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Considering farmers’ situated expertise in using AgriDSS to foster sustainable farming practices in precision agriculture

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Abstract. *Agriculture is facing immense challenges and sustainable intensification has been presented as a way forward where precision agriculture (PA) plays an important role. More sustainable agriculture needs farmers who embrace situated expertise and can handle changing farming systems. Many agricultural decision support systems (AgriDSS) have been developed to support farm management, but the traditional approach to AgriDSS development is mostly based on knowledge transfer. This has resulted in technology being considered an isolated phenomenon, not adapted to farmers’ actual needs or their decision making in practice. This study examined farmers’ use of AgriDSS in relation to their situated expertise and how they manage their fields. The theoretical framework of distributed cognition (DCog) was applied in investigating and analyzing farmers' use of a software tool called CropSAT, developed for calculation of variable rate application (VRA) files for nitrogen (N) fertilization from satellite images. The results revealed that CropSAT could function as a tool supporting decision making and development of situated expertise among farmers, improving their care perspective.*

Keywords. *Sustainable intensification, care, situated expertise, distributed cognition, agricultural decision support systems*

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Introduction

Agriculture is facing immense challenges, including a need for increased food production and growing concerns about environmental issues, biodiversity, and climate change. One approach proposed to solve these challenges is *sustainable intensification*, which aims to increase food production from existing farmland while minimizing the environmental impact, in order to secure the needs of present and future generations (Garnett et al., 2013). 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 (Woodward et al., 2008). Thus progress will clearly require integration of major approaches within research and development of agriculture (Jordan & Davis, 2015). History has shown that there are no generally applicable agricultural development models and instead agriculture has to be flexible to its environment. For this reason, technical and organizational developments are considered important issues (Leeuwis, 2004). In general, 'sustainable' agriculture will require farmers who can manage and co-ordinate more variable farming systems, which means they will need a broad spectrum of knowledge that could be described as *complex, diverse,* and *local* (Leeuwis, 2004). Within the technical dimension of large-scale sustainable agriculture, precision agriculture (PA) plays an important role and introduces a paradigm shift by considering fields as heterogeneous entities with within-field variation in many aspects. Various forms of PA technology provide possibilities for arable farmers to recognize and handle variations to a much better degree than ever before (Aubert et al., 2012). It has been argued that various kinds of information and communication technology (ICT) systems would be a major contributor to the transition towards sustainability, with agricultural decision support systems (AgriDSS) constituting one important example (Aubert et al., 2012).

However, many of the AgriDSS developed to date are for various reasons seldom used to their full potential (e.g., Matthews, 2008; Thorburn et al., 2011; Aubert et al., 2012). Briefly summarized, the traditional and normative approach of AgriDSS development is based on the knowledge transfer perspective, which has resulted in many AgriDSS not being suited to farmers' needs due to low credibility and usability. In particular, it has been claimed that research often considers new technology as an isolated phenomenon, while end-users consider it as one part of a complex system (Röling, 1988). This lack of a systemic perspective results in failure to place technology in the context in which it will be used. Consequently, available technology is often not adopted to, or situated in, farming praxis (Röling, 1988).

The experienced farmer can be viewed as an expert on their own farm, after developing a considerable amount of tacit knowledge in their farming practice (Hoffman et al., 2007). Experienced farmers develop so-called *situated expertise* in their ways of solving problems and interpreting domain critical situations. This involves being aware of the fact that they are required to act, even though the intended action will not be optimal, but is considered necessary given the current situation. An expert has been defined as a person who uses a holistic approach guided by intuition and prior experiences from similar, but not identical, situations in the evaluation of complex situations (Dreyfus & Dreyfus, 2005). A related concept is *care*, which develops from experience in practice and constitutes attentiveness, responsibility and competence (Krzywoszynska, 2015). In sum, care is the result of all practices that make technology and knowledge *work*, where '*work*' in this paper is considered actions towards moving in the direction of increased sustainability. The inter-dependence between care and situated expertise has been pointed out in the farming literature, and in order to increase sustainability in agriculture it is therefore necessary to acknowledge, respect, and support farmers' situated expertise and care (Krzywoszynska, 2015).

The overall aim of this study was to examine whether AgriDSS could support the development of situated expertise and care among farmers. The theoretical framework of distributed cognition (DCog) (Hutchins, 1995) was used as a lense when investigating and analyzing farmers' use in practice of a software tool called CropSAT (www.cropsat.se), developed for calculation of variable rate application (VRA) files for nitrogen (N) fertilization from satellite images. In a workplace study, the unit of analysis was broadened to involve the whole socio-material system of farmers' decision making, including other people and different kinds of tools and artefacts. The analysis concentrated on how CropSAT functions as a tool to support decision making, promoting social learning and development of situated expertise and care, but also the opposite, how a lack of social learning situations could be crucial for the development of these perspectives. Overall, the study examined how farmers' existing situated expertise and care could be employed in the application of AgriDSS in PA, in order to identify whether these ICT systems could provide usable and credible support in decision making and social learning in farmers' current work practice.

