agricultural science should thus focus on developing adaptable *prototypes* and *principles*, instead of absolute *technical packages* and *solutions* (Hoffman et al. 2007) in order to increase farmers' possibilities to adapt the digital technology to their socio-technical system and care. Thus, reconsideration of digital development would provide important opportunities to involve different stakeholders in such learning processes and to frame a change from *goal-orientated thinking* towards *thinking in terms of learning* (Schlindwein et al. 2015). In addition, more studies of farmers' post-adoption use of technology in practice would increase our knowledge on how farmers interact with technology over time and how this use impacts relations and practice on the farm. A changed process from *acting on* to *living with*, from the transfer of knowledge to social learning, in which farmers' care in practice will affect the result and improve digital technology. However, technology impact can be considered bi-directional (Rose et al. 2018), that is, it impacts user behaviour, but the nature of technology is also shaped by the user. Thus, care practices change when new technology is adopted (Holloway et al. 2014), but the farmer also adapts the technology to his/her needs and practice. Nothing impedes technology in care (Mol et al. 2010). '*Technologies, what is more, do not work or fail in and of themselves. Rather, they depend on care work. On people willing to adapt their tools to a specific situation while adapting the situation to the tools, on and on, endlessly tinkering*' (Mol et al. 2010:15). Adoption of digital technology can limit, change, jeopardise or improve the individual's possibility to develop good and broad relations within farm work. Digital technology use could both increase and decrease human ability to provide good care, and we need to reflect on the impact on care work when introducing new technologies. However, technology developers should, to a greater extent, take farmer's requirements into account in digital technology research and development to make it credible, relevant and usable in farmers' practice. Otherwise, they will continue to develop technology that will not be used.

2.6 Theories to analyse care in farming

The thesis work started with a frustration concerning what I regarded as a kind of implementation problem. Accordingly, there was a need for improved knowledge concerning convenient strategies for the design and development of ICT systems to fit in and support farmers' practice and care. To approach this, I turned to the research area of human-computer interaction (HCI) (Issa & Isaias 2015; Rogers 2012). HCI provides established knowledge concerning how to design and develop ICT systems that are usable, efficient and credible to the end-users. The central aspect is to consider user-centred design (UCD) approaches, which agriculture in general, and PA, as well as PLF in particular, would benefit from the design.

Through the early involvement of farmers in the development process of digital technology, farmers' care and requirements from practice can be considered at an early stage. This approach has been broadly missing in the area of precision agriculture for a long time, which is described in papers I and II. This thesis has not considered those issues in dairy using AMS. However, the broad and increasing adoption of AMS in dairy indicates that AMS companies have had a better approach towards end-users in parallel with a provision of an improved work environment that the dairy farmers can better grasp.

The second focus of the thesis was to investigate farmers' care in practice and analyse it in real-life settings. The first context analysed was the fertilisation of winter wheat in crop production using an AgriDSS called CropSAT. The second context was dairy farmers' use of AMS. Farmers' care in complex socio-technical systems involves technical aspects as well as cognitive, social and relational components. To be able to analyse those socio-technical systems, I chose to turn to HCI and modern theories of cognitive sciences applied within the HCI field, aiming to widen the technical, biological and natural scientific approach developed within the field of PA and PLF and bring systemic, cognitive, relational and human-centred issues to the field of digital technology development in agricultural science. Farmers' management has traditionally been studied using theoretical frameworks from economic science (McCown, 2002), similar to the traditional approach within cognitive science, which has resulted in a limited understanding of their situated and naturalistic decision-making and management process that encompasses the whole socio-technical system. To acquire more knowledge of how farmers' care occurs in its socio-technical context *in the wild*, I first performed a workplace study and turned to the more modern approaches of cognitive science and the framework of DCog (Hutchins 1995) to analyse farmers' care and decision-making within that socio-technical system. Subsequently, I chose to perform a study inspired by workplace study methodology to analyse farmers' work in AMS in dairy. The AT was chosen as a lens for the analysis of the collected data (Engeström 2015). DCog and AT have much in common and share the ontological and epistemological bases of interactionism and constructivism that are the pillars of farming systems research (Darnhofer et al. 2012); moreover, they contribute by widening the unit of analysis to include technology and other artefacts as well as humans and non-humans in the studied system. We follow the thesis work chronology and start with the framework of DCog and then the AT. The reason for changing the theoretical lens between the two studies was that the CropSAT study aimed to investigate what was happening right now, while the AMS study aimed to describe a process of development. The learning perspective is more obvious in AT than in DCog, driven by contradictions and activities in the system (Engeström 2001).

2.6.1 DCog as a lens to analyse farmers' care in crop production

DCog developed during the mid-1990s out of criticism within traditional cognitive science regarding the plan-based, individualistic and non-holistic conception of human conduct (e.g. Lindblom 2015; Heath et al. 2000; Rogers 2012). The theoretical framework of DCog was introduced by Hutchins (1995) in response to the more individual models and theories of human cognition, and DCog is a descriptive, systemic perspective that presents an understanding of the complex and temporally interplays of the body, the social and material world and the brain as a whole phenomenon (Clark 1998). From a DCog perspective, human cognition is fundamentally socio-culturally distributed in the socio-technical environment that the individual inhabits. Through its system perspective, DCog discards the idea that the human mind and environment can be separated and states that cognition should instead be considered as a socio-material process, rather than as being contained inside the mind of the individual. Hence, DCog views cognition as socially distributed in a complex socio-technical environment, while cognition, including learning and decision-making processes, is seen as the *creation*, *transformation* and *propagation* of representational states within a socio-technical system (Hutchins 1995). A representational state can be what is expressed in utterances, written or drawn in symbolic language or notification systems, embodied interactions through movements and gestures that carry meaning, or information that is available via artefacts and tools used (e.g. displayed or stored information on an ICT system, a note, or a speedometer). By observing and analysing what is happening within the information flow of whole systems, ongoing cognitive processes are externalised and visualised. An important aspect of the system view is that cognition is seen as a culturally situated activity, and should be studied where it naturally occurs, i.e. *in the wild*. The DCog framework differs from other cognitive approaches in its commitment to two theoretical principles (Hollan et al. 2000). The first principle concerns the boundaries of the unit of analysis for cognition, which is defined by the functional relationship between the different entities of the cognitive system (Figure 2). The second principle concerns the range of processes that are considered to be cognitive in nature. In the DCog view, cognitive processes are seen as coordination and interaction between internal processes, as well as manipulation of external objects and the propagation of representations across the system's entities. When these principles are applied to the observation of human activity *in situ*, three kinds of DCog processes become observable (Hollan et al. 2000): (1) *Across* the members of a group, (2) *between* human internal mechanisms (e.g. decision-making, memory, attention) and external structures (e.g. material artefacts, ICT systems and social environment), and (3) distributed *over* time.

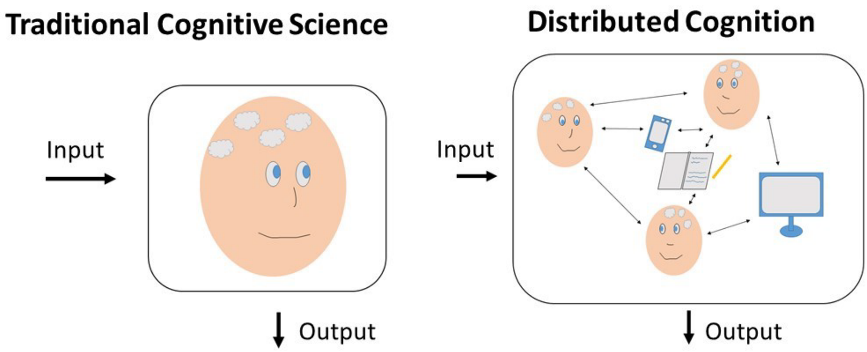

Figure 1. From a traditional cognitive science perspective (left), the unit of analysis is narrowed to inside the individual's head, while from a DCog perspective (right), the unit of analysis is expanded to be distributed across people and artefacts where cognitive processes are the result of the functional relationships of the entities of the cognitive system (Picture: Anna-Karin Johnson).

Different kinds of representational states are central to the unit of analysis in DCog, as cognition is seen as the coordination, transformation and propagation of representational states within a system. Hollan et al. (2000) take the stance that representations are not only tokens that refer to something other than themselves, but they are also manipulated by humans as being physical properties. Humans shift from attending to the representation to attending to the thing represented, which produces cognitive outcomes that could not have been achieved if representations were always seen as representing something else. An example given by Hutchins (1995) is the navigational chart. The chart is used for offloading cognitive effort (e.g.

memory, decision-making) to the environment and to present information that has been accumulated over time. Furthermore, Hutchins (1995) describes the navigational chart as an analogue computer where all the problems solved on charts can be represented as equations and solved by symbol-processing techniques. An important insight in this example is the relationship between the external structure (the chart as a representation) and the internal structure. The relationship between the external and the internal structures constructs a cultural meaning and is part of the same cognitive ecology. By identifying processes, properties and breakdowns in a functional system, the focus is mainly on dynamic aspects of activity (propagation of knowledge through the functional system), rather than static entities (for instance, power and role structures within an organisation) (Rogers & Ellis 1994). Hence, by studying external, material and social structures, properties of the internal mental structures are revealed and become observable.

Human cognition embraces many cognitive processes, including learning and decision-making that can be revealed by applying the theoretical framework of DCog in various situations and contexts. Hutchins's (1995) definition of learning from a DCog perspective is formulated as '*adaptive reorganization in a complex system*'. He describes learning as the simultaneous coordination of many different media within a complex functional system and claims that the proper unit of analysis for learning or cognitive change includes the whole socio-technical environment that humans inhabit. DCog takes a systemic perspective and discards the idea that the human mind and its environment can be separated (Lindblom 2015). Hutchins (1995) does not try to describe any mental mechanisms with which the behaviours of the representations can be modelled. According to Hollan et al. (2000), the environment that encloses people in their everyday life could be viewed as a reservoir of resources for learning, decision-making, problem-solving and reasoning. By interaction with such external resources, internal representations and computational actions could be identified by their visible functional properties.

An important aspect of the systemic view is that cognition is seen as a culturally situated activity that should be studied where it naturally occurs. Therefore, the system-level view makes DCog a fruitful approach for studies of complex socio-technical systems, where different parts of the system provide different but complementary contributions that allow concerted action. In other words, the study of external, material and social structures reveals properties of an individual's internal, mental structures, like decision-making, learning and care. Hence, by studying cognition with this larger scope in mind, it is clear that the functional cognitive system has properties that cannot be limited to the cognitive abilities of the individuals. Using DCog as a theoretical framework provides the researcher with an approach that offers a systemic perspective e.g. farmers' socio-technical context to describe and study farmers' decision-making (Lindblom et al. 2013) and care from the systemic perspective that many agricultural researchers have demanded for years (e.g. Öhlmer et al. 1998; Röling 1988).

DCog has been shown to work well when applied in HCI research, by involving technology in the unit of analysis, instead of putting it outside (Rogers 2012). The theoretical framework of DCog has been applied in many different and complex domains, including ship navigation (Hutchins, 1995), critical care environments (Patel et al. 2008) and information fusion (Nilsson et al. 2012). Therefore, it was reasonable to believe that it would work properly in the agricultural domain, where many farmers' care includes social interactions, interactions with ICT systems, animals, together with other tools and artefacts.

2.6.2 AT as a lens for care analysis

AT provides a comprehensive conceptual framework that can be used for grasping and portraying the structure and development of human activity situated in its technical and social context (Kaptelinin et al. 1999; Kaptelinin 2013). It has roots in early Russian psychology, dating back to the work of the Russian scholar Lev Vygotsky in the 1920s–30s (Kaptelinin 2013). It provides a broad and complex framework for describing and evaluating the structure, development and context of human activity, considering individuals, artefacts and other humans and subjects, as well as their interrelations (Duignan et al. 2006; Kaptelinin et al. 1999). According to AT, the only way to understand the human mind is in the context of human interaction with the world, and this interaction, i.e. activity, is socially and culturally constructed (Kaptelinin 2013). Since its inception, the underlying principles of AT make up an intertwined system forming a whole that represents several aspects of human activity. This creates a need to apply these principles from a systemic perspective because of their interrelatedness, which unfolds over time. One way to do so is to use the extended AT framework called the Activity System model (Engeström 2001,

2015) (Figure. 3). The Activity System model is a way to visualise the different interactions between various elements when performing an activity and its outcome from a systemic perspective. In the Activity System model, the interactions between subject, object, main mediating artefact and community are mediated by specific mediational means. These are: mediating artefacts and tools/ instruments for the subject-object interaction, rules (e.g. norms, work practice and legislation) for the subject-

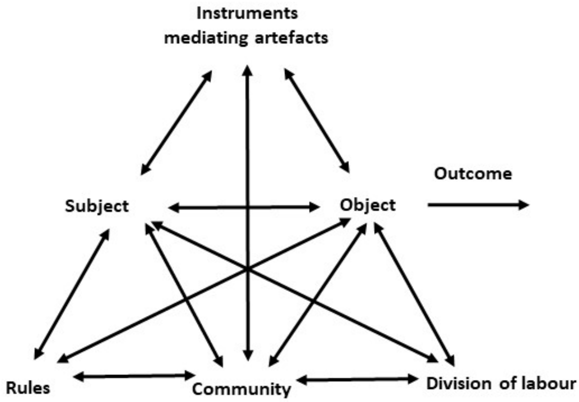

Figure 2. The Activity System model includes the interactions between the elements of the overall activity and its outcome (modified from Engeström, 2015:63).

community interaction, and division of labour for the community-object interaction (Engeström 2001, 2015; Kaptelinin 2013). Moreover, the Activity System model includes the outcome of the activity system as a whole, namely the transformation of the object generated by the activity in question into a suggested outcome. This visualisation approach highlights the continuous process of transformation and development over time.

Engeström (2001, 2015) applies a systemic approach to theorising humans' intentional activities and does not consider humans as passive factors lacking any internal properties or motives. This way of thinking highlights the continuous process of transformation and development over a time horizon of learning. A critical step when analysing an activity system is looking for so-called contradictions within the system, i.e. any misfit within an element in the system, between elements in the system, or between the current activity system and other activity systems (Engeström 2001, 2015). The use of the contradiction term within AT should not be mixed up with the common usage of the term in ordinary language. In AT, contradictions are manifested as challenges, problems, interruptions, workarounds or breakdowns that the subject and the system as a whole need to learn how to handle in an ongoing process of learning (Kaptelinin 2013; Engeström 2015; Lindblom & Alenljung 2020). According to Engeström (2015), when an activity system is under transformation, the actors within the system must develop new forms of activities that are not yet present in the system, often by contradictions; therefore, new activities are learned as they are created. An activity can be understood as a purposeful, transformative and developing interaction between actors (subjects) and the world (objects). In this thesis, *care* is considered both as the activity as such and as the intended outcome of the activity system. AT is built upon five central principles: hierarchical structure of activity, object-orientedness, tool mediation, internalisation-externalisation and development. These principles are aligned with the view of care as the patterning of activities. The hierarchical structure of activity organises an activity into three levels, activity, action and operation, which are related to motive, goal and condition (Kaptelinin 2013; Rogers 2012). The top-level is the activity itself, carried out to fulfil a motive, i.e. providing good care in farming. The middle level, action, is described as conscious processes subordinated to the activity. Actions correspond to what must be done and are directed at specific goals, which may be decomposed into sub-goals, sub-sub-goals, etc., meaning that multiple actions and operations may be nested to fulfil the activity. At the bottom level, the operations function as lower-level units of actions (Rogers 2012). As such, operations do not have their own goals, but are a result of prior actions that have been transformed into automated operations (Kaptelinin 2013). Hence, viewing human activity as a three-layer system offers the possibility for a combined analysis of motivational, goal-directed and operational aspects of human activity of care in the socio-cultural and material world, by interrelating the issues of "why", "what" and "how" within a coherent framework (Kaptelinin 2013; Lindblom & Alenljung 2020; Rogers 2012). The principle of *object-orientedness* states that all human activities are directed towards different objects, and these objects motivate and direct activities. The principle of *tool mediation* is applied broadly. It embraces different kinds of tools and shapes the ways users interact with the world. The principle of *internalisation-externalisation* stresses that human activity has a double nature because every activity has both an external and internal side. Hence, the *internalisation-externalisation* principle is characterised by the ongoing shifting back and forth between what happens internally "in the head", i.e. what the farmers think and reflect upon, and what happens practically and externally "in the open" as a human activity.

As pointed out by Halverson (2002), the Activity System model has been widely used to analyse various work settings, particularly when there are problems with current or newly implemented technology, where the model enables investigators to identify contradictions on both the micro-and macro-level. A suggested approach to frame Activity System model analysis is the eight-step model, developed by Mwanza and Engeström (2005), which offers a structured way to describe the activity and sub-activity triangles in the model. The challenges arising from changing from one production system to another can thus be considered a shift between two activity systems that raise different contradictions, which are managed through learning by developmental cycles from established care to another new form of care.

Although DCog and AT share several similarities, they have developed from two different research traditions. AT has roots in early Russian psychology from the early 1930s, and DCog originates from anthropological work conducted by the American cognitive scientist Edwin Hutchins in the 1980s. It should be highlighted that there are several differences between DCog and AT from cognitive science and HCI perspectives (see Halverson 2002; Rogers 2012), which will not be discussed in detail here. However, it should be emphasised that DCog has strongly been inspired by AT in its focus on tools and mediating artefacts during its inception. The AMS has a much stronger focus on transformation and development between various systems, whereas DCog focuses more on the information flow and propagation of various representational states within the current system. For the purposes of this thesis, the DCog approach was considered more useful for the aim of the AgriDSS studies, whereas AT was more well-aligned with the AMS study.

3. Research design

The work included in this thesis is based on four case studies. The first three case studies were conducted in the context of PA and what the scientific community regarded as the problem of implementation (McCown 2002; Rossi et al. 2014). In the last case study, the context was changed to AMS dairy farming, where the adoption has been extensive in many countries (Eastwood & Renwick 2020). Since my background was in PA, I started there. Later, it was interesting to study care in another high-tech, more complex context.

In order to answer the aims of the project (cf. section 1.2), a qualitative, naturalistic inquiry was conducted in four parts. In this thesis, a naturalistic inquiry is used interchangeably with qualitative inquiry. Such an inquiry involves observations performed in natural settings (Lincoln & Guba 1985), focusing on deep and detailed descriptions of actions, behaviours, conversations, activities and interpersonal interactions from fieldwork (Patton 2002). It studies situations in the real world without manipulating or controlling them and is open to whatever emerges (Patton 2002). In a naturalistic inquiry, the context is incorporated into the analysis, because it is considered important for the interpretation of the meaning of a situation (Lincoln & Guba 1985; Patton 2002). Furthermore, in choosing a naturalistic inquiry, the quality of the data combined with sound conclusions is the most important aspect to achieve scientific rigour (Patton 2002). Patton claims that '*the validity, meaningfulness and insights generated from the qualitative inquiry have more to do with the information richness of the cases selected and the observational/analytical capabilities of the researcher than with sample size'* (Patton 2002:243). Thus, the quality of the study lies in the performance of the study itself.

For the naturalistic inquiry, a case study approach was chosen. A case study is a qualitative method that studies human actions *in the wild*, aiming to describe detailed systemic information to facilitate a holistic analysis (Patton 2002). A case study can be conducted in order to explore a bounded system or systems over time by sampling in-depth data from multiple sources of information that are rich in context (Patton 2002). A case, or the bounded system, can be an individual, a programme, an event, a phenomenon or an activity. Stake (2000) defines three main types of case studies: intrinsic, instrumental and collective instrumental. An intrinsic case study is investigated to understand that particular case in detail. When performing instrumental case studies, the actual case facilitates an understanding of other cases and aims to provide insight or at least a generalisation of other cases. Collective instrumental case studies are extended to many cases that manifest common characteristics, where the individual case may or may not be known in advance.

- The first case study, which took the form of a workplace study, investigated and analysed farmers' care using CropSAT, either alone, with a colleague or together with advisors when making decisions on how to fertilise winter wheat in practice. The DCog framework was used as a lens for the theoretical analysis of farmers' care.

- The second case study mainly had a conceptual approach concerning a shift in the ICT system design methodology in PA to improve the development processes of digital technology. It used empirical data from first-hand experiences of participation in the Swedish network of Precision Agriculture (POS).

- The third case study investigated Swedish crop advisors' thoughts, usage and opinions concerning the AgriDSS CropSAT.

- The fourth case study investigated how Swedish dairy farmers' care developed with the adoption of AMS. Additionally, a questionnaire was sent to Swedish dairy farmers with AMS, complementing the qualitative data with quantitative data from a larger group of farmers. AT was used as a lens for the theoretical analysis of farmers' care.

3.1 Case study one – A workplace study, CropSAT

In case study one, four collective cases were used, and the analysis was conducted as a multiple case study from a workplace perspective (Luff et al. 2000). The case comprised four crop production farmers who showed an interest in PA technology. The study was conducted in 2015 in southwest Sweden, and the digital technology involved was CropSAT (www.CropSAT.se). Workplace studies investigate and analyse people and technology in action and observe how different tools and artefacts are used in practical organisational conduct (Heath et al. 2000). Workplace studies are important to understand natural systems, and they contribute valuable information about the design, usage and evaluation of different technologies. Ethnographic data collection techniques were used, and the collected data were triangulated from participant observations, video recordings and semi-structured interviews (Patton 2002). All farmers were purposefully sampled in order to gain as much information as possible and understand the phenomenon in depth (Patton 2002). Although the number of farmers was small, and therefore, the results are not readily generalisable, such small samples can provide much learning if they are chosen in an appropriate way (Stake 2000). Three of the four farmers employed a personal advisor on crop production.

The selected farmers had different levels of previous experience in using ICT-based crop production software and PA technology, but they all demonstrated an interest in this technology in general and in CropSAT in particular. The workplace study was performed on each farm, through participant observations and ethnographical/contextual interviews. The observations were video-recorded. Every farmer was visited three times (1–3 hours each) during spring and one time in the following autumn, for a follow-up session. In some situations, the farmer was alone, and in other cases, an advisor, colleague or an employee also took part. The meetings were generally held in the farmer's office, farmhouse kitchen or staff lunchroom. The computer sessions were conducted during farmers' ongoing work, which influenced both questions and answers in the interviews. It also made it impossible to arrange and decide exactly how those sessions were conducted. Accordingly, they were different on different farms. The transcripts were read through several times to find interesting episodes that could be further analysed. Those selected episodes were then more fully analysed, taking inspiration from the DCog theoretical framework (Hutchins 1995). This resulted in descriptions of the propagation, distribution and information flow of different representational states, in terms of care, work practices, decision-making, learning and procedures in the socio-technical system (Rogers 2012). When an episode was chosen, the transcript and video recording were used together to make more detailed notations of the different cognitive processes that appeared.

3.2 Case study two – The POS Network

Case study two was conducted in 2014 and mostly involved a conceptual approach that investigated the pros and cons in theory and practice when initiating a shift in the ICT system design methodology for PA from a more technology-centred approach to a more user-centred approach in the design, implementation and diffusion of an AgriDSS (www.CropSAT.se). The empirical data were based on the author's experiences collected at meetings and discussions within the POS, in which the author had a coordinating role. The intention with this purposive sampling was that I had good insights into what had happened so far within PA in Sweden since the vast majority of the professionals involved in R&D on PA technology in Sweden at that time were a part of the POS network. The aim of case study two was mainly to frame the development process conducted so far, based on experiences of the approaches stressed in the human-computer interaction literature, which was rather unknown in this agricultural domain. By using theories, approaches and strategies from the human-computer interaction discipline, unnecessary work could be avoided, as the agriculture domain then does not need to go through the learning process conducted in other domains when trying to develop credible ICT systems. The collected data were analysed by content analysis (Patton 2002) and iterative discussions during the writing-up process. It should be noted, however, that more empirical data were collected in case study one, whereas case study two focused on content analysis using human-computer interaction theory and the approaches advocated as a lens to analyse and discuss the empirical data.

3.3 Case study three – Advisors' considerations concerning CropSAT and PA

This case study was conducted as a follow-up in 2016 and 2017. Fourteen crop advisors from different parts of Sweden were purposively sampled (Patton 2002) due to their role as crop production advisors, presented on the company website. Semi-structured interviews were conducted by telephone with twelve advisors, and notes were taken. Two interviews were conducted as personal meetings. Those were recorded. The interviews concerned the advisor's personal work interests in common, their customers' production and interest, and to what extent and how they used PA technology and CropSAT. The interviews were compiled and analysed thematically.

3.4 Case study four – Farmers' care in AMS

The last case study used a mixed-methods research design (Patton 2002; Creswell & Clark 2017). Mixed methods is a research design approach where researchers collect and analyse both quantitative and qualitative data within the same study. Applying mixed methods design allows researchers to explore diverse perspectives and uncover relationships that exist in multifaceted research challenges. As pointed out by Creswell and Clark (2017), numerous classifications of mixed methods designs are found to exist in the literature; here, a triangulation design was chosen. Triangulation design is the most common and well-known approach to mixing methods, and the main purpose of this design is to collect different but complementary data on the same topic to gain a deeper understanding of the particular research questions and the study's aim. We applied an *inductive drive,* which means that the study design was qualitatively driven with the purpose of expanding qualitative the results with quantitative data (Schoonenboom & Johnson 2017).

Data triangulation (Patton 2002) was performed using different data collection techniques (questionnaire, interviews and field visits). Data collection started with interviews, in order to gain an initial understanding of farmers' experiences and perceived pros and cons with AMS. Nine farmers (eight with AMS and one who had invested in AMS, but then changed back to CMS), four advisors and two AMS representatives were interviewed. The farmers were purposely sampled, in order to get as much information as possible (Patton 2002). The interviews were semi-structured and were conducted in real life (all farmers and the company representatives), by telephone (two advisors) or by Skype (two advisors). All interviews were audio-recorded, except for the telephone interviews, where notes were taken. The questions concerned experiences of AMS in the work environment, production, advisory services and technology use. The companies interviewed were DeLaval, Lely, Växa Sverige, and a sole proprietorship. One farmer, who contacted the first author due to the project, suggested the sole proprietor.

A questionnaire was developed based on an initial analysis of the interview responses. The final questionnaire comprised 29 questions, some with sub-questions, structured into seven topics: 1) background, 2) milk production, 3) experiences of AMS, 4) experienced mental stress, 5) advisory aspects, 6) future possibilities and challenges and 7) the work situation. The questionnaire included questions with Likert scales, ranging from false to true, multiple-choice questions and five open questions, thus mainly subjective results based on farmers' opinions. In Sweden, no complete official statistics exist that collect information about what kind of milking system a particular farm uses. Accordingly, the leading AMS companies in Sweden, DeLaval and Lely, were asked to spread the link to the questionnaire, through their digital newsletters. In addition, the same invitation was sent through a Facebook group for Swedish AMS farmers that comprise more than 3,000 members. Completed questionnaires were submitted via a link, and therefore anonymous. No statistics were performed on the questionnaire data, given the inductive drive in the mixed methods design approach.

Field visits were conducted on three dairy farms to gain a deeper understanding of how AMS work and are used in work practice. The farms were located in western Sweden in the former county of Skaraborg and Jönköping, which are two of the regions with the highest densities of dairy cows in Sweden (Svensson et al. 2018). The farms represented: 1) A large family farm with a very technology-interested female farmer who had a relatively short experience of dairy farming but sometimes tests new technology for DeLaval, 2) A family farm with one female farmer who had a medium interest in technology and long experience of dairy farming and 3) A farm with one male farmer with long experience of dairy production (both CMS and AMS) and an interest in new technology. Each field visit took 1–2 hours. The first and second field visits were performed by the first author in conjunction with interviews with the farmers. No systematic observations were conducted on the farms. During the farm visits, interviews were held in farm offices, where the computerised AMS system was demonstrated, and in cowsheds where the AMS were installed. Visits were conducted together with the farmer or an employee, to observe and gain a deeper understanding of the whole activity system. The third field visit (Farm 9) was conducted as a follow-up by both authors during the analysis of the collected data. In addition, field notes, photographs and video recordings were made during the visits to the cowsheds.

The collected data were analysed as follows: The transcripts from the interviews and the field notes were read through a couple of times and analysed thematically, using the focal points of AT (Mwanza & Engeström 2005). An AT lens was then applied to analyse care (Tronto 1998; Mol et al.

2010; Krzywoszynska 2016). The questionnaire responses were analysed in Excel, and included in the above thematic content analysis, especially the responses to the open-ended questions. The unstructured observations from the field visits were used to complement the other sources of data. It should be emphasised that although the data collection was done sequentially, the overall analysis was done through several analytic *points of integration* where quantitative and qualitative components were brought together (Schoonenboom & Johnson 2017), with the support of the focal points of AT. As pointed out by Creswell and Clark (2017), a primary way to connect qualitative and quantitative data is to use a theoretical framework to bind together the data sets. Qualitative data were used to *illustrate* quantitative results, as well as qualitative data, which were used to describe the underlying *process* for the obtained quantitative results (Schoonenboom & Johnson 2017).

4. Summary of papers

4.1 Paper I: Some considerations about the development and implementation process of a new agricultural decision support system for site-specific fertilisation

The starting point for the first paper was that digital PA technology, so-called agricultural decision support systems (AgriDSS), would contribute to sustainable intensification by providing farmers with possibilities to adapt farming measures to within-field variation. AgriDSS was used for the transfer of knowledge from science to practise. However, many AgriDSS seemed not to be used to their full potential. The paper discussed the so-called *implementation problem*, and its relation to technology driven development. To handle this problem, the paper discussed how user-centred design (UCD) approaches from the research field of human-computer interaction (HCI) could contribute to strategies that would avoid or at least limit the implementation problem. UCD approaches build on design and development processes that involve the end-users from the beginning. Such participatory design approaches are social learning processes where farmers and other end-users bring in their requirements, perspectives and knowledge to contribute to technology development. However, the paper did not mention the care perspective explicitly. It discussed how farmers would contribute with their experience and situated knowledge from practice during development, to ensure that the developed AgriDSS was relevant, credible and usable in practice. Thus, participatory design strategies would be effective in bridging the gap between practice and theory and ensuring that developed AgriDSS would be interesting for farmers. It is not a question of explaining or more clearly arguing for technology benefits, but rather to have a dialogue with end-users from the beginning concerning their needs in practice and thus avoiding unnecessary technology development. The paper aimed to highlight the need for a change of perspective, from knowledge transfer to social learning, which could be interpreted as a change from *acting on* to *living with*. The paper summarises pitfalls and suggestions concerning how to manage such UCD participatory development processes. The main contribution of paper I of the thesis is a critique of the traditional technology driven development of digital technology in PA and the proposal of a change to social learning development strategies.

4.2 Paper II: Promoting sustainable intensification in precision agriculture: a review of decision support systems' development and strategies

This paper was an extended version of paper I and used the same assumptions considering PA. Paper I was peer-reviewed for the proceedings of the 10th European Conference of Precision Agriculture and then published in the journal Precision Agriculture. Paper II was submitted to the scientific journal of Precision Agriculture. Since both papers are published in the journal, I chose to include both in the thesis. Paper II took a conceptual approach by investigating the pros and cons in theory and practice with a shift in ICT system design methodology. This was from a technology-centred approach, based on knowledge transfer to a more user-centred approach in design and implementation, based on social learning. The aim was to address the problem of implementation and suggest strategies to increase the usability and credibility of PA technology by suggesting theories and methodologies from the research field of HCI and UCD methodology. The paper suggested regarding the development of new technology as a social learning process, since farmers' practice and situated and experienced-based knowledge are important to consider from the beginning of technology development. The suggested strategy was to involve farmers as equal partners during the whole development process. A Swedish project that planned to use co-learning design processes for further development of a tool for variable rate application of fertilisers, CropSAT, was used as a case. A list of strategies was suggested to avoid pitfalls or at least reduce them. The contribution to the thesis from paper II was the demand for a changed perspective from knowledge transfer and technology-driven development to social learning strategies and technologies based on farmers' defined problems. The paper did not mention the concept of care explicitly. Instead, farmers' situated and experienced-based knowledge from practice were identified as central in order to develop technology that would be relevant, credible and usable for farmers and thus avoid the implementation problem.

4.3 Paper III. Considering Farmers' Situated Knowledge of Using Agricultural Decision Support Systems (AgriDSS) to Foster Sustainable Farming Practices: The Case of CropSAT

This paper took its starting point from the perspective of digital technology as an important tool to increase sustainability in agriculture. The paper was based on a case study that examined how an AgriDSS called CropSAT could support farmers' decision-making, learning and care in real-life settings. Technology use is a cognitive act for the individual, but it normally involves other artefacts, humans and non-humans. Thus, the traditional way of looking at cognition as something that happens inside someone's head is not fruitful. Instead, the unit of analysis was broadened to the whole socio-technical system. The overall aim was to increase the understanding of the relationship between farmers' experience-based situated knowledge and the use of AgriDSS to develop farmers' care. To study care, participatory observations and semi-structured interviews for data sampling were conducted. The theoretical framework of DCog was used as a lens for the analysis of farmers' use of CropSAT. The result showed that CropSAT 1) use developed and improved farmers' situated seeing, 2) functions as a coordinating mechanism between farmers and advisors, 3) use developed farmers' tool mediated seeing, professional vision and accordingly, farmers developed *enhanced professional vision* and care. Paper III contributes to the thesis with the introduction and analysis of the concept of care and the introduction of the term enhanced professional vision as a combination of farmers' tool-mediated seeing and professional vision. The result revealed that technology supported farmers' relations to their crop and field embedded in their care work. However, this was not explicitly described in the paper. Finally, the study showed that this kind of PA technology supports farmers' work in a sustainable intensification trajectory.

4.4 Paper IV: Motivations and Needs for Adoption of the Agricultural Decision Support System CropSAT in Advisory Services

This study was performed for two reasons. Paper III showed that advisors could have an important role to play in farmers' care concerning the use of a PA AgriDSS called CropSAT. Additionally, the developers of CropSAT were concerned about what they noticed as a limited interest among crop advisers for PA technology. The study aimed to investigate how a group of Swedish crop advisors had reacted to the introduction of the internet-based, free to use AgriDSS CropSAT and how their common strategies for AgriDSS use could be characterised. Semi-structured interviews were performed with fourteen purposively sampled crop production advisors, and data were analysed thematically. The result revealed four advisor strategies: 1) I don't use it, 2) I use it if I have to, 3) I use it myself and tell the farmer and 4) I use it together with the farmer as a social learning tool. Only a few advisors introduced the tool and used it in a social learning context together with other farmers, which probably would have had the largest impact on farmers' care. Some advisors mentioned that the use of CropSAT increased fertilisation complexity, and they requested more support on how to use the tool and combine it with other technologies on the farm. They required back-office support in order to be more active concerning PA AgriDSS. From that follows a risk that pro-activist farmers do not find the advisory service they need, which could hold back an AgriDSS deployment, which farmers otherwise could have taken advantage of. Another risk was that up-front advisors did not get the support they needed to develop their skills concerning PA technology for their customers. The paper revealed a few, albeit competent, advisors who used CropSAT as a social learning tool on their own initiative. Their experiences contribute to the thesis by their confirmation of the social learning value of using AgriDSS together with farmers. Unfortunately, the results also confirmed that there was more to be desired in terms of the adviser's ability and willingness to use PA technology in their work.

4.5 Paper V: Care in dairy farming with automatic milking systems – using an Activity Theory lens

The last paper studied farmers' care and work environment in automatic milking systems in dairy. Previously in the PhD work, farmers' care was investigated in a quite limited socio-technical system. Implementing an automated milking system in dairy, on the contrary, changes the whole production system and thus has a great impact on farmers' care. Dairy farmers' care work is a learning process on different levels in their system, from detailed problems with an individual cow to the complete dairy system.

Care was considered both as the activity as such and as the intended outcome of the system. This paper also considered the care concept as relational more than in paper III. One reason for this would be that relations between humans and animals become more obvious than relations between humans and crops. Another reason would be increased maturity of the researcher. The study used a mixed-methods research design with semi-structured interviews, field visits and a questionnaire. Qualitative as well as quantitative data were collected. The qualitative data were analysed with an AT lens, using the Activity System model. This model is appropriate for investigating complex work settings involving technology. The model offers a structured way to identify both micro- and macro-level issues. The change from a conventional milking system to an automated milking system with robots was regarded as a shift between two activity systems. In each system, contradictions appeared to be managed through adaptation and learning by developmental cycles from one established form of care to a new form of care. To be successful in AMS, farmers and/or stock persons must learn continuously, adapt technology to the local situation, and continually improve their care as a patterning of activities. Even though the AMS is a supportive and complex digital technology, the importance of a stockperson's eye did not decrease with the implementation of AMS. On the contrary, the need for experience and a stockpersons' eye increased after the implementation of AMS, due to farmers' answers to the analysed data from the questionnaire and the interviews. Additionally, farmers and their employees had to develop tool mediated seeing and enhanced professional vision to be able to handle AMS data. The interdependence between farmers and robots became clear. The AMS is dependent on farmers' work practice, but it also shapes the nature of the same practice. AMS improved farmers' physical work environment, but some experienced a worse mental work environment due to the alarms. The relations between humans and cows at the dairy farm became obvious, and those relations motivated farmers to complement AMS data with direct contact with the herd to perform good care. AMS does improve farmers' physical work environment, although it causes increased stress due to alarms for some, resulting in worse mental work environment. Thus, for many farmers learning how to manage alarms, it could be considered a transformation concerning social sustainability. However, from an ecological sustainability aspect, the change had no obvious impact, at least not positive. Again, focusing on the ecological aspect of sustainability, the technology shift supported increased efficacy and sustainable intensification but not the required transformation. The paper contributes to the thesis concerning the application of the AT, which proved to be a possible lens to study and analyse care in complex socio-technical systems. The paper developed the care concept, and the relational aspects of care became clearer.

5. Synthesis of empirical findings

The aim of this thesis was to introduce and apply the concept of care to gain a deeper understanding of how farmers use digital technology in their practice to increase sustainability, more holistically. The concept of care highlights the importance of the individual's actions in his/her practice to utilise available digital technology, as well as to transform farming in the local context. In order to do this, the following four objectives were formulated:

- Present recommendations concerning digital technology development and design processes to ensure relevant, usable and credible technology for end-users that support their care practices.
- Investigate and analyse farmers' use of digital technology as an ongoing learning process of *care* in their socio-technical system.
- Introduce and apply theoretical lenses to study farmers' care in practice from a systemic/holistic perspective.
- Present implications for advisors in their work with farmers, based on the relational perspective of care.

The main findings from the work performed in this thesis are pertinent to the objectives presented in this chapter. They are organised according to the research objectives presented above, and more detailed results from the studies can be found in papers I–V.

5.1 Present recommendations concerning digital technology development and design processes to ensure relevant, usable, and credible technology for end-users that support their care practices.

The first objective was addressed substantially in papers I and II. The starting point was the problem of implementation, a knowledge transfer approach and a technology driven perspective in PA. To support a change in PA, the papers discussed how UCD approaches from the research field of HCI could contribute new strategies that would avoid or at least limit the implementation problem. UCD approaches build on design and development processes, which involve the end-users from the beginning. Such participatory design approaches are social learning processes where farmers and other end-users bring in their requirements, perspectives and knowledge to contribute to technology development. In both papers, some beginner's pitfalls using UCD approaches and suggestions concerning how to solve or at least reduce them were presented. The papers also stressed the risk with a participatory fix as well as a technology fix (Black 2000), as a result of a naïve attitude towards what participatory methods mean in practice. Neither top-down nor bottom-up approaches would be the solution, rather something in between (Ingram 2014). To engage the participants over time, they must be engaged in problem solving, related to the topic and be prepared concerning what is expected of them. Developing a functional work practice based on an in-between approach would require a bit of learning by doing. Such a process could be based on well-known strategies, but also develop continually in communication with the participants. In addition, complex digital technology would be considered as never finished, rather in a continually ongoing development process in communication with the end-users. A new technical solution must be generally interesting for the regarded end-users, but it must, to a certain degree, depending on the problem, also be adaptable to the local situation on each farm.

5.2 Investigate and analyse farmers' use of digital technologies as an ongoing learning process of *care* in their socio-technical system.

This objective was addressed in papers III and V: 1) Care when farmers are making decisions concerning fertilisation of winter wheat, using an AgriDSS called CropSAT and 2) care in dairy with AMS. The concept of care was introduced to highlight digital technology use in agriculture as an ongoing learning process in a socio-technical system. This thesis presents farmers' *enhanced professional vision* developed through the use of digital technology as a mediating artefact of relations in a farming practice. To understand and investigate farmers' use of digital technology, it is not enough to focus on the technology. Rather, the whole socio-technical system in the wild should be considered in order to understand the potential of new technology. Care is thus a concept that catches the tinkering learning process of applying technology in a practice, where farmers' situated knowledge and engagement are crucial to make it work. A technology will not work in practice if farmers do not consider it relevant and worthwhile to invest money and time. I claim that an increase in technology adoption goes hand in hand with the required increased awareness and knowledge among farmers;

technology will not take over! The more technology we invest in, the more human we humans have to be. Our values, worldviews and opinions must control what we do and how we do it in order to enter a transformational pathway, to really increase sustainability, and stop the unilateral focus on efficiency increase, but not forget it. Care has also a perspective of living with (Puig de la Bellacasa 2015) more than humans. This relates to a relational perspective that is central for us to apply in order to start a transformational pathway based on an awareness of our interdependence with more than humans. A relational perspective, conscious or unconscious, is crucial to regard a broad range of relations when reflecting on how to increase sustainability based on farmers' interest and local prerequisites. Accordingly, care could be used instead of management, since care includes much more. We need a systemic concept that comprises relations between farmers' socio-technical (-ecological) system. We need to study and understand their use of and relation to technology as well as the technology mediated relations in farming practice. Finally, we must change our approach from an *acting on* perspective to *living with* to reach a transformational pathway.

5.3 Introduce and apply theoretical lenses to study farmers' care in practice from a systemic/holistic perspective.

Since there were differences between the two studied systems in paper III and paper V (fertilisation in crop production and AMS in dairy), different theoretical approaches were chosen to describe and analyse the concept of care. In the first study, the focus was on what happened here and now, while the second study had a focus on a longer process of AMS use. In section 2.6, more information can be found concerning the two applied theories as well as reflections on theoretical choices.

