Adoption of the Agricultural Decision Support System CropSAT in Extension: Incentives and Needs

Christina Lundström[a], Jessica Lindblom[b] and Magnus Ljung[a]

[a] *Swedish University of Agricultural Sciences, Skara, Sweden. christina.lundstrom@slu.se*
[b] *University of Skövde, Skövde, Sweden*

Abstract: This paper presents several strategies employed by advisors in relation to the use of an agricultural decision support system (AgriDSS) called CropSAT, which is free to use and funded by the Swedish Board of Agriculture. The research question for the study was: How is extension affected and possibly altered when provided with CropSAT? Thirteen crop production advisors were interviewed and the collected data 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 strategies selected by the advisors varied based on the requests and needs of farmers, the advisors' personal interest and competence, CropSAT functionality and uncertainty about how to use it in practice. When using an AgriDSS such as CropSAT in advisory situations, there is greater complexity because there are more parameters to consider, rendering more difficult to make proper decisions. Given this combination of technology and agronomy, the advisors requested more support. 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 both advisors and farmers in order to increase sustainability in agriculture.

Key words: precision agriculture, advisor, fertilisation, crop production, decision support systems

Introduction

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, 130). In a sustainable intensification trajectory, the aim is to increase food production on existing farmland and decrease the environmental impact, 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, and 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, Schroeder, and Grimaudo 2012; Wolfert et al. 2017).

In order to perform PA, certain kinds of ICT systems, known as agricultural decision support systems (AgriDSS), have been developed. However, for various reasons, many available AgriDSS are poorly adapted to farmers' needs and practices and thus are not exploited to their full potential (*e.g.* Matthews et al. 2008; Jakku and Thorburn 2010; Thorburn et al. 2011; Aubert, Schroeder, and Grimaudo 2012; Prost, Cerf, and Jeuffroy 2012; Kerselaers et al. 2015; Rose et al. 2016; Lindblom et al. 2017). As a result, a significant proportion of the available AgriDSS can be considered as an isolated phenomenon and thus are not commonly used in practice (*e.g.* Matthews et al. 2008; Jakku and Thorburn 2010; Aubert, Schroeder, and Grimaudo 2012; Prost et al. 2012; Rose et al. 2016; Kerselaers et al. 2016; Lindblom et al. 2017). Hence, an AgriDSS must fit in with the farmers' practice and be combined with farmers' situated knowledge or experience in order to function properly (Nitsch 1994; Lundström and Lindblom 2016; Lundström and Lindblom, submitted). Instead of considering an AgriDSS as an operational tool to help farmers make decisions, many researchers highlight the possibility of using an AgriDSS as a social learning tool that can facilitate discussions and learning among different stakeholders (*e.g.* Matthews et al. 2008; McCown et al. 2009; Jakku and Thorburn 2010; Hochman and Carberry 2011; Thornburn et al. 2011; Lundström and Lindblom 2016; Lundström and Lindblom, submitted). 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). Advisors play a central role during this learning process.

The aim of this paper was to investigate and analyse extension strategies in advisory situations, based on access to and use of a Swedish AgriDSS for fertilisation called CropSAT (www.cropsat.se). The study is based on the research question: How is extension affected and possibly altered when provided with the AgriDSS CropSAT? Based on the results obtained, we also discuss the preconditions for advisors that are critical to a credible and usable AgriDSS in order for it to be used properly in practice when planning and discussing fertilisation with farmers.

Background

Increased Complexity creates a Demand for new Interventions

In Sweden for many years there has been considerable debate about fertilisation in order to optimise crop yield and avoid environmental impact. The Swedish Board of Agriculture publishes Nitrogen (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 have been encouraged and advised for many years 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 an important 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 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. Finally, in 2015 many farmers produced wheat and malting barley with an insufficient protein content and therefore suffered large economic losses, which in turn increased the interest in precision fertilisation and the use of AgriDSS.

Agricultural Decision Support Systems

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.* Power 2002; Turban et al. 2007; Alenljung 2008).

To date, agricultural researchers have had the intention of using AgriDSS to transfer knowledge from science to work practice, with the aim of increasing farmers' acquisition of scientific knowledge (*e.g.* Leeuwis 2004; McCown et al. 2009; Thornburn et al. 2011). However, most of these AgriDSS have not been acquired and used appropriately in practice (*e.g.* Aubert et al. 2012; Eastwood, Chapman, and Paine 2012; Rossi et al. 2014; Kerselaers et al. 2015; Rose et al. 2016) due to limited adaptation to the needs of farmers and advisors in their farming practice (*e.g.* McCown 2009; Aubert et al., 2012; Pierpaoli et al. 2013; Rossi et al. 2014; Rose et al. 2016). If they are to be used, AgriDSS must be credible and fit well into the decision-making milieu in which they are to be used (Matthews et al. 2008). Consequently, there is a gap between research and practice (Mackrell, Kerr and von Hellens 2009). To narrow this gap, 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.