Background

Experienced farmers as situated experts

Farming is a complex, dynamic system, involving products and impacts that are difficult to measure, let alone predict and control (Woodward et al., 2008). A central difficulty is that exactly the same situation will never appear again, so it is impossible to repeat an action to investigate better alternatives under exactly the same conditions. Hoffman et al. (2007) remarked that '*farmers live in a kind of life-long longitudinal case study set-up*'. They use a phenomenological approach to generalize and understand their context, which means that their learning process is more experiential than experimental. Their everyday life and work is the basis for their decision making and learning processes. Comparisons with formal knowledge and with results obtained in earlier years and in different places are made either consciously or unconsciously, to form new knowledge and rules of thumb. Thus, the experienced farmer could be considered an expert on their farm and could be said to possess a considerable amount of tacit, situated knowledge (Hoffman et al., 2007; Lindblom & Lundström, 2014). Experienced farmers have developed operating skills to "know what" to do, "know that" action is required and also "know how" to solve a problem (Baars, 2011).

Dreyfus and Dreyfus (2005) developed a five-stage model of the cognitive activities involved in directed skill acquisition, ranging from novice, advanced beginner, competent and proficient to expert in real-life, complex situations. According to their definition, expertise develops due to prolonged experience and engagement. Experts use intuitive decision making with a basis in experience and tacit knowledge from earlier, similar situations to solve complex problems. A problem is solved by comparing the actual situation with prior experience from other similar, but not identical, situations. Accordingly, an expert is an engaged individual who uses intuition based on engagement and prolonged experience to evaluate a situation from various perspectives and act upon it adequately. During the progression from a novice to an expert, the skill acquisition process moves from relying on and using abstract rules (e.g., following a recipe) to developing the ability to perform intuitive evaluations of the particular situations. Thus experts do not follow rules when evaluating new situations and instead they apply sophisticated heuristics to the existing facts as a basis for their decision making. Formulating rules from intuitive knowledge is a way of making the situation more simplified, whereupon it is no longer considered expert knowledge. Dreyfus and Dreyfus (2005) claim that increased experiences are followed by decreased concern for assessments of isolated elements, cultivating a holistic perspective. A beginner uses rules just like a programmed computer, while the expert does not. Thus a computer could follow explicit rules and perform better than a beginner, but could not rival an expert whose experience-based, intuitive process is fast, holistic, and accurate. In line with this argument, a skill is never produced by internalizing rules and, accordingly, an expert system could never perform as well as an expert in handling complex situations. Those complex situations are difficult, if not impossible, to define in rules and therefore difficult to solve with a computer program. If the tacit know-how skills possessed by expert farmers could be explicitly addressed in some kind of guidelines or AgriDSS, they would be valuable for others lacking expert knowledge and experience. However, expert farmers have difficulties externalizing their tacit knowledge in formal explanations, since the expertise is no longer dependent on rules, but rather on pattern recognition through experience-based intuition. Nevertheless, an AgriDSS could provide good, credible representations of complex situations that clarify and support actions without losing the complexity at hand and hence support, but not replace, both novices and experienced decision makers in handling complex situations.

Care – a situated practice and a presumption for sustainable agriculture

At the very core of the agricultural transition is the individual decision maker, who makes the strategic, tactical and operative decisions that bridge theory and practice, balancing the desirable with the feasible (Matthews et al., 2008; Van Meensel et al., 2012). If a sustainable farming system is more dependent on *complex, diverse,* and *local* knowledge, as Leeuwis (2004) claims, it is essential to acknowledge and promote farmers' situated knowledge. Krzywoszynska (2015) claimed that experiential knowledge is central for the delivery of the multiple care aspects that society is increasingly expecting and demanding from today's farmers. Care develops from experience in a practice, constituted by attentiveness, responsibility, and competence (Krzywoszynska, 2015), so the actor must recognize the problem, feel responsibility, and have the competence to act upon it, which demands some kind of engagement. This engagement is in line with the Dreyfus and Dreyfus (2005) model of skill acquisition, which states that to reach higher than the third level (competence), the learner must be emotionally engaged. Without engagement there will be no development of expertise and without engagement no care will be delivered. However, 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). 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). Consequently, '***work***' must be set in relation to sustainability to be interesting in the context of the present study. The inter-dependence between care and situated expertise has been noted in the farming literature (Krzywoszynska, 2015; Mol et al., 2010). To increase sustainability in farming, it is necessary to further acknowledge and respect farmers' situated expertise, as well as promoting and cultivating such expertise.