5.3.1 The framework of DCog used to analyse farmers' decision-making and care in crop production using CropSAT.

To increase the understanding of farmers' care, how they make decisions in their practical socio-technical system, the study was performed *in the wild,* and the unit of analysis was broadened outside an individual's head. Accordingly, a perspective of cognition that is distributed in time, place as well as between people was chosen, i.e. the theoretical framework of DCog (Hutchins 1995; Lindblom et al. 2013; Rogers & Marshall 2017). By studying external material and social structures systemically, internal structures and processes are revealed and become observable. In other words, by studying cognition with this larger scope in mind, it is clear that the functional cognitive system has cognitive properties that cannot be limited to the cognitive abilities of the individual(s) (in the head). During the analysis, DCog's theoretical constructs, which emphasise the coordination of internal and external representations in the socio-technical system, were used as a theoretical perspective. This was the filter through which the cognitive work processes in the socio-technical domain of CropSAT use were interpreted. The analysis was thus theoretically driven by the DCog perspective.

The result revealed that by using CropSAT, farmers' professional vision was demonstrated; moreover, it mediated the exchange of experiences between farmers and advisors. The use of CropSAT provided a more detailed representation of a field and resulted in farmers' tool-mediated seeing, and some artefacts were exchanged. The representation of the field in CropSAT supported learning about the field as well as confirmed what the farmers already knew, and their enhanced professional vision became obvious. The result also showed that the advisor could have an important role in promoting CropSAT as a tool for learning, since the interest in the tool could increase if there was somebody with whom the results could be discussed. As far as we know, DCog has not previously been applied to the agricultural domain, although this study showed that it can serve as an appropriate theoretical lens for investigating and analysing the complex work activities in agriculture, providing a portrayal of how people, environment and tools are coupled and related to each other. The well-defined situations, both in time and place, where new satellite images in CropSAT were used, made the use of the DCog perspective useful. The DCog analysis revealed farmers' care in those specific and defined situations.

5.3.2 The AT used to analyse care in dairy using AMS

To support the analysis of AMS from an AT lens, we used the eight-step model of focal points adapted from Mwanza and Engeström (2005:459). Applying the activity system model (Figure 3) on a dairy farm made the continually ongoing work, including collaboration and other influencing factors on the farm, more visible, highlighting the activity within the whole system. The *activity* was to manage a dairy farm using AMS from the perspective of care. Good care for the dairy farm business was regarded as the *outcome* of the activity system, where *good care* meant a learning process aiming to create a viable (defined by the farmer or the farmer leadership) dairy business, which, in turn, motivated (the *objective*) the farmer. The *subject* of the system was the individual farmer (or the farm business leadership), who interacted with several *tools*, of which the milking robot was the *main mediating digital artefact*, together with additional tools and instruments, and psychological tools, such as a stock person's eye, to manage dairy production. The main *object* in the activity system was the cow herd, consisting of individual cows. Many implicit and explicit *rules*, norms and procedures were relevant in the case at hand, e.g. safety and animal welfare legislation and other work-related rules, routines, norms and practices that regulate the use of AMS on the dairy farm and cow care. The *division of labour* in the case referred to the distribution of responsibility for the work regarding the milk production between the farmer or farm leadership, the farmer's family members, and potential stock persons and/or employees at the dairy farm. The *community* considered in this study was limited. The Activity System model highlighted the developmental transformations involved when re-organising and re-mediating the current care activity at the local farm based on the contradictions that arise when shifting from CMS to AMS. Changing a dairy system from CMS to AMS results in contradictions (problems, challenges or benefits) in many parts of the system. We identified three major contradictions when changing the system from CMS to AMS: i) ongoing milking round the clock, ii) cow traffic and related strategies and iii) care accomplished by combining robot data with a stock person's eye. With a starting point in the Activity System Model, the conditions concerning the contradictions were analysed. The AT model worked very well as a lens for analysis of the farmers' care in AMS. In this complex system, the theoretical Activity System Model was very useful to facilitate the understanding of the system from different perspectives. The learning process in AMS, driven by contradictions that the farmers described, also made AT suitable for analysing care.

5.3.3 Reflections on DCog and AT as lenses for analysis of farmers' decision-making and care

The thesis work started with a focus on how farmers make decisions in their socio-technical system and, thus, a focus on one special kind of cognitive ability. As the process progressed, my interest gradually shifted from a relatively limited situation of decision-making, when using a special tool in a special situation, to care. Accordingly, the focus shifted from making certain decisions to making "it" work or from snapshot to process. The increased focus on the care concept moved the unit of analysis from a specific cognitive ability carried out in a specific situation to more of a process of development and learning. Thus, I started with a study on fertilisation using CropSAT for a specific decision-making situation, to continue with milking in AMS dairy production. This entailed a shift from a rather specified situation to an ongoing development process. In both cases, I needed a theory that would shape the object of study and highlight important issues. Halverson (2002) describes a theory as something that should have four different kinds of power to support how we can study phenomena: descriptive, rhetorical, inferential and application power. DCog and AT have very much in common, but they differ in some ways (Cort 2021; Halverson 2002). They have a common heritage, and the fact that they incorporate social and cultural context in cognition makes them diverge from other cognitive theories (Halverson 2002). However, there are some differences that made them differently suitable for use in the two situations to be studied (Halverson 2002). DCog focuses on the whole socio-technical system and the cognitive work and processes of the coordination of internal and external representations that happen within it. To study CropSAT use, with an obvious unit of analysis, both in place and time, the framework of DCog worked very well. It does not provide guidelines, checklists or models for the researcher to follow during the analysis. Still, it was very useful for exploring the cognitive work as interactions between different parts of the system. Cognitive mediation of artefacts, as well as interactions between people and between people and artefacts, appeared very elegant. It provided a kind of snapshot concerning farmers' care in those situations; nonetheless, to me, the theory seemed complicated to use for analysis of a longer tinkering process of development and learning, as I needed to describe care in AMS.

AT has a focus on the individual, who is situated in a socio-technical system, where a process of activity and learning is ongoing (Halverson

2002). That way of describing a system of relations does fit very well with care as a tinkering, relational process of learning. In addition, AT has theoretical constructs as the Activity System model, which supports the analysis and provides the researcher with a usable structure for the analysis, when DCog has few such constructs. Those main differences between the theories made me change from DCog to AT between case study I and IV. The AT focus on the individual situated in a system and a process of activity (learning as a result of contradictions in the system) made it fit very well into the practice that I met on the dairy farms. In addition, the Activity system model was very valuable and useful in the process of care analysis in AMS.

After a comparison of the two theories based on Halversons (2002) defined powers, I would claim that both theories have descriptive power. However, to me, AT had advantages from the perspectives of rhetorical and inferential power. The Activity System Model was helpful to structure, discuss and draw conclusions from the results. Since AT focuses on learning processes due to contradictions in a system, I would claim that AT could also be useful in future studies of farmers' care during transformational pathways in agriculture. In that case, the unit of analysis would be widened, to study farmers socio-technical-ecological system would be studied.

5.4 Present implications for advisors in their work with farmers, based on the relational perspective of care

The biggest challenge for agriculture is to proceed with a process of transformation aiming to reach global goals, stay within planetary boundaries and, at the same time, secure farm viability and ensure food production. At the end of the day, this will be done on the micro-level, by the individual farmer who performs a relational leadership in the local socio-technical-ecological system at his/her farm, surrounded by an agricultural socio-technical regime (systems of culture, technology, practice and institutions) within a regional and/or national framework (structures of regulations, legislation, goals). In this transformation process, advisors have an important role to play, but they must develop their approach. Otherwise, they will not be able to support farmers' care process and relational leadership. In an advisory practice, this will mean to attend a tinkering process that commutes between, on the one hand, the farmer's interest and the conditions on the local farm, and, on the other hand, the framework of rules, legislations and subsidies. The challenge is to make a good mix of them at the local farm together with the farmer. What does the farmer want and how can the individual advisor's knowledge and experience contribute? This process should be characterised by a *living with* perspective, meaning that it is performed together with the farmer, starting with the farmers' interest and local situation. In this sense (as a comparison), the traditional expert would instead use an *acting on* perspective, more or less, to tell farmers what to do. Or, if not to tell them what to do, the starting point is to *act on* crops or animals, aiming to improve the production, which, of course, is also important. However, it is not a relational process based on a systemic view of the farm and its context, I would claim.

A central responsibility for the advisor would be to consider what relations could be important on the local farm in order to make the farm work meaningful, profitable and relationally responsible. Traditionally, such considered relations have targeted the crop to get a good yield or the cow to get enough milk, and technology could mediate those kinds of relations, as we have seen earlier in this thesis. Other relations are already regulated in rules, legislations or subsidies, such as considerations on water and air quality, without considering them as relations. In a transformation process, a wider range of relations must be considered. This could mean with wildlife, biodiversity, customers at the farmer's market, outdoor life or soil health, for instance. In such a process, the advisor's role would be to draw the attention to a broader range of relations than the traditional crop or animal, and support farmers in how to handle them.

Advisors could support farmers' development of care in relation to, if not all of them, at least more entities/factors than is now customary, to handle the mix of farmers interest, local context and society requirements. This implies also functions and ecosystem services delivered from the farm. A relational leadership in farming should be based on a conviction of mutual dependence with more than humans and a broad range of functions. At the same time, there must be a consciousness that it is impossible to do everything correctly. Good care is related to thoughts of what is sought and what is fostered or hoped for, but there will always be relations that are avoided and excluded. Good care requires a continual "dialogue" with others who are unlike ourselves, to do the best possible (Nicholson & Kurucz 2019), namely, a relational leadership based on a relational logic of efficiency.

To support farmers' relational leadership, advisors would need a new competence to facilitate human relations as well as to see and draw attention to relationships that may be interesting and/or important in the local context. I call that competence a *relational eye*. It is an important, but difficult to define competence. It needs a kind of empathy with farming practice to be relevant and trustworthy from the farmers' perspective. This *relational eye* would also be dependent on social competence to facilitate meetings with an individual farmer or a group of farmers and introduce new perspectives. In addition, it will require an ability to read and understand a landscape and the context in which the farm is situated. Rather, an ability to see and to provide relevant questions more than giving correct answers, since when a relation is noticed, other experts can be called in to solve specific problems or to handle that specific interaction. This *relational eye* should be supported by different kinds of technologies, developed based on end-users' requirements. This *relational eye* is a competence, based on a systemic and relational worldview.

A transformation of farmers' practice and a real change from acting on to living with would require a fundamental and broad change. It might be necessary to start in small-scale on a specific field, for instance. It would require a change in worldview and how we think concerning what a farm really is. From a site of mainly food production to a web of relations, in which food production is still prioritised, but in close interaction with more than humans.

A justified question would then be to reflect on what a good farmer is? Since transformation is an ongoing learning process starting in reflection and reconsideration concerning the local practice, it would be the first requirement. For advisors, the central issues would be: How would a process concerning the development from farmer to relational leader be supported? What would be the driving forces? How can such a process be supported by the authorities? What are the risks and who should take those risks? Small groups of very interested farmers have already entered different transformation pathways, based on their own conviction of necessity. However, they testify to the lack of advisers' interest and competence concerning transformation strategies (Lundström unpublished work). So-called niches (Ingram 2015), where the individual farmer or group of farmers make transformations, often in opposition to the current agricultural regime. Such an initiative puts the individual in a position of total responsibility for the risks taken. In addition, they are often questioned from peers, advisors and authorities. They need to really struggle if they should be able to develop from deviants to good examples, or good farmers. Nevertheless, this kind of risk taking, learning and hard work requires, in the long run, peers and social contexts to be successful and to scale both out (more adopters) and up (institutionalisation). In relation to those farmers, Klerkx's (2020:133) questions are relevant: 1) '*How do advisory systems respond to and connect to different transformation pathways, such as AgriTech drive or and regenerative agriculture?' and 2) 'How and why do advisory systems contribute to either transformation away from current systems, or perpetuate 'lock-in' of incumbent systems?'* Do advisors really build bridges between different transformation pathways? Do advisors really contribute to transformation to some extent, or do they mainly contribute to a perpetuation or a 'lock-in' of the existing system? Those questions need to be discussed in the Swedish AKIS.

5.4.1 An advisory checklist based on a care perspective and a holistic view on the farm

The overall aim is to facilitate a process of development on a specific farm that support the farmer in creating a vision of the future prosperous farm considering a broad range of relations. A plan for how to make it happen on short and long term will be developed. This plan should be considered a living document with milestones and goals that needs follow up meetings over some years. Urgent issues always arise that complicate, influence or change intended actions and directions. Accordingly, support is needed to continually adapt and adjust the plan. What is desirable and what steps should be taken to get there? Advisors have mainly a coaching role to ask key questions, but also to bring in lacking knowledge and information and put it in a context of legislation, rules, and subsidies as well as local conditions on the farm and the surrounding region. A relational eye would be useful to pay attention to important relations on a specific farm. The advisor has a checklist for areas to discuss, but also maps and a broad range of basic information concerning the farm. The aim is to reflect on the farm as a farmer led ecosystem that is aiming to increase sustainability and long-term prosperity, while considering a broad range of relations with humans, non-humans and natural settings.

1) Start in a description of what we got. How can the farm be described today?
    a. From a social perspective – what is the farm? A workplace, a way of living or what? For which people is the farm important?
    b. From an ecological perspective? How could ecological values of the farm be described? What kinds of natural settings and wild species characterise the farm? What did, but are now lacking?
    c. From an economic perspective? What is viable, what is not? What is desirable what is not? Are there parts that support other parts financially? What ensure both short and long-term viability today?
2) Due to the farmer: what does the desirable future for the farm look like?
    a. Socially, ecologically and economically?
    b. Challenges?
    c. Possibilities?
3) What are the different possible and desirable pathways for the farmer and the farm?
4) Which pathway do the farmer want to enter?
5) What measures and resources are needed to make it happen? What are the first steps to take?
6) What should characterise a process on this specific farm that will facilitate a desirable change for the farmer?

6. Discussion and conclusion

This thesis aims to introduce and apply the concept of *care* to gain a deeper understanding of farmers' use of digital technology in their practice and to introduce a relational perspective on farm practice and technology use to increase sustainability and to contribute to facilitation of transformational pathways in agriculture. In order to do this, the following four objectives are formulated:

- Present recommendations concerning digital technology development and design processes to ensure relevant, usable and credible technology for end-users that support their care practices.

- Investigate and analyse farmers' use of digital technology as an ongoing learning process of *care* in their socio-technical system.

- Introduce and apply theoretical lenses to study farmers' care in practice from a systemic perspective.

- Present implications for advisors in their work with farmers, based on the relational perspective of care.

This thesis took its starting point on the urgent need to increase sustainability in agriculture and the role of digital technology in this process. The research started based on a frustration concerning the low adoption of digital technology among farmers. To increase our knowledge concerning this phenomenon, the first case study was a workplace study about how farmers really use technology and make decisions in the wild. The results showed, on the one hand, that farmers' situated knowledge is central to their use of technology in practice. On the other hand, use of such technology as a mediating artefact increases farmers' situated knowledge, and they develop an enhanced professional vision by seeing phenomena through digital technology. Social learning proved to be important in facilitating this kind of development. Digital technology is thus dependent on farmers' *care,* but do also impact farmers' care after adoption. Care in this meaning is '*the result of all practices that make technology and knowledge work'* (Krzywoszynska 2016:290). Work, in this sense, is socially constructed and locally dependent.

Care is also defined as a tinkering learning process based on engagement, experience and responsibility. The emphasis on *all practices* is important because it expands the area of interest from specific interactions to a broader context, as part of a wider system, i.e. farmers' socio-technical (-ecological) system. The second case study focused on strategies to change the traditional technology driven development processes in PA to processes that involve end users from the start in order to produce technology that becomes relevant, credible and usable. Those UCD approaches from the research field of HCI could contribute to the development of digital technology that is both interesting for farmers and important to increase sustainability. The third case study focused on advisors' use of a digital PA technology. Four categories of advisor strategies were defined, and only a few of the interviewed advisors used the AgriDSS as a social learning tool. The last case study investigated dairy farmer's care in AMS. The participating farmers were in a continuous learning process of care on different levels in their system, from detailed problems concerning an individual cow to the complete dairy system. Adopting AMS solved some problems and introduced others, and it changed the relation between the cow and the farmer. On the one hand, AMS data provided new data concerning the cow, and farmers enhanced their professional vision by using this data. On the other hand, they developed strategies to maintain direct contact with the cows, since a stock person's eye was still crucial to manage the production. Finally, it became clear that from a perspective of ecological sustainability, PA and PLF technology mainly contribute to an iterative process of increased efficiency and improved work environment, sustainable intensification, and not to transformational pathways in an ecological sustainability sense. Some consider an adoption of digital technology in agriculture as digital transformation (Trendov 2019; Martin et al. 2022). Adoption of AMS impacts work environment for farmers and their employees and affects animal welfare. However, it is still not a transformation from an ecological sustainability perspective. A systemic, relational and ecological perspective on agriculture would facilitate this kind of process. This thesis introduces the concept of care to, on the one hand, highlight that technology is embedded in farmers' practice to work, and, on the other hand, to support transformational pathways in agriculture. We must change our way of looking at agriculture, from a reductionist perspective, or acting on, to a systemic, relational and interdependent perspective of care, or living with.

Accordingly, this thesis highlights that: 1) Sustainable intensification in agriculture is not enough; we must enter transformational pathways. 2) Such pathways should have a relational perspective of interdependence and *living with* concerning humans, non-humans, material things and natural settings to increase sustainability and to keep us within planetary boundaries. 3) Digital technology depends on farmers' care to *work* in practice. *Work* is then, on the one hand, defined by the individual farmer from his/her local context and worldview, and, on the other hand, in a context of agricultural transformation to reach global goals and stay within planetary boundaries. 4) Digital technology has a role to play in a transformational process, but it must be developed in close cooperation with end-users in order to become usable, credible and relevant. The tradition of technology driven development resulting in limited technology use must change. 5) Farmers develop *enhanced professional vision* when using technology as a mediating artefact for farm relations. 6) The care concept was introduced as an alternative to management to show a distinction between the productivist, reductionist paradigm and *acting on* perspective and instead focusing on the constructivist, systemic paradigm with a relational and *living with* perspective, based on an understanding of our interdependence with more than humans. A broader adoption of technology increased the importance of *human* humans. Of human values, worldviews and judgements in the practice where technology is used. However, this perspective is also crucial in the design of new technology in order to make it sustainable through its design. 7) To support farmers in this reconsideration on a specific farm, advisors with a *relational eye*, supported by digital technology would be central. 7) Finally, this thesis suggests theories and methodologies to investigate and increase our understanding of farmers' care in practice in their socio-technical (-ecological) system, where the individual farmer will accomplish real change, with support from digital technology as well as different actors in AKIS.

The main challenge in agriculture is how to enter a transformational pathway. Transformation is a kind of buzzword used in different contexts, but the practical transformational change in the agricultural reality is thus far limited. To enter transformational pathways, we must leave the unilateral traditional perspective of the reductionist paradigm, an acting on perspective and rational leadership and adopt more of a relational, systemic perspective, a relational leadership and the constructivist paradigm to determine the direction of development and not just continue with a one-sided focus on efficiency. Some farmers express it in terms of working *with* nature, instead of an ongoing struggle *against* it. We must look at the local farm as a web of relationships – a world to live with and within. Additionally, we must start with farmers' interest and their local conditions on the farm, within a broader system of rules, laws and subsidies, never forgetting their demand of viability.

We have for long found ourselves in an agricultural regime with a focus on productivity, short-term considerations and a rational logic of efficiency in parallel with ambitions of implementing iterative changes to support environmental goals and increase sustainability. However, there are niches with more transformational focus. Research concerning change processes discusses how new niches (individual or small groups of actors with new ideas) affect a prevailing socio-technical regime (systems of culture, technology, practice and institutions) within a framework (structures of regulations, legislation, goals mm) (Ingram 2015). The knowledge system in these regimes includes research, consulting (both private and state), education, innovation support, companies and beyond. Development within the regimes is driven by a knowledge system that has assigned both legitimacy and research authority from the same regime, and mostly supports the regime's strategies. Accordingly, there is a risk that within a regime, a rather narrow kind of knowledge is developed, stored and exchanged, which fits into the regime that it both creates and is created by. In order to succeed in creating major changes within a prevailing regime, an openness from the regime is required in order to listen to so-called niches, i.e. innovative ideas or thoughts that question what is being done and how it is being done. Actors in a niche share interests and goals, test new ideas and practical applications and learn together in a knowledge system separate from the traditional. This, in turn, makes it difficult for farmers to find colleagues and good advice and for researchers to obtain funding for non-traditional projects. Different niches are therefore fighting on the fringes of current regimes to change and expand them. During this process, the traditional knowledge system is challenged, which should actually encourage innovation, but which instead risks creating the opposite effect. If new ideas are not reflected on and investigated due to cognitive, material, economic or social cultures within the regime, good ideas risk never having a chance to develop. The prevailing view of knowledge and perspectives within a regime has a great impact on how and what kind of knowledge and perspectives that are allowed to develop and gain legitimacy. When niches are rejected for such reasons, the development power in the industry risks being hampered.

In this thesis, none of the case studies really regarded transformation, since transformation '*refers to fundamental shifts in human and environmental interactions and feedbacks*' (Hölscher et al. 2018:1). Transformational change, in a deeper sense, as a fundamental shift in interactions and feedbacks between humans and the environment is not really a question in the context of either PA or PLF, which, in turn, probably is a consequence of the very limited serious discussions concerning what transformation would really mean within the agricultural regime.

A relational and systemic perspective on farming is not new, but the use of the care concept as a way to clarify technology function and use in PA and AMS practice is. That is also true concerning the concepts of relational leadership and a logic of relational efficiency in agriculture, as far as I know. I hope that the prevailing regime will consider those concepts and let them develop further in broad cooperation. To do this, we should reflect on the questions concerning advisory services that Klerkx (2020:133) asks and which probably are relevant for the whole agriculture regime? 1) '*How do advisory systems respond to and connect to different transformation pathways, such as AgriTech drive or and regenerative agriculture?' and 2)'How and why do advisory systems contribute to either transformation away from current systems, or perpetuate 'lock-in' of incumbent systems?*'

The statements from the European Commission (2020) emphasise a systemic view of agricultural. On the one hand, '*there is an urgent need to reduce dependency on pesticides and antimicrobials, reduce excess fertilisation, increase organic farming, improve animal welfare, and reverse biodiversity loss'* (EU commission 2020:8). On the other hand, farmers must start in their local situation and '*make the best use of nature-based, technological, digital, and space-based solutions to deliver better climate and environmental results, increase climate resilience and reduce and optimise the use of inputs*' (European commission 2020:5). I doubt that the perspective is relational in a deeper sense; the basic strategy is still an iterative efficiency increase. However, what it really means is not decided until it is put into practice and policies. It is a start and can be used as an argument to think and reflect from a relational perspective, and it can also legitimise new kinds of measures. Since we cannot solve the problems we have with the same strategy and technology that created them in the first place, we must do differently. By adopting a care perspective on farming, farmers and advisors (and others in the AKIS) must change their starting point to talk about and develop strategies to handle a relational perspective and thus a broader range of relations, a relational leadership and a relational logic of efficiency on a specific farm. Transformation requires a new mindset. We need to change the mainstream ontology of separateness and self-centeredness towards one characterised by connectedness and relatedness (Wamsler & Bristow 2022). Transformative qualities mentioned by Wamsler & Bristow (2022) are aspects of awareness, such as attention, self-awareness, aspects of relations, such as compassion and empathy and human-nature connectedness. In addition we must be aware that "*our inner worlds, such as our emotions, thoughts, identities and beliefs, lie at the root of sustainability challenges and are fundamental to the solutions to some of the world's greatest challenges*" (Ives et al. 2020: 209). The introduction of the care concept and perspective is one way to try to meet those needs.

For the farmer, who considers him/herself as a rational leader, the care perspective, a relational leadership and a relational logic of efficiency have several implications. The new thing would be to look at oneself in a more obvious way, as related to and mutually dependent on a broad range of processes, functions, creatures and so on, and engage, feel responsibility for and act in relation to them. If we know *who to be,* we know *what to do* (Cuncliffe 2009). Relations define who we are and motivate us to act in a specific direction. This should be done with a consciousness that a positive impact in one place of the system causes a negative impact in another. There is not one perfect strategy, rather local trade-offs that must be done in a tinkering reflected process. To support farmers as relational leaders in this process, advisors need to develop a *relational eye* and reflect on what mutual dependence means in the local context on that specific farm. A change in relations could be to reconsider soil from dirt or as something that the crop is growing in as a means of production, to an ecosystem. An ecosystem that we depend on for our survival and which has a value in itself. Talking about relationships and interdependence with the soil and its small inhabitants would likely be regarded as a little unaccustomed, difficult to understand and not so easy to grasp. However, if we do, soil compaction, as every farmer knows is devastating in the long run, would be seriously considered. Relationships with dairy cows would be easier to understand, but would probably raise other questions instead. How should we keep our food-producing animals when we talk about relations? How many animals can be kept together in a cowshed? There is a limit, when the staff do not recognise the individual cow anymore – is that a problem? It is difficult to let a big herd of dairy cows graze, since they are often too many for the nearby pastures, and the feed is not nutritionally appropriate when their milk production is very high. Is it ok that cows do not graze or stay inside all the time, even if it is their own choice? On hot sunny days, many cows stay in the shed voluntarily, since it is cooler; when they are partly black, their big milk production generates much body heat, and the pastures lack shadow. Should the number of cows and the cow-breed be better adapted to the local context of the farm and nearby pastures? There are farmers who adapt their grazing cows to their soil. Should the same be done in dairy production? A relational perspective emphasises the need to readjust the production on the farm to the farm context, and not the other way around, regardless of what production we discuss. Some farmers express it as working with nature and not against it. Such a change would affect the whole food system and society and be a practical application of the perspective of *living with* instead of *acting on*. These are challenging thoughts, but such scenarios are, in my opinion, necessary to discuss when talking about transformation. If we should be able to reach global goals and stay within planetary boundaries, big changes are needed. In addition, energy availability would probably set the boundaries for what kind of agriculture and technology development is possible and desirable in the future.

In an advisory practice, a relational perspective will mean to attend a social tinkering process that commutes between, on the one hand, the farmer's interest and the local conditions as well as the surrounding geographical landscape and, on the other hand, the framework of rules, legislations and regional/national goals. That would require advisors (as well as others) to be open to approach problems in new ways and from new perspectives. The challenge is to make a good mix of them. In section 5.4, I explain further on how I think this could be done in practice. What does the farmer want and how can the individual advisor's knowledge and experience contribute? Such a process should also require digital technologies, new, adapted or both.

The actual transformation in agriculture will happen on the micro-level, by a farmer on a farm. Other parts of the AKIS should support them. We must discuss and reflect on how a process of transformation would look like in this actual context and consider long as well as short-term viability in parallel with caring for interesting and important relations. Care highlights our responsibility for our close relations and that engagement and knowledge are central in order to pay attention and act upon them. The introduction of the care perspective in digital farming aims to increase the focus on the farmer and his/her socio-technical (-ecological) relations, broaden what kind of relations are considered and avoid technology driven development. However, it means not forgetting farmers' dependence on technology and instead considering technology as a mediating artefact that requires farmers' *enhanced professional vision* to handle practice. Since such a change is challenging, advisors should start with interested and up-front farmers, in order to be able to consider them as good examples and thus provide inspiration for a reconsideration of what a *good farmer* means.

Transformational pathways require a reconsideration of worldviews, which is true for farmers, advisors, researchers as well as all others. However, since we are all interdependent, the micro-level needs support from other levels in the system to be successful. Eastwood et al. (2022) claim that the nature of problems in farming could be understood from a researcher's perspective, but that is increasingly not the case in the complex system that the individual farmer is dealing with. Handling things in silos or on a general level is easier than in a real-life complex settings. In addition, a researcher could support farm transformation but cannot make it happen! Digital technology, SMART farming or whatever we call it, will not make transformation happen either, but it can support the development on a farm, if it is relevant, usable and credible for farmer's practice.

During this thesis work, my own perspective of sustainability has changed, from a kind of acceptance of sustainable intensification as the main objective for agriculture and technology development, to realising that this is not enough. A reason for this long acceptance was probably more a difficulty in explicitly being able to expressing the demand for a care perspective than a lack of ability to see the significance of relationships. The discourse of sustainable intensification is dominating in the Swedish agricultural regime. This is no excuse for a late and slow awakening, rather an explanation. It takes time and energy to rethink despite an obvious feeling that we are not doing the right things and to be part of a regime that is heading in a wrong direction. That is not so easy to handle if you want to be a *good* *researcher* and agronomist in the current agricultural regime. Probably, there are also advisors with equal considerations. If the concept of a *good farmer* should be developed and adjusted to a transformational context, this also applies to advisors as well as researchers among others. To change our interpretation of the world, and find a way to express it in scientific terms, what is important and meaningful is not an easy task to do. Accordingly, those who struggle with this need support and social contexts to be able to continue their struggling.

Today, many scholars talk about farmers' uncertainty concerning digital technology benefit in practice, since the results are difficult to evaluate (Trendov et al. 2019; Barret & Rose 2020; Kuch et al. 2020). A *pro-innovation bias* (Rogers 2003) concerning digital technology has been the prevailing discourse. Instead of investigating how technology really works in practice, it is common to say that farmers do not understand or should be convinced or told. This thesis aims to contribute with new methodologies and theories to make further developments *in the wild* research concerning agriculture technology use. Media and policy documents present high-tech smart technology in an overwhelmingly positive light, much more positive than do farmers (Barret & Rose 2020). In addition, media and policy documents focus on increased productivity and profitability, while social and environmental benefits are not as saliently presented (Barret & Rose 2020). Some claim that it is important to also consider low-tech solutions in order to support farmers, people and the planet now (Klerkx & Rose 2020). If we focus on hyped high-tech SMART technology, we even risk missing a lot of low-tech solutions and other ideas from coming to the fore (Klerkx & Rose 2020).

Introduction of new technologies will solve some problems and introduce others. With AMS, the physical work environment improves, but for some farmers, the mental work environment gets worse. In complex environments, we can solve individual problems, but never all of them at the same time. This is the real life for a farmer that they have to handle in practice. Regardless of which agricultural system a farmer adopts, it will have both positive and negative consequences, regardless if it is high-tech systems or agro-ecology systems (Klerkx & Rose 2020). Accordingly, research need to communicate with farmers and investigate their real practices, to be able to develop relevant technology and understand farmers' socio-technical (-ecological) system in which the technology must fit. Thus, it is important to study farmers' practice in the wild with convenient theories and methods and not only turn to other experts, regarding technology's potential in farmers practice as in, for instance, Eastwood and Renwik (2020).

Klerkx and Rose (2020) claim that we must not advocate and focus on high-tech agriculture without really considering its negative consequences. We must also increase the efforts to reconsider already known technologies and practises, and new combinations thereof. For instance, combinations of ideas from agro-ecology, permaculture and digital technology, etc. Small-scale testing and evaluation are important tools for new kinds of combinations. However, it requires new strategies, especially to involve researchers and their competence. In complex situations, farmers need situated, systemic knowledge, while researchers traditionally both develop and are assessed by an opportunity to produce objective and generalisable results. To support farmers' transformation, local systemic knowledge required by the farmers must be prioritised by new strategies, evaluation methodologies and funding. That will become fruitful for farmers, advisors, researchers and the whole society. Finally, we need to give priority to development and use of technology that aims to support transformation based on requirements from farmers' relational practice. To do so, arenas and strategies to develop an increased understanding among technology developers concerning what farmers need to enter and continue transformation pathways. In such a scenario, methodologies that analyse farmers' socio-technical-ecological system in practice are important, and both researchers and advisors have important roles to support both farmers and technology developers.

Technology and modern agriculture increase the distance between the farm (object) and farmers (subject), making the relations to the environment and production more opaque (Herman 2015). This thesis claims that technology does increase the distance, but it should be considered an artefact that mediates and changes relations that are part of the individual farmers' care. Accordingly, new strategies to use and develop such abilities as a *stockperson's eye* or a *relational eye* should be developed in parallel with technology use in order to optimise the production. This approach finds support from the AI researcher Melanie Mitchel (2019a). AI and other digital technology will not, for a very long time, if ever, be able to develop human intelligence (see for further discussions on that topic in for instance Dreyfus 1992 or Lindblom 2015). Accordingly, technology should complement humans and be used for tasks for which it is convenient. This means that technology will never replace the farmer. Therefore, are discourses and perceptions within agriculture, which give rise to those types of comments problematic: 1) '*Among the various digital technologies, robotics stands out since it suggests a substitution of human work or at least a radical transformation of work*' (Martin et al. 2022:65) and 2) Marinoudi et al. (2021:14) suggest: '*Computers are more and more learning to perceive features' interconnected hierarchies in the way the human brains do*'. Mitchel (2019a) claims that we do not need to be afraid that technology shall take over the world. However, she refers to herself as well as colleagues and highlights that the real worry is '*our societies headlong dash to embrace AI technology*' (Mitchel 2019:236). Accordingly, we should be concerned about ourselves and our beliefs concerning AI and digital technologies. *Stupid* technology is something to really worry about. This refers to *stupid* technology that we think can handle things, but we cannot be sure of what they *can* or on what basis it reasons and makes decisions. Technology is very valuable in the right context, as it carries out good and controllable tasks. This is also true in an agricultural context. Technology is here to complement humans and must be embedded and controlled within human practice and care. However, we must work with nature and not fight against it, living with, instead of acting on. We should embrace our unique human competence to interpret and recognise complex situations, our values, ability to socialise, cooperate and use our somewhat deficient intelligence to do what we have to do and start transformational pathways, supported by relevant, usable and credible technology!

6.1 Contributions of the thesis

The main contributions arising from the work presented in this thesis were:

- Introduction of a systemic research approach using theories and frameworks from the research field of cognitive science and HCI in the agricultural domain.
- Applying user-centred design methodologies to propose appropriate strategies in digital technology development, resulting in usable, credible and relevant technology in agriculture.
- Applying the theoretical framework DCog in PA, which was shown to be useful in elucidating farmers' socio-technical system by increasing

our understanding of cognitive processes where digital technology is included in the unit of analysis.

- Applying the AT in AMS dairy production, which was shown to be useful in elucidating farmers' care in the complex socio-technical system of humans, cows and technology.
- Introduction of the care concept in the context of PA and PLF. The application of care depicts farmers' relations in their socio-technical system, providing empirical evidence, indicating that both technology and intuitive experience-based knowledge are necessary to make a farming practice work. Addressing results that elucidate that farmers' development of *situated knowledge* and *care* is not opposed to the use of digital technology.
- Introduction of the concept of *enhanced professional vision*. This concept emerged from the empirically based combination of *professional vision* (Goodwin 1994) and *tool mediated seeing* (Goodwin & Goodwin 1996). Technology supports farmers' development of *situated knowledge* and care, in parallel with technology as mediators of relations in the socio-technical system on the farm.
- A demonstration that social learning approaches are crucial for farmers' development of *situated knowledge* and *care* in relation to technology. 1) User involvement is important during the development of digital technology, where participatory approaches would contribute to better usability, credibility and relevance by input from end-users early in the process, 2) Social learning is important for decision-making and learning during practical use of technology and 3) Finally, social learning is crucial to increase farmers' motivation to adopt and use relevant technology.
- Introduction of the concept of *relational eye*, as a competence to recognise and communicate a broad range of relations on a specific location.
- Introduction of the concepts of *relational leadership* and a *relational logic of efficiency* in agriculture.

6.2 Scientific rigour and limitations of the research

This thesis has an interdisciplinary approach and uses a broad range of theories, frameworks and approaches. Coming from the agricultural field, I do not claim to be an expert in all those. However, my intention was to bring in new perspectives and theories to agriculture in order to contribute to the management of our common challenges. Therefore, some readers may find parts of the thesis too short, undeveloped or with a lack of depth. Hopefully, you can consider the whole thesis work and find its contribution to future agriculture relevant.

Patton (2002:243) claims that '*the validity, meaningfulness and insights generated from the qualitative inquiry have more to do with the information richness of the cases selected and the observational/analytical capabilities of the researcher than with sample size*'. Thus, the quality of the analysis lies in the performance of the study itself.

The most important limitations for the different case studies were:

Case study 1. Concerning the advisors, it was not optimal for two of the farmers to engage the same advisor. That could have limited the richness of the information concerning the advisor's role in technology use, providing social interactions and technology adaptation to the needs of the individual farmer. The main reason for this was an ambition to find interesting farmers. However, as the work developed and the importance of the advisors was identified, a greater number of subjects would have been preferable in order to find a wider range of advisor strategies. However, case study 3 somehow caught a wider range of strategies, even though with less depth in the results.

Case study 2. The pros and cons considering digital technology development described in case study two not being applied to study a whole AgriDSS development process. It would have been interesting to follow a process that really used user-centred design methodology to complement the conceptual work.

Case study 3. The number of advisors was limited, and the results would have been more interesting if it had been complemented with participatory observations or field visits.

Case study 4. No farmer with only one robot was interviewed, but single robot farmers was the dominating group among questionnaire respondents. The interviewed farmers came from a limited area of Sweden. The field visits were limited in scope due to the pandemic. All results from the questionnaire were not reported in the paper, and no statistical analysis was performed on the results. Finally, since there is no Swedish actor with statistics on all Swedish AMS farmers, we chose to use newsletters from the two dominating AMS companies and a Facebook group for AMS farmers to invite respondents to answer the questionnaire. That could have limited the number of farmers who answered the questionnaire.

Despite these limitations in the work, it can be claimed that important knowledge was revealed, in line with earlier discussions and presentations of the findings. When discussing the rigour of my research below, I draw upon Lincoln's and Guba's (1989) four criteria for qualitative research: *credibility*, *transferability*, *dependability* and *conformability*.

Credibility corresponds to validity in quantitative research and regards the match between the description and the explanation. To increase credibility, some strategies are important. Shenton (2004) addresses the Lincoln and Guba (1989) criteria and highlights a couple of guidelines. Using appropriate research methods is important; by using triangulation of data collection techniques, the degree of rigour can be enhanced. In this thesis, I believe that the data collection techniques used were appropriate; in case studies 1 and 4, I used triangulation of the data. In addition, all five papers are peer-reviewed and published in scientific journals. The researcher's familiarity with the study area is also important, as are their background, qualifications and experiences. Due to my long experience from the POS network (see Preface) in combination with long personal experiences from living on a farm, short experience of work on a dairy farm and experiences from using the methodology of ethnographic, naturalistic inquiry and the data collection methods of observations, video recordings and interviews, I would claim a respectable level of credibility for my work. What I did not do was to sample the informants randomly, which Shenton (2004) advocates. However, Patton (2002) argues for purposeful sampling techniques in order to achieve information richness. The path taken in this thesis was aligned with Patton's thoughts. In case studies 1 and 4, I decided to select the farmers purposively, since the number of farmers was low, and it was important to find interested individuals with differences in their farming situations and a willingness to talk about their work. Before starting this work, I also took part in a pilot project (Lindblom & Lundström, 2014), aiming to investigate farmers' decision-making to learn more about theory, methodology and data collection techniques in such processes.

Transferability is the external viability in quantitative research and concerns the possibilities of being able to generalise from the findings (Shenton 2004; Lincoln & Guba 1989). Stake (2000) claims that although every case is unique, it is also an example from a wider group, and the prospect of generalisation should not be immediately rejected. Stake also argues that while knowledge from one case is not generalisable to all others, there is much to learn from a case and, by making broad descriptions, the readers can draw conclusions of their own. In order to increase transferability, I provide written descriptions of the empirical work and the analysis, but until another person conducts a similar study, it is not possible to judge if my work is transferable.

Dependability refers to reliability and the possibility of replicating the study. In order to facilitate replication of this study, I described the process in detail. How successful this may be will only be revealed when another researcher seeks to replicate a study. Shenton (2004) argues that the role of the researcher must be discussed. My experience from farming is long, but I am not a farmer and I have never been one. I would argue that the greatest risk for me would be to think that I *know* when I definitely do not. Experience is valuable in order to understand the context, but in the work of analysing and interpreting the data, I was very conscious about reflecting on my interpretations in relation to what the farmers reported. It was valuable to be able to return to recordings and listen to the exact words, but also to consider the situation in which the words were said. I used this in order to reconsider and reflect on my interpretations.

Conformability refers to objectivity and means that results and interpretations should be based on the collected data and not made up by the researcher. Again, the possibility of following the process by rich descriptions is important, and Shenton (2004) mentions the value of triangulation. Triangulation can consider methods, but I would claim that cooperating with other researchers in conducting and interpreting empirical data is another form of triangulation. In case studies 2 and 3, the empirical material was limited, but we were two researchers who agreed on the implications. I presented examples from the video recordings from case study 1 and my interpretations of them to my co-authors and PhD colleagues at a university course as a step in the analysis work. I have also presented them and the results from case studies 1, 2 and 3 at conferences. Due to the pandemic, I have not presented the results from case study 4 at any conference so far.

6.3 Future work

To further develop this area of research, farmers' and advisors' opinions and requirements concerning a relational perspective on farming with different production orientations using digital technology should be investigated, from a transformational, technical as well as social perspective. Participatory approaches should be applied in new projects involving farmers, advisors, researchers and other relevant actors aiming to:

- Investigate and analyse how farmers' care processes on farms with different production orientations can be supported while entering transformational pathways. What kind of advisory models as well as digital technologies are needed? How will a relational leadership and relational logic of efficiency look, in farming practice to involve all perspectives of sustainability?

- Investigate and analyse good strategies for digital technology use in agricultural practice from a social learning perspective. How can digital technology support social learning among farmers in areas where the exchange of local knowledge and experience are central for farmers' learning?

- Use AT to describe parallel development of care processes and their interactions on different farms. The AT builds on a systemic view of expansive learning and development driven by contradictions in a system. Such research would also be able to further investigate how different kinds of digital technology can be technically merged or synchronised in order to provide better systems of applications and functions in wider farming socio-technical system.

- Perform research concerning best practice of implementation of UCD methodology in the development processes of agricultural digital technology aiming to handle complex situations.