From Expert to professional learning Partner

Moving towards increased sustainability in agriculture, one important lesson learned is that there is no "*generally applicable agricultural development model*" (Leeuwis 2004, 4). 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. Instead, extension advisors, farmers and other actors in the agricultural knowledge and innovation system (AKIS) need to cooperate to bring different knowledge and experience into a social learning process. Consequently, there is a need for a changed perspective in which research should be innovation-driven instead of science-driven, and where cooperation between research, extension and end users is crucial (EU SCAR 2012; Eastwood, Klerkx and Nettle 2017). The new agenda that should be set has to involve farmers and food businesses as an alternative to being a matter of research dissemination. In such a learning process, extension has an important role to play. 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. However, AgriDSS can supplement and facilitate farm management, *e.g.* 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. Thus 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). 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 forwards. 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, Probst and Christinck 2007), which in turn is necessary for the coordination ability of farmers when applying "*complexities of farming on a specific farm*" (Nitsch 1994, 32). 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 with the combination of their situated knowledge and digital representations of the field, their so-called *enhanced professional vision* (see Lundström and Lindblom 2016; Lundström and Lindblom submitted), 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.

Methodology, Data Collection and Data Analysis

Swedish farmers are recommended to fertilise winter wheat one to three times in the 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 internet-based, free AgriDSS 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 2015 there were 4,000 users registered on the website; by 2016 that number had increased to 4,800.

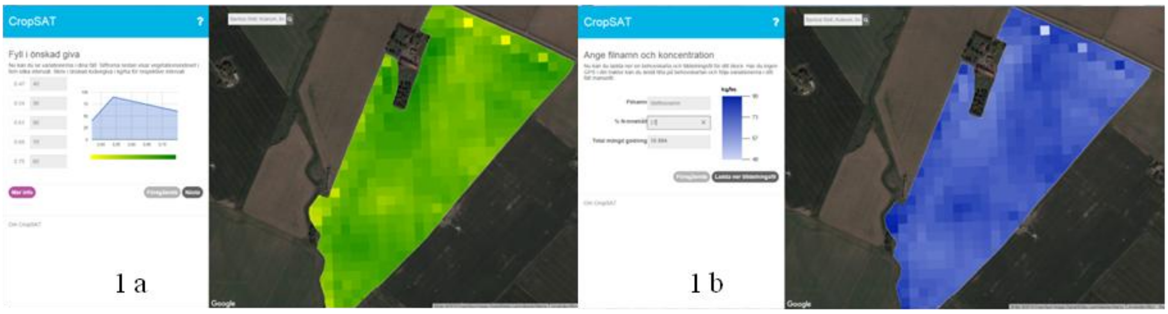

Figure 1 a) Vegetation index (VI) displayed on Google Maps, where the user must enter five levels of nitrogen fertilisation compared with the coloured scale. B) A variable rate application (VRA) file ready to be entered into the fertiliser spreader via a USB memory stick

In order to investigate farmers' socio-technical systems in relation to AgriDSS use in PA, an empirical case study was performed during 2015 in western Sweden. The case study took the form of a workplace study (Luff, Hindmarsh and Heath 2000) through qualitative inquiry investigating the use of CropSAT by four farmers and their advisors in relation to making decisions about the N fertilisation of winter wheat. The analysis was conducted using the theoretical framework of distributed cognition (Hutchins 1995) as a lens (for further details see Lundström and Lindblom 2016 or Lundström and Lindblom submitted). During 2016 and 2017, a follow-up study was conducted in which thirteen additional advisors from other parts of Sweden were interviewed to complement the earlier findings. The interviews were conducted by telephone (eleven advisors; notes were taken) or in personal meetings (two; interviews were recorded). The interviews lasted between 30 and 90 minutes. The recorded interviews were transcribed and all the interviews compiled and analysed thematically. 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 (Kuehne and Llewellyn 2017) because they are either employed by a Swedish agricultural society or by a private firm, but are not resellers.

Findings

The earlier workplace study (Lundström and Lindblom 2016; Lundström and Lindblom submitted) revealed that CropSAT can provide new information about a field and facilitate action, learning and decision-making when considering fertilisation. CropSAT provides new kinds of digital representation formats that visualise 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 identified variation. The major challenge was to deal with biomass variability by setting five levels of N fertilisation. 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 Spadmeter (http://www.specmeters.com/nutrient-management/chlorophyll-meters/chlorophyll/spad502p/) measurements from the field, were valuable and functioned as a coordinating mechanism. Thus, the advisor had an important role to play in the adoption and use of CropSAT by supporting technology use for learning as well as for decision-making (for further details, see Lundström and Lindblom 2016 or Lundström and Lindblom submitted).