Decision making in agriculture and AgriDSS

Farm management and farmers' decision making has traditionally been analyzed using theoretical frameworks taken from economic science (Gray et al., 2009). As a result, the focus has often been on the decision event and not on the decision-making process (Öhlmér et al., 1998; Gray et al., 2009; Lindblom & Lundström, 2014). Decision making is a cognitive process and traditional normative views on cognition in the area of cognitive science have similarities to the normative perspectives on decision making applied in economics, by viewing cognition as the result of internal, individual processes (e.g., Pylyshyn, 1984). However, studies of farmers' decision making in their complex practice have revealed that this kind of description is inconvenient, because it fails to explain decision making in a complex, dynamic and ill-defined context (Gray et al., 2009; Lindblom et al., 2013; Lindblom & Lundström, 2014). Instead, it is important to increase understanding of how farmers actually make decisions, considering their complex socio-technical context, using descriptive theories such as naturalistic decision making (NDM) (Lindblom et al., 2013).

NDM theories have emerged from different theoretical and methodological approaches based on decision making 'in the wild', in which studies are performed in situations where humans make decisions in dynamic and complex domains (Klein, 2008). The individual´s experiences and knowledge are taken into account and time pressure and high uncertainty are also included (Orasanu & Connolly, 1995). However, although NDM focuses on decision making by experts 'in the wild', the unit of analysis is still only the individual, while contextual factors such as technology and other actors are excluded. According to Lindblom et al. (2013), NDM is an appropriate approach to investigate farmers´ decision making. However, it lacks a systemic perspective within the complex socio-material system, and therefore the unit of analysis needs to be widened from the individual to include the social and material context. For this purpose, the theoretical framework of DCog can be a convenient way forward (Lindblom et al., 2013; Lindblom & Lundström, 2014).

The main efforts made to bridge the gap between current agricultural knowledge and innovation systems (AKIS) include implementing new advisory concepts, re-organizing extension services and developing AgriDSS. Many AgriDSS have been developed, but not used to any wider extent, mainly as a result of the normative way of development based on the perspective of knowledge transfer, where knowledge is produced by research and end users are looked upon as passive receivers (e.g., McCown, 2002; Matthews, 2008; Thorburn et al., 2011; Aubert et al., 2012). Accordingly, there is a need for functional and usable AgriDSS that promote sustainable farming practices by providing proper and credible representations of complex situations that clarify and support farmers' decision making, without losing the complexity at hand. Any AgriDSS must therefore match farmers' naturalistic decision making and challenge their learning, without replacing their 'gut feeling' (i.e., intuition) (Hochman & Carberry, 2011). In addition, the AgriDSS has to support farmers' experimentation with options, rather than presenting optimal solutions, because when farmers are handling messy, real-world problems they tend to satisfy current needs rather than optimizing performance. Many researchers have shown that an AgriDSS can be a useful tool for the ongoing transfer of scientific knowledge and 'best practices' (e.g., Woodward et al., 2008; Jakku & Thorburn, 2010; Hochman & Carberry, 2011; Van Meensel et al., 2012). Another important aspect is social learning among farmers and stakeholders (e.g., Jakku & Thorburn, 2010; Hochman & Carberry, 2011).

DCog: Broadening the unit of analysis

The theoretical framework of DCog 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-material environment that humans inhabit. DCog takes a systemic 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 as distributed in a complex socio-technical environment and cognition, including decision making and learning processes, is viewed as the creation, transformation and propagation of representational states within a socio-technical system (Hutchins, 1995). 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, 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 of these 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 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.

When these principles are applied to the observation of human activity *in situ*, three kinds of distributed cognitive 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, social environment); and (3) distributed *over* time. Different kinds of representations are critical to the unit of analysis in DCog. Hollan et al. (2000) argue 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.

Method and performance

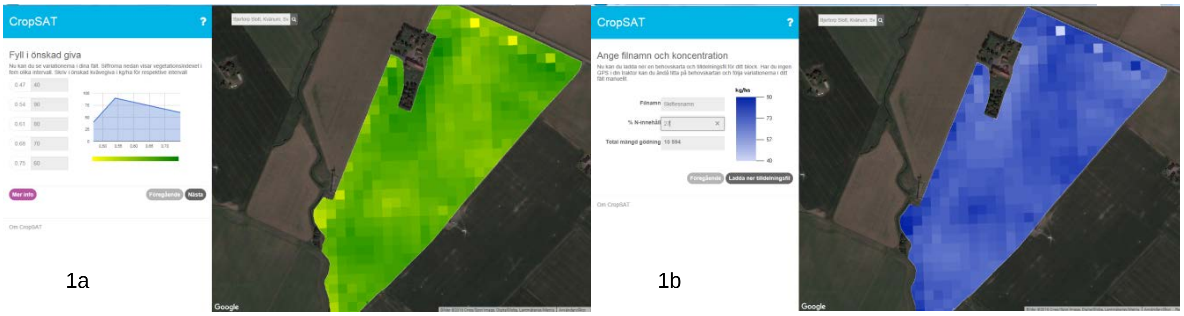
The chosen approach

The present analysis was conducted in spring 2015 and took the form of a *workplace study* (see Luff et al., 2000). The study adopted a qualitative approach, using ethnographical data collection techniques, and the collected data were triangulated from participant observation, video-recordings and semi-structured interviews. The interviews were conducted with four purposively sampled farmers in western Sweden who had previous experience of using ICT-based crop production software (CPS) and demonstrated an interest in PA technology.