- Identify and formulate important research questions concerning digital technology and a relational perspective of agriculture in Sweden, using Ingram et al. (2022) as a model. This thesis work criticises the dominant agricultural regime in Sweden and beyond, due to a focus on the productivist paradigm and a perspective of acting on, instead of living with. Accordingly, a process, as described by Ingram et al. (2022), would be valuable to challenge the regime and cooperatively develop suitable strategies for regime development and provide possibilities for the exchange of perspectives and worldviews.

A future that requires more competent farmers will also require higher levels and different forms of competence among advisors. Accordingly, a central issue for the agricultural sector must be to secure access to high-quality advisory services, with social skills and competence in agriculture and digital technology. Finally, in order to move agriculture along transformational trajectories, the care perspective and new or adapted digital technology would be crucial. Thus, a discussion concerning a relational perspective of farming as well as work to develop and/or adapt new technology to farmers' needs must continue in increased cooperation between different stakeholders from the agricultural domain and with acknowledgment of farmers' situated knowledge, expertise and care.

6.4 Conclusion

High-tech large-scale agriculture, which, through an iterative process, increases its efficiency, does not stay within the planetary boundaries; thus, a transformation process is urgently required. A focus on care, relations and a perspective of living with does not change things either automatically or easily. However, such a perspective can help us reconsider, revaluate and enter a process of transformation and change. Important steps on this journey would be:

- To start to question the prevailing regime in agriculture and open up for more perspectives.
- To consider technology as embedded in farmers' socio-technical system of a tinkering learning process of care and dependent on their *enhanced professional vision* to *work* in practice, where *work* relates to all three perspectives of sustainability.

- To apply care and a relational perspective on farming, aiming for transformational processes based on the individual farmers' interest and development of relational leadership for interesting and important relations, the local situation and requirements from legislation, rules and subsidies.
- To use care as a living with perspective, meaning that farmers have an increased responsibility for their close relations to humans, non-humans and natural settings on the farm.
- To use care as a living with perspective for researchers and advisors, in their connection to farmers and their farms.
- To make advisors with a *relational eye* available to support local transformation processes on farms. They will need new forms of funding and an increased degree of freedom to develop new functional advisory models.
- To increase our knowledge concerning how farmers really use technology in practice. This thesis provides theoretical frameworks for that kind of analysis.
- To develop digital technology that is important in transformation pathways. Such technology must be developed in close cooperation with end-users to consider their practice and care.
- To develop strategies for evaluation and small-scale testing of technology on farms in their context and practice.
- To use some kind of participatory research design to facilitate transformational pathways. The AT can be used for analysis.
- To develop evaluation models concerning new technology in a socio-technical system that goes beyond the actual measurements of what the technology is planned to do. Here, theories and methodologies suggested in this thesis would be usable.

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Popular science summary

Agriculture needs transformation in order to meet future challenges. Transformation will take place in the individual farmer's local practice, with support from surrounding systems. Digitization and digital technology are seen as important pieces of the puzzle to manage those challenges in society as well as in agriculture. The hopes and confidence in PA, SMART or digital farming are widely presented in the mass media as well as in research and development, while farmers in many cases have proven to be more doubtful. Especially when it comes to technology that is meant to handle complex situations, but with results that is difficult to evaluate. For a long time, research has focused on the technology itself and not on farmers' socio-technical system or practice, where the technology should be used and where technology depend on farmers to work. Consequently, many technologies has been developed, but adoption has often been limited. Technology that is developed must be relevant to the user and work in practice! To do so, farmers practice, or socio-technical system must be understood and end-users need to be involved in development processes. Technology studies should therefore be supplemented with studies of technology use in practice. Technology can support people, but not replaced them, in dealing with complex situations. This thesis deals with two kinds of complex situations, fertilization with a decision support system based on satellite images in crop production and automated milking systems in dairy.

The focus in research and development has so far been to increase efficiency in resource use or to improve work environment. More seldom, do digitization concern an improved ecological sustainability, with the exception of reduced impact as a result of more efficient resource use. However, today it is not enough to focus on increased efficiency, although that is also important. Instead, transformation of agriculture is required with more comprehensive changes. However, such discussions are only carried out to a limited extent. The discussion about the development of agriculture should therefore change focus from efficiency increase to transformation. Transformation must be based on farmers' interest and local conditions, within the framework of laws, regulations and subsidies. Given a transformation, what kind of technologies do such processes require? To find out, knowledge concerning farmers' practice is required in parallel with development processes that involve end-users from the beginning, in order to make technology credible, usable and relevant in the same practice.

This thesis aims to introduce the concept of care in agriculture to increase knowledge about the practical use of digital technology in farmers' socio-technical systems, as well as to introduce a relational perspective on technology use in farming. Care is described as a relational and systemic alternative to management, that includes everything that makes technology, information and knowledge work. The thesis has four goals: 1) To develop recommendations, based on theories from the field of Human Computer Interaction, concerning how development and design of digital technology in agriculture can be improved and thus relevant and useful for end users. 2) To investigate and increase knowledge about farmers' practical use of digital technology as an ongoing learning and care process in their socio-technical system. 3) To introduce and apply theories from other research fields to study and describe farmers' care in practice. 4) To reflect on how a relational and systemic perspective of care would affect advisors' work. To achieve these goals, four case studies were conducted. Three with a focus on crop production and one with a focus on milk production. The first studied farmers' use of the decision support system CropSAT for grain fertilization and analysed the data using the theoretical framework of Distributed Cognition (DCog). In case study two, theories and methods from the research field of human computer interaction (HCI) and user centred design (UCD) were introduced, with the aim of presenting improvements regarding the development process of new technology. The third case study concerned crop advisors' strategies regarding their use of the decision support system CropSAT in their work as advisors. The final case study studied dairy farmers' experiences regarding introduction of robotic systems. The Activity Theory was used to analyse the results. In the first and fourth case studies, the term care was used to describe the process that took place in practice.

Crop production and animal husbandry aims to manage biological systems to get desired results. In order to succeed, relationships are created, even if we in everyday life do not talk about relations between farmers and field or crop or between farmers and cows. Relations between cows and stockpersons may feel more obvious. However, this thesis describes a broader range of mutual relations in a farming practice.

Farmers work depend on technology. On the one hand new technology requires learning and adaptation from farmers. However, on the other hand technology must be adapted to and embedded in farmers' practice to work. Introduction of new technology affects farmers' relations. In this thesis, the AgriDSS CropSAT was studied with cereal farmers and AMS in dairy. With CropSAT, the farmers got a different perspective on their fields when the crop was seen through the satellite image. The picture of the crop was, however, supplemented by experiences, their own or the adviser's, from visits to the field, either by tractor or by foot. When robots take over the milking, the relationship between farmer and cow also changes. The stockperson no longer touches each cow on a daily basis, but must instead learn to see the cow through robot data. To do this they develop *enhanced professional vision*. Dairy farmers made clear that AMS provided important data about each cow, but a stockperson's eye was still considered equally important or more important by the majority of farmers with experience from conventional milking systems, after AMS was introduced. Nobody believed that the need for a stockperson's eye decreased significantly after the introduction of AMS. Accordingly, on the one hand, introduction of new technology means that the farmers must develop *enhanced professional vision*. They must learn to see the cow through robot data. On the other hand, the stockpersons eye is still very important for production and therefore stockpersons must find new ways to see the cows directly, without a filter of technology. Technology complements humans, but does not replace us. The robot presents a wealth of valuable and useful data, but the human capacity for holistic assessment, commitment, attention to deviations and the ability to act based on both formal knowledge and experience cannot be replaced by technology. A good result therefore requires both heart and brain. The person's values, which guide the work in a desired direction, as well as their will, commitment and knowledge, both theoretical and experience-based, then control how well the person concerned is able to understand, interpret and handle a certain situation!

By introducing the concept of care into studies of agricultural practice, both heart and brain are involved. It is about steering away from a focus on natural scientific demands of objectivity, general knowledge and a perspective of acting on. Care in this thesis is instead based on a relational and constructivist perspective, based on a perspective of mutual dependence and living with. The concept of care comes from the ethics of care, with a point of departure telling that individuals have greater responsibility to engage in, pay attention to and act on what is close to us. Good management is traditionally considered as being rational, acting on things, using economic terms for results and thus a rational logic of efficiency. The concept of care instead has a relational starting point telling that we live with other things and others. The concept is based on a relational logic of efficiency. Being effective then means favouring many different relationships, so that the entire system of relationships survives on a long-term basis. Care is based on experience and situated knowledge. In a complex system like a farm, it is never possible to do "right" from all aspects at the same time. An optimal action in one part of the system causes negative impact in another part. This is something that farmers always have to deal with. They use their experience and knowledge to try to do the best they can in a given situation, considering also viability in both short and long term. The concept of care helped make relationships visible in the situations studied, but also gave a wider picture of what factors that are important in a complex practice where technology is used. Both Distributed Cognition and the Activity Theory were found to function well as analytical lenses of the concept of care.

Despite the need for transformation in agriculture, no cases were studied where technology really supported a transformation with a focus on ecological sustainability. There are two main reasons for that. Coming from a PA context, I had a focus on sustainable intensification. In addition, there are few suitable cases to study, where technology supports transformation in traditional agriculture. I hope that the introduction of the care concept, a relational approach that assumes that humans are part of nature and therefore mutually dependent on each other, natural settings, different organisms and ecosystem services, can support us in our work for agricultural transformation. If we understand our interdependence with nature, change our perspective from management to care, from acting on, to living with, without forgetting the requirement of viability, I think we can more easily see what we need to do and what kind of technology such a transformation requires.

Populärvetenskaplig sammanfattning

Svenskt lantbruket måste ställa om för att möta de stora utmaningar vi står inför. Omställningen kommer genomföras av den enskilde lantbrukaren, på den enskilda gården, men med stöd från det omgivande systemet. Digitalisering och digital teknik ses som viktiga pusselbitar för att hantera dessa utmaningar såväl i samhället i stort som i lantbruket. Förhoppningarna och tilltron till precisionslantbruk, SMART eller digitalt lantbruk mm, presenteras brett inom massmedia såväl som i forskning och utveckling, medan lantbrukarna i många fall har visat sig vara mer tveksamma. Det gäller framförallt teknik som är tänkt att hantera komplexa situationer, men där resultatet inte alltid är så lätt att utvärdera. Forskningen har under lång tid haft fokus på tekniken i sig och inte på lantbrukares socio-tekniska system eller praktik, där tekniken ska användas och där den är beroende av lantbrukaren för att fungera. Därför har mycket teknik utvecklats, men sen fått begränsad spridning. Teknik som utvecklas måste helt enkelt vara relevant för användaren och fungera i praktiken! För att göra det måste teknikutvecklingen ske nära praktiken, och slutanvändare måste involveras i utvecklingen. Studier av olika tekniska lösningar bör därför kompletteras med studier av praktisk användning. Vid hantering av komplexa situationer, kan människor stödjas av teknik, men inte ersättas. Det gäller framförallt människor med erfarenhet av liknande situationer. Teknik kan däremot bidra med hantering av stora datamängder, eller genom att tydliggöra saker som vi människor inte kan uppfatta med våra sinnen. I denna avhandling behandlas två komplexa situationer, gödsling med satellitbaserat beslutsstöd och robotmjölkning.

Forskning och utveckling har hittills huvudsakligen handlat om effektivare resursanvändning, förbättrad djurvälfärd eller förbättrad arbetsmiljö. Mer sällan handlar digitalisering om förbättrad ekologisk hållbarhet, med undantag för minskad påverkan till följd av effektivare resursanvändning. Omställning kräver dock mer än ökad effektivisering, även om det också är viktigt. Istället krävs mer genomgripande förändringar, men sådana diskussioner förs endast i begränsad omfattning. Diskussionen om lantbrukets utveckling bör därför ändra fokus från i huvudsak effektivisering, till omställning. Omställning måste baseras på lantbrukares intresse och lokala förutsättningar, inom ramen för samhällets lagar, regler och stöd. Om målet inte enbart är effektivisering utan omställning, måste vi undersöka vilken teknik som då kan behövas? Detta kräver i sin tur studier av lantbrukares omställningsprocesser och teknikutveckling i nära kontakt med praktiken, så att tekniken blir relevant och verkligen fungerar praktiskt. Digitala lösningar kan sannolikt ha en viktig roll för att stödja omställningsprocesser i både växtodling och djurhållning.

Denna avhandling syftar till att introducera begreppet omsorg (*care*) i lantbruket för att studera användningen av digital teknik i lantbrukares socio-tekniska system, och för att introducera ett relationellt perspektiv på teknikanvändning. Omsorg beskrivs då som ett relationellt och systemiskt alternativ till management, och omfattar allt görande som får teknik, information och kunskap att fungera praktiskt. Avhandlingen har fyra mål: 1) Att med stöd av teorier och metoder från forskningsfältet människa-datorinteraktion ta fram rekommendationer för hur utveckling och design av digital teknik i lantbruket kan förbättras, så att tekniken blir relevant och användbar för slutanvändare. 2) Att undersöka och öka kunskapen om lantbrukares användning av digital teknik som en pågående lär- och omsorgsprocess i deras socio-tekniska system. 3) Att introducera och tillämpa teorier från andra forskningsfält för att studera och beskriva lantbrukares praktiska omsorg. 4) Att presentera vilka effekter det skulle få för rådgivare, om deras arbete skulle ta utgångspunkt i ett relationellt och systemiskt perspektiv som omsorg. För att nå dessa mål genomfördes fyra fallstudier. Tre med fokus på växtodling och en med fokus på mjölkproduktion med robotsystem. Den första fallstudien handlade om lantbrukares användning av beslutsstödet CropSAT för gödsling av spannmål och analyserade data med hjälp av det teoretiska ramverket distribuerad kognition. I fallstudie nummer två introducerades teorier och metoder från forskningsområdet människa datorinteraktion (HCI), med syfte att presentera förbättringsförslag vad gäller design och utveckling av ny teknik. Den tredje fallstudien rörde växtodlingsrådgivares strategier avseende användning av beslutsstödet CropSAT i rådgivningen. Den sista fallstudien handlade om mjölkproducenters erfarenheter från introduktion av robotsystem. Här användes Aktivitetsteorin för att analysera resultaten. I den första och fjärde fallstudien användes omsorgsbegreppet för att beskriva den process, som pågick i praktiken.

Odling och djurhållning syftar till att sköta biologiska system så att det får eftersträvat resultat. För att lyckas med det skapas relationer, även om vi inte i dagligt tal uttrycker exempelvis växtodling som en relation mellan lantbrukaren och hens gröda eller mark. Relationer mellan kor och djurskötare kan kännas mer självklart. I denna avhandling beskrivs båda fallen som relationer baserat på ett ömsesidigt beroende.

Ny teknik kräver lärande och anpassning från lantbrukarens sida, men tekniken måste också anpassas och bäddas in i hens praktik för att fungera. Samtidigt är lantbrukaren beroende av teknik för att verksamheten ska fungera. Introduktion av ny teknik påverkar lantbrukarens relationer. I denna avhandling studerades beslutsstödet CropSAT hos spannmålsodlare och robotar i mjölkproduktion. Med CropSAT fick lantbrukaren ett annat perspektiv på sina fält när grödan skulle ses *genom* satellitbilden, vilket ändrar relationen till grödan. Bilden av grödan kompletterades dock med erfarenheter från besök i fältet. När robotar tar över mjölkningen ändras på samma sätt relationen mellan människa och ko, genom att människan inte längre tar i varje ko flera gånger per dag. Istället ska de lära sig att *se* kon genom robotdata. Bägge exemplen leder till att lantbrukaren utvecklade en vidgad professionell blick (*enhanced professional vision*). Mjölkproducenterna framhöll att roboten gav viktig information om den enskilde kon, men djurskötarens djuröga ansågs minst lika viktig eller viktigare efter introduktion av robotsystem, hos en majoritet av lantbrukarna. Ingen menade att behovet av djuröga minskade signifikant efter introduktion av robotsystem. Så å ena sidan innebär introduktion av ny teknik att människans professionella blick måste utvecklas. De måste lära sig att se kon genom robotdata. Men å andra sidan är djurskötarens djuröga fortfarande avgörande för produktionen och därför måste djurskötare hitta nya sätt att se korna direkt, utan ett filter av teknik. Tekniken kompletterar därmed människan, men ersätter oss inte. Roboten presenterar en mängd värdefulla och användbara data, men den mänskliga förmågan till helhetsbedömning, engagemang, uppmärksamhet på avvikelser och förmågan att agera utifrån både formell kunskap och erfarenhet går inte att ersätta med teknik. Ett gott resultat kräver därför både hjärta och hjärna. Människans värderingar, som styr arbetet i önskad riktning, samt hens vilja, engagemang och kunskaper, både teoretiska och erfarenhetsbaserade, styr sedan hur väl vederbörande klarar att förstå, tolka och hantera en viss situation!

Denna avhandling introducerar omsorgsbegreppet i studier av lantbrukspraktiken för att visa på behovet av ett relationellt perspektiv och behovet av både hjärta och hjärna. Det handlar om att styra bort från ett ensidigt fokus på naturvetenskapens krav på objektivitet, generell kunskap och synsättet att det handlar om att *agera på* något. Omsorg i denna avhandling bygger istället på ett relationellt och konstruktivistiskt perspektiv, med utgångspunkt i ett ömsesidigt beroende och att *leva med*, ett ömsesidigt beroende. Omsorgsbegreppet kommer från the ethics of care, och bygger på att vi som individer har större ansvar att engagera oss för, uppmärksamma och agera på det som finns nära oss. Gott management är traditionellt att vara rationell, att *agera på* saker, använda ekonomiska termer för resultat vilket baseras på en rationell logik av effektivitet. Omsorgsbegreppet har istället en relationell utgångspunkt, att vi *lever med* och är ömsesidigt beroende av annat och andra och begreppet grundas istället på en relationell logik av effektivitet. Att vara effektiv blir då istället att gynna många olika relationer, så att hela ekosystemet av relationer överlever på kort och lång sikt. Omsorg bygger på erfarenhet och situerad kunskap. I ett komplext system som ett lantbruk, går det aldrig att göra ”rätt” ur alla aspekter samtidigt. Rätt åtgärd i en del av systemet, medför negativ påverkan i en annan del. Det är något som lantbrukare alltid har att förhålla sig till. De använder sin erfarenhet, kunskap och sina tillgängliga verktyg för att i en given situation göra bäst möjliga på kort och lång sikt utifrån deras mål med verksamheten och med krav på lönsamhet. Omsorgsbegreppet hjälpte till att synliggöra relationer i de situationer som studerades. Både distribuerad kognition och aktivitetsteorin visade sig fungera som analytiska linser av omsorgsbegreppet.

Trots behovet av omställning i lantbruket, studerades inga fall där teknik verkligen stödde en omställning med fokus på ekologisk hållbarhet. Orsakerna är flera. Dels har detta avhandlingsarbete medfört att jag lämnat mitt tidigare fokus på hållbar intensifiering, vilket var fokus i min licavhandling och i mitt arbete med precisionsodling. Och dels finns få lämpliga fall att studera, där digital teknik stöder omställning i traditionellt lantbruk. Jag hoppas att omställningsarbetet kan stödjas genom introduktion av omsorgsbegreppet och ett relationellt perspektiv, vilket utgår ifrån att människan är en del av naturen och därför ömsesidigt beroende av andra människor, olika organismer, naturliga miljöer och ekosystemtjänster. Om vi ändrar perspektiv från management till omsorg, från att *agera på*, till att *leva med*, utan att för den skull glömma kravet på lönsamhet, tror jag att vi lättare ser vad vi behöver göra och vilken teknik det därmed finns behov av. Lantbrukare behöver utveckla ett relationellt ledarskap utifrån en medvetenhet om vilka relationer som är relevanta och intressanta på deras specifika plats för att våra miljömål ska nås och för att vi ska hålla oss inom ramen för de planetära gränserna. Om åkermarkens långsiktiga hållbarhet beror av dess jordhälsa, kommer relationen till de organismer som skapar jordhälsa upplevas viktiga. Det i sin tur kräver nya strategier för att exempelvis undvika markpackning. Ett problem som alla känner till, men som vi sällan förmår att verkligen undvika. Samtidigt vet vi att det är omöjligt att göra allt rätt, det krävs medvetna och reflekterade prioriteringar. En rådgivare som ska arbeta utifrån ett omsorgsperspektiv som denna avhandling beskriver det, måste vidga fokus från lantbrukarens traditionella relationer till grödor och kor med flera, och involvera många fler typer av relationer. De behöver utveckla en *relationell blick* för att stödja lantbrukaren med arbetet att undersöka vilka relationer som är intressanta och relevanta på den specifika platsen, utifrån lokala förutsättningar samt inom ramen för lagar, regler och stöd! Till detta behovs teknikstöd. Fallstudie tre visade att några rådgivare använde CropSAT som underlag för diskussion och lärande, medan andra inte gjorde något alls förrän de blev tvungna. En central fråga för svensk lantbruksrådgivning och lantbrukssystemet i stort är, huruvida vi jobbar med effektivisering eller med omställning och vilka som verkligen driver utvecklingen för ökad hållbarhet?

Teknik är värdefull i många sammanhang, då den underlättar arbetet samt kompletterar och stödjer människan där vi har begränsningar. Men den måste styra i önskvärd riktning och vara inbäddad i en mänsklig praktik för att fungera i komplexa situationer. Riktningen på vårt arbete måste vara att arbeta med naturen, inte mot den och inse vårt ömsesidiga beroende, *leva med*, inte bara *agera på*. Vi måste basera vårt arbete på ett relationellt synsätt, där fler relationer än idag tas hänsyn till, för att på riktigt ställa om svenskt lantbruk med stöd av relevant och användbar teknik.

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The thesis is about relations. We must identify and take responsibility for a broader range of relations around us than we usually do and not just with other humans. These kinds of relations have been important to me all my life, without me actually putting it into words until now! However, at the end of the day, it's still you, the people around me, who create most of the meaning in life and provide such social contexts that is necessary for me as a human being. Thank you for allowing me to be part of your specific herd!

II

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Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies

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Abstract Precision agriculture provides important issues toward a more sustainable agriculture. Many farmers have the necessary technology to operate site-specifically, but they do not use it in practice, and thus available information and communications technology (ICT) systems are not used to their full potential. This paper addresses how to reduce the so-called "problem of implementation", based on the knowledge that participatory approaches during the design and development process is one of the most important factors to frame technology adoption. The development of sustainable ICT systems through theories and methodologies from the fields of human computer interaction and user-centered design (UCD) is presented and an ongoing Swedish project for development of an agricultural decision support system (AgriDSS) for nitrogen fertilization is used as an example to frame the issue. The overreaching aim is to develop AgriDSSs that are sustainable *in design* as well as *through design* by stressing the importance of participatory approaches for the successful development of AgriDSSs. The Swedish project has the intention to apply a UCD approach, and some pitfalls on starting to use this way of working is identified as well as some suggestions on how to reduce them through co-learning processes. Despite the challenges presented in this paper, ICT can contribute significantly to long-term sustainable development. Thus, several competences and scientific disciplines need to act in concert to help develop a sustainable development of agriculture via a transdisciplinary approach that can make an impact on society at many levels.

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Keywords Agricultural decision support system · User-centered design · Sustainability · Problem of implementation · Co-learning · Transdisciplinarity

Introduction

The challenges facing agriculture are immense—the agricultural sector is supposed to fulfil several goals and societal values simultaneously (e.g., increased food production, preserving and developing cultural heritage, biodiversity, climate change and recreational values), while at the same time being both sustainable and economically viable on a long-term basis (EU SCAR 2012). Sustainable development has famously been characterized with the wording of the Brundtland Commission (World Commission on Environment and Development 1987) as “development that meets the needs of the present without compromising the ability of future generations to meet their needs” (Huang et al. 2009). The sustainability discourse is commonly based on the idea of three overlapping areas, or pillars, covering environment, economy, and social development (Boström 2012). A generic path to sustainability is to stimulate people to change towards more sustainable practices and behaviours, irrespective of whether it concerns. Environmental sustainability, for example, is concerned with aspects such as renewable resources, reduction of pollution, finding substitutes for non-renewable resources, and sustainable land-use (e.g., Aubert et al. 2012; Daly 1990). A commonly used concept in agricultural research is *sustainable intensification,* which has the overreaching goal to increase food production from existing farmland while minimizing the pressure on the environment (Garnett et al. 2013). Briefly stated, the concept can be considered as a response to the challenges of the increasing demand for food, feed and energy from a growing global population, in a world where the natural resources are overexploited and used unsustainably. Therefore it has been stated that efforts to ‘intensify’ biomass production have to be properly aligned to making the process ‘sustainable’, otherwise the capacity to produce food, feed and energy in the future will be undermined and subsequently may fail (e.g., Caron et al. 2014a, b; Halberg et al. 2015).

At the very core of all changes towards a more sustainable agriculture are the individual decision-makers as the decisions of each farmer will have positive or negative effects on sustainable intensification (Matthews et al. 2008; Van Meensel et al. 2012). In the agricultural sector, it is the farmers who have to transform facts and figures into daily work practices. It has also been argued that an appropriate way to address sustainability aspects in design of interactive technology is to focus on everyday practices and routines (Pierce et al. 2013). Information and communications technology (ICT) is spreading into almost every aspect of people’s daily lives, and hence it must integrate sustainability aspects into applications used by people, e.g., features that can stimulate change in practices and behaviours. An important component is decision supporting ICT systems as a mediator in this context, commonly referred to decision support systems (DSS). A DSS is an ICT system that supports either a single decision-maker or a group of decision-makers in making more effective decisions when dealing with unstructured or semi-structured problems (Alenljung 2008). A DSS can either support the decision maker in an on-going decision situation or it can prepare the decision-maker to perform better in the future through decision training (Alenljung 2008).

It is argued by several researchers that agricultural DSS (AgriDSS) can contribute significantly to long-term sustainable development, but yet the role of AgriDSS as both an actor and a solution within sustainable development is receiving only limited attention in current research (e.g., Aubert et al. 2012; Korte et al. 2012, 2013). Properly designed, an AgriDSS can promote and scaffold environmentally sustainable lifestyles and decisions of humans (e.g., Hanks et al. 2008; Susi et al. 2015). However, current AgriDSS available to farmers are not used to their full potential and are not adapted to the trade-offs and high complexity characterizing farmers' decision making (e.g., Eastwood et al. 2012; Mackrell et al. 2009; Van Meensel et al. 2012). This has been called the "*problem of implementation*" (e.g., Mackrell et al. 2009; Matthews et al. 2008; Rossi et al. 2014) within the agricultural domain. The uptake and acceptance are low, partly because existing AgriDSS are based on what scientists and ICT system developers consider as necessary knowledge that should be implemented in the decision support, but in reality they fail to capture the tacit knowledge and practical needs of farmers. Other reasons for the low adoption rate of AgriDSS by farmers are, e.g., a perceived problem of complexity, lack of observability, level of knowledge of the users, lack of confidence, poor user interface design, tedious data input requirements, low adaptation to the farm situation, no frequent information update, lack of incentive to learn and adopt new practices, and the fear of replacing advisors (e.g., Eastwood et al. 2012; Kerr 2004; Rossi et al. 2014; Van Meensel et al. 2012). Thus, there is an obvious gap between research and practice that McCown et al. (2009) define as the "*gap of relevance*" which has to be bridged, or at least decreased.

Precision agriculture (PA) plays an important role in a sustainable intensification, and it is recognized as a contributor to farming efficiency and environmentally friendly farming practices. Briefly stated, PA is a management concept based on observing, measuring and responding to intra-field variability in crops. PA technology allows crop farmers to recognize variations in the fields and to apply variable rate treatments with a much finer degree of precision than earlier possible. The emergence of PA technology represents a paradigm shift in farming practices: it permits the consideration of the field as a *heterogeneous entity* that allows for selective treatment instead of a *homogenous entity* that is treated equally (Aubert et al. 2012). However, the common practice among many crop farmers and their advisors is to regard the fields as *homogenous entities* leads to suboptimal treatment, which often results in an over- or under-supply of fertilizers and pesticides. Sub-optimal treatment results in considerable costs for farmers and constitutes a major source of environmental pollution, which in the long run does not contribute to sustainable agriculture (Aubert et al. 2012).

In order to perform adequate PA, credible and usable AgriDSS are needed. It should be pointed out that the single unifying predictor of success or failure of an AgriDSS, which has been put forth by multiple authors, is the extent to which the end users are involved in the ICT system development process. The necessity of a user-centered design (UCD) approach has been stressed by, e.g., EIP-Agri Focus group report (2015), Cerf et al. (2012), Mărușter et al. (2008a, b), Matthews et al. (2008), Thorburn et al. (2011), and Van Meensel et al. (2012). User-centered design is an approach within the field of human–computer interaction (HCI), aiming to develop and adapt the ICT system based on the users' needs as well as the context of use, rather than forcing the users to change their behavior to accommodate to the ICT system from a top-down perspective (e.g., Benyon 2014; Dix et al. 2004; Hartson and Pyla 2012; Preece et al. 2002; Rogers et al. 2011). Major shortcomings of today's AgriDSS are a consequence of a lack of understanding of farmers' decision-making in practice as well as their actual needs. These shortcomings need to be addressed in order to accomplish an AgriDSS that considerably facilitates sustainable agriculture in general and PA in particular, aiming for a sustainable intensification (Caronet et al. 2014a, b).

Hence, several competences, approaches and scientific disciplines need to act in concert to help develop a sustainable agriculture; since the overall trend in agriculture is towards a more complex, technologically-based crop production with increasing regulation and supervision regarding the use of fertilizers, pesticides and other chemicals (e.g., Rossi et al. 2014). Hanks et al. (2008) point out the importance of sustainability for design, focusing on sustainable design (SD) which is the perspective that sustainability can and should have a central focus within UCD and HCI. The focus in SD has since then centered on the dual link between environmental sustainability and ICT by addressing both *sustainability through design*—how ICT can be used to promote more sustainable behaviors, and *sustainability in design*—how sustainability can be the governing principle of the design process of the ICT systems themselves (e.g., Hanks et al. 2008; Issa and Isaias 2015).

The paper aims to investigate and discuss "the problem of implementation" and the related "gap of relevance" from a more sustainable trajectory as well as identifying pros and cons in the shift of ICT system design methodology, from a more technology-centred approach to a more user-centred approach in the design, implementation and diffusion of an AgriDSS for computation of variable-rate application (VRA) files for nitrogen fertilization. This paper uses precision agriculture Sweden (POS) AgriDSS development process as an illustrative case to raise these issues, being influenced by an abductive approach (Thagard and Shelley 1997). This provides us with an opportunity to address this process from two different, but complementary perspectives. On the one hand, the agricultural perspective addresses ideas regarding what kind of AgriDSS farmers may need in PA in order to further develop sustainable intensification. On the other hand, the HCI perspective that addresses generic ICT system development methodologies that provide various kinds of user-centred approaches, but lack in-depth experience of the agricultural domain. Both perspectives put sustainability high on the research agenda, and want to reduce the "problem of implementation" and decrease the "gap of relevance" through insuring high usability, i.e., adapting the AgriDSS to the end users' and stakeholders' needs and goals, and the possibility of reaching satisfied users and AgriDSS success increases significantly. The target group for this work is researchers and other stakeholders who have noticed problems in the process of implementing new technology, such as AgriDSSs, in agricultural practice.

The remainder of this paper is structured as follows. The background section provides some identified failures and success factors in AgriDSS that motivates and frames the topics discussed in this paper. Secondly, it briefly presents some experiences from Sweden regarding design and development of PA technology with the focus on optimizing the use of nitrogen in farming practices. The next sections present sustainable ICT, and introduce the concepts of HCI, UCD methodology and how to handle the challenge of the "problem of implementation". Next, some beginners' pitfalls in applying UCD/PD methods and some suggestions on how to reduce them are outlined. The paper ends with a discussion and some conclusions.

Identified failures and success factors in AgriDSS

Many researchers have viewed the development of new AgriDSSs as possibilities for providing scientific knowledge and information to farmers with the aim of increasing sustainability and facilitate innovation (e.g., Fountas et al. 2005; McCown et al. 2009; Thorburn et al. 2011). During the last 30 years, research and development has produced a large number of AgriDSSs, but most of them have not been used appropriately in practice (e.g., Aubert et al. 2012; Eastwood et al. 2012; Korte et al. 2012, 2013; Mackrell et al. 2009; Matthews et al. 2008; McCown 2002; Rossi et al. 2014; Van Meensel et al. 2012). Aubert et al. (2012), for example, claim that factors influencing the adoption of innovations are tightly linked to work practices that are more complex than just the mere perspectives of technology acceptance or diffusion of innovations, while Fountas et al. (2005) point out that time requirement, lack of technical knowledge and cost are the most important impediments in the implementation of AgriDSS in PA. One central failure issue is the fact that researchers often focus on one specific area or problem, while the farmers must have a holistic view of the crop production with a wide range of problems (Rossi et al. 2014). Van Meensel et al. (2012) also point out that some AgriDSSs are too complex, and their terminology and functions are not adapted and are irrelevant to the intended users and their activities and context of use. The AgriDSSs are often developed as a result of technology push instead of a request grounded in a defined problem or an expressed need. A related explanation for this is that common technology acceptance models fail to take public resources, such as the environment, into account when analyzing the adoption of ICT systems (Melville 2010). Thus, there is an obvious gap between research and practice (e.g., Mackrell et al. 2009; McCown et al. 2009). Concerning the "problem of implementation", various explanations for the low adaption rate of AgriDSSs have been put forward, ranging from individual characteristics of farms, farmer's age and education level, resource availability, ease of use, and experienced usefulness to farmer's risk management attitude (e.g., Aubert et al. 2012; Pierpaoli et al. 2013) as well as high costs in investment and learning (e.g., Kutter et al. 2011). Two reasons that are explicitly stressed are how well the farmers perceive the PA technology as 'useful' and its 'ease of use' (e.g., Aubert et al. 2012; Pierpaoli et al. 2013). Lack of relevant standards and poor compatibility between different equipment, have for instance strong negative influence on the ease of use. The effort to develop user profiles of prospective end-users and their length of experience working with PA technology, as well as the length and frequency of using basic and advanced features of several AgriDSS, are factors that may have an impact on the ease of use. Hence, one major identified reason for the "problem of implementation" is the normative way of developing new technology without considerations of the actual needs of the end-users (e.g., Leeuwis 2004; McCown 2002, 2005; McCown et al. 2009).

The lack of knowledge about farmers' decision-making in practice is another reason for the failure of a transition toward sustainability. Existing research on how decisions are made, on which grounds and by which means, is based on overly rationalistic assumptions rather than on empirical data from decision-making processes in real-life settings (e.g., Gray et al. 2009; McCown 2005; Parker and Sinclair 2001; Öhlmér 2001; Öhlmér et al. 1998), though there are some exceptions (e.g., Bradford 2009; Lindblom and Lundström 2014; Lindblom et al. 2013). Success factors are, e.g., the level of involvement and trust that farmers' experience (Ljung and Källström 2013; Ljung et al. 2014), why over the last two decades it has become widely accepted that participatory approaches to sustainable land management may deliver additional benefits over non-participatory initiatives. The identified need to revise the study of decision-making of farmers toward more naturalistic decision-making models has taken initial steps. In other words, there seems to be a lack of knowledge concerning farmers' daily practices. The results from empirical studies of farmers' decision-making processes in practice show the potential usefulness of AgriDSS for agriculture (Lindblom and Lundström 2014; Lindblom et al. 2013).

Nevertheless, a well-designed AgriDSS is a useful tool for the ongoing transfer of scientific knowledge and "best practices" within the field of agriculture. Parker and

Sinclair (2001), for example, claim that the single unifying predictor of success or failure of an AgriDSS is the extent to which users are involved and participate in design and development process. Moreover, Jakku and Thorburn (2010) as well as Van Meensel et al. (2012) stress the importance of participatory approaches for the successful development of AgriDSSs as well as the role and relevance of social learning by the stakeholders involved in the participatory AgriDSS development process. From this perspective, the lack of HCI, UCD and participatory approaches is the core of the identified “problems of implementation” of most AgriDSSs. Hence, there is a need to develop AgriDSS that simultaneously enables farmers to get access to the best knowledge available, while at the same time involving them in the design process of developing the AgriDSS. In other words, a sustainable agriculture is crucially dependent on sustainable ICT systems and UCD methodologies.

Experiences from Sweden

The technological development in PA has been rapid since the 90s, while a wide-ranging implementation and practical use of the technology has been much slower. Many farmers buy new machinery with built-in functions for variable measures and PA technology, without actually using it. This can be illustrated by the following quote from one of the farmer’s involved in an ongoing project related to POS: “That is the situation nowadays … you have a lot of technology, but you don’t use it … either is it a question of interest or knowledge … often there is a lot of technology in a machine that you don’t need … and a lot of people do not use it … far from”. In the late 1990s the Yara N-sensor was introduced on the Swedish market. Initially few farmers, some working as subcontractors, embraced the N-sensor technology; while the majority of farmers, advisers as well as the authorities remained rather passive, despite a continuous promotion of the technology in the farming press, exhibitions and by manufacturers. It had support from the manufacturers and distributors but there were few field experiments to secure reliability about the benefit of the N-sensor technology from the start. Still the Yara N-sensor is an apparatus difficult to fully evaluate on individual fields without field experiments. Nevertheless, in 2015 most Swedish farmers have heard about the Yara N-sensor and during the season 2015, it has been estimated that approximately 130 Yara N-sensors are in practical use on Swedish farms. The growing condition was very favorable for cereals in 2015 with high yield potential and a high nitrogen demand to secure baking quality (i.e., protein content). Many farmers and advisor did not notice this increased N-demand until after harvest! However, fields fertilized with VRA based on N-sensor showed higher N-content both in wheat for milling and malting barley (pers. com. K Nissen Yara AB Sweden). The dominating Swedish flour mill claims that VRA of fertilizer is a necessity for production of wheat with the right quality for flour (http://www.kungsornen.se/).

The Yara N-sensor detects the status of nitrogen and biomass of plants by measuring canopy reflectance in parts of the red and near infrared electromagnetic spectrum (Link et al. 2002). The obtained spectral information is combined with a fertilizing algorithm which allows site-specific nitrogen fertilization within a field. Lammel et al. (2001) point out that the Yara N-sensor is valuable to avoid over- and under fertilization within a field resulting in increased yield, decreased lodging and more homogenous ripening. Other researchers accentuate that usage of the N-sensor only have resulted in small differences in yield (Berntsen and Thomsen et al. 2006; Jørgensen et al. 2006) and Zillmann et al. (2006)

point out that the N-sensor technology work when nitrogen is the main growth-limiting factor. The usage of Yara N-sensor reduces nitrogen leaching if areas with lower requirements for nitrogen fertilization within the field can be identified (Delin and Stenberg 2014). Thus, the N-sensor technology could have benefits for farmers as well as for a more sustainable society in the long run. It has been recognized by stakeholders in the Swedish farming community that growers where crop quality and payment is strongly linked to the nitrogen content, such as malting barley and bread wheat, or where soil mineralization ability varies greatly for example due to high manure supply or variation in soil type, have the most important potential benefit of the N-sensor technology.

Generally speaking, most farmers realize that yield varies within a field as well as the amplitude of the variation can vary a lot between different fields. In theory, farmers should not have any problems to grasp the usefulness of the Yara N-sensor. Nevertheless many farmers do not use variable nitrogen application. The reasons could be higher costs, extra work, doubts of the credibility or cost-benefit. In fact, not even in special crops, for example in potatoes, where varied fertilization has been shown to provide a direct added value due to a better quality, the technology has been broader adapted.

In the early 2000 different assisted steering systems, such as auto steering, were introduced on the Swedish market. ICT systems as auto steering or guiding systems are intended to decrease overlaps, working hours, reduce energy consumption and facilitating new farming concepts such as controlled traffic. At least some of those described advantages are both easy to understand and become obvious just by watching the use of the technology in action, i.e., they provide momentary visual feedback in the fields. Farmers' interest has been comprehensive from the beginning and these PA technologies reached high popularity directly after being launched. The experience of the implementation of those straight forward PA applications is shared in Germany (Busse et al. 2014) as well as in Central and Northern Europe, the USA and Australia (EIP-Agri Focus group report 2015). It should be pointed out that compared to the Yara N-sensor, using a steering system also requires new technological knowledge by the farmer, but the two systems do demand slightly different kinds of decision making support. The Yara N-Sensor requires data input of expected yield and fertilizer need at the reference site, while the steering system only requires making an operative decision concerning the distance to the next track. A steering system in a tractor or harvester has a few obvious pedagogical benefits compared to the Yara N-sensor in providing an understanding of the environmental and economic consequences of the actions done, the immediate effects that can be experienced while driving the tractor in the field. The performance of straight lines and the avoidance of double runs or missing rows are obvious and immediate results for the farmer. The farmer's immediate senses of the obtained advantages of the N-sensor compared with the assisted steering technologies thus differ. Payne et al. (2016) described nine extension strategies for technology adoption dependent on the kind of technology that would be adopted, from technology push to co-development strategies. Technologies that fit with the technology push strategy is characterized by non-complex issues, observable impacts, high compatibility and easy to implement, while more complex technologies without immediately observable benefits and difficulties in testing and implementation do instead need co-development strategies in order to be adopted. This is probably a central explanation to the differences between the adoptions of auto-steering systems compared with the Yara N-sensor.

An alternative to optimize the use of nitrogen is the AgriDSS named CropSAT (http://www.cropsat.se/), developed by POS during the years 2013–2014. CropSAT uses satellite images for calculation of a vegetation index (Qi et al. 1994) for computation of VRA files for nitrogen fertilization in cereals. The vegetation index in CropSAT is correlated to measurements done with the Yara N-sensor (Söderström et al. 2015). In order to utilize CropSAT, the user starts the application on the internet, marks a field in a Google Earth application and the vegetation index from a chosen satellite image is calculated and shown on the marked field in Google Earth. To get a VRA file the user must decide on five levels of nitrogen amount related to the vegetation index (see Fig. 1). When the five levels are set a VRA file for the actual field can be calculated (see Fig. 2) and transferred to a spreader by an USB memory stick. The recommendation is that the user goes out into the field and verifies the nitrogen levels by measurements of absolute N-status with a so-called Spad-meter (https://www.konicaminolta.eu/en/measuring-instruments/products/colour-measurement/chlorophyll-meter/spad-502plus/introduction.html) or just verifying the need of additional N with his or her own experience and knowledge about canopy greenness and N-status. During 2015 a high-fidelity prototype of CropSAT was available on the internet, free to use due to funding by the Swedish Board of Agriculture. Farmers and advisors have shown a considerable interest in CropSAT. CropSAT could be seen as an alternative to the N-sensor, but with lower resolution. CropSAT enables direct observation of the within filed variation in canopy status which seems very interesting for the farmers taking part in ongoing project related to POS. So far, however, it has been pointed out by farmers that the procedure/process of setting the five levels of nitrogen amounts seems to be more complicated than expected, and needs to be studied further.

The above described PA technologies have had different impact on the Swedish market. The Yara N-sensor was launched in the 90s, represented an investment for the user in both learning and cost resulting in a new kind of decision making support equipment in order to governing fertilization. Steering systems was launched on the Swedish market in early 2000 and was rather quickly adapted broadly. This was probably due to the obvious advantages in cost reductions as well as easily and momentary produced instruction for VRA of N. It should be stressed that it is too early to evaluate the market penetration reply of the CropSAT technology. The fact that a significant number of farmers already have the technology needed to use the CropSAT technology, it is free of charge and free to use, funded and paid by Greppa Näringen (an advisory service funded by the Swedish government and EU through the Swedish Board of Agriculture) might be important aspects for its availability and impact. Hopefully it can contribute to lowering the barriers of entrance to VRA of N and have positive impact on Swedish farmers' usage of PA technology. Of major importance for the future impact is whether or not it is perceived as credible and useful for the farmers' work practices impact is whether or not it is perceived as credible and useful for the farmers' work practices and in comparison with the Yara N-sensor, and to what extent the CropSAT system is considered *sustainable through design* remains to be evaluated.

Sustainable ICT: increased farmer participation through the application of HCI and UCD methodology

Ideally, the endeavour for sustainable development should permeate all human activity, and since ICT is a pervading element in most people's lives (at least in wealthier countries), ICT plays an important role in this effort (Susi et al. 2015). The issue of designing ICT systems for human use, including a sustainability perspective, is receiving increased attention in ICT related research. In terms of the design and implementation of sustainable ICT solutions, the wording of the Brundtland definition has been reinterpreted to address

Fig. 1 Variation in vegetation index calculated by the AgriDSS CropSAT (http://www.cropsat.se) from a satellite image and visualized on a chosen field in Google Earth. Five levels of nitrogen application are set and can be used as a basis for calculations of a VRA

current challenges. A sustainable ICT system is, for example, characterized by longevity, simplicity, accessibility, responsiveness, and adaptability (Misund and Høiberg 2003). In particular, there is an increasing need for ICT studies with *demonstrable impact* on mitigating the threats to environmental sustainability (e.g., vom Brocke et al. 2013; Malhotra et al. 2013). The development and deployment of future sustainable agriculture requires acquisition, application and adaptation of knowledge, with the support of appropriate ICT systems (Dutta et al. 2014). Hence, the primary role of ICT systems within sustainable development is to create and communicate action possibilities for sense-making and sustainable practicing (Seidel et al. 2013).

Sustainability through design

To account for this need for sustainability in future deployments, *Sustainable ICT Systems* have been put forward as a new direction within the banner of ICT research, and for instance, e.g., in fields like HCI, and its subfields UCD, sustainable interaction design (SID) and sustainable design (SD) (e.g., DiSalvo et al. 2010; Huang et al. 2009; Håkansson and Sengers 2013; Issa and Isaias 2015; Pierce et al. 2013; Pink et al. 2013).

This paper directly acknowledge the dual link between environmental sustainability and ICT by addressing both (1) *sustainability through design*—how ICT can be used to promote more sustainable behaviors, and (2) *sustainability in design*—how sustainability can

Fig. 2 The VRA file applied to a Google Earth map, ready to be saved on a USB memory stick and transferred to the spreader

be the governing principle of the design of the ICT systems themselves (Hanks et al. 2008; Mankoff et al. 2007). Hanks et al. (2008) point out the importance of sustainability for ICT design, focusing on SID which is the perspective that sustainability can and should have a central focus within HCI. The importance of considering sustainability within interaction design was put forward by Blevis (2007), and the focus in SID has since then centered on the linkage between environmental sustainability and ICT. However, Hanks et al. (2008) stress that it should be unavoidable for interaction designers to consider not only the ICT systems themselves from a perspective of environmental effects, but also the contexts of use and design for cultural alteration that can affect more sustainable human attitudes and behaviors.

In this paper the focus is on *sustainability through design*, and as pointed out by Susi et al. (2015), a number of different research genres regarding this perspective are labelled by DiSalvo et al. (2010). Firstly, they mention *persuasive technologies*, whose purpose is to influence the users to act in a more sustainable way, and such ICT systems are now in use in diverse domains, e.g., energy consumption, transportation habits healthcare, as well as education and training. Secondly, *ambient awareness systems* are based on so-called calm computing and ambient screen displays, with the purpose to increase the user's awareness of his or her current (un) sustainable behaviour. This can be brought about by making certain behaviour visible and a particular activity pattern promoting sustainability rewarding. Thirdly, SID focuses on fundamental reconsideration of ICT system design methodologies in HCI to tackle sustainability issues (e.g., DiSalvo et al. 2010; Issa and Isaias 2015). Within this genre, a turn to practice has evolved (Wakkary et al. 2013), which also is an emerging trend in HCI lately (Rogers 2012). Fourthly, the genre of *formative user studies* concerns an effort to understand users' ways of conceiving sustainability in their everyday life, and practices, as a means to creating new ICT design solutions

(DiSalvo et al. 2010; Håkansson and Sengers 2013). Fifthly, *pervasive and participatory sensing* is concerned with the use of sensors that monitor and report the conditions in focus, with the intention of changing the conditions (DiSalvo et al. 2010).

In order to reduce the "problem of implementation" as well as the inter-related "gap of relevance" addressed in this paper, it has been argued by several authors that the design methodology of AgriDSSs needs to be user-centred, where the intended end-users actively participate throughout the whole design process. It should be pointed out that humans undergo activities that are contextual and it is the varieties in people's context that make the design of ICT systems challenging.

HCI and UCD methodology

The field of HCI is commonly characterized as; "…a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them" (The ACM SIGCHI group 1992). Generally speaking, HCI, as an interdisciplinary field, focuses on the various ways in which humans interact with ICT, and many textbooks have successfully highlighted the central principles in the analysis, design, development for achieving usability of these human-technology interactions (e.g., Benyon 2014; Dix et al. 2004; Hartson and Pyla 2012; Issa and Isaias 2015; Preece et al. 2002; Rogers et al. 2011). The interdisciplinary of HCI consists of a range of disciplines; including computer science, cognitive science, graphical design, industrial design, human factors, sociology and anthropology, resulting in a mix of science, engineering, and design aspects. It should be pointed out that designing usable ICT systems is not always straightforward, as the many poorly designed ICT systems show. One of the challenges of HCI design is to keep alongside of technological developments and to ensure that these are adapted for best possible human benefit. However, software developers often have poor understanding of HCI issues, and therefore it is of major importance that HCI specialists explicitly address their knowledge of how to think in terms of future users' needs, values and supportable tasks and how to translate that knowledge into a functional and usable ICT system, which fits well for the needs and capabilities of the people for whom they are intended (e.g., Hartson and Pyla 2012; Issa and Isaias 2015; Preece et al. 2002; Rogers et al. 2011).

To achieve the goals of HCI, a number of design methodologies can be utilized, which generally have the following characterizations in common: (1) user involvement throughout the whole design process, (2) integration of different kinds of disciplines and expertise, (3) conducting effective formative and summative usability evaluations, and (4) managing an iterative system design process (e.g., Benyon 2014; Dix et al. 2004; Hartson and Pyla 2012; Issa and Isaias 2015; Preece et al. 2002; Rogers 2012; Rogers et al. 2011).

Since the mid 1980s, several methodologies have become an important issue in the design of ICT systems, in order to achieve good usability. The concept of usability has been fairly defined in ISO 9241-11 (ISO 9241-11 1998), which describes an engineering approach where usability is specified in terms of measurable usability attributes and characterized as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use". However, good usability does not appear by itself, since it has to be systematically and consciously designed for. In order to integrate usability and to involve HCI professionals in ICT development, the need of design methodologies for usability is put forward by many scholars and practitioners.

The interdisciplinary field of HCI research offers a large amount of interesting UCD methodologies, showing user involvement to be a critical factor in successfully developing ICT systems in general (Harris and Weistroffer 2009). The result of employing a UCD methodology when designing and developing an AgriDSS is a more efficient, satisfying and usable experience for the user, which is likely to increase user acceptance, learnability and confidence of the system (Hartwick and Barki 2001). Generally speaking, UCD may be described as a practice, craft, framework, philosophy, discipline, or a methodology for design by involving users in the design process, and integrating UCD with other ICT development activities (Andreasson et al. 2015). ISO 9241-210 (ISO 9241-210 2010) is a standard that provides guidance for the "human-centered design process for interactive systems". It acknowledges the standard for usability, and defines UCD from a more general perspective than the various developed UCD methodologies.

Generally, UCD methodologies consist of three major iterative phases, i.e., the *analysis phase*, the *design phase*, and the *evaluation phase*. Basically, the purpose of the analysis phase is to understand the need of the intended users as well as the context of use, while the design phase involves the creation of a conceptual design concept, the interaction pattern, the "look and feel" of the product, and prototyping to realize different design alternatives. The evaluation phase focuses on verification and refinement of the design solution (Andreasson et al. 2015). According to Andreasson et al. (2015), some common UCD methodologies are *user-centered systems design* (UCSD) (Gulliksen et al. 2003; Göransson et al. 2003), *usability engineering* (UE) (Faulkner 2000; Mayhew 1999), *goal-directed design* (GDD) (Cooper et al. 2007), and *participatory design* (PD) (Bjerknes et al. 1987). Briefly stated, UCSD is a method that focuses on usability through the entire ICT system life cycle. Gulliksen et al. (2003) addressed a lack of a shared definition for the approach and identified 12 key principles of UCSD. The principles are based on both theory and experience from software development projects and revolve around users and the understanding of their needs. The key principles emphasize a clear user focus with user involvement, iterative and incremental system development with early and continuous prototyping, and evaluations performed in the context of use. User-centered systems design consists of three major phases; requirements analysis, evolutionary systems development (which is both iterative and incremental), and implementation. Gulliksen et al. (2003) stress the importance of a well thought-out transition process where the introduction must be planned, where user education and training is performed as well as the need for necessary support and instruction manuals (for further details, see Gulliksen et al. 2003; Göransson et al. 2003).

Usability Engineering was first introduced by usability professionals, which used the term to refer to concepts and techniques for planning, achieving, and verifying objectives for system usability (Faulkner 2000; Mayhew 1999). The key idea of UE is to define measurable usability goals early in the ICT system design process and, with repeated assessment, ensure that they are achieved (Rosson and Carroll 2002). The method of UE is defined in the usability engineering lifecycle, which consists of three phases that describe a set of tasks and the order they should be applied in during an ICT development lifecycle (Mayhew 1999). The lifecycle is highly structured and contains several different tasks and techniques for the developers to perform in each of the lifecycle's three phases (for further details, see Mayhew 1999).

The GDD method is usually qualitative and anthropological, where ethnographic underpinnings to the process are noticeable. Cooper et al. (2007) describe that the initial phases focus on providing data about (actual or potential) end-users of the intended ICT system and to identify behavior patterns, which provides an understanding of the end-users' tasks, goals, and motivations. In the design phases, the designers first create the overall concept of the ICT system, its general design solution and interaction flow, before an increased focus on details and implementation occurs. Finally, the authors emphasize the importance of a supportive work environment in which the designers and the developers cooperate and support each other when making tradeoffs or adjusting the final ICT design solution (for further details, see Cooper et al. 2007).

Finally, a more radical UCD approach is the "Scandinavian model" of PD emerging within the system development field among a group of Scandinavian researchers who focused on the democratization of working life (Bjerknes et al. 1987). Participatory design as a design approach is characterized as attempting to actively engage all users and stakeholders (they all are seen as equal partners) in the ICT design process in order to achieve that the product designed fulfils their needs and is useful. Participatory design stresses the importance of processes and procedures of design and is more responsive to their stakeholders' and users' cultural, emotional, and way of working practices and learning (Bjerknes et al. 1987).

In sum, UCD and PD methods have the vision of insuring high usability, i.e., adapting the system to the 'end-users' and 'stakeholders' needs and goals which increase the possibility of satisfied users and AgriDSS success significantly. The final AgriDSS is not an end in itself; rather the system is a *means* towards the end of providing good usability, and for supporting the actual tasks for the intended users. Applying these UCD methods to the design of sustainable ICT systems, the question is how a digital artifact in form of an ICT system can be designed such that users will prefer sustainable behaviors to unsustainable ones.

Sustainable HCI

Sustainability is a complex issue and it presents challenges but also opportunities for ICT interventions, and it has been argued that the HCI community "embodies knowledge and expertise that will be crucial to addressing the design, interaction, and usage issues surrounding sustainable technologies and practice" (Huang et al. 2009). Thus, ICT-related research fields, have the potential to contribute to our common future by directing substantial research efforts towards sustainable development (Susi et al. 2015). As pointed out by Pierce et al. (2013) environmental sustainability has established itself as a mainstream concern for HCI since Blevis (2007) seminal paper in 2007. Since then, HCI researchers have begun to recognize that the complexity and apparent uncontrollability of working towards sustainability offers serious challenges to the current and traditional HCI approaches to solve problems. Contrary, Pierce et al. (2013) stress that this should not be faced as a problem at a first glance. Instead, it could be considered as an opportunity to understand the limits of HCI as currently constituted and as a way forward to further development and possibilities for the field of HCI.

The majority of work in sustainable HCI has so far focused on how to change individuals' attitude and behaviors to become less resource-intensive and be more aware of environmental and sustainability issues. This way of research has drawn mainly on theories and concepts from social psychology and behavioral economics (Pierce et al. 2013). According to Pierce et al. (2013) one recently identified methodological limitation is the overwhelming dependence in HCI research on individuals as the unit of analysis for design, development and evaluation. Instead, as they point out, recent work within sustainable HCI offers an alternative approach to sustainable HCI by shifting the unit of analysis from *individual action* to *everyday practice*. They highlight that this shift of focus and scope, to consider organizations and reorganizations of shared activities and routines rather than individual behaviours and general social values and norms, results in looking beyond isolated interactions between humans and computers and instead view them as necessary ingredients of *practice* rather than simply something that humans interact with (Pierce et al. 2013). Taking *practice* as the unit of analysis, it offers HCI researchers new ways to investigate the dynamics of (un)sustainability, generating understandings of the interactions between humans and other material artefacts that more fully capture the complexity of everyday practices as they are enacted and change over time (Pierce et al. 2013). As pointed out by Watson's commentary of the special issue on practice-oriented approaches to sustainable HCI (in DiSalvo et al. 2013), to consider different aspects of the potential relationship between practice theories and the role of design and HCI in creating future changes in everyday life can contribute to a socio-technical change towards better and greater sustainability.

The issue of sustainability has recently been incorporated into the *new participative methodology for sustainable design* (NPMSD) developed by Issa and Isaias (2015). They intend that the NPMSD should support designers when developing new ICT systems to paying more attention on sustainability in general, addressing both *sustainability in design* as well as *sustainability through design,* without explicitly referring to Hanks et al. (2008) and Mankoff et al. (2007). Briefly stated, NPMSD is an ambitious method and is divided into ten stages namely: usability evaluation; functionality testing, planning, analysis, design, maintenance, user participation, iteration, and content management systems. The *design* stage, for example, addresses six identified factors regarding sustainability, which are the following: *design* (e.g., easy to add new software and to recycle), *safety* (e.g., reducing carbon footprint, consumption and waste of resources), *manufacture and energy* (e.g., use less energy and raw materials), *recycling* (e.g., using recycled and renewable materials), *efficiency* (e.g., having long life), and *social needs* (e.g., having clean emissions and good ethical principles). The importance for HCI specialists to understand the impacts of their actions on the earth, particularly the ICT use, are stressed in NPMSD. Issa and Isaias (2015) aim to safeguard our planet by raising HCI specialists' awareness regarding their moral responsibility to create sustainable design for a sustainable future.

Reducing the "problem of implementation"

Some recent successful examples of active user-involvement in the design process of AgriDSSs are exemplified in the work by Jakku and Thorburn (2010) as well as Van Meensel et al. (2012). Jakku and Thorburn (2010) highlight the importance of involving stakeholders as active participants throughout the whole ICT design process. A central issue they address is the changed view on the agricultural innovation process, stressing the importance of viewing agricultural innovations as complex interactive processes of co-learning and negotiation, in which social learning practices are fostered. The final report from the EIP-Agri focus group Precision Farming (2015) emphasizes the creation of frameworks where farmers, advisors, researchers and the industry cooperate to increase innovations in PA. In such frameworks, AgriDSS can function as a "discussion tools", facilitating the dialogue between different key stakeholders within agriculture, such as farmers, scientists, advisors, and extension officers. Moreover, Van Meensel et al. (2012) point out that decision-making in pig farming is considered as a typical case of the simultaneously improvement of productivity and the effort to reduce environmental pressure, primarily produced by nutrient emissions (Van Meensel et al. 2012). They identify some success factors in the PD approach of an AgriDSS named Pigs2win. The aim of Pigs2win was to develop an AgriDSS that is scientifically sound, usable in practice, and supported by the pig sector in the actual region. Critical success factors that affected the Pigs2win project include, flexibility, perceived usefulness, accessibility, credibility, maintenance and adaptability, and focus on the intended users. Central issues for the success of the participatory approach during the whole development process are: (1) selection of appropriate stakeholders and high level of transparency to the stakeholders, (2) constructive collaboration among stakeholders that resulted in active involvement and a consensus of common goals for the AgriDSS, and (3) a flexibility in the development process, respecting the available time and scope, but accepting adaptation during the process and not following a priori detailed road map (Van Meensel et al. 2012). As a result of using a participatory process, the stakeholders identified 14 outcomes that the AgriDSS should be able to handle properly, which then were digitally implemented in 12 features in Pigs2win. The result is an AgriDSS that allows for identifying farm-specific suboptimal KPIs (key performance indicators), and assessing aggregate economic and environmental effects of improving these KPIs. Van Meensel et al. (2012) stressed that the AgriDSS does not provide any direct advice on what concrete decision to make. This means, the actual decision is left for the intended user (advisor) to do, but the AgriDSS provides information on the KPIs that is useful in supporting the activities of pig farming via ICT support.

Summing up, UCD and PD methods in ICT system design stress the importance to understand the contexts in which the activities take place, getting to know the people involved, establishing a dialogue of mutual sharing of different perspectives, and working together to reach common goals. Additionally, Thorburn et al. (2011) emphasize that apart from increased adoption and acceptance of the developed AgriDSS, PD approaches seem to enact co-learning as a result of the development process. They stress that learning is a valuable process in increasing sustainability in agriculture, so that the application of AgriDSS in a social learning context may make a contribution to the global challenges faced by agriculture. They point out that the value of participatory development processes of AgriDSS as a co-learning process is an outcome that traditionally has not been appreciated enough by AgriDSS developers and one identified issue that is likely to tackle the challenges faced by agricultural sustainability.

Some beginners' pitfalls in UCD/PD methods and some suggestions on how to reduce them

Although there is convincing evidence in the scientific literature concerning the benefits of applying a PD approach in the development and design process of AgriDSSs, there are still some challenges that need to be addressed in practice. Ideally, it is recognized (Bjerknes et al. 1987; Marti and Bannon 2009) that the end-users should be regarded as equal partners in the development team, and being involved from the very beginning of the design and development process. Designers and end-users should be of equal importance, learning from each other in order to create a mutual understanding of the limitations and possibilities of the developing AgriDSS.

The development and design process of the POS network's AgriDSS for calculation of VRA files has begun and a high-fidelity prototype was presented during 2015. User participation to this point has been very limited, and the ambition is to introduce user participation in the upcoming iterative development, evaluation and implementation process. Precision agriculture Sweden intends to apply a UCD/PD approach in order to avoid the "problem of implementation" as well as the "gap of relevance". However, some doubtful comments for such an approach have been expressed among the team developing Crop-SAT, illustrated by the following utterances; "we can do it ourselves", "it takes a lot of time", and "we should not believe that the farmers always know". The POS development team has raised the following questions for the future design and development process of the AgriDSS:

- What information is needed?
- When is the information needed?
- Who needs it?
- Where is it needed?
- Why is it needed?

The expressed doubts are relevant from their perspective, and some necessary methodological support is available in the UCD methodologies (e.g., UCSD, GDD, UE, PD, and NPMSD) presented in "Sustainable HCI" section. They can serve as starting points for the continued design process. In so doing, a group of relevant stakeholders consisting of end-users such as farmers, advisors and some researchers will be recruited, and they will meet on a regular basis. Furthermore, the initial project members have also identified the need of a HCI specialist in the role of a user advocate/facilitator who aims to act as an intermediate link/coach between different participants in order to create a common ground and reach consensus within the newly established development team. Although the intention of introducing aspects from a UCD/PD approach is beneficial, for the technical development team consisting of researchers, there are some identified pitfalls to consider which are listed below:

- Non-familiarity with addressing usability work and specific work activities and processes in PD.
- General lack of knowledge concerning UCD methodology, and PD methods in particular.
- General lack of discussions of the usefulness of usability work during the analysis, design and evaluation phases as well as lack of practical experience of usability work.
- Lack of a common vocabulary in order to properly discuss usability and related design issues in the team as a whole.
- Lack of time for informing the new members of the implicit history of previous design and development decisions, resulting in insufficient transparency.
- Introducing new ways of working that aim to foster knowledge exchange and equal impact.
- If a facilitator/user advocate will not be recruited as a HCI specialist, who in the present team has the competence and skills to fulfill this important role?

Although the above list, at first glance, may be discouraging, it serves as an initial step to reduce the pitfalls, given the fact that they are identified and made explicit. The list provides a good starting point for the forthcoming work process in the technical development team, and its additional members (i.e., the intended end-users of their AgriDSS). Some actions that are being considered to reduce the pitfalls are:

- Inviting an external HCI specialist in usability work to introduce UCD/PD to POS members, aiming to reach acceptance for the UCD/PD approach by an introduction workshop. With a long experience of the "problem of implementation" of new ICT systems, the aim is that POS will begin to use this approach in future development processes.

- Recruiting farmers and advisors as end-users that are considered as early adopters and "willing and able" to participate in this kind of UCD/PD project.
- Choosing a user advocate/HCI specialist, with responsibility for mediating between end-users and technical developers that will lead the UCD/PD work activities. The central question is who that will be? Should the user advocate be an external consultant or should somebody from POS be responsible for this role and learn through apprenticeship during the UCD/PD process?
- Planning for the future design and evaluation work will be performed together with all members in the UCD/PD team, focusing on evaluating the prototype and also identifying and developing and designing additional, needed functionalities.
- Fitting the developed AgriDSS into the existing farming ICT system context, for example, farmers' plant production system or governmental system for extension services.
- Establishing a long term connection with a usability expert in order to manage conflicting collected user data and user opinions as well as functioning as a guide/coach in the development/learning process.

The intention is that the UCD/PD approaches presented above will initiate the turn of the tide for POS's future design and developmental work with PA technology, such as the exemplified AgriDSSs, in order to reduce the "problem of implementation". This way of working makes it easier to bridge the gap between theory and practice. The involved stakeholders in the POS project may reach an increased understanding of the "problem of implementation" through a social co-learning process. In the progressive development of the CropSAT technology, the design and development team is in the middle of a social co-learning process themselves. Coming from different disciplines, with a broad spectrum of several kinds of experiences and knowledge, it has been recognized that some common concepts are used in slightly different ways, and subsequently the need for co-learning and negotiation is obvious. To conclude, this paper argues that applying a UCD/PD approach when developing an AgriDSS will lead to innovative and more applicable farm management practices which in the long run should increase sustainability in agriculture despite the addressed challenges.

Discussion and conclusions

It is argued in this paper that a sustainable intensification of agriculture is closely linked to our ability to interpret and apply the increasing amount of information generated in the agricultural system. But for farmers, who are the ones that finally make the decisions, the perceived relevance of this information as well as the applicability of introduced AgriDSS might not be as anticipated. This paper has mentioned different reasons for the so-called "problem of implementation", which is one challenge for sustainable intensification. It is conceptual and contributes by introducing sustainable ICT as a key approach for successful development of AgriDSS in the agricultural domain in general and in precision agriculture more specifically. By integrating different research fields the aim is to address some challenges when working towards sustainable intensification through PA, but also to the general discussion about emerging socio-technological systems in modern agriculture.

In the context of agricultural sustainability, the role of learning in changing farming practices is obvious (Leeuwis 2004). The learning perspective is strengthened when applying more participatory approaches and focusing on involvement, especially when it takes place early in the development process. This is valid for most new practices, and it is not only a technical question of improving the usability and the ease of use. It also concerns building trust and stronger relations between the actors involved. The "problem of implementation" is therefore as much a reflection of a learning deficit as it is a question of not having relevant incentives to induce change.

Historically the discussion on implementation of new technologies and management concepts in agriculture has belonged to the tradition of knowledge transfer, i.e., there are predefined senders, intermediaries as well as receivers of knowledge, where knowledge is thought of as flowing in one predestined direction from science to practice (Leeuwis 2004) that Black (2000) labelled as the "technological fix". It should be noted however that despite raised critique of knowledge transfer models, there is still a need for access to reliable scientific knowledge (Ingram 2014).

In this paper, the assumption of "technological fixing" has been criticized, and instead a more sustainable trajectory that demands a changed perspective on different stakeholders' roles and importance for the development of new knowledge and practices has been proposed. This is in line with Hoffmann et al. (2007), who advocate that farmers could be regarded as experts in their own domain, and as such they cannot easily be replaced by other persons. This stance is properly aligned with the view of end-users in HCI, where users are considered as experts of their work practices, and one of the major challenges in developing useful ICT systems is to grasp their tacit knowledge "in the wild" (e.g., Rogers 2012). Nowadays it is obvious for many researchers that farmers' own knowledge, grounded in experience of their complex life situations or "life-world", must be carefully considered in the development process of agricultural innovations (e.g., Eastwood et al. 2012; Lindblom and Lundström 2014; Lindblom et al. 2013; Marra et al. 2003). This shift in perspective of the "problem of implementation", from persuasion of farmers to co-creation of knowledge, technology and meaning, develops agriculture in a desirable trajectory. It is the individual farmers that make a decision to implement or refrain to use an innovation as long as they are not forced by legislation or motivated/economically dependent due to subsidies. Farmers' decision making processes are complex situational practices that need to be acknowledged within its social-technical context, using an alternative to the historical, normative model framework (e.g., Rogers 1995).

This paper wants to stress that the call for more participatory approaches does not mean that one should be naïve when it comes to the challenges facing how to organize and facilitate participatory processes, neither the question whose knowledge counts in these design processes that Black (2000) labelled as the "participation fix". There is still a need to provide for active participation by farmers in agricultural research and development processes. Consequently, Ingram's (2014) view that the territory in-between the two ends of the spectrum of the top-down knowledge transfer, i.e., the "technological fix" based on scientific knowledge and the bottom-up participatory approaches, i.e., the "participatory fix", drawing on farmers' own practices and local knowledge, is of most interest.

There are no predefined answers to these questions concerning how to handle the territory in-between; instead it is by learning-by-doing that desirable and feasible methods will emerge. Nevertheless, inviting stakeholders with different perspectives and competences is important for a socially robust end result, as well as a capacity to manage conflicts that can arise in the negotiation between these different views. This also implies that all actors involved have something to learn from each other. The main purpose for development of new AgriDSSs in PA is to change current practices to a more sustainable farming. Therefore, in an agricultural context of uncertainty and unpredictability continuous learning processes for everybody involved are required that incorporate new information, knowledge and experience. Accordingly, farmers and other relevant stakeholders and institutions have to change established frames of mind and ways of acting. This approach is qualitatively different from minor adjustments in certain conventional farming behaviours, since it rather enables an adaption of transformal farming practices based on alternative norms and values cultivating a sustainable agriculture.

Indeed, this is a truly transdisciplinary and social learning approach to the development of the next generation AgriDSS, which does not work by itself, but there is not any proper alternative to reach the ambitious goals. We are living in the middle of an exciting time, where sustainable farming systems are dependent on the quality of ICT, and where ICT must integrate a sustainability perspective. If so the two domains will reinforce each other in the development of sustainable farming practices. On the one hand, Aubert et al. (2012), for example, argue the agricultural sector has received far less attention in order to improve decision making and ICT research, although its importance, compared to the manufacturing and financial sectors that have received much more interest, which is somewhat surprising given its critical role in securing food supply globally, environmental issues and the strong potential contribution of ICT in agriculture. On the other hand, Rogers (2012), for example, highlights that many HCI researchers are very motivated by addressing societal goals, but there is the tension of trying to help a community through “developing” and implementing appropriate ICT as opposed to trying to make contributions to the HCI field to get published. Rogers (2012) provides a striking example where a team of HCI researchers can spend long periods of time to set up a new ICT infrastructure that locally supports a more efficient water supply only for it not to be considered methodologically rigorous enough to deserve publication in the CHI community.

Indeed, the HCI community is beginning to learn to be more open and transdisciplinary, which in the future ultimately will demonstrate how to develop user experiences and human augmentation that covers a range of human values that can make an impact on society, at many levels. As presented in this paper, ICT can contribute significantly to long-term sustainable development. Thus, several competences and scientific disciplines need to act in concert to help develop a sustainable development of agriculture.

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Considering farmers' situated knowledge of using agricultural decision support systems (AgriDSS) to Foster farming practices: The case of CropSAT

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A B S T R A C T

Precision agriculture is an important part of the sustainable intensification of agriculture, where information and communications technology and other technologies are necessary, but not sufficient for sustainable farming systems. The technology must fit into farmers' practice and be handled by their experienced-based, *situated knowledge* in order to contribute to increased sustainability in their farming. This study analysed the relationship between farmers' experience-based situated knowledge and the use of agricultural decision support systems in order to develop *care* by farmers in their practice. The theoretical framework of distributed cognition was used as a lens when investigating and analysing farmers' use of an agricultural decision support system called CropSAT developed for calculation of variable rate application files for nitrogen fertilisation from satellite images. In the case study, the unit of analysis was broadened to the whole socio-technical system of farmers' decision-making and learning, including other people and different kinds of tools and artefacts. The results revealed that social contexts could support farmers' development of cognitive strategies for use of agricultural decision support systems, e.g. CropSAT, and could thus facilitate decision-making and learning through development of *enhanced professional vision* that hopefully may increase farmers' situated knowledge and care in PA.

1. Introduction

It is acknowledged that precision agriculture (PA) is one part in a sustainable intensification trajectory where information and communications technology (ICT) and other technologies are necessary to increase sustainability of large-scale farming systems (Aubert et al., 2012; Lindblom et al., 2017). Sustainable intensification has to harness the complexity of a wider range of agro-ecological and socio-technological processes (Garnett et al., 2013), in order to "*more than doubling of the agri-food production while at the same time at least halving our ecological footprint*" (Sundmaeker et al., 2016, p. 130). To increase sustainability in agriculture we need knowledge that is *complex, diverse* and *local* (Leeuwis, 2004). Various kinds of ICT systems in PA are expected to be contributors in handling a higher complexity as well as an increased local adaptation (Aubert et al., 2012). PA can be viewed as a farm management concept based on observing, measuring and responding to within-field variations in both temporal and spatial components. Earlier it was complicated to respond in an effective and reliable way, instead measurements were used for calculation of an average need for each field of for instance nitrogen. Hence, PA technology provides possibilities for farmers to recognise and handle within-field variations to a much greater degree than ever before (Aubert et al., 2012; Wolfert et al., 2017). Better adaptation of field measures to crop requirements may decrease sub-optimal treatments, which in turn hopefully increases profitability due to higher efficiency in usage of inputs and land, better crop quality and a decrease in negative environmental impact (Lindblom et al., 2017).

In order to perform PA, certain kinds of ICT systems, known as agricultural decision support systems (AgriDSS), have been developed. However, many available AgriDSS are for several reasons poorly adapted to farmers' needs and practices and thus not exploited to their full potential (e.g. Jakku and Thorburn, 2010; Lindblom et al., 2017; Matthews et al., 2008). Important reasons are that the questions of AgriDSS design and usability are not regarded as central issues in the agronomic research community, even though the lack of credible and usable AgriDSS is viewed as a major problem (Prost et al., 2012). Technology development is often based on what researchers and developers of AgriDSS consider usable and credible and therefore not adapted to farmers' actually needs and practices (see Lindblom et al., 2017 for a detailed review of these topics). As pointed out by Röling (1988) technology should not be considered an isolated phenomenon. Instead of developing an AgriDSS as a straight operational tool to

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support farmers in making decisions, many researchers highlight the possibility of using an AgriDSS as a social learning tool that can facilitate discussions and promote learning among different stakeholders (e.g. Hochman and Carberry, 2011; Jakku and Thorburn, 2010; Matthews et al., 2008; McCown, 2002; McCown et al., 2009; Thorburn et al., 2011). Used in this way, an AgriDSS could frame a change from goal-orientated thinking to thinking in terms of learning (Schlindwein et al., 2015). Schlindwein et al. (2015) proposed that in high complexity situations, as e.g., adaptation to climate change, crop-models should not be used as an isolated tool for deterministic, specific answers, i.e. goal-oriented thinking. Instead they should be integrated in a wider learning system, i.e. thinking in terms of learning. This kind of learning approach, is the perspective we take in this paper.

The present study examined how an AgriDSS for PA called CropSAT could provide possibilities to support and promote farmers' decision-making and learning in situ, studying them in the socio-technical system. The overall aim was to increase the understanding of the relationship between farmers' experience-based situated knowledge and the use of AgriDSS in order to develop farmers' *care* in PA, in the sense used by Krzywoszynska (2015). She characterised care as "*the result of all practices that make technology and knowledge work*" (2015, p. 290).

The theoretical framework of distributed cognition (DCog) (Hutchins, 1995) was used as a lens when investigating and analysing farmers' use in practice of CropSAT, an AgriDSS for PA which enables variable rate application of nitrogen. With this view on PA as a complex socio-technical system, the need to study both cognitive and social activities in practice becomes evident, and also the need for incorporation of external resources that are available to perform a PA practice. The DCog framework (Hutchins, 1995) is one of the most prominent *research-in-the-wild* (RITW) approaches that were introduced nearly three decades ago. Hutchins (1995) started to write about cognition being-in-the-wild, stressing that e.g. decision-making and learning - when being observed as it unfolds in practice – is distributed and embodied in the social and material sphere and situated in the moment (Rogers and Marshall, 2017). A key concern in RITW studies is to reveal what actually happens in the real world, how do humans act and behave in situ, what kind of material and social resources do they use, when, and in what ways? When contrasting RITW approaches to quantitative studies where researchers try to hypothesise and predict human performance, running in situ studies often provides unexpected findings and uncovers insights about human actions in practice beyond the scope and grasp of more traditional research approaches. In other words, it is argued that RITW uncovers the unexpected rather than confirming hypotheses or aspects already known (Rogers and Marshall, 2017). Rogers and Marshall (2017) point out that this way of conducting research may at first glance be viewed as if it is lacking the rigor associated with the more dominated research paradigm of conducting behavioural studies. However, despite the lack of control and randomized sampling in RITW studies, it is argued that this approach can be the most revealing when it comes to discovering what actually happens in the real world by studying more deeply just a few numbers of participants that are purposely sampled. These studies also provide a greater ecological validity compared with inferring result from more quantitative studies (Rogers and Marshall, 2017). Therefore, the outcome from RITW studies can provide new insights and understandings of human behaviour in the real world where technology is embedded and used in everyday life, and it is stressed that RITW studies is becoming more widely accepted as a way of doing research when studying e.g. human cognition, human-technology interaction, and human-computer interaction. In this way, RITW is complementing but also questioning the validity of the traditional quantitate research paradigm (Rogers and Marshall, 2017). This way of performing studies in PA, may in the long run hopefully promote a more sustainable farming practices.

The remainder of this paper is structured as follows: A background section provides a description of the individual's role in promoting a sustainable transition in the agricultural domain, in relation to AgriDSS as learning tools that motivate and frame the work discussed in this paper. This section also presents theories on decision-making concerning such processes in practice, and introduces the theoretical framework of DCog. Subsequent sections outline the chosen empirical approach and the findings. The paper ends with a discussion, some conclusions and a list of implications for PA.

2. Background

At the core of the transition towards sustainable intensification in agriculture is the individual decision maker, making strategic, tactical and operative decisions bridging theory and practice and balancing the desirable with the feasible (Matthews et al., 2008; Van Meensel et al., 2012). Farmers' daily work activities are complex because they require knowledge and consideration of a wide range of biological, technological, practical, political, legal, economic, ethical and social factors and circumstances (e.g. Lindblom et al., 2013; Nitsch, 1994). During this knowledge development process, a broad range of different individual and social learning situations are of major importance in influencing the farmer. They develop operating skills to *know that* action is required, *know what* to do, and also *know how* to do it, even if it is clear to them that the actions they perform will not always be optimal (Baars, 2011). It is argued that farmers learn in action through a kind of lifelong longitudinal case study set-up, which means that their learning process is more experiential than experimental (Hoffmann et al., 2007).

2.1. Situated knowledge, care and technology in farming practice

Comparisons with formalised knowledge and results obtained in earlier years and in different places are made either consciously or unconsciously by farmers, in order to form new knowledge and rules of thumb for their work. Thus, experienced farmers could be considered experts on their own farms and are in possession of a considerable amount of so-called intuitive, situated knowledge (Clancey, 1997; Hoffmann et al., 2007; Lindblom and Lundström, 2014). The concept of situated knowledge can briefly be defined as knowledge based on experience and is to a certain extent a product of the activity, context and culture in which it is developed and used (Brown and Collins, 1989). Accordingly, Dreyfus (1992) argued that intelligence and situated knowledge require a *background of common sense*, with which humans are equipped by virtue of being embodied and situated in their physical, social and cultural world. As a result, it would not be possible to represent human intelligence and situated knowledge within a computer program, as exemplified in an expert system or an AgriDSS.

In relation to agriculture, Krzywoszynska (2015), for example, claimed that this kind of embodied, experiential and situated knowledge is central for the development of the multiple *care* aspects that society is increasingly expecting and demanding from agriculture. However, in this sense care is not considered an obligation, a principle or an emotion, but "*the result of all practices that make technology and knowledge work*" (Krzywoszynska, 2015, p. 290). Accordingly, Mol et al. (2010, p. 14) remarked that good care could be described as "*persistent tinkering in a world full of complex ambivalence and shifting tensions*". This means that care is not something a person learns by imitation, but rather is "*infused with experience and expertise and depends on subtle skills that may be adapted and improved along the way when they are attended to and when there is room for experimentation*" (Mol et al., 2010, p. 14).

Good care requires situated knowledge based on *attentiveness*, *responsiveness* and *adaptation* to constantly changing circumstances, as is the case in farming practice (Krzywoszynska, 2015). The actor, i.e. the farmer, must recognise the problem, feel responsibility and have the competence to act upon it. Therefore, it is of major interest to acknowledge and promote the role of farmers' situated knowledge in order to develop care in farming practices and thus to increase sustainability.

According to Nitsch (1994, p. 30), the very core of farm management lies in "*the ability to coordinate complexity under uncertainty*". Farming needs a wide range of competences to manage its complexity, including: i) knowledge about the subject (crop production etc.), ii) skills in formal planning (the ability to keep economic records and make a budget), iii) practical skills (the ability to organise and to get farm tasks and chores done in time) and iv) orientation about compliance with the institutional environment (legislation, market conditions, agricultural policies and other institutional factors). The farmer does not need to possess all the above competences him/herself, instead he/she may for example use advisory services and other external support. Regardless were the competences come from it is not enough: "*The crucial element is the ability to apply them in the coordination of the complexities of farming on a specific farm*" (Nitsch, 1994, p. 32). This coordination ability is personal and cannot be separated from the person who has acquired it. An experienced person uses intuitive decision-making that is grounded from within, enacted by experience-based, embodied and situated knowledge from earlier, similar situations, to cope with and solve complex problems (Dreyfus, 1992; Dreyfus and Dreyfus, 2005). Accordingly, Nitsch (1990) remarked that computers can support some of the competence needed for farming, but that the coordination ability cannot be totally replaced by any ICT system.

On the one hand, situated knowledge is difficult to externalise and formalise in ICT systems, given that computers are able to carry out arbitrary sequences of arithmetic operations automatically, following generalized sets of operations, i.e. software programs. However, these programs are still designed from the outset by the programmer (Dreyfus, 1992). In addition, computers are not embodied or situated and therefore lack *practical intelligence* and situated knowledge. Consequently, Dreyfus (1992) claimed that computers can be considered *existentially* stupid, despite the fact that they can successfully deal with formal languages and logical relations (see Lindblom, 2015, for further details). On the other hand, it is widely acknowledged that ICT systems can supplement and facilitate farm management, e.g. an AgriDSS for PA is essential in handling big data samples, and measuring properties that cannot be detected by the human vision system and providing valuable, credible representations of complex situations that clarify and support actions without losing the complexity at hand. Hence it can support, but not replace, the decision maker. Consequently, PA requires AgriDSS to handle big data quantities and measurements of crop and soil properties, in order to better adapt field interventions to within-field variations in order to increase agricultural sustainability.

2.2. Decision support systems and agricultural decision support systems

ICT systems that support users in decision-making are called decision support systems (DSS) (Alenljung, 2008). The aim with DSS is to reduce the effects of human decision-making weaknesses or cognitive limitations by increasing the user's ability to process huge amounts of information or by expanding the perception or imagination of the decision maker. DSS can support decision makers in making more effective decisions when dealing with unstructured or semi-structured problems, which are often ill-defined and complex without clear and obvious solutions. By definition, DSS do not intend to replace decision makers, but rather support them in the decision-making process. They are interactive, which implies that there is an exchange between the system and the user. Decision makers must be able to confront a change in conditions, which is why DSS must be adaptive and flexible to meet user needs and capable of being modified by the user (e.g. Alenljung, 2008; Power, 2002; Turban et al., 2007).