Setting the scene

During 2013-2014, a new AgriDSS for N fertilization, CropSAT (www.cropsat.se), was developed by the Precision Agriculture Sweden (POS) network (www.precisionsskolan.se/). CropSAT uses satellite images to calculate a vegetation index (VI) (Qi et al., 1994) and VRA files for N fertilization in cereals. During 2015, a high-fidelity prototype of CropSAT was made available on the internet for use, free of charge, thanks to funding by the Swedish Board of Agriculture. To support farmers in their N fertilization strategy, a minimum of three satellite images were published during the period April-June 2015. The recommended strategy for fertilizing wheat is to apply N two or three times during spring (Albertsson et al., 2015).

To calculate a VRA file in CropSAT, the user visits its 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 N fertilization within five VI classes, which are estimated automatically from the satellite data (Figure 1a) and used to calculate VRA files for N for the field (Figure 1b). The VRA information is transferred to the tractor and spreader via a USB stick.



Fyll i önskad giva

Nu kan du se variationerna i dina fält. Siffrorna nedan visar vegetationsindexet i fem olika intervall. Skriv i önskad kvävegiva i kg/ha för respektive intervall

0.47 40
0.54 90
0.61 80
0.68 70
0.75 60

Ange filnamn och koncentration

Nu kan du ladda ner en behovskarta och tilldelningsfil för ditt block. Har du ingen GPS i din traktor kan du ändå titta på behovskartan och följa variationerna i ditt fält manuellt.

Filnamn: Skiftesnamn
% N-innehåll: 27
Total mängd gödning: 18 894

Figure 1 a) Vegetation index displayed on Google Maps, where the user must enter five levels of N fertilization compared with the colored scale. b) A VRA file ready to be entered into the fertilizer spreader via a USB memory stick.

To set the N levels for each VI class, the user is recommended to go out into the field and verify the N status with a so-called Spadmeter (https://www.konicaminolta.eu/en/measuring-instruments/products/colour-measurement/chlorophyll-meter/spad-502plus/introduction.html), or to simply estimate the need for additional N based on observation of the canopy and prior experience. When new satellite images were published during spring 2015, the farmers included in the present analysis studied crop development on their actual farm using CropSAT. On some occasions, a VRA file was calculated and later used for variable fertilization. On other occasions, the images were used to get an overview of the status or used in the decision-making processes regarding fertilization with a Yara N-Sensor (YNS) (http://www.yara.se/crop-nutrition/Tools-and-Services/n-sensor/).

Findings

Swedish farmers fertilize winter wheat one to three times during spring in order to optimize yield and protein content. They have a fertilization plan for each field, and in this study all farmers used an ICT-based CPS for creating these plans. In the fertilization plan, an average amount of N per field is specified, but can be adjusted to a wide range of factors during the season. Farmers can use CropSAT or some kind of tractor-based N sensor to apply a variable rate of fertilizer, using the planned average amount of N as a basis. The units of analysis in these decision-making processes include a wide range of artefacts, e.g., CropSAT (images on VI and VRA files used in computers, mobile phones, and tablets), CPS (tables and field maps in computers, mobile phones, and tablets), paper-based field maps, calculators (in mobile phone), Spadmeter, and notepads (Figure 2). The images created in CropSAT are visual digital representations that display crop biomass complexity in a way that is difficult to achieve by walking or driving in the field. Below, some selected brief episodes that illustrate decision-making processes and requirements for development of *situated expertise* and *care* within the distributed cognitive system are described and analyzed.

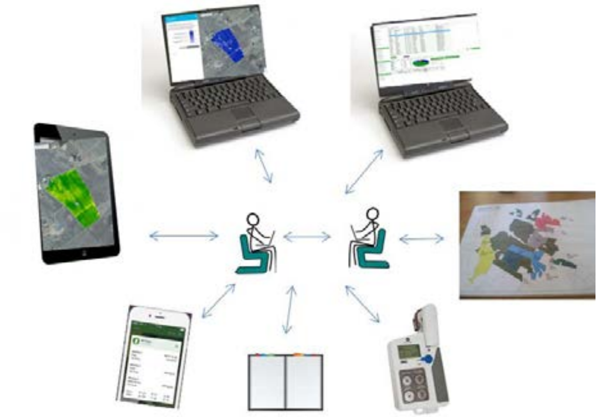


Figure 2. Unit of analysis of the DCog system, where cognitive processes are distributed: (1) *across* the members of a group, (2) *between* human internal mechanisms (e.g., decision making, perception, memory) and external structures (material artefacts, ICT systems, social environment), and (3) *over*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

Situated expertise visualized by CropSAT usage

Farmers are aware of the occurrence of within-field variation in crop yield. On looking at satellite images in CropSAT, farmers with long experience easily recognized and explained much of the visualized variation in crop biomass. In the first episode described, an experienced farmer in his 50s using CropSAT for the first time took a closer look at one of his fields of winter wheat. He had a strong interest in technology and 15 years of experience of using VRA files and YNS. He compared and contrasted his acquired practical knowledge of the characteristics of the particular field with the satellite image displayed in CropSAT. He then said while pointing at the image (see Figure 3): "*This bit is more or less gravel esker … the ground rises here… it must rise by at least a few meters. 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*".

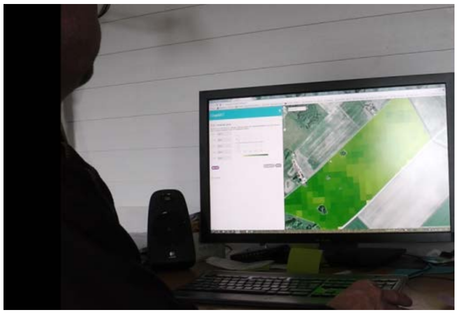


Figure 3. The experienced farmer was easily able to explain a significant proportion of the within-field variation, pointing at the image while talking about the field.

The image thus went from being a representation of the field to being the field itself while the farmer was talking about the field conditions viewed through CropSAT, in combination with long experience of farming the field. Hence, CropSAT provided a representation of the field, elucidating a complexity difficult to obtain in other ways. The aspects of the complexity, some of which are already known and some which are not, allow the farmer to learn more about the field and increase his situated expertise of it through both the bird's eye view and the variation in biomass that he could not distinguish with his own eyes.

CropSAT and the importance of a social learning context

The farmer described above and a group of partners farm 1000-2000 hectares in total and still own their farms. They practice reduced tillage and the farmer cited above has a deep interest in improving the cultivation system in relation to long-term sustainability issues, specifically in relation to soil fertility. When we first met, he revealed his situated expertise in the usage of CropSAT, while his deep interest in improving soil management was exemplified through his aim to increase sustainability, both economically and in terms of the foundation for his farming – the soil. He reported that he wanted to buy a drone to get regular aerial views of his fields, but that CropSAT provided an interesting tool to follow crop development. When asked what he wanted to see from above, he could not really articulate his intentions and just reported wanting to get a better view of the fields to increase his experience and learning, which we suggest would further promote his situated expertise and care. However, CropSAT proved to be a disappointment for him in practice because it did not provide the kind of detailed images from the fields that he wanted. He already used an YNS and therefore CropSAT was also not interesting as a fertilization tool.

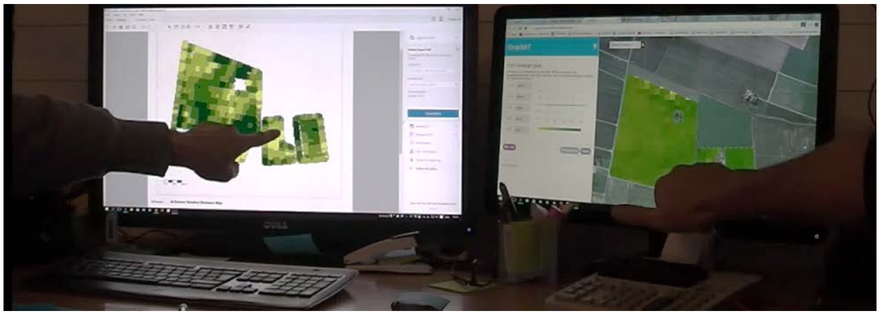


Figure 4. The farmer and a partner farmer comparing a CropSAT image with a YNS map; both pointed at the images when discussing how to interpret the differences in color.

However, CropSAT provided additional value to the farmer, as shown in an episode that took place in fall in which the farmer and a partner farmer in the group were comparing an YNS map with an image from CropSAT taken the day after YNS fertilization in June. It was not an easy task to compare and contrast these images. First, there were some problems with identifying the YNS maps due to inadequate notation in June. When an YNS map and the corresponding CropSAT image were identified and displayed on two parallel computer screens (Figure 4), interpretation of the images was still not easy. When asked if they usually looked at the YNS maps after fertilization was completed and reflected 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'.*"

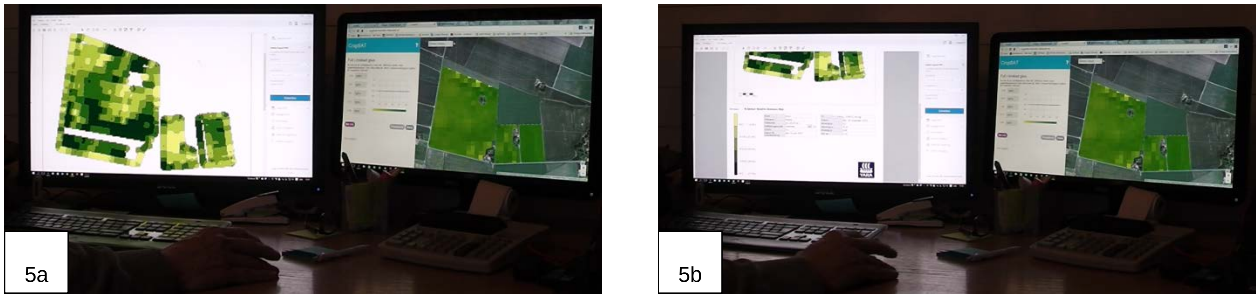


Figure 5a. What did the images show and what was really measured? An YNS map compared with an CropSAT Image. b) How should the scales be interpreted?