To date, agricultural researchers have used AgriDSS to transfer knowledge from science to practical work, aiming to increase farmers' acquisition of scientific knowledge (Leeuwis, 2004; McCown et al., 2009; Nitsch, 1994; Thorburn et al., 2011). However, most of these AgriDSS have not been used appropriately in practice (e.g. Aubert et al., 2012; Eastwood et al., 2012; Matthews et al., 2008; McCown, 2002; Rossi et al., 2014). Important reasons are that AgriDSS developers often come from a knowledge transfer tradition, but also normally consider just one issue, the technology, while the farmer must consider the technology in the whole complex situation of practice. Therefore, it is important to gain a better understanding of how individuals in complex situations actually make decisions and use AgriDSS for social learning. It should be acknowledged that most existing research on farmers' work practices is based on rationalistic assumptions rather than on empirical data from practice studies in real-life settings, although there are some exceptions (e.g. Bradford, 2009; Lindblom and Lundström, 2014; Lindblom et al., 2013, 2017).

2.3. Decision-making, learning and theories considering such processes in the wild

Decision-making is a cognitive ability and the scientific literature on this topic is huge and dates back to the 19th century. The major focus in the present study was on individual decision-making, which can be considered from three different approaches: normative, prescriptive and descriptive theories (Alenljung, 2008). In short, normative theories describe how decisions should be made rationally and are often conducted in laboratory settings to achieve a high degree of control. The intention is to predict future behaviour in well-defined tasks (e.g. Kahneman and Tversky, 2000; Plous, 1993). Prescriptive theories concern how people can be helped and trained to make better decisions (Alenljung, 2008), while descriptive theories concern how people actually make decisions. The study of decision-making in natural environments, *naturalistic decision making* (NDM) (Orasanu and Connolly, 1995), has emerged, since it is considered difficult to mimic the complexity of the situation that occurs in daily life in controlled settings. NDM theories refer to different theoretical and methodological approaches based on decision-making *in the wild*, which means studying people making decisions in dynamic and complex domains. The individual's experiences and knowledge are considered, as are factors such as time pressure and high uncertainty (Orasanu and Connolly, 1995). Although NDM focuses on decision-making in the wild, the unit of analysis is still only the individual and contextual factors such as technology and other actors are not included.

In order to increase the understanding of how farmers actually make decisions in their socio-technical system and in relation to AgriDSS use in PA, the unit of analysis needs to be broadened. For this purpose, the theoretical framework of DCog may be a convenient way forward (Lindblom and Lundström, 2014; Lindblom et al., 2013; Rogers and Marshall, 2017). This framework was introduced by Hutchins (1995) in response to more individual models and theories of human cognition. From a DCog perspective, human cognition is fundamentally distributed in the socio-technical environment that humans inhabit. DCog takes a systemic and socio-cultural perspective and discards the idea that the human mind and its environment can be separated (see Lindblom, 2015 for further details).

Hence, DCog views cognition, including decision-making and learning, as distributed in a complex socio-technical environment and as creation, transformation and propagation of representational states within a socio-technical system (Hutchins, 1995). Hutchins's (1995, p. 289) definition of learning from a DCog perspective is formulated as "*adaptive reorganization in a complex system*". He described learning as simultaneous coordination of many different media within a complex functional system and claims that the proper unit of analysis for learning or cognitive change includes the whole socio-technical environment that humans inhabit. Hutchins (1995) does not try to describe any mental mechanisms with which the behaviours of the representations can be modelled. According to Hollan et al. (2000), the environment that encloses people in their everyday life could be viewed as a reservoir of resources for learning, decision-making, problem solving and reasoning. DCog takes a systemic and cultural perspective and discards the idea that the human mind and its environment can be separated (Lindblom, 2015). The DCog framework differs from other

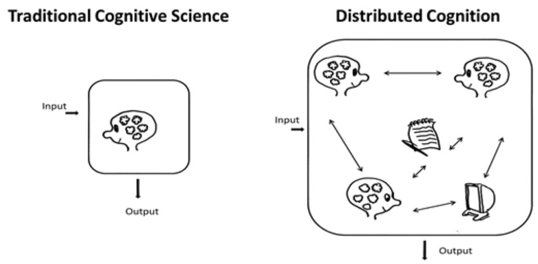


Fig. 1. From a traditional cognitive science perspective (left), the unit of analysis is narrowed to inside the individual's head, while from a distributed cognition perspective (right) the unit of analysis is expanded to be distributed across people and artefacts where cognitive processes are the result of the functional relationships of the entities of the cognitive system. (Image: Lindblom et al., 2013).

cognitive approaches in its commitment to two theoretical principles (Hollan et al., 2000). The first of these principles concerns the boundaries of the unit of analysis for cognition, which is defined by the functional relationship between the different entities of the cognitive system. The second principle concerns the range of processes considered to be cognitive in nature. In the DCog view, cognitive processes are seen as coordination and interaction between internal processes, as well as manipulation of external objects and the propagation of representations across the system's entities (Fig. 1).

When these principles are applied to the observation of human activity in situ, three kinds of distributed cognitive processes become observable, being simultaneously interwined (Hollan et al., 2000): (1) *Across* the members of a group, (2) *between* human internal structures (e.g. decision-making, memory, attention) and external structures (e.g. material artefacts, ICT systems, social environment), and (3) distributed *over* time. A fundamental aspect in DCog is its focus on cognitive artefacts and the manner in which information is propagated and transformed in the socio-technical system. It is therefore common in DCog research to provide detailed analyses of particular tools and artefacts, as *coordination mechanisms* between external and internal structures. In other words, studying material structures such as tools reveal properties of cognitive structures that become visible *beyond the skull*. Another important aspect of cognitive artefacts and tools is that they may serve as *mediators* in social interaction. Thus, it is important to recognise how information is transformed when mediated through tools. The use of strategies such as taking advantage of external structures or tools to coordinate cognitive activity might be considered a complementary way of explaining intelligent action. These external structures function as a kind of supportive framework or *scaffolding*, i.e. external resources to support and simplify cognitive activity for the individual (Clark, 1997).

Different kinds of representations are central to the unit of analysis in DCog. Hollan et al. (2000) argued that representations should not only be seen as tokens that refer to something other than themselves, but also as being manipulated by humans as physical properties. Hence, humans shift from attending to the representation to attending to the thing being represented. An example used in Hutchins (1995) is the navigational chart, which is used for offloading cognitive efforts (e.g. memory, decision-making) to the environment and for presenting information that has been accumulated over time. An important insight in this example is the relationship between the external structure (the chart as a representation) and the internal structure (the biological computation). Hence, by studying the external material and social structures, properties about the internal, mental structures are revealed and become observable. In other words, by studying cognition with this larger scope in mind, it is clear that the functional cognitive system has cognitive properties that cannot be limited to the cognitive abilities of the individual(s).

An important aspect related for developing situated knowledge is *situated seeing*, which can be characterised as elegant ways of seeing the world where internal structures are placed on top of available external structures in order to construct an understanding or *mind's eye* of the task at hand in a certain situation (Hutchins, 1995). In order to accomplish situated seeing, the use of external devices, e.g. physical artefacts, plays an important role for the way in which cognition and learning can be performed by manipulating these physical devices, where these external structures are not explicitly represented in the artefact itself but are instead supplied by the situated looking of the person actively using it. In navigation, there is coordination between several internal and external structures in the cognitive unit of analysis, where the ways in which a person operates a navigation instrument, i.e. a cognitive artefact, is viewed as an example of situated seeing that is implemented in the artefact. The artefact is then a part of the cognitive system that envisions internal structures and external structures (the landmark) onto a common visual image space and, "*in so doing, gives meaning to the thing seen that goes beyond the features of the thing itself*" (Hutchins, 1995, p. 123). The cognitive strategy of situated seeing is then accomplished by the navigator when looking at certain scale labels on the instrument, while ignoring other aspects, and in this way a complex form of cognition emerges in the understanding of the task at hand. Hutchins (1995) argued that it is difficult to place the emergence of meaning inside or outside the person, since some component of the emergence of meaning may be established by a sort of situated seeing in which the meaning only emerges in the "*active process of superimposing internal structure on the experience of the external world*" (Hutchins, 1995, p. 300). Hutchins noted there are several types of external structures, some of which are man-made, i.e. designed external tools and artefacts for thinking, and mentioned various navigation instruments, but also the existence of natural resources like the stars. The stars are not man-made artefacts, but they have a certain structure in the sky by which navigation by the stars is possible, in interaction with the right kinds of internal structures (strategies for seeing) of the navigator. Consequently, the combination of the stars in the sky, available landmarks and the cognitive strategies for seeing becomes the structured representational medium of a functional cognitive system for navigation, thus emphasising the power of this sort of situated seeing in a skilled navigator's image of the stars being present in a certain situation. This means that the environments of human thinking are not only natural environments, but mostly cultural environments, because humans enact their own cognitive powers by creating environments in which they exercise those advanced cognitive skills (Hutchins, 1995).

Substantial work has been done to apply the DCog approach in different settings and domains, including ship navigation (Hutchins, 1995), human-computer interaction (e.g. Hollan et al., 2000), aviation (Hutchins, 1995), healthcare (e.g. Hazlehurst et al., 2007) and manufacturing (Andreasson et al., 2016; Andreasson et al., 2017; Lindblom and Thorvald, 2017). To our knowledge, DCog has not previously been applied to the agricultural domain, although it can serve as an appropriate theoretical lens for investigating and analysing the complex work activities in agriculture, providing a portrayal of how people, environment and tools are coupled and related to each other (but see Lindblom et al., 2013 for an exception).

2.4. Method, data collection and data analysis

In order to investigate farmers' socio-technical system in relation to AgriDSS use in PA from a RITW perspective, an empirical case study was performed during 2015 in south-west Sweden. In line with the RITW approaches, a workplace study was the chosen methodological approach with DCog as its theoretical framework for the case study. Workplace studies aim at studying, discovering, and describing how people accomplish various tasks in the wild (Luff et al., 2000). Furthermore, workplace studies have been described as a prominent method for addressing the interactional organisation of a workplace and the way different tools and technologies are used to support work tasks and collaborations (Heath et al., 2000). The case study investigated and analysed use of CropSAT (www.cropsat.se) by four purposively sampled farmers, either alone or together with advisors, colleagues or employees, when making decisions on nitrogen fertilisation of winter wheat. The purposively selected farmers, all were men between 32 and 62 years old, had different levels of experience of using PA technology, but they all demonstrated an interest in general and in CropSAT in particular. The farm sizes varied from 150 ha to 1200 ha. The workplace study was performed on each farm, mainly through participant observations and contextual interviews which all were video-recorded. The farmers were visited three times during spring and once in autumn for a follow-up session, by the first author. The data collection was carried out through triangulation of the fieldwork, with participant observations, video-recordings and contextual interviews. The analysis was conducted using DCog as a lens to investigate and describe farmers' decision-making and learning in their socio-technical system when using CropSAT in their practice.

The Swedish Board of Agriculture annually provides fertilisation recommendations for agricultural crops (Albertsson et al., 2016). These recommendations take their starting point in adapting fertilisation on a field base, but they also discuss PA and the opportunity to variable rate application, since many Swedish farmers have access to the needed technology without using it. Normally farmers have a fertilisation plan for each field in which an average amount of nitrogen per field is specified the year before harvest. This level is then adjusted one to three times in spring depending on crop quality, intended use and appearance of the plant stand after winter (Albertsson et al., 2016). All four farmers included in this study used ICT-based crop production software (CPS) for creating these plans. However, fertilising correctly, so to speak, regardless if it is on a field level or in more detail, is impossible, since there is a long period between fertilisation and harvest that influences the yield. Nevertheless, technological support of fertilisation can be improved, e.g. by adapting the amount of fertiliser to the variation in biomass amount as late as possible before stem elongation, improving fertilisation efficiency (Albertsson et al., 2016).

CropSAT is developed at the Swedish University of Agricultural Sciences (Söderström et al., 2017) and funded by the public Swedish project Focus on Soil (http://www.greppa.nu/om-greppa/om-projektet/in-english.html), which has provided farmers free of charge advisory since 2001 with the aim to reduce nutrient leaching. CropSAT is an internet-based, free of charge AgriDSS that uses satellite images for calculation of vegetation indices (VI) (Qi et al., 1994) and variable rate application (VRA) files. To calculate a VRA file in CropSAT, the user visits the website and selects a field and a satellite image. As a result, the VI is calculated and shown in Google Maps. To receive a VRA file, the user must decide the level of nitrogen fertilisation within five VI classes, which are estimated automatically from the satellite data (Fig. 2) and used to calculate VRA files. The VRA information can then be transferred to the tractor and spreader via a USB stick. The images created in CropSAT are visual digital representations of the field that display crop biomass complexity in a way that is difficult to achieve by walking or driving in the field. Visualisation of the variation in biomass in CropSAT can be used by an experienced farmer to explain the variation to a certain extent, but it would be impossible to estimate the differences in biomass by human vision, let alone act upon them.

2.5. Findings

This section firstly presents the broadened unit of analysis and next some themes that were derived from the data analysis that illustrate how cognition is distributed within the socio-technical system of nitrogen fertilisation of winter wheat with the use of CropSAT. In accordance with a thematic analysis (Braun and Clarke, 2006), the selected episodes do not represent a chronological order of what was observed at the farms, but were instead selected as they characterise how the farmers and advisors cooperate and collaborate in making decisions of fertilisation in practice.

2.6. Broaden unit of analysis - CropSAT used in the wild

Generally speaking, the DCog-inspired analysis revealed that the socio-technical system concerning the decision-making on nitrogen fertilisation of winter wheat was complex and composed of many artefacts (Fig. 3). The units of analysis in the decision-making processes related to the CropSAT use could include a wide range of artefacts, e.g. CropSAT (images on VI and VRA files used in computers, mobile phones and iPads), CPS (tables and field maps in computers, mobile phones and iPads), paper-based field maps, calculator (in mobile phone), Spad-meter (http://www.yara.co.uk/crop-nutrition/Tools-and-Services/n-tester/) and notepads (Fig. 3).

The images created in CropSAT are visual digital representations that display crop biomass complexity in a way that is difficult to achieve by just walking or driving in the field.

2.7. Theme 1: CropSAT develops and improves experienced farmers' situated seeing

It is widely recognised that experienced farmers have acquired considerable situated knowledge and know that crop yield varies within fields. When looking at the satellite images in CropSAT, they could easily recognise and explain much of the visualised variation in crop biomass, i.e. they have what has been called *professional vision* (Goodwin, 1994). Goodwin coined the term when studying the discursive practices that were used by professionals in an archaeological field excavation to create and shape their lifeworld. He investigated and analysed how the development of their practice-based theory of action and knowledge emerged via three practices. 1) Coding that alters the phenomena observed in the particular archaeological setting into knowledge objects which are crucial and specific for the discourse in the particular setting. 2) Highlighting that makes some specific

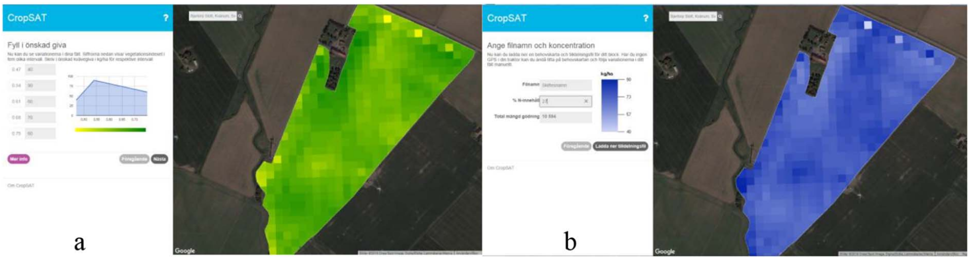


Fig. 2. a) Vegetation index (VI) displayed on Google Maps, where the user must enter five levels of nitrogen fertilisation compared with the coloured scale. b) Variable rate application (VRA) file ready to be entered into the fertiliser spreader via a USB memory stick.

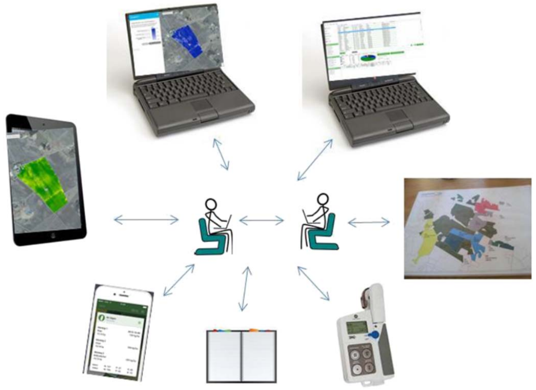


Fig. 3. Unit of analysis of the DCog system, where cognitive processes are distributed: (1) *across* the members of a group, (2) *between* human internal mechanisms (e.g. decision-making, perception, memory) and external structures (material artefacts, ICT systems and social environment), and (3) *over* time.

phenomena in a complex perceptual field salient by displaying them in some way or another, and 3) producing and articulating several material representations (Goodwin, 1994). Thus, professional vision is a socially organised way of seeing and understanding events that are of interest in the domain and to the social group (Goodwin, 1994). Goodwin's concepts can be transferred to the agricultural domain, where farmers and advisors have developed discursive practices with domain-specific objects of knowledge for farming, acquired skills to *see* their crop and fields from a professional perspective that significantly differs from a novice.

In this particular episode, an experienced farmer (Farmer 1) in his 50s using CropSAT for the first time took a closer look at one of his fields of winter wheat. He had 15 years of experience of using VRA files and a Yara nitrogen sensor (YNS) (http://yara.com/). He compared and contrasted his acquired knowledge of the characteristics of the particular field with the satellite image displayed in CropSAT. He then said: "*Well, this [field] is a bit poorer, you could say … it's farther away from the old farmhouse, so over time it almost certainly got less manure, and besides the soil is lighter up here* […] *So it looks like I expected… I could have drawn [the map] myself*." It should be noted, however, that CropSAT provided a much more detailed visual representation of the field than could ever be observed with a bird's eye view or even achieved with the human vision system alone. Furthermore, the bird's eye view of the variation in crop biomass is difficult to observe while merely walking in the field, and that the CropSAT image provides another kind of representation that visualises more of the within-field variation. From a DCog perspective, this means that the digital visual representation/cognitive artefact of the field from CropSAT functioned as a primary coordination mechanism between external and internal structures. Following this way of reasoning, it can be argued that fertilising more correctly with regard to variations in the field, a kind of care improvement, may practically be impossible without support from usable and credible technology. In other words, the digital representation functions as an *artefact for thinking* within the socio-technical system.

To use CropSAT for fertilisation, the farmer must set five levels of nitrogen in relation to the variation in crop biomass, which is not a simple task. The image reveals details and differences that the obtained professional vision (Goodwin, 1994) of an experienced farmer cannot see clearly due to biological characteristics of the human colour vision system and it adds important details to the cognitive system. This is what Goodwin and Goodwin (1996) called *tool-mediated seeing*, which is characterised as seeing aspects relevant for a task only through the use of tools and artefacts. Commonly used examples of tool-mediated seeing are when an operator on a submarine uses the periscope to see above the surface of the sea, or the human use of binoculars and spectators to amplify human visual perception. The usage of the satellite images in CropSAT could also be considered to possess several aspects of tool-mediated seeing. Tool-mediated seeing provides an initial step towards enabling the farmer to handle the variations that he is aware of, but unable to fully perceive with his eyes only, but through the use of technology. Thus, the farmer uses what Hutchins (1995) denoted situated seeing, which is an important aspect in developing situated knowledge. Situated seeing is the refined way of perceiving the within-field variation where the farmer's internal structures (prior knowledge of his field) are placed on top of available external structures (the CropSAT images) when constructing an understanding of the decisions that need to be made with regard to fertilisation of the particular field in order to improve care. To accomplish situated seeing, the use of external devices, e.g. the CropSAT images, plays an important role for the way that decision-making and learning can be performed by manipulating these physical devices, where these external structures are not explicitly represented in the image itself, but are instead supplied and enhanced by the situated looking of the person actively using the images. Thus, situated seeing goes beyond tool-mediated seeing, implying the development of new cognitive strategies that combine internal resources (knowing and experiences) with external resources (information provided from CropSAT images) to change, and in this case hopefully improve, crop yield and quality. In addition, the farmer's situated and embodied experiences of his fields are part of the cognitive system, functioning as internal resources where the farmer's image of the fields is not a man-made artefact. Instead, the present status of the crop as assessed during field walks represents some kind of structure which, in interaction with the right kind of internal strategies for seeing and the external resources of the CropSAT images, is part of the cognitive system. The cognitive system envisions internal and external structures (the first-hand experience of the fields and the CropSAT images) onto a common visual image space that offers meaning in the active process of coordinating internal structures on the experience of the external world, e.g. the current field's varying need for nitrogen fertiliser.

When looking at the satellite images in CropSAT, Farmer 1 easily recognised and explained much of the visualised variation in crop biomass. He said this about a 30-ha field that he had farmed for 30 years: "*This bit is more or less gravel esker … the ground rises here… it must rise by at least a few metres. Then there's a ridge here and a little hollow there… and of course it's all lighter soil … there's heavy clay here. It's exactly what the field looks like … here it's really fertile and nice… here it's really … exceedingly good … it's good there too, but not as good as it looks here … but it will come… because of course the soil is still cold.*" In other words, the way Farmer 1 used the cognitive artefact/digital representations of the field, may further have developed his strategy of situated seeing where the current status of the field emerged in the "*active process of superimposing internal structure on the experience of the external world*" (Hutchins, 1995, p. 300). From a DCog perspective, the changes in the coordination and propagation of internal and external structures of the socio-technical system may constitute a form of learning.

The above arguments were reinforced in an episode when the younger, university-educated Farmer 2 with shorter farming experience had some difficulties in grasping how to use the CropSAT images (Fig. 4). In the particular situation described here, he was re-planning the amount of nitrogen fertilisation in a particular field with winter wheat. He had previously set the average level to a standardised amount in the CPS, together with his advisor. It became obvious that deciding on the five levels of nitrogen in practice was not an easy task for him and therefore he needed some assistance from his advisor. He widened the cognitive system by calling her on the phone and the conversation went as follows: "*Hi … we're sitting here with the files for variable rate application and vegetation index and I'm wondering about what doses to use, or how much I should vary it … for wheat … yes the main dose*

Fig. 4. Telephone support to set nitrogen levels in CropSAT. The farmer pointed at the image while speaking to his advisor.

for wheat is given as 80 kg N per ha and then … yes, you get a beautifully coloured map, but the question is how much variation you need to use".

During the discussion, the farmer repeatedly pointed to different aspects on the screen, e.g. nitrogen levels, the VI scale or different parts of the field (Fig. 4). Thus it can be deduced that in this situation the satellite image ceased to be a representation of the field, and instead became the field itself while the farmer pointed at the image when discussing. Thus he acted as though he were looking at the field itself, rather than looking at a map of the field. In this situation, CropSAT mediated a discussion and functioned both as a coordinating mechanism between external and internal structures, and as a mediator in social interaction within the cognitive system. Since CropSAT is internet-based, both the farmer and the advisor were able to use the tool and, independently of each other, try different levels of nitrogen and look at the same or different images, while sitting in their own offices, broadening the unit of analysis in time and across space. Farmer 2 and his advisor had a long and intense discussion concerning how to set the five levels of nitrogen. CropSAT hence challenged the common work practice, i.e. fertilising with the same amount throughout the whole field or using the YNS. Instead, the emergence of an altered cognitive strategy for nitrogen fertilisation, i.e. developing a new sense of situated seeing in this particular context with the available external and internal resources, was needed. When his work practice altered, Farmer 2 was hesitant about deciding the levels and sought support from his advisor. From a DCog perspective, Farmer 2 was in the process of changing the very process of fertilisation practice, by including the digital representations into the cognitive system. The changes that can be made with CropSAT (setting nitrogen levels) take much shorter time to learn than the changes to the cognitive strategies of situated seeing that CropSAT is supposed to support. This means that these changes need to be coordinated and occur into coordination with each other, resulting in a development of the fertilisation practices over time. In the same way as the interaction with CropSAT constitutes the conduct of the activity itself, it also produces change within the social and cultural setting, i.e. the ongoing practice of advisory service. Thus, the socio-technical system is the proper unit of analysis for considering learning, which includes "*a web of coordination among media and processes inside and outside the individual task performer* [Farmer 2]" (Hutchins, 1995, p. 289).

2.8. Theme 2: CropSAT as a coordination mechanism in the decision-making process for crop production

The following two episodes show Farmer 3, an experienced farmer in his 50s, discussing fertilisation with his advisor. The first episode in May, started after they had been walking in the fields and were sitting in the farm canteen to discuss the current situation and the decisions to be made. They used CropSAT to get representations of the fields and compared those representations with their first-hand and earlier experiences. They had different opinions on how to interpret the visualised differences in biomass on the representations, which resulted in intense discussions and comparisons with earlier images (Fig. 5). The advisor said: "*Salt from the road destroys the clay colloids, resulting in soil compaction*" and the farmer answered: "*We stored straw bales here, which they picked up with a truck*". In this conversation the digital representations functioned as central coordination mechanisms and the circumstance that this little conversation ended with the advisor acknowledging the farmer's answer by responding "*Of course*" revealed two things: They both had important and relevant situated knowledge and experience that was able to bring the discussion forward and they also accepted without any comments that this was the case. The social interaction and the relations between the actors seemed to illustrate important characteristics for a well-functioning social relation, which in turn could be of major importance for the information flow and propagation of information in the socio-technical system. This implies that the digital representations also functioned as mediators in the social interaction. This way of acting, organising various kinds of internal and external structures in the socio-technical system, highlights several facets of learning. The result of including technology into the unit of analysis, may have improved the understanding of the fields and promoted the development of the cognitive strategies of situated seeing for nitrogen fertilisation, which in the long run could improve the farmer's care in practice.

In the next episode the task was to decide how to fertilise seven fields of winter wheat in the beginning of June. Instead of using CropSAT to calculate VRA files, the intention was to use the YNS. The motivation for this way of working was that YNS could provide a more detailed representation of the distribution of nitrogen. During this meeting, the cognitive system consisted of all tools and artefacts displayed in Fig. 3 and the satellite image taken three weeks earlier was also used for comparing how much nitrogen had been utilised by the crop. Before the meeting, the advisor had used a Spadmeter in the fields to measure the need for additional nitrogen fertilisation based on the canopy greenness. These measurements were then related to the CropSAT images and used as a point of reference in the ensuing discussion.

The role of advisors is of major importance when introducing new technology in decision-making situations in the wild, because they can promote new cognitive strategies for situated seeing, i.e. fostering innovative combinations of new technologies with earlier situated and embodied experiences in farming practices. In this particular case, the advisor acted as a role model in his way of using the available tools and artefacts, advocating a *willing and able* approach that positively influenced Farmer 3. However, the different digital representations of the

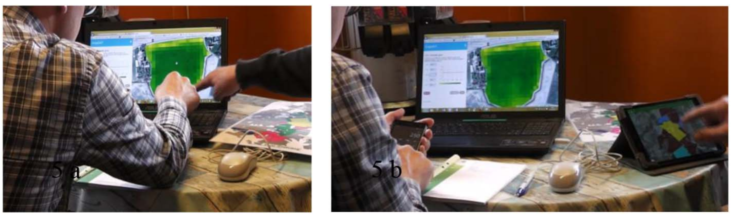


Fig. 5. a) Discussions about within-field variation in crop biomass due to soil compaction at the first meeting. b) Different tools and artefacts used in the distributed cognitive system.

Fig. 6. The farmer explaining differences in biomass variation between two different images, an older image on the left side and the present image on the right.

fields in various ICT systems offered additional, but artificial, perspectives on the fields. They were all central cognitive artefacts and used as coordination mechanisms. Because there were many coordinating mechanisms present, the many ways of organising the different internal and external structures of the socio-technical system were more complex. The key question was how to correctly utilise and combine the different representations and the acquired intuitive, situated knowledge, in order to improve the farmer's care, which was realised through the development of improved cognitive strategies. The use of the DCog lens made it possible to observe cognitive processes as they unfolded in practice – distributed and embodied in the social and material sphere and situated in the moment. It revealed what actually happen in the real world, how humans did act and behave in situ, what kind of material and social resources they used, when, and how they used it (Rogers and Marshall, 2017).

The available digital representations from CropSAT initiated new kinds of discussions about the fields and current farming practices that were not possible previously due to the lack of detailed representations of with-in field variation in biomass at the time of fertilisation planning. However, the improved detail in the digital representations that were available facilitated comparisons between different factors, e.g. VRA files for phosphorus fertilisation and the satellite image, and developed the farmer's situated knowledge. On the one hand, the new digital representations provided more detailed information than before, which in turn provided additional support for making decisions regarding fertilisation. On the other hand, the additional information possibly resulted in a more complex decision-making process, since the farmer lacked prior experience in how to interpret and use the added information, i.e. the digital representations. They have to be interpreted, compared and situated in the farmer's decision-making context, resulting in an ongoing social learning process to further improve and develop situated seeing, involving both the farmer and the advisor. In other words, the perspective of professional vision is intensified through the process of tool-mediated seeing (Goodwin and Goodwin, 1996). Taken together, this adds another dimension to Goodwin's (1994) initial term professional vision and Goodwin's and Goodwin's (1996) term tool-mediated seeing, which can be denoted enhanced professional vision. This enhanced professional vision incorporated both the above terms, because these visual skills need to be combined when making decisions on the use of the digital representations in CropSAT and situated knowledge. Furthermore, the users also needed to improve their situated seeing, i.e. cognitive strategy, to accurately use the digital artefacts in the existing practice. In this particular situation, this was done through choosing and interpreting the digital representations of the within-field variations in biomass, combined with the prior situated and embodied knowledge and first-hand experiences by walking in the fields.

Let us now turn to the decision on how to decide the average amount of N and then calibrate the YNS to fertilise winter wheat for the last time in the spring. In order to accomplish these tasks, the farmer and advisor first compared the earlier satellite image with the current image, discussing intensively how to interpret the images and then explaining what had happened in the field (Fig. 6). They agreed that the crop had developed satisfactorily and that the winter wheat fields were looking good.

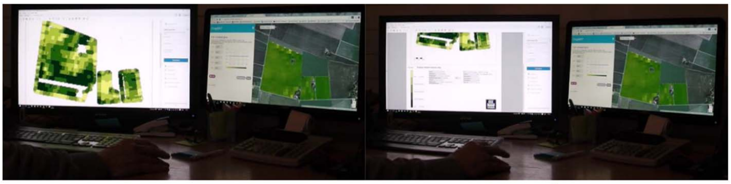
Based on the planned amount of nitrogen in the CPS, the measurements from the Spadmeter, earlier first-hand experiences and the satellite images (both older and present), the farmer and advisor decided the average amount of nitrogen for each field. In order to calibrate the YNS (for further details see www.yara.com), the advisor pointed at the screen displaying the satellite image and then showed where to drive the tractor to cover the variation in crop biomass (Fig. 7). Calibrating the YNS was not an easy task, because it was necessary to select appropriate spots to optimise the calibration.

This example illustrates how the participants explored new ways of using the available technology, i.e. CropSAT and YNS, in combination with their situated knowledge to improve care. This involved using the CropSAT images as a means to calibrate the YNS, which was not the intended contribution of CropSAT and was an example of participants' development of situated seeing. Although this usage of CropSAT was beyond the developers' intention, it may have contributed to generating more sustainable farming practices through cultivating ongoing learning processes. Thus, it can be argued that the AgriDSS functioned as a social learning tool. In particular, learning occurred on several levels. On the one hand, the skill of enhanced professional vision needed to be developed further, i.e. learning to perceive the digital representations in CropSAT. On the other hand, the cognitive strategies, i.e. situated seeing of using different AgriDSS when fertilising winter wheat, also had to be developed further. From a DCog perspective, this means that the decision-making of the need for nitrogen fertilisation is a highly interactive process, and it is likely that essential kinds of learning take place in every performance of this task. Regardless of the way it may be executed in the actual field, all these representations (internal and external structures) are simultaneously in coordination with one another, i.e., the digital representations of the actual field, the situated knowledge and the interpretation about the appearance of the field, and the professional vision of walking in the field are all mutually constraining one another in the emergence of tool-mediated seeing of that particular field. Altogether, it is revealed how technology is part of the cognitive system and it should not be considered an isolated phenomenon. Consequently, this way of acting hopefully has a positive impact on the farming practices, resulting in improved care.

2.9. Theme 3: combining CropSAT and YNS to increase farmers' situated knowledge

In an episode that took place in autumn in which Farmer 1 and his partner farmer were comparing an YNS map with an image from

Fig. 7. Image sequence where the advisor (right) is making a suggestion on where to drive the tractor to calibrate the YNS to cover the within-field variation in biomass.



a b

Fig. 8. a. What did the images show and what was really measured? An YNS map compared with a CropSAT Image. b) How should the scales be interpreted?

CropSAT taken the day after YNS fertilisation, additional possibilities for the development of new cognitive strategies of situated seeing became obvious. However, when an YNS map and the corresponding CropSAT image were identified and displayed on two parallel computer screens, it became obvious that it was not an easy task for the farmers concerned to compare and contrast these visual representations (Fig. 8). This means that they both lacked the visual skill of enhanced professional vision when comparing the images and thus lacked situated seeing for how to use the images in the decision-making process of fertilisation. When asked if they usually looked at the YNS maps after fertilisation was completed in order to reflect on the results, the partner farmer answered: "*Far too little … we just run the sensor and do all that and then … we do far too little with the material we get. Unfortunately!*". When he was asked to clarify what he meant by *unfortunately*, he replied: "*It would be really great to do that … you could at least sit down and look at the maps … you get some information just sitting and looking like this*".

The partner farmer seemed a bit frustrated and concluded that he had realised that they lacked a lot of knowledge and needed to learn. Then he said: "*I want to see what you can't see … if I can put it like that*". And continued "*You don't know your land, you just know the external features… then when it's so tight well … that's where you can get a benefit from this* [the technology]". The partner farmer and Farmer 1 were experienced YNS users and described how they adjusted the YNS while driving. YNS was a tool that they could use properly according to their prior experience. They had developed some sense of situated seeing in order to combine numerical representations from YNS measurements with their own experience and immediate impression of the field to adjust the sensor, while driving. The partner farmer also pointed out the importance of technology in supporting farm workers, such as an inexperienced YNS driver, to carry out fertilisation with more accuracy. On the one hand, the farmers agreed on the added value of technology in supporting both less experienced and experienced drivers to make better decisions in the field. On the other hand, they did not accept the YNS evaluation as a fact, but rather believed that they themselves could sometimes evaluate the situation better than the YNS, even though they also lacked detailed results with which to compare their fertilisation strategies. However, they both noted that they wanted to learn and develop their situated knowledge, from both CropSAT and YNS maps, but that they needed support with finding and improving their cognitive strategies for interpretation of the new digital information to improve their practice and care. In sum, they needed social support, better possibilities for merging between different AgriDSS to develop their prior situated seeing in order to improve their situated knowledge and care in nitrogen fertilisation. Thus, their present cognitive system could not provide sufficient information in order to perform the task properly.

Furthermore, Farmer 1 wanted more and different (not calculated/interpreted) kinds of information than CropSAT could provide. He wanted regular field images so as to get representations of the field, to get a bird's eye view and a detailed representation, in order to recognise small differences in crop development to learn from: "*It would start in April and you could get one of these once a week and then you could go down and zoom in and see exactly and then you could follow the field and see this here. Now it's 25 mm here … so you see this … how this … it's like … on my farm I can know a bit, but you get a whole different … you get this here from above… you can't compare them*". The partner farmer, who was not as interested, added: "*Yeah… but then it's too late*". Farmer 1 then replied: "*Yeah, but even if it's too late you can draw a certain conclusion and you can maybe do something next time*". Thus they verbalised two perspectives of situated knowledge in this conversation. The partner farmer wanted to have access to information to act upon and use for decision-making, whereas Farmer 1 focused on the possibilities to learn by reflection through access to a bird's eye view of the fields. Farmer 1 could not verbalise what exactly he wanted to see, but he was strongly convinced that he should learn more about the fields in order to make better decisions in the future, drawing conclusions from his prior experiences combined with information displayed in new images. This line of argument could be interpreted as an example of both expertise and care development. According to Dreyfus and Dreyfus (2005), an expert is deeply engaged and evaluates situations in relation to many other experienced situations. Farmer 1 had identified an opportunity to get access to new representations of his fields to evaluate them and increase his situated knowledge and situated seeing, without being able to externalise in words what he really wanted to see.

Indeed, Farmer 1 and his partner farmer were eager to find new ways of interacting socially that could help them develop their crop production, i.e., their care. They were not satisfied with the existing advisory service in the area, so they did not use it. Instead, they had started a learning group of their own with corresponding colleagues. However, while satisfied with that, they still wanted an advisor who would work closely with their company. Consequently, they described a lack of high-quality professional partners in their cognitive system. In a situation when Farmer 1 and his partner farmer were comparing maps from CropSAT and YNS, it became obvious that they wanted a professional advisor to take responsibility for handling the data and facilitating interpretation of the data, in order to learn more about their fields and about how to use the technology more efficiently. By looking at maps in retrospect, the participants reflected on the results and, consequently, reflective learning could take place. Without an attending advisor who could facilitate the use of the different AgriDSS and interpretation of the data, limited learning occurred, except that it could be interesting to evaluate the maps in retrospect if it were possible. Later on, Farmer 1 became nostalgic about when they started their farming company with a group of partner farmers. "*In those days we sat until two in the morning … but now we have been doing this for 15 years so maybe the trigger is not as strong as it was to begin with*". His partner farmer agreed: "*We have done so many years now that we have become blind to it … we must bring in new eyes!*". Thus, these companions had previously been able to act as learning facilitators for each other, but now needed new partners who could contribute more information, ideas and strategies about how to improve their farming practices, preferably with the help of usable and credible AgriDSS.

The examples above showed socially distributed cognition over time and how the whole socio-technical cognitive system, which in this case would include farmers, advisors, partner farmer and the available tools and associated artefacts, is capable of performing much more than the individual farmer could on his own. In other words, the coordination of different external and internal resources is an emergent property of the system as a whole, not easily reduced to an evident property of a certain entity (human or artefact/tool). Hutchins (1995) argued that ascribing to individuals minds in isolation the properties of the whole cognitive system (which is actually composed of individuals manipulating a systems of cultural artefacts), then we have attributed to individual minds cognitive processes that they do not necessarily possess. Hutchins then pointed out that "*this sort of attribution is a serious but frequently committed error*" (p. 1995, 173). Thus, this systemic view is the central foundation of the DCog approach; the whole is more than the sum of the individual parts, as the whole socio-technical system demonstrates emergent properties. Thus, cognition is viewed as creation, transformation and propagation of representational states within a socio-technical system (Hutchins, 1995).

2.10. Reflections on findings

It should be acknowledged that the CropSAT images provided different kinds of representation formats that visualised the within-field variation with more clarity than could be achieved with the human eye and it provided a possibility to apply nitrogen fertiliser adapted to the variability in biomass. Hence, CropSAT provided representations of the field, elucidating a complexity impossible to obtain with the human vision system, by what Goodwin and Goodwin (1996) called tool-mediated seeing. The aspects of the complexity, some of which were already known and some which were not, would enable the farmer to add the revealed complexity at the representations from CropSAT to his own professional vision (Goodwin, 1994) based on experience, to increase his situated knowledge about the field and, in the long run, improve his care. This combination of the experienced farmers' professional vision based on experience and the tool-mediated seeing from CropSAT contributed to the new concept called enhanced professional vision. In a sustainable intensification trajectory of agriculture, farmers need to adapt their practice more after the local situation (Leeuwis, 2004). However, they also need to improve their care in practice, where care is the sum of all practices that make technology and knowledge work (Krzywoszynska, 2015). The newly coined concept of enhanced professional vison explains how use of an AgriDSS can provide possibilities to support farmers' situated seeing, learning, decision-making and, in the long run, the development of situated knowledge and care in the agricultural socio-technical system.

The major challenge in using CropSAT was that the farmer had to act upon the variability by setting the five levels of nitrogen fertilisation in relation to the visualised variation in crop biomass. In this cognitively demanding decision-making process, social interactions with the willing and able advisor, reflecting on older CropSAT images from the same year and other representations (soil maps) from the fields, were valuable and functioned as coordinating mechanisms during the decision-making process. In some cases, Spadmeter measurements and experiences from the field on the same day (farmers or advisors or both) and from history (farmers) also added valuable aspects on the process. Altogether, the farmers made their final decisions using the functional entities in the whole cognitive system, where CropSAT constituted one central part.

The observations revealed that the advisor had an important role to play in the adoption and use of CropSAT. Their support in handling the technology and suggestions considering new practices and their confident handling of the tool seemed to encourage the farmers to use it themselves. Thus, it seems as though the advisor can have a crucial role in introducing new technology to the farmer in this more informal learning situation. Farmer 2, who was very competent in the use of computers, called his advisor on the phone and used CropSAT as a mediating and communication tool when discussing the levels of N fertilisation by phone.

To sum up, CropSAT can reveal information on the object of interest to both provide representations of complex situations by tool-mediated seeing (Goodwin and Goodwin, 1996) and facilitate action, learning and decision-making about fertilisation. However, setting the levels of nitrogen or using CropSAT for evaluation in retrospect in combination with other representations proved difficult in practice and high-quality social interactions were crucial. CropSAT supported farmers' professional vision by providing possibilities for tool-mediated seeing of complex situations and it resulted in enhanced professional vision. This in turn improved their situated seeing, which in the long run may foster the development of the farmer's situated knowledge and care.

3. Discussion and conclusions

The purpose of this paper was to acknowledge farmers situated knowledge in the use of AgriDSS in PA in order to hopefully increase sustainability. By studying farmers' naturalistic decision-making in their socio-technical system, our aim was to increase the understanding of the relationship between farmers' experience-based situated knowledge and the use of AgriDSS in order to develop farmers' care in PA practice, in the sense used by Krzywoszynska (2015). This workplace study represents an initial step towards revealing the complexity of using CropSAT in farmers' socio-technical context when developing enhanced professional vision and improving their situated seeing when making decisions on nitrogen fertilisation of winter wheat.