Because the farmers encountered problems with interpreting the images (see Figures 4 and 5), they decided to call an expert on YNS and CropSAT for assistance. The expert explained the significant differences (via a cell phone in speaker mode), and after a while reached the conclusion that the YNS image offered a better and more detailed representation of the field than CropSAT, which instead provided images of crop development between fertilization events. After the call ended the partner farmer seemed a bit frustrated and concluded that he had realized 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*". When asked to elaborate on this, he said: "*Take my farm … at my place … I know it so well, right? and I can see these big differences … if I'm sitting on the machine myself……then I can adjust it when I'm sitting there … but it's the things I cannot see that I need help with".* The partner farmer and the case study farmer were experienced YNS users and described how they adjust the YNS while driving. YNS was a tool that they could use properly according to their experience. Coincidently, they realized that the sensor could 'see' more than they could themselves with their eyes only. The partner farmer said: *"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 also pointed out the importance of technology in supporting farm workers, such as an inexperienced YNS driver, to carry out fertilization 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 sometimes could evaluate the situation better than the YNS and they did not leave an inexperienced employee to decide on a strategy for the YNS. Hence, they described two different approaches to decision making on fertilization, rather than the two complementary tools (CropSAT and YRS) available to promote learning more about their fields. However, they both noted some learning possibilities, the farmer preferably from plain images (CropSAT was not detailed enough), while the partner farmer declared that he could learn just by looking at the YNS maps. However, they had not yet developed the practice of using the tools in their everyday farming.

During this discussion the case farmer returned to the desire he expressed from the earlier episode to get regular field images in order to recognize small differences in crop development and simultaneously pointed at the screen while saying: "*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 'von oben'… you can't compare them".* The partner farmer added: "*Yeah… but then it's too late*". The farmer replied: *"Yeah, but even if it's too late you can draw a certain conclusion and you can maybe do something next time"*. Hence, the two perspectives of situated expertise and care were made visible in this conversation. The partner farmer wanted to have access to information to act upon, whereas the case farmer focused on the possibilities to learn by reflection through access to a bird's eye view of the fields. That farmer could not verbalize 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 the images.

This line of argument could be interpreted as an example of expertise development. According to Dreyfus and Dreyfus (2005), an expert is deeply engaged and evaluates situations in relation to many other experienced situations. The case farmer identified an opportunity to get access to more situations to evaluate via his tacit knowledge, without being able to externalize in words what he really wanted to see.

The need for extension services was also raised. The partner farmer pointed out the importance of having the support of extension services in order to utilize the technology to a wider extent, but added that the farm business did not use any extension services in connection with crop production due to earlier disappointments with the services available*.* The farmer recalled how he and the group of colleagues started the farm business fifteen years ago, which generally triggered various learning processes. He then said: '*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!".* They had tried to secure appropriate extension services, but failed. Instead, they had started a learning group and invited other farmers and experts in to discuss interesting and related farming issues in order to get new inputs and broaden the basis for knowledge and experience. They had identified a need for on-going social learning processes and had found their own solution, but they really wanted an extension services agent who could focus on their farm in cooperation with them to further improve their crop production.

When the partner farmer left, the case farmer once again reflected on the use of CropSAT, saying that it could be really interesting, as the expert had suggested, to use the CropSAT image before YNS fertilization. Then he considered on the differences between the partners in the group, where some of them wanted to solve problems and be able to act upon them directly when they occurred, rather than "*digging deeper into them*" as he himself wanted to do. The analysis revealed that he wanted to learn more and increase his understanding and knowledge of his fields, not necessarily to solve a certain problem.

Even though this particular farmer was at great pains to point out that the farm business's viability was the most important issue for him, he was still passionate about learning more and developing his reduced tillage approach in order to increase the long-term fertility of the soil. Thus this farmer is an example of an engaged and experienced individual whose engagement has led him to fight for his development of care in a sustainable trajectory, but he was lacking support about deeper soil-related issues from partners, extension services or other sounding boards in his immediate surroundings. Although his partner farmer also seemed to be very engaged, he acted from a more problem-solving perspective. The case farmer pointed out the great need for good extension services which could assist and support his use of technology to a wider extent with the aim of increasing viability and sustainability. In terms of the framework applied in the present analysis, this way of working can be said to further develop the farmer's expertise and care.