The findings highlight specific characteristics related to the coordination of internal and external cognitive structures during decision-making and learning in AgriDSS use. During the analysis, DCog's theoretical constructs which emphasise the coordination of internal and external representations in the socio-technical system were used as a theoretical perspective (cf. Decortis et al., 2000). This was the filter through which the cognitive work processes in the complex socio-technical domain of the AgriDSS use in PA was interpreted. Therefore, it should be noted that our empirical work was primarily guided by, and possibly constrained by, the DCog perspective that was used in analysing and interpreting what was studied and therefore determined what was considered relevant. The analysis was thus theoretically driven by the DCog perspective and the identified themes that were most related to the aim of the study. The aim of the analysis was to increase the understanding of farmers' decision-making and learning in practice. The interest shown by both farmers and advisors indicates that CropSAT has potential to fit within practice. However, new technology needs novel social and organisational arrangements, such as rules, perceptions, agreements, identities and social relationships, in order to function properly (Leeuwis and Aarts, 2011). Thus, advisory services have a central role to fulfil, to situate the AgriDSS in practice, where they provide opportunities to be used to a wider extent than just for decision-making.

This DCog study was limited to a small number of farmers and advisors in an advisory situation and studied individual farmers during four occasions. We are fully aware of the limitations in the data collection, e.g. lacking first-hand participation in the field visits before the episodes reported in this paper and fertilisation in practice. Due to circumstances in this case, it was not possible to collect such data. This means that we cannot confirm that all the decisions regarding fertilisation portrayed in the findings were realised in practice. However, this workplace study serves as an important starting point for conducting naturalistic inquiries on AgriDSS use in PA in the wild. Rogers and Marshall (2017) mention that research in situ often need a pragmatic approach to the collection and analysis of data. This way of working enables the researchers to explore and document even unanticipated phenomena that can only be revealed in RITW studies (Rogers and Marshall, 2017). Furthermore, we do not aim to generalise from this sample to the population of PA farmers and advisors. However, we claim that the DCog lens, with its naturalistic approach and with the unit of analysis being the whole socio-technical system, brings a valuable perspective to PA research.

Our analysis supports theoretical generalisations regarding application of the theoretical lens of DCog to understand how decision-making and learning can be handled within the domain of PA. Apart from the basic levels of representational states and situated seeing, the

DCog lens provides few theoretical constructs (Rogers, 2012). This aspect has enabled researchers to use the DCog framework according to the context of study and also to include additional concepts (e.g. professional vision and tool-mediated seeing). We therefore introduced and coined the term enhanced professional vision to characterise the combination of professional vision (Goodwin, 1994) and tool-mediated seeing (Goodwin and Goodwin, 1996). This study showed that more detailed representations of fields used in a social context, through enhanced professional vision and situated seeing, provided added value in relation to farmers' development of situated knowledge and care.

Based on the findings in this study, we recommend:

- Developing and including advisors' competence regarding the role and relevance of ICT systems usage in advisory services.
- Reconsidering the role of advisors and AgriDSS in advisory situations, changing from focusing on decision-making events/outputs towards thinking in terms of learning how to improve farmers situated seeing, and care.
- Incorporating better compatibility between different AgriDSS and other PA technologies in order to fit into a wider decision-making system.

Regarding the first point, it was evident that the advisor had a central role in promoting the use of different AgriDSS. Considering the rapid development of ICT technology in agriculture, advisors should widen their area of competence and embrace AgriDSS more fully. Being a crop production advisor already demands dual expertise as agronomist and communicator. Adding a third competence, technology, could be challenging for some advisors and force them outside their comfort zone (see Lundström et al., 2017).

Regarding the second point, with increasing farmer competence, the function of advisors as information providers and experts needs to change to a role as facilitator of social learning, thus resulting in a change in current AgriDSS use from a goal orientation to a learning orientation (Schlindwein et al., 2015). Such a change may hopefully support and foster both decision-making and learning processes that could develop farmers' situated seeing and care, which we view as critical for a sustainable intensification trajectory in agriculture. Lastly, increased compatibility between different AgriDSS and other PA technologies is crucial in order to improve the scope for comparisons of different systems and fit them into a wider system of decision-making and learning in future farming practices. Generally speaking, technology should not be considered an isolated phenomenon in farming practice, as pointed out by Röling (1988). Rather, it should be considered one part in a larger socio-technical system, resulting in improved care in farming. Handling big amounts of unstructured heterogeneous data in PA requires "*a smart interplay between skilled data scientists and domain expertise*" (Wolfert et al., 2017, p. 79) promoting a transdisciplinary approach. It is cognitively demanding to convert and interpret the collected data into available and meaningful pieces of information that could be acted upon, and simultaneously combine it with additional historical and several other kind of available data and information (Sundmaeker et al., 2016; Wolfert et al., 2017).We would argue that both farmers and advisors contribute with domain expertise, and the farmers' unique expertise is aligned with what Nitsch (1994) referred to as the coordination ability which in turn originates from situated knowledge.

Thus the major implication of this study is that different AgriDSS should be considered part of a wider agriculture knowledge information system involving different kinds of ICT systems, tools, artefacts and social learning processes. There are three critical components in relation to AgriDSS in PA: the *hardware* (i.e. technology), the *software* (i.e. knowledge) and the *orgware* (i.e. social context). Once all three are considered, AgriDSS could become increasingly important components in a sustainable intensification trajectory of agriculture, by on the one hand ensuring provision of scientific knowledge and on the other hand encouraging development of farmers' situated knowledge to support their care in practice.

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IV

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MOTIVATIONS AND NEEDS FOR ADOPTION OF THE AGRICULTURAL DECISION SUPPORT SYSTEM CropSAT IN ADVISORY SERVICES

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A B S T R A C T

This paper presents several strategies employed by advisors in relation to the use of a Swedish agricultural decision support system (AgriDSS) called CropSAT, which is free to use and funded by the Swedish Board of Agriculture. The research questions for the study were: How is extension affected and possibly altered when provided with CropSAT? 2) How can advisory strategies in relation to PA technology use be categorised? Fourteen crop production advisors were interviewed, and the collected data were analysed thematically. The findings revealed four different extension strategies in relation to CropSAT use: 1) I do not use it, 2) I use it if I have to, 3) I use it myself and tell the farmer how to fertilise, and 4) I use it with the farmer. The obtained results indicate that the strategies selected by the advisors varied based on the requests and needs of farmers, the advisors' personal interests and competences, CropSAT functionality, and uncertainty about how to use it in practice. When using an AgriDSS such as CropSAT in advisory situations, the complexity increases because there are more parameters to consider, and thus it could be experienced as more difficult to make proper decisions. As a result of the combination of technology and agronomy, the advisors requested more support. We argue that this request must be met by research, the authorities and the companies responsible for developing the AgriDSS. We claim that in order to increase the use of AgriDSS to optimise crop treatment at the right time and on the smallest possible scale, there is a need for a change in mind-set by among both advisors and farmers in order to increase sustainability in agriculture.

Keywords: Precision agriculture, advisor, fertilisation, crop production, agricultural decision support systems (AgriDSS), situated seeing.

INTRODUCTION

In Agriculture is facing huge challenges given the requirement for what is known as sustainable intensification (Garnett *et al*., 2013) to bring about a *"more than doubling of the agri-food production while at the same time at least halving our ecological footprint"* (Sundmaeker *et al.,* 2016). In a sustainable intensification trajectory, the aim is to increase food production on existing farmland and decrease the environmental impacts, using context-dependent strategies that take both social and natural scientific knowledge into consideration (Garnett *et al*., 2013). In such a trajectory, different stakeholders, including individual farmers, will need to develop situated knowledge that is complex, diverse and local (Leeuwis, 2004). In order to handle an increase in complexity in large-scale farming systems at least, information and communications technology (ICT) and other technologies have an important role to play (Aubert, Schroeder & Grimaudo, 2012). Various kinds of ICT systems and concepts, such as smart farming and Precision Agriculture (PA), are expected to be important tools in dealing with this complexity (Sundmaeker *et al.,* 2016; Wolfert *et al.* 2017). PA is a management concept that is based on observing, measuring and responding to within-field variations, providing farmers with opportunities to recognise and handle within-field variations to a much greater extent than ever before (Aubert *et al.,* 2012; Wolfert *et al.,* 2017).

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In order to perform PA, certain kinds of ICT systems, known as agricultural decision support systems (AgriDSS), have been developed. An AgriDSS must fit with the farmers' practice and be combined with farmers' situated knowledge and experience in order to function properly (Nitsch 1994; Lundström & Lindblom, 2016; 2018). Instead of considering an AgriDSS as a strict operational tool, to help farmers make decisions, many researchers highlight the possibility of using an AgriDSS for social learning, that can facilitate discussions and learning among different stakeholders (e.g. Evans *et al.,* 2017; Hochman & Carberry, 2011; Jakku & Thorburn, 2010; Lundström & Lindblom, 2016; 2018; Matthews *et al.,* 2008; McCown *et al.,* 2009; Thornburn *et al.,* 2011). When an AgriDSS is used as a learning tool, it could frame a change from goal-orientated thinking towards thinking in terms of learning (Schlindwein *et al*., 2015). To facilitate such learning processes, advisors play a central role.

In previous work, we studied farmers' socio-technical systems through qualitative inquiry, investigating the use of a Swedish AgriDSS called CropSAT by four farmers and their advisors in relation to making decisions about the Nitrogen (N) fertilisation of winter wheat (for further details see Lundström & Lindblom, 2016; 2018). The study revealed that CropSAT can provide new information about a field and facilitate action, learning and decision-making when considering fertilisation (Lundström & Lindblom, 2016; 2018). Hence, CropSAT provided new kinds of digital representation formats that visualised the within-field variation in biomass with more clarity than can be achieved with the human eye alone, as well as a possibility of applying N fertiliser adapted to this recognised variation. The major challenge identified was how to deal with biomass variability by setting the five levels of N fertilization in CropSAT. In this cognitively demanding process, social interactions with a willing and able advisor, reflecting on field observations as well as different representations such as soil maps and other measurements from the field, were valuable and functioned as coordinating mechanisms. Thus, the advisor had an important role to play in the adoption and use of CropSAT by supporting technology use for both learning and decision-making (for further details, see Lundström & Lindblom, 2016; 2018).

The present study was conducted during 2016-2017, in which fourteen additional advisors from other parts of Sweden were interviewed to complement the earlier findings (Lundström & Lindblom, 2016; 2018). The aim of this paper is to investigate and analyse extension strategies in advisory situations, based on access to and use of CropSAT (www.cropsat.se). The research questions were: 1) How is extension affected and possibly altered when provided with the new AgriDSS CropSAT? 2) How can advisory strategies in relation to PA technology use be categorised? Based on the results obtained, we also discuss the preconditions that make an AgriDSS credible and usable for advisors in practice when planning and discussing fertilisation with farmers.

Theoretical background: In Sweden, for many years there has been considerable debate about fertilisation in order to optimise crop yield and avoid environmental impacts. The Swedish Board of Agriculture publishes N recommendations for crop production on a yearly basis (Albertsson *et al.,* 2016). Based on these recommendations decision-makers should take a great many parameters into account and adapt the amount of N to crop yield, but still consider an average yield for each field. Although farmers, for many years have been encouraged and advised to take soil samples, and even if most farmers know from experience that the yield could vary considerably within a field, the tradition of adaptation to crop need without considering within-field variation does not seem to be a common consideration. However, over the last couple of years there appears to be increasing complexity in the N fertilisation of wheat and malting barley. Some of the underlying reasons for this way of acting can be summarised as large differences in weather conditions, new varieties that have considerably higher N optimums under good conditions, discussions about stagnating yields, reasonable prices and common access to the AgriDSS CropSAT that visualises within-field variation via an open-access website funded by the Swedish Board of Agriculture. In 2015, there were high yields and low protein content in winter wheat and malting barley (http://www.sverigeforsoken.se/se/sok.asp) and therefore many farmer' suffered economic losses, which in turn increased the interest in precision fertilisation and the use of PA AgriDSS. Thus, increased complexity creates a demand for new interventions, which turn us to the next topic, AgriDSS.

ICT systems that support users with decision-making are called decision support systems (DSS) (Alenljung, 2008). The aim of DSS is to reduce the effects of weaknesses in human decision-making or cognitive limitations by increasing the user's ability to process huge amounts of information or by expanding the perception or imagination of the decision-maker. DSS can support decision-makers in making more effective decisions when dealing with unstructured or semi-structured problems, which are often ill-defined and complex and without clear and obvious solutions. By definition, DSS are not intended to replace decision-makers, but rather to support them in the decision-making process. They are interactive, which implies that there is an exchange between the system and the user. Decision-makers must be able to identify a change in the conditions, which is why DSS must be adaptive and flexible to meet user needs and allow modification by the user (e.g. Alenljung, 2008; Power, 2002; Turban *et al.,* 2007). To date, agricultural researchers have had the intention of using AgriDSS to transfer knowledge from science to practice, with the aim of increasing farmers' acquisition of scientific knowledge (e.g. Evans *et al.,* 2017; Leeuwis, 2004; McCown *et al*., 2009; Thornburn *et al*., 2011). However, if the AgriDSS will be used, it must be credible and fit well into the decision-making milieu of the user (e.g. Matthews *et al.,* 2008). Consequently, it is important to acquire a better understanding of how individuals in complex situations actually make decisions and use AgriDSS for social learning, taking into consideration the whole complex socio-technical context in which extension has an important role to play. Moving towards increased sustainability in agriculture, one important lesson learned is that there is no *"generally applicable agricultural development model"* (Leeuwis, 2004). Rather we need knowledge that is complex, diverse, local and probably developed in close cooperation between different stakeholders (Leeuwis, 2004). Thus, the traditional knowledge transfer model for extension, with an expert sending a message, an intermediary and a receiver, is no longer a useful model. Extension is about communication, with people exchanging meanings with the aim of reaching cognitive change and changes in action (Leeuwis, 2004). The knowledge needed to deal with complex situations is diverse and thus different people with different skills and expertise are required as well as technology. An AgriDSS can supplement and facilitate farm management, i.e. technology is essential for handling large data samples, measuring properties that cannot be detected by the human vision system, and providing valuable, credible representations of complex situations that clarify and support actions without losing the complexity. Consequently, they support, but do not replace decision-makers (Lindblom *et al.,* 2017). The adoption of new technology or knowledge is a learning process that involves 1) the collection, integration and evaluation of new information and 2) the adaptation of the innovation to the user's situation (Pannel *et al.,* 2006). Thus, relevant knowledge must be provided both from the inside (probably the farmer) and the outside (possibly an advisor), and it is more likely that the inside knowledge will be the dominant force in an innovation process (Leeuwis, 2004). An experienced farmer could be considered an expert on his or her farm due to the development of a considerable amount of situated knowledge (Hoffmann *et al.,* 2007), which in turn is necessary for the coordination ability of farmers when applying *"complexities of farming on a specific farm"* (Nitsch, 1994).

Thus, we should not consider the advisor as an expert and the farmer as a passive receiver, but rather that both are individuals with different but complementary knowledge that is required in order to drive the learning process forward. When using an AgriDSS as CropSAT for decision-making and learning, the user needs to combine the visualisation of the crop by satellite images with, for instance, other digital representations, previous experience or situated knowledge as well as field observations. Consequently, a significant role for the advisor is to support the adaptation of new technology into farming practice. In so doing, the advisor should facilitate farmers in combining their situated knowledge with the digital representations of the field, thus supporting their development of their so-called enhanced professional vision (see Lundström & Lindblom, 2016; 2018), with the aim of achieving fertilisation interventions that are closer to the optimum. In the case of N fertilisation, this is a process that presents new prerequisites each and every year.

The users of an AgriDSS need to develop new strategies or a situated seeing (Hutchins, 1995; Lundström & Lindblom, 2018), i.e. their cognitive strategy to accurately use the digital artefact in the existing practice to enhance farmers professional vision and develop their situated knowledge. Situated seeing can be characterised as ways of seeing the world where internal structures (individual experience and knowledge) are placed on top of available external structures (AgriDSS, the field, maps etc.) in order to construct an understanding of the task at hand in a certain situation (Hutchins, 1995). In order to accomplish situated seeing, the use of external devices, e.g. physical artefacts, plays an important role for the way in which cognition and learning can be performed by manipulating these physical devices. In this particular situation, the advisor need situated seeing for using and interpreting the digital representations of the within-field variations in biomass in an AgriDSS like CropSAT, combined with prior situated and embodied knowledge, maybe first-hand experiences by walking in the fields and finally probably in interactions with a farmer. Hence, the development of situated seeing is considered as a learning process where the individual's learning ambitions or interests are crucial for the result.

Rogers's (1995) diffusion of innovation theory defines the innovation process as *"a process by which an innovation is communicated by a communication channel over time to members of a social system".* Individuals are characterised in four groups due to their interest in innovation adoption: innovators, early adopters, late adopters and laggards. In the process, change agents have a central role to facilitate the innovation process and in agriculture, advisors are viewed as central change agents due to their role in the agricultural knowledge and innovation system (AKIS). When stimulating better management practices, farmers' can either be more or less pro-active or re-active in their relationship with advisors, and the relationship can be steered by either the advisor, or the farmer, or it can be more equal (Ingram, 2008).

The combination of experienced farmers' knowledge and advisors' knowledge would probably have the best/optimal impact of local intervention on a farm. Consequently, more equal meetings are preferable, where the role of the advisor is more of a facilitator than an expert, all participants take an active part, share their knowledge and experiences and trust each other (Ingram, 2008; Evans *et al*., 2017). Klerkx *et al.* (2017) use a typology of farmers due to their interest in using advisory services:

- Pro-activists, who actively seek advice from advisors;
- Do-it-yourselfers, who develop their farming in their own way, for example, by experimenting or seeking alternative sources of information;
- Wait-and-see-ers, who seek advice but implement this to a lesser degree or at a slower pace;
- Reclusive traditionalists, who do what they have always done or think they know best.

Advisors must have professional skills as well as personal qualities, when handling this broad range of personalities. They also need to balance between specialization and universality. The first group, the pro-activists, is considered the optimal one, but also a demanding group to handle (Klerkx *et al.,* 2017). If the advisors do not meet the farmers' needs, there is a risk that they turn to another company, either nationally or internationally, or become a do-it-yourselfers. These characterisations could also be applied on advisor's strategies in relation to CropSAT use.

MATERIALS AND METHODS

Swedish farmers are recommended to fertilise winter wheat one to three times in spring in order to optimise yield and protein content (Albertsson *et al.,* 2016). In order to calculate and apply a variable rate of N, farmers need AgriDSS support using an average amount of N for the target field as a basis. During the spring this amount is reviewed in relation to crop quality and plant stand. In 2015, a new AgriDSS called CropSAT was introduced in Sweden by Focus on Nutrients, a state-funded project aiming to reduce agriculture's environmental impact. CropSAT is an open-access website that uses satellite images to calculate vegetation indices (VI) (Qi *et al.,* 1994) and variable rate application (VRA) files. To calculate a VRA file in CropSAT, the user visits the website and selects a field and a satellite image. The VI is then calculated and shown in Google Maps. To receive a VRA file, the user must decide the level of N fertilisation within five VI classes, which are estimated automatically from the satellite data (Fig. 1) and used to calculate VRA files. The VRA information can then be transferred to the fertiliser spreader via a USB stick. In spring 2017, approximately 4,100 unique users were registered on CropSAT and they normally visited the website two times (personnel information Johan Martinsson, Dataväxt AB).

During 2016 and 2017, the present follow-up study was conducted in which fourteen additional advisors from other parts of Sweden were interviewed to complement the earlier findings (for further details, see Lundström & Lindblom, 2016; 2018).

The participating advisors where purposively sampled (Patton, 2004) by the first author due to their area of interest mentioned on the advisory organization's websites, in order to get as much information as possible from important agricultural regions in the south of Sweden. Some advisors were sampled due to recommendations from their colleagues. The semi quantitative interviews were conducted by telephone (eleven advisors; notes were taken) or in personal meetings (two interviews were recorded). The interview questions concerned the advisors' professional interests in common, what kinds of customers (type of crop production, acreage, technology interest etc.) they have and to what extent and how they used CropSAT in their advisory work. The interviews lasted between 30 and 90 minutes. The recorded interviews were transcribed and all the interviews were compiled and analysed thematically (Patton, 2004). It should be noted that in Sweden farmers pay for most of the extension work to improve agricultural production issues. In this paper, the participating advisors were categorised as independent according to Kuehne's and Llewellyn's (2017) taxonomy because they were either employed by the Rural Economy and Agricultural Societies in different regions or by a private firm, but were not resellers. According to Klerkx's *et al.* (2017) typology they would be considered part of an elitist fraction of the national extension system.

Figure 1a. Vegetation index (VI) displayed on Google Maps, where the user must enter five levels of nitrogen fertilisation compared with the coloured scale.

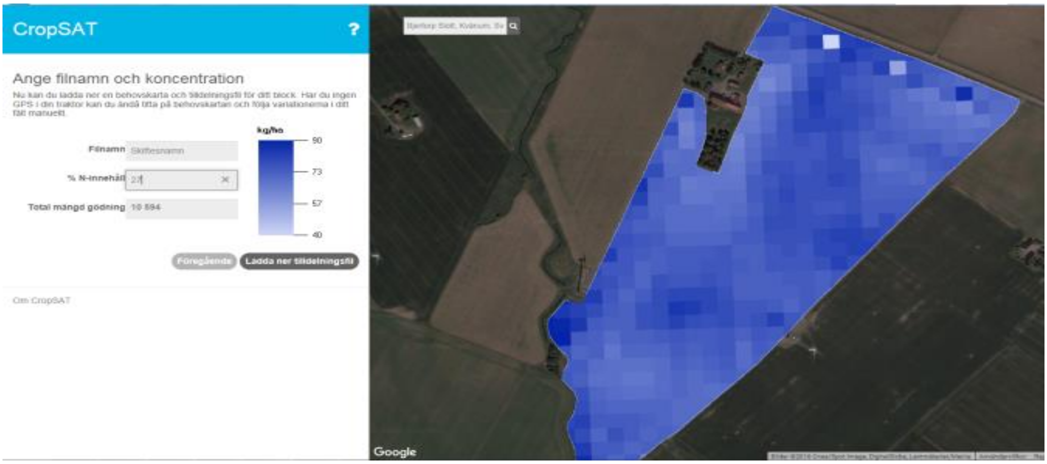

Figure 1b. A variable rate application (VRA) file ready to be entered into the fertiliser spreader via a USB memory stick.

RESULTS

"*First of all you have to get a carrot to pay attention to this… then the farmers require … there are probably those who are skilled and can handle this themselves… but most of them would probably need an advisor who pushes".* Uttered by a PA experienced Pro-activist farmer in a previous project, who together with his colleagues in the company have become Do-it-yourselfers. The obtained results from the interviews conducted with advisors revealed a wide acceptance of the occurrence of within-field variation, familiarity with CropSAT by all participating advisors and an expressed interest for the tool from the majority of advisors. Nevertheless, there were extensive differences in whether and how the advisors used CropSAT in their extension practice. The analysis from the collected data from the interviews revealed four categories of advisor strategy for CropSAT use, where individual advisors were being able to use several strategies:

- I do not use it!
- I will use it if I have to!
- I use it myself and tell the farmer how to fertilise!
- I use it with the farmer!

CropSAT measures a vegetation index that should be related to the actual field. The index in a specific area should be related to the same area in the field and then the user has to decide the amount of N using the same tools as they would when deciding an average amount for the whole field. However, our interpretation of the obtained result is that if the advisors perceive themselves to be experts who ought to provide reliable answers to complex problems, the increased complexity when using CropSAT could then be considered negative.

One user of the first strategy was an advisors in the most productive region of Sweden, who described the situation as:" What *this field needs on an average I think is easier to say ... than what that specific spot should have and that specific spot should have ... Because when you work with general values for the whole field ... then it will be ... largely on average ... and ... yes ... what you think about the yield and so on... But ... it's not as critical ... as when you're going to decide exactly on a specific spot*". Consequently, the answers revealed that it is easier to suggest an average amount for the whole field, knowing that it is not optimal, rather than a specific amount for a specific part of a field. Especially if you do not have access to, do not want to use or do not trust other handheld tools that could support such kinds of technology-mediated decisions. As one advisor said: *"When you do not know, you can as well provide an average amount of N." And:" What is correct, is not very well proved!"*

Another advisor mentioned fertilisation as a difficult intervention: *"It is convenient with customers who say: Yes we fertilised yesterday… because I don't know the true answer".* Our interpretation is that if you consider yourself an expert whose role is to tell the truth, fertilisation is difficult from the beginning and the use of this kind of technology, which increases complexity, could be considered to complicate it further. The answers grouped into the first category seemed to depend on unwillingness to learn, starting to use new technology and change advisor strategies. But, also an addressed uncertainty considering how to relate the satellite image to crop need and consequently how to determine the N demand at a specific spot in a proper way due to a perceived lack of a scientific foundation for the functionality of the AgriDSS CropSAT. Which in turn, this opinion/view was a misunderstanding about the functionality of CropSAT, since the AgriDSS only visualise differences in biomass in order to make it possible for the user to adapt the amount of fertiliser with traditional methods. Using Klerkx's *et al.* (2017) typology of farmers, this group of advisors could be characterised as Reclusive traditionalists, either due to limited interest in new technology and change in advisory practices or due to a sense of uncertainty towards the functionality and scientific rigor of the AgriDSS.

The second identified strategy was used mainly in areas with lower productivity and by a higher proportion of organic and dairy farms. Accordingly, the advisors said that their farmers did not have *"that kind of farm",* the farmers were not interested or *"not so technically advanced"* and "when nobody asks the question, nothing will happen", but *"if somebody do ask, it will be solved".* They waited for the farmers to react and said: *"the customer pushes the development by demand".* This was definitely a group of advisors that could be characterized as so-called Wait-and-see-ers using Klerkx's *et al.* (2017) vocabulary.

The third identified strategy was to use CropSAT when the farmers requested it, but normally not together with the farmer. Instead, the advisors performed the calculations in their offices and provided the farmer with a suggestion for the average amount of N or with a USB memory stick with a CropSAT file. Using this kind of strategy, one advisor said that she could test the AgriDSS by herself in order to know what to say to the farmer, reflecting that she felt that there were expectations that she was an expert who ought to be able to tell the farmer what detailed actions to take. Another advisor said that this strategy was used when the farmer was not interested enough to take part of the discussion, but still wanted to use CropSAT. This strategy could be considered aligned with Klerkx's *et al.* (2017) Do-it-yourselfers, either due to limited support for AgriDSS use from the provider of the AgriDSS or due to farmers' requirements.

The fourth identified strategy was to use CropSAT with the farmer, either in the office or in the field, as a basis for discussion and sometimes for fertilisation. One advisor said: *"CropSAT is part of my concept" but* claimed that every advisor plans their work individually. This group was positive about using other PA tools as well: *"This feels like the right way to go"*. Those advisors constitute a mix of Do-it-yourselfers and Pro-activists using Klerkx's *et al.* (2017) typology. They found their own strategies but did also require information from research. When they experienced a lack of answers from Swedish experts and researchers, they turned to Denmark to find solutions to develop what we described as situated seeing when using CropSAT.

Reflections on results: Our earlier work revealed that when farmers and advisors used CropSAT collaboratively it could be used as a social learning tool and support farmers' situated knowledge and enhance their professional vision (Lundström & Lindblom, 2018). However, the advisor need the cognitive strategy of situated seeing when using the tool in order to be able to facilitate the development of this enhanced professional vision.

The findings from this study revealed that the majority of advisors did not use CropSAT as a social learning tool. We claim that the strategies used by the advisors could also be related to farmers' requests and needs, and advisors' personal interests and doubts about their expertise, knowledge or role. Furthermore, AgriDSS functionality, personal choice and uncertainty about how to use it in practice. When using an AgriDSS such as CropSAT in fertilisation, the complexity increases because there are more parameters to consider. Thus, it could be perceived as more difficult to make correct decisions.

Another option would be to let technology itself solve the problem, by using an expert system. Accordingly, some advisors requested an expert system, providing an optimal N amount for the five levels instead of exchanging experience with the farmer: This aspect was illustrated in the following utterance: "*Now you really need knowledge about the field… and to have a dialogue with the farmer"!* When asked about whether it would be possible for an ICT system to give the exact amount of N demand, one advisor with 25 years of experience answered: *"Yes I really hope so … since I know so little myself …"* Expectations on the technology also increased the demands. *"You want up-to-date satellite images … every, or every other day",* otherwise the advisors did not seem to trust them. Our interpretation is that for some reason they suddenly expected an accuracy in relation to the N amount presented by the AgriDSS that was far beyond the accuracy in the traditional fertilisation strategy with an average ratio of N. Some expressed a difficulty and complexity around making decisions in relation to the crop, but they also expected the technology to manage it much more effectively. They hoped for an expert system or what Black (2000) would call a "technology fix" and obviously, they missed the need for using situated seeing in handling CropSAT.

However, some of the advisors interpreted CropSAT as an AgriDSS. One advisor commented:*"what we have here is a tool that can help you make decisions, however… you can never get a better result than what you tell it to do".* Another one said:" the *technology will never provide the exact truth… which seems to be a problem among my colleagues. However, this is closer to the truth than before*", suggesting that what was needed was:*"a successive change in mind-set".*

In summary, the actors responsible for designing new technology need to provide credible explanations, valid data and advisory strategies to ensure adaptation to farming practice. Farmers need to be acknowledged for their situated knowledge and experience, which is central to increase sustainability. At the same time, they must not consider themselves to be passive receivers of knowledge, but rather accept their responsibility as knowledge providers. Advisors should reconsider their roles as being more of a sounding board or facilitator, taking part in a social learning process than as experts who can provide exact answers. They must also step out of their comfort zone and start introducing technology use in crop production, considering an AgriDSS as a support for decisions and not view it as an expert system. There could be a need for new actors who support the use of technology in the farming practice. However, when using technology as a tool for crop production, agronomy knowledge is essential.

DISCUSSION

This study revealed that the mindset among some Swedish advisors within crop production has changed or is slowly changing from considering the field as a uniform entity to considering within-field variation as something that is worth bearing in mind. We argue that this way of acting is a step towards increased sustainability in large-scale agriculture. When the central basis for fertilisation changes, there is suddenly a challenge to deal with and resolve in order to adapt more effectively to crop need. This could be the first step towards addressing the frustration of, for instance, the European Parliament (2016), which points out that: "the full potential of precision agriculture is not yet harvested. We only see a first series of precision farming practices implemented on small number of farms. These precision farming are making farming more easy rather than giving crop plants and animals the optimal treatment at the right time and lowest scale possible. For the latter, the adoption rate is still very low" (European Parliament, 2016).

Swedish agriculture has faced demands to adapt fertilisation to crop need for a long time, but only at an average level in a specific field. However, all the actors know that there is within-field variation in biomass. Free access to an AgriDSS such as CropSAT makes the variation more obvious, and for farmers who already have convenient technology, it also offers a possibility to do something about it. However, additional knowledge about the field increases complexity and highlights the complicity of finding a true answer. Based on the results, we suggest that there is a need for more back-office support for advisors in order to facilitate their development of situated seeing in relation to technology use, to increase their understanding of the functionality of an AgriDSS, but also back-office discussions about the advisor role. Is the advisor an expert who tells the truth or a sounding board involved in a social learning process? Therefore, a discussion about different expectations from all parts of extension needs to be performed. Traditional crop advisors struggle with their ambition to contribute to improving production, with changes in their roles due to increased complexity and with supporting farmers in using new technology. We recommend a shift from viewing extension as knowledge transfer, towards perceiving it as a joint learning process, where knowledge from both the inside and outside is required. That kind of shift also means that farmers need to consider themselves as knowledge providers not just knowledge consumers (Ingram, 2008). However, this joint learning process probably needs to involve other actors as well, such as researchers, technology providers and, in the case of CropSAT, the government organisation funding the AgriDSS.

Accordingly, an important step to increase the adoption of technology would be a changed mind-set among advisors and farmers, without expecting a technology fix (Black, 2000). Advisors' uncertainty in relation to some technology is somehow understandable since they sell and feel responsible for the advices they provide and will not risk to blindside their customers. PA technology requires support structures to facilitate learning, thus reducing uncertainty and supporting adoption (Eastwood *et al.,* 2017). In the case of CropSAT the technology does not answer the question of how much N the crop needs, it just provides an opportunity to adapt N fertilisation more effectively to biomass variation. The actual amount must still be set by people who use the same tools as those found in traditional fertilisation and those traditional issues are actively discussed among advisors, fertilisation companies and the Swedish Board of Agriculture, supporting the advisors with this kind of information.

Dreyfus (1972/1979, 1992), among others, argued that intelligence and situated knowledge require a background of common sense, with which humans are equipped by virtue of being embodied and situated in their physical, social and cultural world. As a result, it would not be possible to represent human intelligence and situated knowledge within a computer program, as exemplified in an expert system. In a similar line, Evans *et al.* (2017) addressed the need to move beyond R&D methods that strive to provide the precise answer to methods that will facilitate constant improvement in the ongoing social learning process of crop producers, and those who offer expert advice to them. We identify a parallel line of argument to our previous work, where farmers learn how to properly act upon the digital representations provided from CropSAT. Meaning, moving away from knowing how to deal with a certain digital image or *"piece of information"* to making that information being properly used via situated seeing and enhanced professional vision in their farming practices. Consequently, acting in a way that creates added value to them, and in the long-run hopefully cultivates a sustainable agriculture (Lundström & Lindblom, 2016; 2018). However, some voices have been raised arguing that the role of humans in analysis, planning and decision-making in farming practices is further taken over by machines and other smart farming systems of the future, so that the decision-making cycle will be fully autonomous (Wolfert *et al*., 2017). On the other hand, some researchers argued that humans are still being in the decision-making loop "*but probably at a much higher level of intelligence"* (Sundmaeker *et al.,* 2016). Handling big amounts of unstructured heterogeneous data requires "*a smart interplay between skilled data scientists and domain expertise*" (Wolfert *et al.,* 2017) promoting a transdisciplinary approach. Additionally, it would be a cognitively demanding ability to convert and interpret the collected data into available and meaningful pieces of information that could be acted upon, and simultaneously combined with additional historical and several other kind of available data and information (Evans et al., 2017; Sundmaeker *et al*., 2016; Wolfert *et al.,* 2017). We would argue that this higher level of intelligence in form of domain expertise is aligned with what Nitsch (1994) referred to as the coordination ability, which in turn is based on situated knowledge and experience. Thus, the major implication of this study is that different AgriDSS should be used for learning as well as decision-making and considered part of a wider socio-technical system involving different kinds of ICT systems, tools, artefacts and social learning processes. Furthermore, in the case of N fertilisation, every year offers new conditions because automation in a continually changing environment is difficult and demands human supervision.

CONCLUSION

To use AgriDSS to evaluate crop need, the user/farmer/advisor needs knowledge of the crop, understanding of how the technology functions, confidence in the technology and finally situated seeing in order to know how to use it in combination with other information sources and experiences. The requested confidence for new technology is traditionally provided by public research and extension (Eastwood *et al.,* 2017). Crop production advisors have knowledge about crop production. However, the development of 1) enhanced professional vision (interpretations based on technology visualisations) and 2) situated seeing (experience based strategies for combining information sources) for using CropSAT or other AgriDSS, will demand engagement from the advisors as well as increased support from research and back-office in their organisations, otherwise the technology's potential will not be exploited. Better support from external as well as back-office sources, would prevent advisors changing from Pro-activists to for instance Do-it-yourselfers or Wait-and-seers and thus provide higher quality services for farmers. Based on our results, we can identify two major risk scenarios in Swedish agriculture: 1) Pro-activist farmers using new PA technology are not provided with Pro-activist advisors and as a result advisory services is/are refrained, 2) Pro-activist advisors become Do-it-yourselves or Wait-and-seers because they are not provided with the support they may need. Both scenarios would be negative for the innovation capacity in Swedish agriculture. We believe that a change in mind-set among both advisors and farmers is required, in line with within-field variation, technology use and expectations as well as relevant expertise, which all is vital to increase sustainability in agriculture. To manage our addressed change of advisory services, advisor organisations need to develop their back-office work with the aim to jointly develop advisory strategies, in relation to PA AgriDSS (Lundström & Lindblom, 2016; 2018). Advisors also needs to be involved in PA technology development and design to increase its legitimacy and provide a better fit with practice, in the same way that farmers need to be involved (Jakku & Thornburn, 2010; Lindblom *et al.,* 2017; Rose *et al*., 2017). It is widely acknowledged that different kinds of ICT support have come to stay in agriculture and agricultural advisory services, and these technologies need to be further incorporated into the farming practice of both farmers and advisory services. However, different technical support needs to be developed and designed to support the farmer and counselling and not hinder them in their professional practice. There is relevant research in the fields of human-computer interaction (MDI) and user experience design (UXD) that has been used successfully in the development and design of ICT systems in general and in the agricultural domain explicitly (for further details see Lindblom *et al.,* 2017). If support of the individual advisor is becoming more available through back-office as well as from technology developers we would claim that advisors more easily could move from so-called Reclusive traditionalists, Wait-and-see-ers, and Do-it-yourselfers to Pro-activists, which would be of importance in order to increase sustainability in large-scale agriculture. Future research and development is much needed that addresses both farmers' and advisors' requirements for better support in their social learning processes of using AgriDSS and developing their situated seeing in order to take the next step in PA. It should be mentioned that we fully agree with Evans *et al.* (2017) who reject the term *"decision agriculture"* because the current use of the term appears to imply that on-farm decision-making will be improved solely by better access to site-specific, data driven information according to them. Accordingly, farmers and advisors are still making the similar decisions as before, albeit at an increasingly finer scale, through the use of PA technology. Hence, we want to stress the need to also include the social and learning dimensions in the decision-making loop, because AgriDSSs and other ICT systems only provide a means for cultivating sustainable practices, which can affect practices on individual and group level, but also affect societal values and policies. Thus, in the long run, developing and cultivating sustainable farming practices. A sustainable society ultimately depends on the resources it can muster in terms of human resources, and an important means towards the goals of sustainability is through farmers', advisors', and technology developers' everyday practices (Susi *et al.,* 2014). Sustainability cannot be transferred to, or induced upon their learners–it has to come from 'within', through individuals embracing sustainable practices in order to gain sustainability of the everydayness of farming life that includes the whole agricultural knowledge and innovation system, from a socio-technical perspective.

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Care in dairy farming with automatic milking systems, identified using an Activity Theory lens

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ABSTRACT

Context: In Sweden, 34% of herds in official statistics 2021 (77% of the cows) have an automatic milking system (AMS) and keep 19% of the dairy cows.

Objective: This study should be considered in relation to the rapid increase of digitalisation in agriculture. It aimed at investigating Swedish farmers' experiences and reflections in dairy farming concerning AMS use from a care perspective, based on two research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

Methods: A mixed method approach was performed, using method triangulation through a questionnaire, interviews, and field visits. The Activity Theory (AT) was used as a theoretical lens to consider care practice in the dairy farming as a learning system.

Results: AND CONCLUSIONS: Participating dairy farmers were found to be in a continuous learning process on different levels in their system, from detailed problems with an individual cow or the herd to the whole dairy system. Implementation of AMS required learning in order to manage, and thus care for, a system comprising of animals, technology, and humans, to increase business viability. In successful AMS use, willingness to learn, adapt to the local situation, and continually improve practice, or *care* as a patterning of activities, appeared to be the most important factors. With more people involved, differentiations were possible, which in turn accentuated the need for more trained staff who can perform more complicated tasks. The findings indicated high importance of experience and a 'stockperson's eye', in combination with *tool-mediated seeing* using data from the robot, in developing *enhanced professional vision* and good *care*. A good stockperson had broad competence combining a stockperson's eye with experience with robot data. One of the greatest challenges for dairy farms was finding a good stockperson as staff or advisor. Increased flexibility in work and better physical health were important driving forces for implementing AMS, while handling alarms was mentally stressful and gave different perspectives on AMS vulnerability. Overall, the analysis of the collected data showed that AMS had brought major, primarily positive, changes in daily work and increased work satisfaction for most farmers, with a clear majority of the respondents feeling good in their work situation and enjoying their work.

Significance: Application of AT in studying AMS from a care perspective, represents a shift from traditional research that normally addresses technological inventions, to studying farmers' socio-technical system. The AT lens revealed the work practices in performing care, as a patterning of activities accomplished by a tinkering learning process, in the rich and messy matrix of humans, cows, and technology.

1. Introduction

The recent and rapid development of technology-oriented agricultural trends, such as smart farming, digital agriculture and agriculture 4.0, reflects agricultural production within the dominant technocratic paradigm (e.g. Ayre et al., 2019; Clay et al., 2020; Finstad et al., 2021; Klerkx et al., 2019; Lioutas et al., 2019; Rijswijk et al., 2021). Milking robots or automated milking systems (AMS) fit this paradigm, since it

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has entailed new possibilities for data collection on the individual cows as well as the whole herd. The first commercial AMS was installed in the Netherlands in 1992 (de Koning, 2010), and since then adoption has increased steadily, especially in European countries (Salfer et al., 2017). In 2015, there were more than 25,000 dairy businesses with AMS worldwide (Barkema et al., 2015), and some estimates show that there were over 35,000 units on farms in 2017 (Salfer et al., 2017). The Nordic countries and the Netherlands have led in implementing AMS systems, with the highest percentage of AMS herds (Barkema et al., 2015). The first AMS in Sweden was installed in 1998 (Bergman and Rabinowicz, 2013). By August 2020, Sweden had 3250 dairy businesses, with on average 94 cows each (https://www.lrf.se). National statistics for 2021, covering 77% of Swedish cows, indicate that 35% of Swedish herds had AMS (735) (Växa, 2021). With the introduction of AMS, the whole practice of milking and related work practices or *care* has to be re-organised around the new robot device (Butler et al., 2012; Driessen and Heutinck, 2015). The AMS provides much data for each cow, suggesting that the care perspective in AMS could be based on robot data, replacing the physical contact and visual inspection of each individual cow in conventional milking systems (CMS). However, some research indicates that care in AMS must be based on more than robot data to be successful (Lundström and Linblom, 2020; Stræte et al., 2017). It is therefore necessary to consider the interdependencies between humans and analogue and digital technologies, since technologies provide meaning only when embedded in social practice (Barrett and Rose, 2020; Darnhofer, 2020; Finstad et al., 2021; Suchman, 2007). In a socio-technical perspective on dairy farming, the AMS is dependent on the farmer's work practice (Finstad et al., 2021; Rijswijk et al., 2021). Hence, it is not enough to study technology such as AMS in themselves, rather there is a recent quest to study how AMS are integrated into farmers' work practices from a systemic perspective, which includes people, technology, and cows.