To sum up, the farmers studied had prior first-hand experience of their fields and were able to recognize within-field variation to a certain extent in those fields, but they made an clear distinction between an experienced farmer and an advanced beginner. According to Goodwin (1994), this is an example of professional vision. However, the analysis also revealed that even the experienced farmers could not observe all differences with their own eyes or act upon fuzzy within-field variations, and in order to do that they needed support from ICT systems. This is an example of what Goodwin and Goodwin (1996) call *tool-mediated seeing*, which is characterized as seeing aspects relevant for a task only through the use of tools and artefacts, i.e., the satellite images in CropSAT. Due to lack of a proper social learning context, the case farmer studied here did not use CropSAT. However, when an expert suggested a way of using CropSAT in relation to YNS fertilization, the farmer started to reflect on it. The farmer also wanted a tool-mediated bird's eye view from a drone to increase his knowledge of his fields. The farmer and his partner farmer considered YNS as a tool to help them in handling fertilization, but neither trusted the technology blindly, moreover, neither reflected afterwards on the results of the spreading in practice. One important reason was the lack of results to compare with. They had performed yield mapping in the past, but as they did not find any real use for the maps they had abandoned that approach. Based on our analysis, we argue that there is a need for putting the different tools in a broader context, both technically and socially. The farmer was willing and interested in doing a lot of work himself, but needed some kind of sounding board, while the partner farmer was more interested in support from an interested extension worker who could help develop the business further. However, both farmers lacked a convenient social learning context to use the available AgriDSS to a wider extent. This is in line with the value of considering an AgriDSS as an object for social learning, not just as tool for decision making (Thornburn et al., 2012). For the farmers analyzed here to increase their use of technology, they explicitly requested new input to develop their farming practices and reported that lack of good extension services had resulted in them starting a learning group with carefully chosen farmers as participants. However, this learning group could not fully compensate for the lack of good extension services.

CropSAT as a basis for development of situated expertise and enhanced professional vision

In a third episode, another experienced farmer in his 50s was discussing how to fertilize seven fields of winter wheat with his extension services agent. This farmer also had access to YNS and did not use CropSAT to calculate VRA files. However, this farmer had only limited experience of YNS usage. His reason for prioritizing YNS over CropSAT was that YNS provided a more detailed picture of the biomass variation and consequently the amount of N could be distributed more precisely. Nevertheless, CropSAT was used as a basis for the discussion, as an improved alternative to the paper field map. During this meeting, all tools and artefacts displayed in Figure 2 were available and a satellite image taken three weeks earlier was used for comparing how much N had been utilized by the crop (Figure 6). Before the meeting, the extension services agent had used a Spadmeter in the fields to measure the need for additional N fertilization based on canopy greenness. These measurements were used as a point of reference in the ensuing discussion.

As mentioned above, the role of the extension services is critical when introducing new technology. In this particular case, the agent acted as a role model in his ways of using the available tools and artefacts, advocating a ‘willing and able’ approach that influenced the farmer. However, the different digital representations of the fields in various ICT systems offered additional, but artificial, perspectives on the fields that differed significantly from first-hand experiences when walking in the fields. The key question was how to correctly utilize and combine the different representations and the acquired situated knowledge, in order to develop more sustainable farming practices. In this case the sustainability aspect lay in efficient utilization of inputs and high crop yield of expected quality.

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 within-field variation in biomass at the time of fertilization planning. The only option available previously to obtain an overview of the field was to walk through it or to measure within-field variation in biomass with some kind of field sensor. However, the enhanced detail in the digital representations that was available with less effort than using a field sensor triggered and facilitated comparisons between different factors, e.g., VRA files for phosphorus fertilization and the satellite image. For example, the farmer and extension services agent discussed how variation in soil characteristics and phosphorus values could explain the within-field variation in biomass. The farmer said: “*We used that variable rate application file last year there. We fertilized according to P content with it '. 'I am so fascinated by this, it’s completely insane*”. On the one hand, the new digital representations provided more detailed information than before, which in turn provided additional support for understanding the situation in order to make decisions regarding fertilization. On the other hand, the additional information may have 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 have to be interpreted, compared and situated in the farmer’s decision-making context, resulting in an ongoing social learning process involving both practitioner and extension worker.

In other words, the digital representation offers a more detailed view of the situation, which will improve the farmer's situated expertise and also the development of care. This is linked to the perspective of *professional vision* through the so-called process of *tool-mediated seeing* (Goodwin and Goodwin, 1996). In this particular situation, this was done through interpreting the digital representations of the within-field variations in biomass.

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

Let us now return to the decision on how to decide the average amount of N and then calibrate the YNS to fertilize winter wheat for the last time in the spring. CropSAT offered the possibility to compare and discuss the development of the crop and its N uptake in relation to earlier fertilization. In order to accomplish these tasks, the farmer and extension agent first compared the earlier satellite image with the current image (Figure 6), discussing intensively how to interpret the images and then explaining what had happened in the field. They agreed that the crop had developed satisfactorily and that the winter wheat fields were looking good.

Based on the planned amount of N in the CPS, the measurements from the Spadmeter, earlier first-hand experiences, and the satellite images (both older and present), the farmer and extension agent decided the average amount of N for each field. In order to calibrate the YNS, the agent pointed at the screen displaying the satellite image and then showed where to drive the tractor to cover the variation in crop biomass (Figure 7). Through this, calibrating the YNS could be improved by support from the ICT system in order to select appropriate spots to optimize the calibration.