There are many approaches for evaluating work practices that include both people and technology. According to Krzywoszynska (2015), among others, the care perspective is becoming central to the current reconceptualisations of agrarian space and practice in modern agriculture. Krzywoszynska (2015, p. 1) paraphrases the classic definition of care by Tronto (1998) as "the totality of those activities which enable the maintenance, continuation, and repair of the farming 'world'". Today, it is acknowledged that good care is viewed as essential for any kind of good farming. The care perspective was applied in the present study, partly because of its criticisms of the technocratic and productivist paradigm in agriculture (Puig de la Bellacasa, 2017). Krzywoszynska's (2015, p. 2) description of care goes as follows: "the totality of practices that make technology and knowledge work", which means that she considers care as a patterning of activities. As pointed out by Mol et al. (2010), care is situated and place-based, as it involves developing local solutions to specific local problems. Moreover, care takes a relational approach that is built on mutual dependencies (Puig de la Bellacasa, 2017). The emerging understanding of care within farming is therefore considered as a non-normative proposition and an amalgam of vital affective states, ethical obligations, and ongoing tinkering practices that have their roots in early feminist social science and political theory (Puig de la Bellacasa, 2012). In this present paper, we investigate and analyse care as a patterning of activities in dairy farming with AMS.

Implementation of AMS on-farm requires learning in order to manage, and thus care for, an entire socio-technical system comprising animals, technology and humans, in order to create a viable dairy business. Learning is required by the farmer to properly manage an automated system, based on robots milking the cows, and by the cows to fit into the particular system. It is a learning process for all to manage the system and provide good care. Thus, care is both considered as a process as well as the outcome of this process in the present paper.

The study of care does not have any accompanying methodological approach other than naturalistic inquiry in general for doing the analysis. We therefore suggest that a viable approach to investigate and analyse care on the dairy farm as a patterning of activities that includes a learning perspective is to use Activity Theory (AT) as a theoretical lens (Kaptelinin et al., 1999; Kaptelinin, 2013). Application of AT in studying a socio-technical system such as AMS represents a shift in the research focus from addressing the technological inventions to considering the ways in which farmers as human actors interact with the technology, the animals, other humans and with each other within a conceptual framework that is regulated by specific requirements and constraints (cf. Bannon, 1995). Therefore, the AT lens can reveal the work practices of performing care as a patterning of activities in the rich and messy matrix of humans, cows, and technology, which can shed some light on the ways in which AMS influence care as well as result in care (Lioutas et al., 2019). A major strength with AT is its focus on learning within the socio-technical system from a systemic perspective. Activity Theory has been widely and successfully applied in research on human-technology interactions in various domains since the mid-1990s (Rogers, 2012), and has recently been suggested for use in studies on automated intelligent systems like robots (Lindblom and Alenljung, 2020), agriculture (Lioutas et al., 2019) and dairy production using AMS (Lundström and Linblom, 2020). We therefore consider that AT fits as hand in glove for a systemic way of studying care in dairy farming with AMS.

This study aimed at investigating Swedish farmers' experiences and reflections from the perspective of care in dairy farming using AMS. The work was based on the following research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

In Section 2, we first summarise previous work on the reasons for and against investment in AMS and outcomes of the transition from CMS to AMS. Next, we introduce the care perspective and its application in AMS studies and then elaborate on the tenets of AT. In particular, we assess the suitability of AT for studying human-technology interaction in general and use of AMS as an advanced socio-technical farm system in particular. In Section 3, we describe the overall study design, while the empirical results obtained are presented in Section 4. The implications of the results are discussed and some areas for future work are indicated in Section 5, while overall conclusions are presented in Section 6.

2. Background and related work

2.1. Development and impact of AMS on humans and cows on the dairy farm

The digital transformation of AMS introduction meant replacement of CMS with milking robots based on digital technology and automation to handle the daily milking of dairy cows (Douphrate et al., 2013; Holloway et al., 2014b; Karttunen et al., 2016; Lunner Kolstrup and Hörndahl, 2013; Lunner Kolstrup et al., 2018; Rijswijk et al., 2021; Salfer et al., 2017). Multiple reasons for farmers investing in AMS have been identified, including economic reasons (Vik et al., 2019). Other common reasons are to increase flexibility, efficiency and animal welfare aspects, decrease heavy physical workload, improve farming lifestyle and wellbeing, reduce the amount of hired labour (Eastwood and Renwick, 2020; Hansen et al., 2019; Stræte et al., 2017), reduce physical risks, and increase the possibility for succession or to grow without additional labour (Stræte et al., 2017). In the Swedish context, improved physical work environment has been identified as the most important reason for investing in AMS, while high capital investment cost is the main reason for not investing (Bergman and Rabinowicz, 2013). Implementation of AMS is complex, due to the interactions between the social, the cyber, and the physical (Rijswijk et al., 2021), where much can go wrong in daily operations (Gustafsson, 2009).

Data on Swedish and UK farms show that AMS does not decrease working hours by as much as expected, but gives farmers greater flexibility and allows them to milk more cows with fewer staff (Gustafsson, 2009; Butler et al., 2012; Stræte et al., 2017). According to a Norwegian study, AMS farmers are more revenue-efficient than CMS farmers are, after a transition period of approximately four years (Hansen et al., 2019). Milk production per cow, labour costs and milk production per robot are the main factors affecting profitability (Salfer et al., 2017). An AMS can result in labour savings, as some work tasks are reduced or eliminated, but new tasks are added (Bergman and Rabinowicz, 2013; Eastwood and Renwick, 2020; Hansen, 2015). Mental stress caused by the monotonous, repetitive, fast-paced and urgent milking work in CMS decreases after switching to AMS (Karttunen et al., 2016; Lunner Kolstrup and Hörndahl, 2013). Mental stress can still arise with AMS, due to night alarms, lack of sufficiently skilled labour/staff and 24/7 readiness of the milking robot (Butler et al., 2012). However, farmers can adapt the AMS to their own needs and thus reduce the number of alarms (Hansen, 2015).

The transition from CMS to AMS also alters the role of the stock person (Ouweltjes and de Koning, 2004; Butler et al., 2012; Holloway et al., 2014b; Stræte et al., 2017). With AMS, a wider range of data are collected on the cow herd, the individual cow and milk quality, which together can improve milk production (Bugge and Skibrek, 2019; Butler et al., 2012). Less time is spent on milking, but more time is needed for analysis and evaluation of AMS data and observation of cowherd behaviours (Stræte et al., 2017). Some even suggest that a change from CMS to AMS changes the meaning of 'stockmanship', from referring to a person with knowledge and skills based on close contact with animals to a computer-based worker with increased distance to the animals, using the robot and computer as intermediaries (Stræte et al., 2017). Holloway et al. (2014b) refer to cows 'hiding' in technology. Another reason for a change in stockmanship is that AMS often means more cows in the herd and increased efficiency in the dairy industry, leading to shorter cow life and thus more limited possibilities for relationships to develop (Burton et al., 2012).

The introduction of AMS requires learning on how to handle a highly automated system based on robots that milk the cows, instead of people doing it (Hansen et al., 2019; Tse et al., 2017). There are challenges in integrating conventional work practices with multiple technical and digital systems in a dairy farming context (Eastwood et al., 2012; Lunner Kolstrup et al., 2018). Farmers' engagement with AMS data varies widely (Holloway et al., 2014b; Stræte et al., 2017). Some use data intensively and others are either unaware of the kind of data available or unable/unwilling to use these data. Increased use of technical and digital systems could result in significant changes in the relationship between humans and animals, giving rise to various socio-ethical dilemmas (Stræte et al., 2017). On the one hand, farmers with AMS are expected to care for their cows using AMS data. On the other hand cows are expected to look after themselves and behave according to the demands set by the AMS or, if not, they must be persuaded, enticed or forced (Holloway et al., 2014a).

Regardless of their reasons for changing milking system, farmers must be motivated to learn and develop relevant skills to use AMS in the local situation on their dairy farm (Stræte et al., 2017). This means there are learning costs connected with the transition from one milking system to another (Hansen et al., 2019). Thus, AMS farmers/companies need to have a genuine interest in both cows and technology (Bergman and Rabinowicz, 2013).

To summarise, from a socio-technical system perspective shifting from CMS to AMS does not simply involve introduction of a new kind of technology, but also requires an entirely new management system with altered milking and working practices both humans and cows. The focus on work practices is a well-established research field within socio-technical systems in general, but has not been applied to AMS in particular. Inclusion of new technology in an existing socio-technical system is a more complex issue than technology acceptance, because it requires integration into existing complex work practices that sometimes are implicit (Lindblom et al., 2017; Lundström and Lindblom, 2018). A promising approach to gain a systemic view on the practice of including technology, humans and work is to apply the care perspective as a patterning of activities.

2.2. *Care as a practice*

The care perspective has been used in relation to farming (Mol et al., 2010), wine production (Krzywoszynska, 2015), permaculture (Puig de la Bellacasa, 2017) and agricultural soils (Krzywoszynska, 2019, 2020; Puig de la Bellacasa, 2015, 2017) and concerns humans as well as non-humans and natural settings (Krzywoszynska, 2019; Puig de la Bellacasa, 2017). Using care as a perspective is a way to highlight the value of experiential and situated knowledge, an ethos built on attentiveness, responsibility, and interdependent relations in a practice. Care is not considered an obligation, a principle, a role or an emotion, but the result of all practices that make technology and knowledge work in complex domains (Krzywoszynska, 2015). Care, from our point of view could be considered a process of development and learning as well as the resulting outcome, in practice. Accordingly, the care perspective is useable to describe what Finstad et al. (2021) call a relational learning process in adoption, integration, and use of AMS as well as a way to conceptualise farming as a relational process, which according to Darnhofer (2020) is dynamic, changing, emerging, and difficult to predict. Hence, we consider that the care perspective encompasses this shift from focusing solely on technology or an engineering mindset (Jacob, 1977), and instead focuses on the patterning of activities as a relational process as well as the resulting outcome of these activities. This means that care is both the means and the end.

Farmers' daily work practices are complex, as they require knowledge and consideration of a wide range of biological, technological, practical, political, legal, economic, ethical and social factors and circumstances (e.g. Lindblom et al., 2013; Nitsch, 1994). The farmer needs to manage a wide range of competences, including: 1) knowledge about the subject (dairy etc.), 2) skills in formal planning (economic records etc.), 3) practical skills, and 4) knowledge of the institutional environment (legislation, market conditions etc.) (Nitsch, 2009). However, "*The crucial element is the ability to apply them in the coordination of the complexities of farming on a specific farm*" (Nitsch, 1994, p. 32). This kind of knowledge practice and skills, expressed as care in this paper, is personal. The increase in technology aspects of farming entails an increased risk of concealing or blurring reciprocal relationships and dependencies, which the care perspective may be able to clarify. Nothing impedes any kind of technology in care according to Mol et al. (2010, p. 15): "*Technologies, what is more, do not work or fail in and of themselves. Rather, they depend on care work. On people willing to adapt their tools to a specific situation while adapting the situation to the tools, on and on, endlessly tinkering*". This makes the care perspective a suitable perspective for studying learning processes in complex agricultural systems.

At first glance, dairy farming involves individually rather easy interventions, such as feeding cows, cleaning floors, milking, etc. On closer inspection, however, dairy farming is complex and demands tacit knowledge and highly complicated skills in simultaneously handling animals, technology and more. The overall management of the dairy system is a question of routines, technology, knowledge, experience, planning and a stockperson's eye, to perform good care in dairy production. With adoption of AMS, farmers' physical distance to the animals increases and care changes (Bergman and Rabinowicz, 2013; Driessen and Heutinck, 2015; Stræte et al., 2017). Adoption of new technology can limit, change, improve and even jeopardise the individual's possibility to develop good and broad relations to non-humans within the farming context. The crucial factor is the need for tinkering within existing strategies and use of attentiveness and experiential knowledge to deliver as good care as possible in continually evolving situations.

When a dairy farm changes from CMS to AMS, this brings major changes in how care is expressed and manifested in the daily work (Bergman and Rabinowicz, 2013; Driessen and Heutinck, 2015; Stræte et al., 2017). In AMS, the lives of the cows are less controlled, especially with free cow traffic. Holloway et al. (2014b) claim there is also a change in the meaning of good stockmanship on changing from CMS to AMS. In CMS, good stockmanship is based on knowledge and skills developed from long-term first-hand contact with the cows and acquired experience of e.g. milking. In AMS, good stockmanship is mostly based on computer usage, data interpretation and responding to suggested computer-based interventions, with increased distance between the stockperson and the animal(s) (Holloway et al., 2014b). 'Knowing' or 'seeing' through a technical device, instead of in reality, means *tool-mediated seeing* (Goodwin and Goodwin, 1996). In CMS, experiential knowledge of milking and handling cows results in a *professional vision* (Goodwin, 1994), but in AMS farmers must develop *enhanced professional vision* (Lundström and Lindblom, 2018), in order to use technology to 'see' the cows and thus use AMS effectively. Consequently, AMS restructures the relationships between humans and animals (Holloway et al., 2014b). Farmers receive more data on each cow, and can get to 'know' each cow better via the digital management system of the AMS, while cows have more freedom to decide concerning milking, resting, and feeding.

The transformation from CMS to AMS means a lateral shift in responsibility from the farmer to the individual cow (Driessen and Heutinck, 2015; Holloway et al., 2014b). In AMS, cows are expected to make the correct choices and can be "*variously persuaded, motivated, forced or 'tricked' into doing so through, for example, installing devices which enforce particular patterns of movement, or by direct human interventions such as 'fetching' or culling reluctant cows*" (Holloway et al., 2014a. p. 139). Thus, the cows need to learn to 'take care of themselves' within the AMS, but care is also distributed in the sense that the cows are simultaneously worked on/taken care of by the farmer (Driessen and Heutinck, 2015). "*The freedom for both cows and humans promoted by the manufacturers as a benefit of robotic milking becomes a responsibility to take care/be taken care of and to foster productive life*" (Holloway et al., 2014a, p. 140). The farmer must provide good prerequisites for the dairy system, but the individual cow must in turn adapt to the particular system.

Although the care perspective is very promising and accurate in describing the means and ends of care in work practices at the intersection of technology, humans, and cows on dairy farms that use AMS, there is currently no explicit way or methodology suggested for investigating and analysing the care perspective in a systemic way. Most care studies are conducted using various naturalistic study approaches (Mol et al., 2010; Krzywoszynska, 2015). As argued in the Introduction, Activity Theory (AT) could enable a more structured approach to study the wider socio-technical system of AMS in dairy farms, as it has a broader unit of analysis, focusing on the mediating role of technology use while situating the users at the centre of the social and material context. The focus in AT on studying so-called contradictions during technology mediation also provides insights for learning and development, which are aspects well aligned with the care perspective.

2.3. The conceptual framework of Activity Theory (AT)

Activity Theory, sometimes called Cultural-Historical Activity Theory (CHAT), provides a comprehensive conceptual framework that can be used for grasping and portraying the structure and development of human activity situated in its technical and social context (Kaptelinin et al., 1999; Kaptelinin, 2013). Activity Theory emerged in the 1920s–1930s and has since undergone three generations of research (Engeström, 2001). It provides a broad and complex framework for describing and evaluating the structure, development, and context of human activity, considering individuals, artefacts and other humans and subjects, as well as their interrelations (Duignan et al., 2006; Kaptelinin et al., 1999). According to AT, the only way to understand the human mind is in the context of human interaction with the world, and this interaction, i.e., activity, is socially and culturally constructed (Kaptelinin, 2013).

Since its inception, the underlying principles of AT make up an intertwined system forming a whole that represents several aspects of human activity. This creates a need to apply these principles from a systemic perspective, because of their interrelatedness, which unfolds over time. One way to do so is to use the extended AT framework called Activity System model (Engeström, 2001, 2015) (Fig. 1). The Activity System model is a way to visualise the different interactions between various elements when performing an activity and its outcome from a systemic perspective.

In the Activity System model, the interactions between subject (user, which in this context is the farmer), object (cows on the dairy farm), main mediating artefact (the milking robot and supporting instruments and digital tools) and community (society, advisors etc) are mediated by specific mediational means. These are: mediating artefact and tools/instruments for the subject-object interaction, rules (e.g., norms, work practice, and legislation) for the subject-community interaction, and division of labour for the community-object interaction (Engeström, 2001, 2015; Kaptelinin, 2013). The Activity System model also includes the outcome of the activity system as a whole, namely the transformation of the object generated by the activity in question into a suggested outcome. This visualisation approach highlights the continuous process of transformation and development over time (Fig. 1). It should be pointed out that Engeström (2001, 2015) applies a systemic approach to theorise humans' intentional activities, without considering humans as passive factors lacking any internal properties or motives. This way of thinking highlights the continuous process of transformation and development over a time horizon of learning.

A critical step when analysing an activity system is looking for so-called contradictions within the system, i.e., any misfit within an element in the system, between elements in the system, or between the current activity system and other activity systems (Engeström, 2001, 2015). The use of the contradiction term within AT should not be mixed up with common usage of the term. In AT, contradictions are manifested as challenges, problems, interruptions, workarounds, or breakdowns that need to be handled or coped with. In AT, these contradictions are usually regarded as sources of development, because human activities are often a work in progress to handle the current contradiction(s) (Engeström, 2001, 2015; Kaptelinin, 2013; Lindblom and Alenljung, 2020). These contradictions do not always address themselves explicitly, but rather are manifested implicitly via small changes in the subject's mundane work actions (Engeström, 2000).

According to Engeström (2015), when an activity system is under transformation, the actors within the system must develop new forms of activities that are not yet present in the system, often by contradictions, and therefore new activities are learned as they are created. Engeström (2015) describes the learning process as developmental cycles, in which contradictions are the driving force, as expansive cycles. Therefore, it is of major importance to study contradictions from several perspectives, shifting focus from the actions and operations of the individual to zooming out to the broader activity context and then zooming in again (Lindblom and Alenljung, 2020).

An activity can be understood as a purposeful, transformative and developing interaction between actors (subjects) and the world (objects). In the present paper, *care* is considered both as the activity as such and as the intended outcome of the activity system in dairy farming with AMS. In order to gain a deeper understanding of the activity concept that is fundamental in AT, the five central principles that AT is built upon are briefly presented below: hierarchical structure of activity, object-orientedness, tool mediation, internalisation-externalisation, and development. These principles are aligned with the view of care as the patterning of activities.

The hierarchical structure of activity, i.e., the care perspective in dairy farming with AMS, organises an activity into three levels, activity, action and operation, which are related to motive, goal and condition (Kaptelinin, 1996, 2013; Rogers, 2012). The top level is the activity itself, carried out to fulfil a motive, i.e., providing good care in dairy

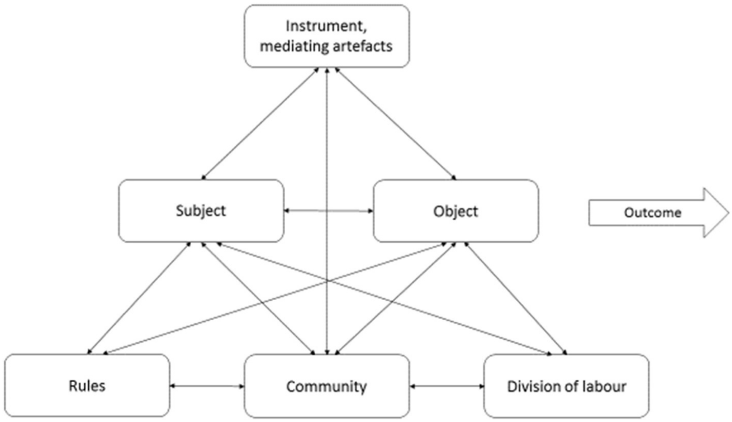

Fig. 1. The Activity System model includes the interactions between the elements of the overall activity and its outcome (modified from Engeström, 2015, p. 63).

farming. The middle level, action, is described as conscious processes subordinated to the activity. Actions correspond to what must be done such as feeding, cleaning stables, washing AMS items, and milking cows and are directed at specific goals, which may be decomposed into sub-goals, sub-sub-goals etc., which means that multiple actions and operations may be nested to fulfil the activity. Thus, each action of milking cows is decomposed into hierarchical levels. In the bottom level, the operations function as lower-level units of actions (Kaptelinin, 1996; Rogers, 2012). As such, operations do not have their own goals, but are rather a result of prior actions that have been transformed into automated operations (Kaptelinin, 2013). Hence, viewing human activity as a three-layer system offers the possibility for combined analysis of motivational, goal-directed and operational aspects of human activity of care in the socio-cultural and material world, by interrelating the issues of "why", "what" and "how" within a coherent framework (Kaptelinin, 1996, 2013; Lindblom and Alenljung, 2020; Rogers, 2012).

The principle of *object-orientedness* states that all human activities are directed towards different objects (e.g. cows on the dairy farm) and these objects motivate and direct activities. Activities such as providing care when running a dairy farm are coordinated around objects, so analysis of objects is necessary for understanding human activities, both at the individual and collective levels. In other words, object-orientedness refers to the current context and setting of usage, where the human (subject) interacts 'indirectly' with the context (objects, the cows on the farm) through various mediating tools/artefacts (Kaptelinin, 1996, 2013; Lindblom and Alenljung, 2020). In this paper, the most prominent mediating artefact is the AMS.

The principle of *tool mediation* is at the core of Russian cultural-historical psychology (Vygotsky, 1978; Lindblom and Ziemke, 2003). The tool concept is broadly applied, and embraces material, physical tools (e.g., computer screens, milking robot) and psychological tools (e.g. charts, tables, and figures from the AMS software), shaping the ways users interact with the world. Placing tool mediation in the broader social context means that mediation enables various forms of acting in and interacting on the world (Kaptelinin, 2013). The object of activity is the actual setting and meaningful context in which the milking robot is used, i.e., the cows on the dairy farm.

The principle of *internalisation-externalisation* stresses that human activity has a double nature, because every activity has both an external and internal side. Hence, the internalisation-externalisation principle is characterised by the ongoing shifting back and forth between what happens internally "in the head", i.e., what the farmers think and reflect upon and what happens practically and externally "in the open" in human activity, i.e., how the farmers acquired practical knowledge and skills are manifested in their actions and operations of milking and conducting care in dairy farming with AMS. The internal and external sides of activity are gradually becoming more intertwined in human work practices and daily life from a developmental perspective manifested in the shift from CMS to AMS (Kaptelinin et al., 1999; Kaptelinin, 2013; Kaptelinin and Nardi, 2018). The socio-cultural dimension of tool mediation which is evident in the fact that mediation enables various *developed* forms of acting in the world. (Engeström, 2015). However, use of tools not only transforms the objects themselves, but is a mutual 'two-way process', where tools reflect previous experiences of using the tool and how to design the tool, i.e., tools embody a set of social practices and their current design reveals a history of particular usage, such as current AMS compared to CMS.

As pointed out by Halverson (2002), the Activity System model has been widely used to analyse various work settings, particularly when there are problems with current or newly implemented technology, where the model enables investigators to identify both micro- and macro-level issues. A suggested approach to frame Activity System model analysis is the eight-step model developed by Mwanza and Engeström (2005), which offers a structured way to describe the activity and sub-activity triangles in the model. The challenges arising on changing from CMS to AMS can thus be considered a shift between two activity systems of milking that raises contradictions, which are managed through learning by developmental cycles from an established care to another new form of care.

3. Method and research design

The present study used a mixed methods research design (Creswell and Clark, 2017; Patton, 2002). Mixed methods is a research design approach where researchers collect and analyse both quantitative and qualitative data within the same study. The growth of mixed methods research design has increased as a way to study increasing complexity on the object of study within the social sciences community. Applying mixed methods design allows researchers to explore diverse perspectives and uncover relationships that exist in multifaceted research challenge. As pointed out by Creswell and Clark (2017), numerous classifications of mixed methods designs are found to exist in the literature, and we have chosen to use triangulation design. Triangulation design is the most common and well-known approach to mixing methods and the main purpose of this design is to collect different but complementary data on the same topic to gain a deeper understanding of the particular research questions and the study's aim. We apply an *inductive drive* which means that the study design is qualitatively driven with the purpose to expand qualitative results with quantitative data (Schoonenboom and Johnson, 2017).

Data triangulation (Patton, 2002) was performed using different data collection techniques (questionnaire, interviews, and field visits). Taking on a *sequential* design (Schoonenboom and Johnson, 2017), data collection started with interviews, in order to gain an initial understanding of farmers' experiences and perceived pros and cons with AMS. Nine farmers (eight with AMS and one who had invested in AMS, but then changed back to CMS), four advisors and two AMS representatives were interviewed (Table 1). The farmers interviewed had 2-8 robots, in use for 2–11 years. The number of cows on the farms varied from 120 to 425, and the sample included farms with both free and guided cow traffic. The farmers were purposely sampled, in order to get as much information as possible (Patton, 2002). The interviews were semi-structured, lasted 1–2 hours and were conducted in real life (all farmers and the company representatives), by telephone (two advisors) or by Skype (two advisors). All interviews were audio-recorded except for the telephone interviews, where notes were taken. The questions concerned experiences of AMS in relation to work environment, production, advisory services, and technology use. The companies interviewed were DeLaval, Lely, Växa Sverige, and a sole proprietorship. The sole proprietor was suggested by one farmer, who contacted the first author due to the project.

A questionnaire was developed based on initial analysis of the interview responses, which means that the questionnaire design was *dependent* on the initial analysis of the collected data from the interviews (Schoonenboom and Johnson, 2017). The final questionnaire comprised 29 questions, some with sub-questions, structured into seven topics: 1) background, 2) milk production, 3) experiences of AMS, 4) experienced mental stress, 5) advisory aspects, 6) future possibilities and challenges, and 7) the work situation. The questionnaire included questions with Likert scales ranging from false to true, multiple-choice questions and five open questions, thus mainly subjective results based on farmers' opinions. In Sweden, no complete official statistics exist that collect information about what kind of milking system a particular farm uses. The Swedish cattle statistics 2021 from the company Växa Sverige comprise 77% of the Swedish cows and 35% of the herds (735 herds) had AMS (Växa, 2021). Therefore, we asked the leading AMS companies, DeLaval and Lely to spread the link to the questionnaire, through their newsletters. In addition, the same invitation was sent through a Facebook group for Swedish AMS farmers that comprises of more than 3000 members. Swedish farmers are well educated and we assumed that this approach could reach many AMS farms in Sweden.

Completed questionnaires were submitted via a link, and therefore anonymous. Accordingly, it was impossible to calculate the response rate. In total, 293 responses to the questionnaire were submitted. Since this study examined the whole milking system on dairy farms, only answers from those who defined themselves as owners are presented in the results section (207 owners). With dropouts due to few questions answered, the results presented represent answers from 188 respondents. When a question concerned a comparison between CMS and AMS, only answers from owners with experiences of both systems were included. No statistics were performed on the questionnaire data given the inductive drive in the mixed methods design approach. It should be pointed out that we did not aim for generalisability with the questionnaire, but to add additional and complementary quantitative data to the qualitative data.

Table 1
Data on the farmers interviewed and the farms visited.

Farm	Nr of robots	cows/ robot	Introd/ end of AMS	Organic/ conventional	Cow traffic	Interview/ field visit
1	2	65	2008	conventional	guided	Interview
2	4	65–75	2010	conventional	guided	Interview/ field visit
3	0	–	2011/ 2018	conventional	–	Interview
4	4	68	2010	organic	free	Interview
5	2 and 1 rotary milk. parl.	60–65	2017	organic	free	Interview
6	8	50	2014	conventional	free	Interview
7	4	70	2011	conventional	free	Interview
8	2	60–65	2009	conventional	guided	Interview/ field visit
9	2	45–50	2008	conventional	guided	Interview/ field visit

Field visits were conducted on three dairy farms in order to gain a deeper understanding of how AMS work and are used in work practice. The farms were located in western Sweden in the former county of Skaraborg and Jönköping, which are two of the regions with the highest densities of dairy cows in Sweden (Svensson et al., 2018). The farms represented: i) a large family farm with a very technology-interested female farmer who had relatively short experience of dairy farming but sometimes tests new technology for DeLaval (Farm 2); ii) a family farm with one female farmer who had medium interest in technology and long experience of dairy farming (Farm 8), and iii) a farm with one male farmer with long experience of dairy production (both CMS and AMS) and an interest in new technology (Farm 9). See Table 1 for data on all three farms. Each field visit took 1–2 h. The first and second field visits were performed by the first author in conjunction with interviews with the farmers. No systematic observations were conducted on the farms. During the farm visits, interviews were held in farm offices, where the computerised AMS software was demonstrated, and in cowsheds where the AMS were installed. Visits were conducted together with the farmer or an employee, in order to observe and gain a deeper understanding of the whole activity system. The third field visit (Farm 9) was conducted as a follow-up by both authors during analysis of the collected data. In addition, field notes, photographs, and video-recordings were made during the visits to the cowsheds.

The collected data were analysed as follows: The transcripts from the interviews and the field notes were read through a couple of times and analysed thematically, using the focal points of AT (Mwanza and Engeström, 2005). An AT lens was then applied to analyse care (Mol et al., 2010; Krzywoszynska, 2015; Tronto, 1998). The questionnaire responses were analysed in Excel, and included in the above thematic content analysis, especially the responses of the open ended questions. The unstructured observations from the field visits were used to complement the other sources of data. It should be emphasised that although the data collection was done sequentially the overall analysis was done through several analytic *points of integration* were quantitative and qualitative components were brought together (Schoonenboom and Johnson, 2017), with the support of the focal points of AT. As pointed out by Creswell and Clark (2017), a primary way to connect qualitative and quantitative data is to use a theoretical framework to bind together the data sets. Qualitative data was used to *illustrate* quantitative results as well as qualitative data was used to describe the underlying *process* for the obtained quantitative results (Schoonenboom and Johnson, 2017).

4. Results

In this section, we apply the eight-step model of focal points developed by Mwanza and Engeström (2005) (subsection 4.1) and present more detailed findings on the focal points related to success factors and challenges in using AMS. We then zoom out and consider the activity of learning and using AMS on dairy farms from a *care* perspective (subsection 4.2).

4.1. Application of the activity system on dairy farms using AMS

To support the analysis of AMS from an AT lens, we used the eight-step model of focal points as depicted in Table 2. The first step refers to

Table 2
The eight-step model of focal points (adapted from Mwanza and Engeström, 2005, p. 459) in the activity system adapted to analyse the activity: *care,* on a dairy farm with an automated milking system (AMS).

Step	Focal points	Description
1	Activity	Managing a dairy farm using AMS described from the perspective of care
2	Objective	The objective on the dairy farm is a viable business, where the farmer or the farm leadership define what viable means. The motives that drive the farmer to use the available mediating artefacts and additional tools to transform the object of activity (the *cows* on the dairy farm) to accomplish a viable farm
3	Subject	The farmer or the farm leadership
4	Mediating artefact and other tools and instruments	External: the milking robot(s), including the accompanying digital systems, is the main mediating artefact, together with digital information systems, sensors on cows, feeding system etc. Internal: knowledge, skills and experience (as a stockperson's eye) of taking care of cows
5	Rules	Safety and animal welfare legislation and other work-related rules, norms, routines and practices that regulate the use of AMS on the dairy farm and cow care. The regulations of actions and interactions within a dairy farm using AMS as an activity system
6	Division of labour	Distribution of responsibility of the work in relation to milk production between the farmer or the farm leadership, family members and potential employees on the dairy farm. To a large part this refers to the work environment
7	Community	Advisors, employees, family members, bankers, friends, colleagues, veterinarians and salesmen
8	Outcome	Good care, meaning a learning and tinkering process aiming for a viable dairy farm, where "viable" is defined by the farmer or the farm leadership

describe the activity under investigation. The second step refers to asking the "why" motive behind the activity. The third step refers to identify the actors/subjects who perform the activity in the first step. The fourth step refers to identifying the main mediating artefact and the tools that mediate this activity. The fifth step clarifies the rules that constrain and regulate the activity. The sixth step tries to grasp and describe how labour is divided and distributed among the actors/subjects who participate within the activity system. The seventh step refers to explaining the community of actors involved in the activity.

Applying the activity system on a dairy farm made continually ongoing work, including collaboration and other influencing factors on the farm, more visible, highlighting the activity within the whole system. The *activity,* in this paper was managing a dairy farm using AMS from the perspective of care. Good care for the dairy farm business was regarded as the *outcome* of the activity system, where *good care* meant a learning process aiming to create a viable (defined by the farmer or the farmer leadership) dairy business, which in turn motivated (the *objective*) the farmer. The *subject* of the system was the individual farmer (or the farm business leadership), who interacted with several *tools*, of which the milking robot was the *main mediating digital artefact*, together with additional tools and instruments, and psychological tools such as a stockperson's eye, to manage dairy production. The main *object* in the activity system was the cow herd consisting of individual cows. Many implicit and explicit *rules*, norms, and procedures are relevant in the case at hand, e.g., safety and animal welfare legislation and other work-related rules, routines, norms, and practices that regulate the use of AMS on the dairy farm and cow care. The *division of labour* in the case referred to the distribution of responsibility of the work in relation to milk production between the farmer or farm leadership, the farmer's family members, and potential stockpersons and/or employees at the dairy farm. The *community* considered in this study was limited, but advisors, bankers, friends, colleagues, veterinarians, salesmen etc. could be a part of the community in this kind of activity system (Table 2).

One of the research questions posed in this study was "What kinds of success factors and management challenges do farmers experience with AMS usage?" The outcomes identified were mapped out onto the focal points of the underlying activity system. Below we present more detailed findings for each focal point, starting with the farmer's objective and general reflections on AMS usage. One central issue addressed was the work environment, under the focal points of *rules* and *division of labour*.

4.1.1. The farmers' objectives and general reflections on AMS usage

In total, 293 responses to the questionnaire were obtained. In order to study the whole milking system on the farm, only answers from those who defined themselves as owners are presented here. Those comprised 207 owners (61% male, 39% female; 50% Delaval (www.delaval.com/), 48% Lely (www.lely.com), 2% SAC (www.sac.dk). According to official Swedish statistics covering 77% of Swedish cows, there were 735 dairy companies with AMS 2021 (Växa, 2021). Following dropouts because of few questions answered, answers were analysed for 188 respondents, of which 154 also had prior experience of CMS. The results from the questionnaire were grouped into owners with experience of both CMS and AMS ($n = 154$) and all owners ($n = 188$). The age distribution was: 3% < 31 years, 13% aged 31–40 years, 34% aged 41–50 years, 35% aged 51–60 years of age, and 15% aged 61–70 years. The respondents had the following distribution of numbers of cows: 3% of the farms had <50 cows; 48% of the farms had 51-100 cows; 28% of the farms had 101-150 cows; 10% of the farms had 151-200 cows; 7% of the farms had 201-300 cows; 3% of the farms had 301-400 cows and finally 1% of the farms had 401-500 cows.

45% of the farms had only one robot. 32% of the farms had two robots, and the rest had more than two robots. Most commonly, there were 51–60 cows per robot (44% of farms), but 14% had a maximum of 50 cows per robot, 36% had a range of 61–70, and 6% had more than 71 cows per robot. Most farms had free cow traffic (62%), conventional production (70%) and at least one employee (83%). The interviewed farmers fitted the descriptions in Table 1.

The overall picture from analysis of the data obtained in interviews, the questionnaire and field visits was that most farmers were positive to AMS usage and deployment of new technology in general. In the questionnaire, some respondents queried the robustness and functionality of the new technology or claimed that it is too expensive, and some had ethical concerns. This ethical concern considered, what he experienced as a focus on technology instead of animals. Two of the farmers interviewed were quite critical of AMS usage. One had returned to CMS and the other was winding down the business due to staffing problems. In the questionnaire responses, more than 90% of owners with experience from both CMS and AMS agreed, in part that introduction of AMS had brought major differences in daily work, primarily with positive changes, and that their work satisfaction had increased (Fig. 2).

None of the farmers interviewed mentioned income or profitability and just a few mentioned time saving as main reasons for introduction of AMS. In fact, some farmers reported that running and servicing the AMS was expensive and that they do not work any less with AMS. However, almost 90% of the questionnaire respondents with experience of both CMS and AMS reported that time spent per cow decreased with AMS, at least to some extent. In addition, more than half of the respondents who answered the question thought that AMS increased profitability, and 70% had seen an increase, at least to some extent, in milk production per cow (Fig. 3).

The questionnaire did not ask about motives for implementing AMS. Instead, it asked an open question about the greatest advantages with AMS. In the replies, 58% of the respondents mentioned flexibility, 41% mentioned improved work environment and less physical strain, and

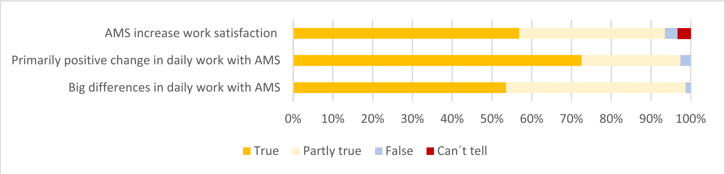

Fig. 2. Differences in daily work and work satisfaction after changing to an automated milking system (AMS) according to owners (n = 154) with experience of both AMS and conventional milking systems (CMS).

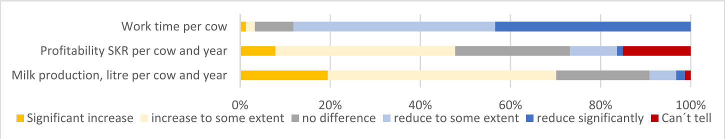

Fig. 3. Differences in profitability, working hours and milk production per cow between conventional and automated milking systems (CMS and AMS), according to owners (n = 154) with experience of both systems.

26% mentioned improved animal health. A few also mentioned interest in robot data, decreased working time, increased milk production, more joy in work, more time for the animals, easier to find staff and improved udder health. When asked why they had invested in AMS, the farmers interviewed gave several reasons. One said that the choice was either AMS or no dairy cows at all, for his own health: "*I want to be able … I don't want to hobble around on new hip joints … my knees must work … I want to be a human being*". Improved flexibility was mentioned by others, possibly including flexibility in private life as robots make it possible to stop work early now and then. Having AMS also lowers the dependency on hired labour. One farmer said: "*If all the staff leave … I can still keep going here for a while*". Some farmers interviewed described AMS as a strategy to attract employees with higher competence.

In the beginning of the AMS era, such systems often had lower production than conventional systems in Sweden (Bergman and Rabinowicz (2013), which is not the case today (https://www.vxa.se/fakta/styrning-och-rutiner/mer-om-mjolk/). One of the advisors explained this as follows: "*Now dairy farmers who are interested in the animals have started to buy robots … in the start it was only the tech freaks who didn't like cows … bit of an exaggeration … but they're still living creatures … and they must come in calf in time and be taken care of.*"

4.1.2. Cows as object

Animal welfare legislation sets rules for dairy production and care of individual cows, but this was beyond the scope of this study. However, AMS usage entails changes for the cows, with the nature of these changes depending on the previous and current system. The changes include increased demands on physical conformation of the cows, such as the shape of the udder and the teats, and the distance between udder and floor. If the cow's appearance does not fit the robot, this could be a problem when milking and the cow will sooner or later be replaced. In cowsheds with free cow traffic, the cow has greater control over her daily life. The stockperson influences the cow's needs by implementing a feeding strategy to attract her to behave in a certain way. Instead of being driven to be milked two or three times a day or standing in her own stall and being milked and fed without doing anything, the cow must choose to walk to the robot.

In systems with guided cow traffic, the possibility for the cow to take responsibility and decide for herself is more limited by smart gates steering her way through the cowshed, but she must still walk to the robot. If not, sooner or later she will appear as a catch cow (or fetch cow, push cow) in the robot system and then be driven or helped to be milked. A majority of the farmers interviewed reported there was always some cow or cows who needed help or must be driven to the robot.

High-ranking cows can be a problem for lower-ranking cows by impeding their access to the robot. According to one company representative; "*some* [cows] *are incredibly dominant and stubborn and refuse to let the other cows pass, so they risk disrupting the whole traffic*". In some cases, farmers mentioned keeping cows with different problems (e.g. udders that did not fit the robot or cows posing a threat to other cows or stockpersons) in another cowshed with CMS. On a dairy farm with both AMS and CMS with a rotary milking parlour, the strategy was to let all heifers calve in the AMS and keep all cows in the CMS. According to the farmer, that resulted in 10 kg more milk per heifer in the AMS compared with heifers in the CMS from the beginning. The farmer attributed this to three instead of two milking occasions per individual in the AMS and a more peaceful environment. If the cow accepts and learns to be milked by the robot, the robot "behaves" more predictably from one occasion to another than CMS operated by different persons.

4.1.3. AMS as a tool – the milking robot as the main mediating artefact

In AMS, the primary mediating artefact is the milking robot, including the computerised system/software that collects, processes and presents the data from the robot. According to the farmers interviewed here, AMS have good functionality and their credibility has increased over the years. Some of the farmers thought that the robots nowadays are very reliable. One said: "*there is no tractor … nothing runs as well as our milking robots*".

A central issue in AMS usage is how to handle the cow traffic. A major challenge is to have highly productive cows visit the robot two to three times a day and then milk rapidly, without delay. The individual cow needs to find her own individual rhythm in order to use the robot optimally. Many cows per robot, slow-milking cows or dominant cows increase the vulnerability in the system. The number of cows per robot varied widely (from 45 to 75) between farms (see Table 1).

4.1.4. Rules - handling of milking robots, AMS data and alarms alter work practices

Implementation of AMS is a learning process among all involved, people and cows. It alters the work practices, comprising actions and interactions carried out when handling the milking robot. AMS companies or advisors could support farmers in the initial phase with implementing new strategies for functional cow traffic, feeding and robot data follow-ups. The AMS software provides a wide range of ratios and an advisor could support the farmer in creating a strategy for selecting ratios to investigate in more detail, and how often to assess each ratio. The results from the questionnaire showed that a majority of the respondents considered that the statements "AMS require more computer experience than expected" and "Much more time is spent sitting in front of the computer screen" were at least partly true (Fig. 4). Almost 90% reported that the AMS provided data that increased their knowledge of the individual cow (Fig. 4). However, one advisor said: "*there is a jungle of key data … so you need to boil these down to: It's important that you do this*!" Later on, other ratios can be more interesting.