Figure 7. Image sequence where the extension services agent (right) is making a suggestion on where to drive the tractor to calibrate the YNS to grasp the within-field variation in biomass.

This example illustrates how the two participants in the social situation explored new ways of using the available technology, i.e., CropSAT and YNS. This involved using the CropSAT images as a means to calibrate the YNS, which was not the intended contribution of CropSAT. Although this usage of CropSAT was beyond the developers' intention, it still contributed to generating sustainable farming practices through ongoing learning processes. Thus, it can be claimed that an ICT system can function as a social learning tool, contributing to the farmer's development of situated expertise and care when put in a proper social context. 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 need to be combined when making decisions regarding care on the use of ICT support and situated knowledge in PA.

The examples above show socially distributed cognition and how a whole socio-technical cognitive system, which in this case would include farmers, extension services agents and available tools and associated artefacts, is capable of performing much more than the individual farmer could. In other words, the coordination of different representations (external and internal) is an emergent property of the system as a whole, not easily reduced to an evident property of a certain entity (human or artefact and tool). 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.

Discussion and conclusions

Precision agriculture can be a keystone in a sustainable intensification trajectory where ICT and other technologies are necessary for sustainable management of large-scale farming systems (Aubert et al., 2008). In this context, PA should follow a direction described by Schlindwein et al. (2015) as '*beyond the dominance of empiricist prediction*', where a model could be considered one of many tools available to explore possibilities to develop sustainable farming systems. Putting the technology in the context of practice is essential, as is developing tools that could be used both for decision making and social learning (Hochmann & Carberry, 2011; Thornburn et al., 2012). It is necessary to avoid the knowledge transfer approach and fit AgriDSS into the decision making milieu and practice of farmers and other stakeholders (Röling, 1988). In so doing, it is important to avoid what Carolan (2015) observed in his research on agrifood-based technology, namely that conventional agriculture was "*using a kind of communication more interested in telling than listening, in directing rather than following and in effecting rather than learning to be affected*".

Experienced farmers are experts on their fields (Hoffman et al., 2007) and their situated expertise and enhanced professional vision are central for the development of care. Care itself is the totality of practices that makes knowledge and technologies work in a sustainable direction, based on attentiveness, competence and responsibility (Krzywoszynska, 2015), and is crucial for the everyday environmental impact of individual farmers. With increased demands for sustainability in farming practice, more knowledge of a form considered *complex, diverse,* and *local* is needed (Leeuwis, 2004), which in turn increases the necessity for farmers to express flexibility, situated expertise, and care in their farming practice. New technology needs social and organizational arrangements, such as rules, perceptions, agreements, identities, and social relationships, to function properly (Leeuwis & Aarts, 2011), as also revealed in the present analysis. Even experienced, engaged, and pro-technology farmers still require relevant sounding boards to continuously develop and improve their farming skills. Thus, extension services have a central role to play in putting the technology in a proper context where it has the potential to be used to a wider extent. To achieve this, it is essential that different groups of stakeholders are involved in development and design of new AgriDSS (e.g., Woodward et al., 2008; Jakku & Thorburn, 2010; Hochman & Carberry, 2011; Van Meensel et al., 2012) and that a plan for embedding the AgriDSS in farmers' practice is created early in the development process (Hochmann & Carberry, 2011; Thornburn et al., 2012).

Based on the present analysis, in order to increase sustainability in agriculture there is a need for AgriDSS that promote sustainable farming practices by providing good, credible representations of complex situations that clarify and support farmers' situated expertise and actions, without losing the intrinsic complexity. Such AgriDSS can contribute to farmers' development of care and enhanced professional vision, which is critical for increased sustainability in agriculture. Even farmers who according to McCown (2002) *'rely heavily on intuitive judgment underpinned by experience'* would benefit from the use of better representations of complex situations, e.g., in the case of crop biomass the human eye cannot perceive all the variation and allow the farmer to act upon it. Thus research and usage related to PA should change from goal-oriented to learning-oriented. We agree with Lacoste and Powles (2016), who noted that the trial of ideas is more likely to succeed in contributing to learning and practice change than providing an expert system with optimized, but not transparent, answers. AgriDSS that support the use of a mixture of local, scientific and situated tacit and externalized knowledge could be used in the knowledge-generating mechanisms that Caron et al. (2014) regard as necessary in the transition towards sustainable intensification.

The implication of this study is that CropSAT should be considered part of a wider agriculture knowledge information system (AKIS) involving different kinds of ICT systems, tools, artefacts, and social learning processes. CropSAT provides ‘hardware’ that still needs further improvement of the ‘software’, while the immature ‘orgware’ requires additional development and discussion. Once this has been achieved, CropSAT could become an important component in the trajectory of sustainable intensification in agriculture, by using scientific knowledge to support development of situated expertise and care among farmers and enhancing their professional vision.

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