One farmer said: *"Lely was really good at helping us with the lists we should check in the morning and those we should check at night"*. The same farmer remarked how valuable the robot data are: "*We identify sick cows really quickly … We have very few cadaver cows or cows that fall seriously ill …. . We are so good at using the lists that we often find cases of sickness before the cow has become really ill."* Another aspect, reported by an advisor, was that it is easy to spend too much time sitting by the computer. She said that routines are very important to avoid this, since: *"Otherwise you can easily spend all your time at the computer and cow care then takes place there"*. According to the questionnaire responses, one-third of respondents felt at least some mental stress concerning interpretation and/or setting up their AMS.

Measurements and collected data from the milking robot's software, *if interpreted correctly*, can mediate information and increase staff knowledge about the cows. Data and robot information were reported to be used as input for discussions and contributed to learning among staff. AT states that a tool comes fully into being only when being used. Knowing when to use the collected robot data and how to use these data, i.e., correctly interpret the figures presented and put them into context based on prior knowledge, is a crucial part of tool mediation. Robot data, when correctly interpreted, can signal problems or act as a good management reference. Some farmers interviewed claimed that when the AMS actually 'identifies' a sick cow, that cow should already have been discovered by humans walking in the herd. It should be emphasised that learning to interpret the collected data from the AMS is an interpretative sense-making process, in which prior knowledge and experience provide the frame of reference for reaching reasonable and sound outcomes. Hence, successful robot management also depends on proper actions taken, such as routines for taking care of the milking robot (washing, maintenance, service etc.) and selecting relevant data and being able to make credible interpretations.

Implementation of milking robots fostered new perceptions among the farmers. During one of the visits, the farmers suddenly stopped talking because she heard a signal from one of the robots that a cow needed help. On another farm visit, that farmer suddenly said: "*I can hear that the robot has problems … now I have to stop. My husband can't hear the noise, but I can*". This could be considered *tool-mediated hearing* (cf. Lundström and Lindblom, 2018 on the topic of *tool-mediated seeing*).

Continual milking round the clock is a prerequisite for AMS, since a stoppage in the milking system is critical. All farmers interviewed reported some stress in relation to alarms from the AMS, but differed in their possibilities to share responsibility for the alarms. "*I can't even go to the cinema without finding out, when I switch my phone back on, that it may have been ringing for an hour*". It is not easy to let employees take responsibility for alarms, since they work in daytime and are employed. One farmer had a rather interesting solution. "*We have learnt how to go on holiday … we travel as far as possible so we end up in another time zone … so we can have the night alarms and the like in the evening … we fly to the USA … there we can walk on the beach and milk cows*!". Of course they need a back-up person at home who can solve problems *in situ*, but the farmer claimed that many problems could be solved over the internet. Good routines for washing, maintenance, service etc. could minimise the alarms, but some will still be present. "*The technology works … but the problem with alarms differs … we can shut off a lot of things and manage, so we avoid alarms … and we decide a lot ourselves*". Nightly alarms caused at least some mental stress for 50% of the respondents and the rest reported insignificant or no stress. When responsible for the AMS all the time, approximately half of the respondents reported stress concerning those issues, but only 10% reported significant mental stress (Fig. 5).

A great majority of respondents had experience of both CMS and AMS, and they considered that AMS increase udder health, animal welfare and cow comfort, at least to some extent (Fig. 6). One farmer reported that they learnt to wash the outside of the robot teat cups with hot water and washing-up liquid once a day, instead of just hot water, and suddenly milk quality considerably improved. This very small and certainly not high-tech or complicated intervention had a great impact: "*No new cases of mastitis*". Nobody had told the farmer about this intervention, he had to draw his own conclusions and learn.

4.1.5. Division of labour – shifting from milker to stockperson

On a small farm, the individual farmer must have competence in many areas. As the business grows, employees, partners or other family members can complement each other with different skills, competences and areas of interest, which can result in higher competence in different areas and less vulnerability. When the number of employees increases, the demand for better communication within the team also increases. The robot software is one such communication channel, where some or all personnel can interpret a cow as a catch-cow or make other decisions about the cows. One of the farms reported arranging a personnel meeting every week and had a designated Facebook group to improve communication. This farm had chosen AMS in order to retain their Swedish personnel, and the farm's stockperson was given much influence in planning the system from the very beginning.

The most obvious shift in division of labour with introduction of AMS seemed to be the change from milker to stockperson. An advisor commented: "*If you have a robot … you often have personnel with more training … or at least experienced personnel*". Hence, the stockperson needs a stockperson's eye, animal interest and skills to act appropriately.

Some farmers described AMS as a strategy to get Swedish staff, as this facilitates communication and mutual interchange of knowledge and experience. Farmers wanted long-term cooperation and stable solutions in order to make working hours more enjoyable. "*You know how it is with a good colleague … they lift you … you are happy about coming in to work and you become a better person yourself"*. The required competences were described as taking responsibility, having a stockperson's eye, thinking autonomously and acting on issues uncovered: "*The robot system is based more on making your own decisions and taking care of things yourself (*as employee) … *so you need a much higher level of basic knowledge compared with standing in a milking pit*".

One of the advisors interviewed summarised success factors for

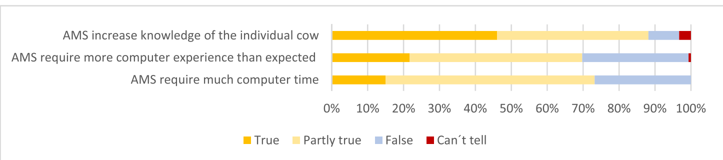

Fig. 4. Opinions on need for computer experience, computer time with an automated milking system (AMS) and increased knowledge concerning the individual cow, according to all owners, with and without experience of conventional milking systems (CMS) (n = 188).

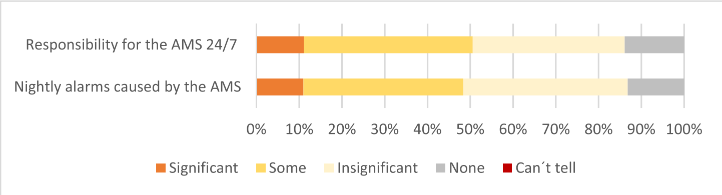

Fig. 5. Perceived mental stress in relation to alarms and full-time responsibility for the automated milking system (AMS) among all dairy farm owners (n = 188).

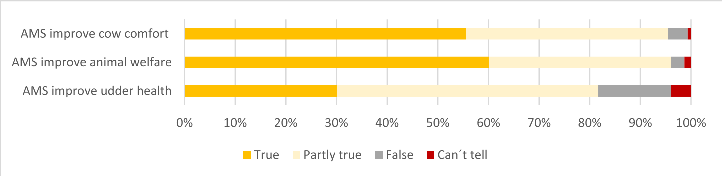

Fig. 6. Differences between conventional and automated milking systems (CMS and AMS) regarding cow comfort, animal welfare and udder health, according to owners (n = 154) with experience of both systems.

farmers in modern dairy production: "*They must keep up with developments but still not be the kind of person who goes for everything … I think they must be very interested in cows and cow comfort … I think actually that cow comfort is the most important thing for production … and they must also be very interested in feed production and they must be very good at managing their staff … There are very few of the small businesses left and those that can manage their staff well, I think, they'll be the winners in the future … So staff management, cow comfort and feed … I think that will take you a long way.*"

A topic of particular interest was farmers' perceived working environment when using AMS, which was considered an important part of social sustainability in this study.

4.1.6. *Outcome of AMS usage on work environment*

More than 90% of respondents to the questionnaire agreed that a change from CMS to AMS decreased the physical strain on farmers, at least to some extent. For mental stress the picture was more varied. Approximately one-third had experienced an increase in mental stress, one-third had experienced a decrease, and the remaining one-third experienced no difference between AMS and CMS (Fig. 7).

Mental stress could have different causes. One of the open questions in the questionnaire was about the greatest challenges with AMS. The most common challenge reported (25% of respondents) concerned the robustness and operational reliability of the robots. The second most common challenge was managing cow traffic and the related feeding strategy (20%). The responses to questions grading stress-related issues reinforced the earlier answers, with 26% of respondents reporting significant stress in relation to AMS vulnerability and risk of downtime and 68% at least some stress in this regard. However, 15% reported significant stress concerning the AMS's operational reliability and 36% at least some kind of stress (Fig. 8).

The farmers had different kinds of agreements with robot companies for service and repairs. The interviews showed that relations with representatives of the robot companies were very important. One farmer said that they were the first to have AMS in their neighbourhood, in 2008. An important reason for choosing AMS, and DeLaval as the supplier, was personal contact with a representative from DeLaval, who helped them. If that representative had sold another brand, the farm would have bought that instead. "*It's about personal chemistry and trust*". Relations with AMS companies caused at least some stress among 25% of the respondents, while the corresponding figure for stress caused by maintenance and service of the AMS was 34% (Fig. 8).

Finally, the respondents were asked some questions about the social situation in their business. More than 95% reported enjoying their work and more than 80% felt good in their current work situation (Fig. 9). Despite this high percentage of satisfied owners, many reported having some problems. Almost 80% believed they worked too much and approximately 50% felt stressed because of their workload and had some kind of physical problems caused by the work (Fig. 10). Almost 25% felt stress concerning the financial situation in the business. [It is worth noting that number of responses to these questions varied quite widely.]

4.1.7. *Community – focusing on advisory inputs*

The community consisted of the farmer(s), employees, the bank, advisors, sellers, vets, colleagues and others connected to the farm and providing information, knowledge or other input influencing the subject, object or tools. When a dairy farm shifts to AMS, the community must learn new strategies and activities, literally simultaneously as they are created. There is actually no competent teacher in that specific system, although advisors, vets or others with experience from similar systems can support the learning process on the farm. At the end of the day, the new social-technical system, with people, animals, technology and structures, must all adapt, or be adapted, to the local prerequisites (Fig. 12).

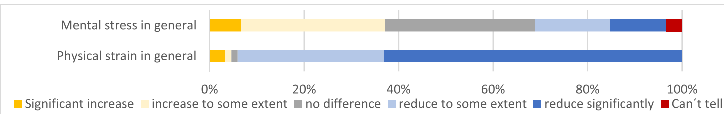

Fig. 7. Changes in mental stress, physical strain and injury risk with animal handling when changing from conventional milking system (CMS) to automated milking system (AMS), according to owners (n = 154) with experience of both systems.

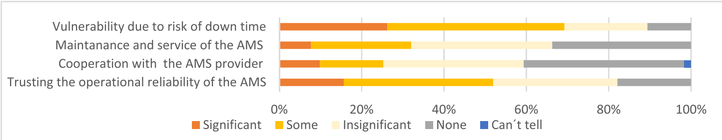

Fig. 8. Perceived mental stress in relation to vulnerability for downtime, operational reliability, cooperation with automated milking system (AMS) retailers, and maintenance and service of the AMS among all owners, with and without experience of conventional milking systems (CMS) (n = 188).

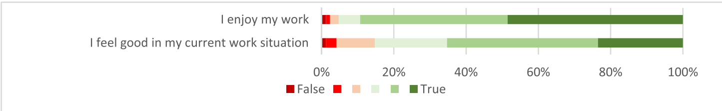

Fig. 9. Owner's opinions concerning their work situation (n = 170).

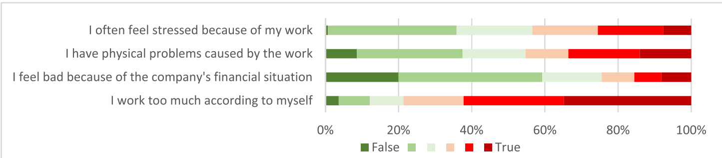

Fig. 10. Owner's opinions concerning stress (n = 145), physical problems (n = 128), financial situation (n = 135) and amount of work ((n = 165).

The respondents to the questionnaire were quite satisfied with the advisory services they bought and a majority bought feed advice. Concerning AMS data handling, there was a gap between bought advisory services and need for support. Approximately 50% of the farmers reported needing more support to improve AMS data usage. However, less than 40% bought some kind of advisory service from AMS companies and less than 30% reported that they discuss AMS settings with their production advisor (Fig. 11).

Advisors could be an important part of the farm community, but not all farmers paid for advisory services on milk production. One farmer said that they wanted to focus more on their family life, and did not have the time to change their work practices and learn. "*We have what we need financially and we don't need anything more complicated than that … we haven't time just now*". Some of the farmers were critical of advisory service quality. One struggled to change the advisory concept that the local firm offered and one bought advisory services from abroad. Some of the farmers were very goal-oriented, wanted continual learning in order to improve their production and claimed that they could not find what they were looking for in Sweden. Some claimed that Swedish dairy advisors concentrate on small and middle-sized farms, leaving the largest and maybe most up-front farmers to develop their production and business on their own: "*The best farmers are driving development*".

Networks of other farmers or colleagues were important for all farmers interviewed. One said that with the telephone, Facebook and YouTube, colleagues are never far away. One of the interviewed farmers described with great satisfaction groups organised by advisors, where farmers regularly exchange experiences and data on their production. In a few other cases, farmers had organised such groups by themselves.

One advisor mentioned that the bank often wanted the farmer to have as many animals as possible in the herd. "*You think this will bring in a lot of money … but that's not always the case*". She claimed that different farmers can handle different amounts of cows per robot "*It depends partly on the farmer and partly on how much they trim the system … how much they're involved*". The goal is to find an optimal number of cows in the specific herd, with the specific staff. There is no point in having more cows without getting more milk. One of the farms had 70 cows per robot and one of their robots milked around 2850 L per day, among the best in Europe. However, another farmer had 50 cows per robot and said: "*We believe that the robots should have a bit of free time … at the start we ran them at the limit and then we had more sick cows … those that don't compete as well, they … fall through … so better with slightly fewer cows … then they milk more and feel better*". That farmer had worked a lot on streamlining the production, but increasing the number of cows per robot was not an option. When they built a new cowshed, production increased: "*There was more space, so the cows were healthier and had better feet … an extra milking … feed all the time and … yes most was positive for the cows … and they thanked us by producing more milk*".

To summarise, this section analysed the data and defined and

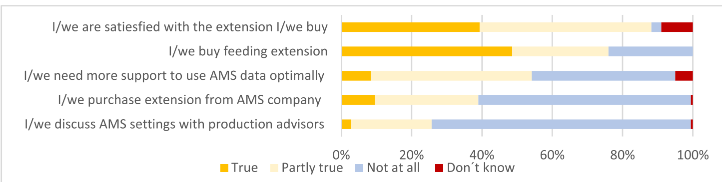

Fig. 11. Questions concerning purchased extension, automated milking system (AMS) support and need for additional support among all owners, with and without experience of conventional milking systems (CMS) (n = 188).

Fig. 12. Images from the field visits.

characterised the elements of the Activity System model. The bigger picture, about the interrelations between the components and the learning dimension within the AMS from a care perspective, is presented in the next section.

4.2. Care practices - the outcome in the activity system

In order to improve *care* and increase the viability of the farm, the individual farmer needs to have the motivation to learn, act and reflect. Learning can thus be considered a practice situated in a social-cultural context (Lave and Wenger, 1991). This learning practice is mediated by individual incentives and involves knowledge, tools and other resources. The activity on the dairy farm and the outcome can be considered two sides of the care component, more or less under continuous learning and improvement. Thus, an ongoing care activity is based on attentiveness, responsiveness, knowledge, and relations (Krzywoszynska, 2015) that keep the whole socio-technical system running and becoming. Care help us consider AMS usage as a dynamic, changing and emerging practice, difficult to predict. We used the Activity System model to highlight the developmental transformations involved when re-organising and re-mediating the current care activity at the local farm based on the contradictions that arise on shifting from CMS to AMS. Resolution of these contradictions could be considered a developmental cycle in running a dairy farm.

4.2.1. Two different activity systems for cultivating care

As seen in section 4.1, changing a dairy system from CMS to AMS results in contradictions (problems, challenges or benefits) in many parts of the system. The majority of farmers reported that the benefits outweighed the problems when changing from CMS to AMS, but a broad range of new ways of care needed to be developed. We identified three major contradictions when changing system from CMS to AMS: i) ongoing milking round the clock, ii) cow traffic and related strategies, and iii) care accomplished by combining robot data with a stockperson's eye. Although these contradictions only had an impact on certain areas of the Activity System model (Fig. 13), the model should be considered as a web where changes in one entity result in changes being distributed across the whole system.

The *first contradiction* is that milking goes from being a task performed twice or three times a day to an operation that runs continually. The impact on the physical and mental work environment on study farms, as discussed in sub-section 4.1.6, included both positive and negative changes. However, milking 24/7 means that milking are especially vulnerable to problems with the AMS, since a robot can only milk one cow at a time and, with a full schedule for the robot, there is little space available for recouping lost time. Dairy cows are sensitive to irregular milking, which can result in decreased milk production and, on longer time horizons, health issues. Thus, the AMS must not be interrupted or, if interrupted, must be re-started quickly. Therefore, it is important that the farmer develops good routines, has the AMS serviced regularly and reacts quickly to alarms.

The *second contradiction* with introduction of AMS is how to manage the cow traffic. Either cows move as they wish in the cowshed (free cow traffic) or there is a gate system that steers cow movements. A critical influencer of cow traffic is the feeding strategy, which should tempt the cow to visit the robot. Regardless of the system used, voluntary milk visits are essential in order to use AMS capacity effectively. To maintain high production, each cow must be milked two or three times a day. Thus, a major challenge is to have cows with udders that fit the robot and that are also highly productive and voluntarily visit the robot two to three times a day, milking fast without delay.

The *third* and most important *contradiction* in care of an AMS farm concerns the change from looking at every cow and touching every udder to letting the robot do the milking and making use of robot data, in combination with a stockperson's eye, in order to develop good care. First, decisions must be made concerning what data to look at and when, and how to interpret these data, in order to provide good care. The digital robot software can provide much data, but cannot measure cow health directly. Hence, a person needs to interpret the information from the software and relate the information to prior experience and acquired knowledge, as well as having first-hand contact with the cows. Therefore a stockperson's eye is still needed in AMS (Fig. 14). When robots have

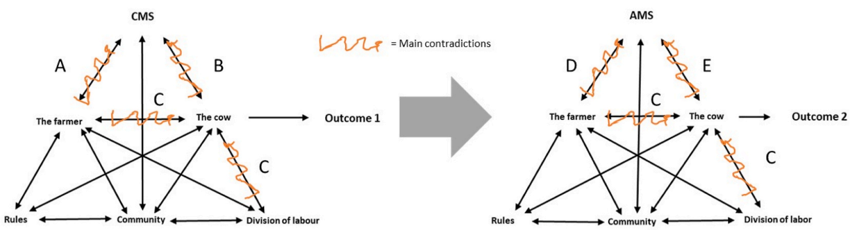

Fig. 13. A change in dairy system from conventional (CMS) to automated milking (AMS) requires adaptation, learning and thus a change in care. Contradictions could be problems, challenges or potential for change. Identified contradictions depicted in the Activity System model are: A) Physical strain, B) limited access to cow data, C) stockperson's eye, D) milking 24/7 and use and interpretation of robot data, and E) cow traffic and related issues. It should be emphasised that the contradictions are present between the same entities in CMS and AMS, but the content of the contradictions differs.

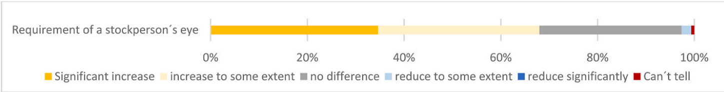

Fig. 14. In requirements for a stockperson's eye after change from conventional to automated milking systems (CMS and AMS), according to owners (n = 154) with experience of both systems.

taken over the milking, time and space for development and use of a stockperson's eye must be incorporated in other kinds of daily work or by spending time in the herd, to complement the available robot data.

According to one of the advisors interviewed, "(AMS) *actually needs a better stockperson's eye*". That was confirmed in the questionnaire, where almost 70% reported a greater need for a stockperson's eye to some extent on changing from CMS to AMS (Fig. 14). Just a few percent believed that this requirement decreased to some extent when implementing AMS. One farmer expressed it like this: "*The robot system works really well if you want to be half a day too late all the time … because all facts are based on the cow having visited a feed station or a robot … that's where it transmits all information on the amount of milk it produces, or how much it weighs or how much it eats … a sick cow doesn't go to the feeding station, a sick cow doesn't go to get milked … so you don't react until it's too late*!"

Accordingly, robot data alone are not sufficient for provision of good care, while the same is true for a stockperson's eye alone. In Fig. 15, the AT lens is applied to two Activity System models based on two different mediating artefacts: robot data and a stockperson's eye. It is clear that neither kind of care is good enough on its own, rather both kinds are needed. Another farmers said: ""*You can't gauge the general condition of the cow from data*", and continued: " *… when you enter a robot system you have to have that feeling that something might be wrong … go up and check, temperature … then you can react early and prevent the cow from getting very sick*". One of the farmers interviewed claimed that the robot is a decision support system, meaning that one cannot depend on the technology alone to obtain a good result, but it can certainly support and act as a good check-up tool (Fig. 16).

With many cows in the herd, it is difficult for the stockperson to recognise all individuals. However, one farmer said: "*We spend much more time on the animals now* [compared with CMS], *we don't need to talk to each individual cow … and each individual might not want to talk to us … and they are very clear about that … but we have one who always wants to engage and help … and who comes and tells you in the morning if something has happened … she runs over and stands there by the gate … then you know there is a calf on the floor or something*". This farmer did not recognise all the individual cows in the herd, but she did recognise the very social cows. Likewise, she and others recognised cows repeatedly listed as catch cows. Thus, relations between the stockperson and cows within a herd depend much on the individuals (both cows and humans). Catch-cows are reported by the robot and identified by the cow's unique number. Cows that want to be scratched or stroked or that want to 'tell' the stockperson something try to communicate with the stockperson, and the stockperson must be attentive and have the competence to interpret and respond adequately to the cows' behaviour. This demands relations between humans and non-humans, in examples of mutual care. For stockpersons with a poor or limited eye for stock, such relations will not be developed. As one of the farmers stated: "*Not everyone has it*". Unfortunately, those who don't have it won't miss it, or will find it difficult to develop.

4.2.2. *Requirement of care competence among advisors*

Advisors also need experience and a stockperson's eye. In one interesting example, a farmer talked about a very competent foreign advisor who wanted to see the wholeness and started the visit with approximately 1 h by himself in the cowshed. "*How the cows are, and the like … that gives him an idea of whether it's working … or not working. He doesn't need to see any figures and things … he sees that in the cowshed … how many are lying, how many are ruminating, what the manure looks like … the coat … that gives him a feeling for when things aren't right … … then he starts to check the data … milk yield, feed, diseases and the like*". This is an example of a person first using his attentiveness, experience and knowledge to provide advice concerning care for dairy cows. Later, different sources of robot data are used as input to the discussions, which also requires theoretical knowledge, to support the farmer in a broad range of topics.

One advisor said that she started with a university degree in agriculture and then worked for eight years in practice in Sweden and abroad. "*Then I changed sides.*" She commented that she had gained experience both from dairy production and from being the farmer in an advisor-farmer relation: "*Piecemeal advice is not good!*" but "*it's difficult to cover everything*".

Automated milking systems, or other systems that provide a lot of data (Dela Rue et al., 2019), change farmers' need for support. Data that were previously handled, interpreted and presented to the farmer by advisors are now produced, interpreted and available on the farm. This changes the role and possibly the power relation between advisor and farmer.

One farmer made a comparison between crop production and dairy production advisors. "*I would say that crop production and economics are easier than the production side …* [milk production] *is tricky … many crop*

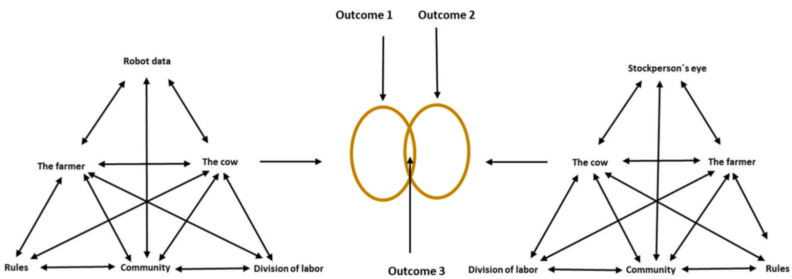

Fig. 15. Two interactive Activity System models applied to different mediating tools, robot data and stockperson's eye, resulting in two different kinds of care outcome: (1) Care based on robot data and (2) care based on a stockperson's assessment. Outcome 3, care based on both systems, would give the best results. (Based on Engeström (2001), p. 136).

Fig. 16. Images of cows from the field visits.

advisors have their own farm, and grow crops and test products … so even it if it is at hobby level, they are passionate about their work … but there are no young women who work as production advisors and run their own dairy farm". Thus, first-hand experience-based competence must come through their work as an advisor, so 1) farmers play a central role in educating advisors; and 2) it is easier to start an advisory career with interventions and support related to some kind of robot data or control. Another farmer expressed it thus: "*Unfortunately today there are many very young* [advisors] *with little experience from their own farm … so you have to sit and teach the advisor about a lot of things … and pay 900 Krona an hour for that*".

To summarise, care in dairy farming is a complex matter. As one farmer said concerning what it takes to be a successful dairy farmer: "*It's quite complex to run a farm like this. You have to go to school and learn things … you have to think that it's interesting to calculate and see connections here and there … many think that you're only a farmer, but it's not that easy, you have to be an all-rounder and know a lot … you have to be an economist and a stockman, handle technology … you should also have a social network … to cope … to ring for help*". New care processes need to be developed for everyone involved, humans and non-humans in an ongoing learning process. This care encompasses robot data, which are used as input for making proper decisions on results to check at different intervals and in interpretation of viewed data, to plan feeding strategy and cow traffic, teach cows how to be milked, choose regular intervals of service for the AMS, handle alarms, find staff and advisors if needed and finally combine information from robot software or other devices with a stockperson's eye, in order to provide as good conditions for the cows as possible.

5. Discussion

The care perspective applied in this study to robot milking is opposed to the dominant technology-oriented view on agricultural production, commonly referred under labels like smart farming, digital agriculture and agriculture 4.0 (e.g. Ayre et al., 2019; Clay et al., 2020; Finstad et al., 2021; Klerkx et al., 2019; Lioutas et al., 2019; Rijswijk et al., 2021). Applying the care perspective emphasised the need to use a systemic perspective in farming, which were stated by, for instance, Darnhofer (2021), Klerkx et al. (2019) and Rijswijk et al. (2021). Using the perspective of care, considers the interdependencies between farmers and the technologies in robot milking (Finstad et al., 2021; Rijswijk et al., 2021), because AMS provides meaning only when it is enrolled in its work practices (Suchman, 2007). Applying the socio-technical perspective to dairy farming implies that the AMS is dependent on the farmer's work practice in which it will be implemented and used in such a way that it shapes the nature of the work practices of running a dairy farm (Finstad et al., 2021; Rijswijk et al., 2021). We applied the care perspective because of its criticism of the technocratic and productivist paradigm (Puig de la Bellacasa, 2017), where care is characterised as the result of all practices that make technology and knowledge work, considering care as a patterning of activities.

The aim to study Swedish farmers' experiences and reflections from the perspective of care in dairy farming using AMS was examined here based on two research questions: 1) What kinds of success factors and management challenges do farmers experience with AMS usage? and 2) How do farmers view their work environment in this kind of system?

We used AT to enable a more structured approach to investigating and analysing care in the socio-technical system of AMS in dairy farming. The focus in AT on studying contradictions during technology mediation also provided insights for learning and development when shifting from CMS to AMS, aspects well-aligned with care.

The majority of farmers who participated in the study saw more advantages than disadvantages with AMS. A possible bias is that farmers who have made large investments in AMS might focus on the advantages. However, the obvious improvements in physical health and workload for the majority of the farmers, despite increased mental stress caused by frequent alarms, the increased profitability and milk production for most farms provide a positive picture of AMS in Swedish dairy production. However, farmers also reported poor service from the AMS companies, problems concerning the entire management on the farm and challenges to find competent employees as well as advisors.

The findings showed the importance of local adaptation. The main starting point was the interests, motives, knowledge and experience of those responsible for milk production. There was no general 'truth' concerning e.g. the optimal number of cows per milking robot. Some farmers preferred to intensify production by having many cows per robot, while others chose a lower number of cows per robot to increase cow health and cow comfort, thus increasing milk yield per cow. Variation in the number of cows per robot was also reported in a survey of Canadian dairy farms (range 27–72 cows per robot, median 52) (Tse et al., 2017). Different farmers have different motives and goals for their businesses, as long as they consider it viable. High milk production and profitability are not the only motives for a farmer, e.g. cow comfort, flexibility in work hours, work satisfaction etc. are other relevant motives.

5.1. *Contributions, challenges and need for an interest in animals and a stockperson's eye*

The most important finding of the study was the need for a stockperson's eye or a *professional vision* (Goodwin, 1994) regarding cows. Less surprising was the need for *tool-mediated seeing* (Goodwin and Goodwin, 1996), to choose and to use robot data in a value-creating way. Even though milking robots provide much data, the stockperson's eye cannot be replaced. Thus, *professional vision* and *enhanced professional vision* (Lundström and Lindblom, 2018) using robot data are needed in order to use AMS effectively. In this context, *tool-mediated seeing* (Goodwin and Goodwin, 1996) means being able to interpret credible robot data and apply the outcomes in care for cows. This study identified two examples of *tool-mediated hearing*, when a farmer could hear that the robot needed "help".

On implementing AMS, farmers working with robot data enter a continuous learning process, in which they start to recognise what data to focus on and learn how to apply and use it in practice to manage the individual cow and the herd. This means that farmers develop *tool-mediated seeing* in order to improve their *professional vision* (Goodwin, 1994). The experienced farmer's combined *professional vision* and *tool-mediated seeing* emerge from the process of learning to choose, interpret and correctly use data from computerised technology like AMS, which we call *enhanced professional vision* (Lundström and Lindblom, 2018). To be successful in dairy production, farmers need to adapt their practice and technology to the local situation, thus improving their *care*, where care is the sum of all practices that make technology and knowledge work (Krzywoszynska, 2015).

Another way to express this is that AMS is not for high-tech farmers, but for cow farmers (Driessen and Heutinck, 2015). This was obvious from the responses in interviews and to the questionnaire, and has also been mentioned by others (Butler et al., 2012). The robot technology can be used as an expert system, a decision support system (Lindblom et al., 2017) or for check-ups. Our results show that AMS technology cannot supersede human experience and a stockperson's eye in providing good care in milk production. To use AMS effectively, farmers also need to develop their *enhanced professional vision* (Lundström and Lindblom, 2018) to choose and interpret robot data in specific situations in an on-going learning process. Consequently, good care in AMS dairy production must be based on AMS data and on interest in animals and a stockperson's eye. This applies to the farmer, the stockperson and the advisor. The challenge for educators and the dairy industry is to facilitate more systemic training of future farm staff and dairy production advisors.

There are training opportunities available for people working with cows concerning the skill to read cow behaviour. For example, Växa Sverige, the largest advisory service company for dairy production in Sweden, educates animal handlers in reading so-called cow signals, i.e. how to interpret cow behaviour (https://www.vxa.se/). However, reading cow signals is a rather technical description concerning cow behaviour, which needs to be recognised and then interpreted and acted accurately upon. In order to interpret the signals from cows, the individual needs attentiveness, experience and knowledge of cows, which are the key elements in the care perspective.

The care perspective builds on the ethics of care (Gilligan, 1977) as a relational matter, i.e. not as acting on, but rather living with (Puig de la Bellacasa, 2017). Care ethics do not build on roles and moral principles, but on interdependent, contextual relations in practice, in the vicinity, in relations where people have or take responsibility (Puig de la Bellacasa, 2017). Instead of rules or moralities, care ethics build on compassion, sympathy, relations and mutual dependency (Lonkila, 2021; Puig de la Bellacasa, 2017), creating good solutions in practice within a local situation (Mol et al., 2010). To care is to be in a relationship with humans, non-humans and/or natural settings, and continually develop relevant patterning of activities.

In the technological fix approach (Black, 2000), which is well-aligned with the dominant technology-oriented view on agricultural production, some challenges persist. In our view, there is a lack of ongoing discussion concerning the requirements for establishing good relations built on mutual dependency between the user of technology and the non-human or natural setting in which the technology facilitates action in order to deliver good care. The possibilities to build (mutual) good relations through a filter of technology, i.e. by *tool-mediated seeing*, are currently limited. On the contrary, there is a risk of the rapid and recent implementation of technology increasing the distance between humans, non-humans and natural settings that they act upon. According to AT, the tools used, i.e., AMS as the main mediating artefact, should not be viewed as an interaction device between the farmer (subject) and the cows (object). Rather, the interaction with cows is *mediated* by the AMS. Consequently, the use of technology increases the need for alternative strategies for creating *mediating* relations. Based on our findings, a relation-creating strategy with AMS might be spending time within the herd, and systematically observing the cows. It is possible to use AMS without other forms of relation creation, but the result will not be very satisfactory, as is obvious from the results in this study. Since the experienced dairy farmer with a good stockperson's eye knows the importance of contact with individual cows (i.e. relation creation), they develop strategies to achieve this.

Using care as a perspective forced us to think of mutual dependences and relations to humans, non-humans or natural settings in the case of AMS. Use of technology also increases the need for new relation-creating strategies among decision makers with responsibility for strategic decisions, who must have an understanding of the importance of reciprocal relationships. As Mol et al. (2010: p 15) state: "*Technologies …. do not work or fail in and of themselves. Rather, they depend on care work*". Without understanding and insights into the dependence on relationships with humans, non-humans and natural settings, it is easy to overlook the fact that performed measures are necessary, but not sufficient, to cultivate good care. AMS is a very clear example of connections that exist everywhere, but are not always noticed. AMS is an animal-dependent operation using technology, but cows are high-value individuals with possibilities to live long lives. Cow comfort or a holistic view on the dairy system is important to achieve business viability. Dairy farmers often have a great interest in animals and a stockperson's eye, and thus understand the value of human-cow relations. The need for good care based on relations between humans, non-humans and natural settings also arises for instance in crop production. However, the connections and mutual dependencies are probably not as obvious as with cows in AMS. Cow comfort and soil health are interrelated by the holistic perspective, but the cow is much easier to recognise, acknowledge and relate to than the very small creatures in the soil. Cow comfort also has a direct and obvious influence on farm profitability, in both the long and short term, while soil health is much more elusive. Nevertheless, the care perspective shows that a relational approach towards non-humans and natural settings, based on attentiveness, experience and responsiveness, could be valuable in a broad range of agricultural topics. We are hopeful that the socio-technical systems approach to dairy farming with AMS will have additional attention, as recent publications within the field emphasise the need for studying the work practices from a systemic perspective (Darnhofer, 2020; Finstad et al., 2021; Rijswijk et al., 2021). We interpret recent attempts from what Rijswijk et al. (2021) call socio-cyber interactions and socio-physical interactions as a perspective of care.

5.2. Limitations

The scope of this study was narrow and there were some limitations that could have influenced the results. For example: i) No farmer with only one robot was interviewed, but single robot farmers was the dominating group among questionnaire respondents. ii) The interviewed farmers came from a limited area within Sweden. iii) The field visits were limited in scope due to the pandemic. iv) All results from the questionnaire are not reported in this paper. Finally, v) since there is no Swedish actor with statistics on all Swedish AMS farmers, we chose to use newsletters from the two dominating AMS companies and a Facebook group for AMS farmers to invite respondents to answer the questionnaire. Swedish farmers are well educated and due to an investigation 2021, 73% of all Swedish farmers used digital tools for communication and 87% have rather good or very good internet connection on their farms (lantbrukspanel_maj_2021_den-digitala-lantbrukaren.pdf (landshypotek.se). That was the main reason for us to use digital newsletters and Facebook to reach the farmers, even though we realised that it may have precluded some AMS farmers from answering the questionnaire. This strategy also, made it impossible to calculate a response rate. However, this study do not claim any generalisability, rather it has a descriptive approach. Despite these weaknesses in collection and analysis of the data, the results are interesting and provide deeper knowledge and insights into the socio-technical system of AMS in dairy production.

The purpose of using a mixed methods research design conducted via triangulation was to combine several sources of quantitative and qualitative data to reveal how care on dairy farms with AMS was manifested. This research design and analysis of the collected data is rather descriptive, and aims to provide initial step towards an increased understanding of how care is manifested as a socio-technical system of dairy farming via an AT lens. The AT lens was mainly due to the care perspective not having its own analytic method. The analysis was inspired by thematic analysis but constantly informed by AT and its focal points and their interrelatedness. However, there were trade-offs between the level of granularity for the analysis and the concepts included in the analysis due to the scope of the paper. Our main focus was on care as the main activity, and future work could go into much more detail about how the patterning of activities are realised in practice via the entities and basic principles in the AT framework at several farmers with AMS. The AT lens proved suitable for the analysis, and the Activity System model visualised the main contradictions within the socio-technical system of dairy farming. Using AT as a lens for studying care, including the Activity System model, forced us to pay attention to all entities in the model and interrelations that might otherwise have been neglected, as well as focusing on the learning and development perspective originating in the notion of contradictions. However, there were some limitations with the use of AT, e.g. it can be rather cumbersome to apply and, as in Rogers (2012), it was used here as a conceptual tool-making sense of a dairy domain rather than for offering ready-made answers. While AT is one of the most prominent approaches used for studying socio-technical systems, its success still relies on the analyst's skill in interpretation and orientation when analysing the collected data and relating these to AT concepts (Lindblom and Alenljung, 2020; Rogers, 2012). Therefore, it takes time to obtain an acceptable level of understanding and competence in using AT appropriately. However, the structure provided by the AT lens and the Activity System model offered a viable way to unravel several aspects of the care perspective.

5.3. Future work

This study suffered from limitations regarding the amount and duration of field visits on dairy farms with AMS. Future work should involve more extensive ethnographic studies with participatory observations on one or a couple of specific farms, in order to collect more in-depth data and gain further insights on care. Future work should also involve a deeper theoretical analysis of the relations between the care perspective and the entities and basic principles of the AT lens, in order to confirm that the approach used in this study can provide viable insights on how technology such as AMS is integrated into the work practices on the farm.

Some farmers reported mental stress in handling and interpreting robot data. Examination of farmers' digital work environment, by integration of knowledge and methods from Human-computer interaction (HCI), in particular from a user experience (UX) perspective, is one future need of research. In HCI, researchers study and evaluate the quality of interaction in a systematic way (ISO 9241–210:2019; Lindblom and Alenljung, 2020).

Future work could also apply the care perspective through an AT lens to other agricultural systems. If farming should be considered as: "*an ongoing and open process of transformation, involving manifold humans and nonhumans who are themselves conceptualised as processes connected to other processes.*" (Darnhofer, 2021, p. 15) and "*The aim is thus to identify and better understand how relations and constellations enable or impair transformation and change, how these relations are constantly made and remade, stabilised or undone*" (Darnhofer, 2021, p. 15). Then, the perspective of care, analysed with AT, would be a valuable tool and a possible way forward.

To conclude, the obtained contributions in this paper emphasise the need to consider the rapid increase of digitalisation in agriculture beyond the technocratic paradigm. In a similar vein as addressed in the emergence of Industry 5.0 (Longo et al., 2020), we want to highlight the need for a similar emerging Agriculture 5.0, which we view as taking more profound care perspective. Industry 5.0 is characterised as an approach that focuses on the symbiotic relationship between technology and humans as well as addressing the need for putting the farmers and their work practices, ethical issues, and value-based aspects back at the centre of attention.

6. Conclusions

By focusing on the ongoing transformation of actions that characterise handling of contradictions as expansive cycles of learning, application of an Activity System model to dairy farming revealed that the work practice of care is constantly evolving when using AMS. The activity of managing a dairy farm for producing milk is continual, and the alterations and modifications of the milking robot and its related tools change work practices, in turn re-shaping the tools used in dairy farm management.

6.1. Success factors and challenges in AMS

In successful dairy farming with AMS, willingness to learn, adapt to the local situation and continually improve practices seem to be the most important factors. This requires learning strategies for the farmer and strategies to get support from others, e.g. on feeding strategy, crop production, interpretation of data, cow comfort, service of technology etc. Conditions will differ depending on farm size and number of people involved. With more people involved, knowledge and competence could be differentiated. In that case, competent people who understand why things are done, are attentive and then act upon what they have found are needed. This study revealed the importance of experience and a stockperson's eye, in combination with *tool-mediated seeing*, for developing *enhanced professional vision* and good care in dairy farming. A good stockperson has broad competence, combining a systemic view of cow health and comfort, assessed using a stockperson's eye, and experience with robot data. Finding competent staff for AMS farms is a major challenge. Another challenge is finding advisors with experience and broad competence in AMS dairy production. Combining *robot-mediated seeing* with a stockperson's eye is demanding, but is an important component of achieving good care in AMS dairy production, whether farmer, stockperson or advisor.

6.2. Farmers' experience of work environment in AMS

Increased flexibility in work and better physical health appear to be important driving forces for implementing AMS. Handling alarms was mentally stressful for almost half of the respondents to the questionnaire. Other issues that caused mental stress were perceived AMS vulnerabilities. A questionnaire-based survey clearly showed that AMS had brought major, primarily positive, changes in daily work and increased work satisfaction for most farmers. More than 80% of the respondents reported feeling good in their work situation and enjoying their work.

Author statements

The authors declare no conflict of interest.

Declaration of competing interest

The authors declare that they have no known competing financial interests or relationships that have influenced the work reported in this paper.

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This thesis: 1) Introduces methods and theories from the field of human-computer interaction in the agricultural domain, to improve design and development of digital technology. 2) Introduces the concept of care to increase our knowledge about farmers' technology use in their socio-technical system or practice concerning, fertilization with CropSAT and automated milking systems, as well as to introduce a relational perspective in agriculture. 3) Evaluate two theoretical lenses to study care in practice, Distributed Cognition and Activity Theory.

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