The interviews conducted with advisors in the follow-up study in 2016 and 2017 elucidated their wide acceptance of the occurrence of within-field variation and the familiarity of all of them with CropSAT. Nevertheless, there were extensive differences in whether and how they used CropSAT in their extension practice. The analysis from the interviews revealed four categories of advisor strategies for CropSAT use, with individual advisors being able to several strategies:

1. I do not use it!
2. I will use it if I have to!
3. I use it myself and tell the farmer how to fertilise!
4. I use it with the farmer!

The answers grouped into the first category seemed to depend on: 1) uncertainty among advisors as to 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 2) a perceived lack of a proper scientific foundation for the functionality of the AgriDSS. 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 is that if the advisors perceive themselves to be experts who ought to provide reliable answers to complex problems, this increased complexity could be considered negative. Some of the answers from the advisors 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.

The second strategy was mostly used 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 that "*the customer pushes the development by demand*".

The third 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 that could be used in the spreader. Using that 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 action to take.

The fourth strategy often used 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*".

The earlier workplace study revealed that CropSAT could be used as a social learning tool to support farmers' situated knowledge and that it enhanced professional vision when farmers and advisors used it collaboratively together. However, the additional interviews with advisors resulted in four kinds of strategies in which 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, AgriDSS functionality, personal choice and uncertainty as to how to use it. When using an AgriDSS such as CropSAT in fertilisation, the complexity increases because there are more parameters to consider, and thus it could become more difficult to make correct decisions. One of the advisors who preferred the first category described it 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 so critical ... as when you're going to decide exactly on a specific spot*". Our interpretation is that if you consider yourself an expert whose role is to tell the *truth*, the use of this kind of technology, which increases the complexity, is viewed as much more complicated. On the other hand, this could be solved by making the technology responsible. Accordingly, some advisors requested an expert system, providing an optimal N amount for the five levels instead of exchanging experience with the farmer: "*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 answered: "*Yes I really hope so … since I know so little myself …*" Expectations of 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.*

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*".

Based on these findings, we suggest that there is a need for more support for advisors and for discussions about the functionality of this kind of AgriDSS, user strategies and the role of the advisor. Is the advisor an expert who tells the truth or a sounding board involved in a social learning process? Dreyfus (1972/1979, 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. Furthermore in the case of N fertilisation, every year is a new year/situation because automation in a continually changing environment is difficult and demands human supervision.

In summary, the actors responsible for designing new technology need to provide credible explanations, valid data and implementation strategies to ensure adaptation to farming practice. Farmers need to be acknowledged for their situated knowledge and experience, which is central to increased sustainability. At the same time, however, they must not consider themselves to be passive receivers of knowledge, but rather accept their responsibility as consumers. Advisors should reconsider their roles as being more of a sounding board taking part in a social learning process than as experts who 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 an expert system. There is probably a need for new actors who support the use of technology. However, when using technology as a tool for crop production, agronomy knowledge is essential.

Discussion and Conclusion

The aim of this paper was to investigate and analyse extension strategies in advisory situations, based on access to and use of a Swedish AgriDSS called CropSAT (www.cropsat.se). The research question was: How is extension affected and possibly altered when provided with the new AgriDSS CropSAT? Based on the results obtained, we also discussed the preconditions that are critical to a credible and usable AgriDSS for advisors to use it properly in practice when planning and discussing fertilisation with farmers.

This project 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 be dealt with and resolved 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 says 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 some 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, 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. To use an AgriDSS to evaluate crop need, the user needs knowledge of the crop, understanding of how the technology really works, and confidence in the technology too. This kind of confidence is traditionally provided by public research and extension (Eastwood, Klerkx, and Nettle 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. Using CropSAT or other AgriDSS will demand more engagement from the farmer and the advisor, otherwise the technology's potential will not be exploited. However, in this combination of technology and agronomy, the advisors seemed to be aware of the increased complexity and requested more support to use it. This request must be met by research, the authorities or companies who are responsible for the AgriDSS in order to support the advisors who feel responsible for the advice they give.

Different expectations from all parts of extension need to be discussed. Traditional crop advisors struggle with their own ambition to contribute to improving production, with changes in their roles due to increased complexity and with supporting farmers in using new technology. Accordingly the next important step to increase the adoption of technology would be a changed mindset among both advisors and farmers, without expecting a technology fix (Black 2000). We recommend a shift from viewing extension as knowledge transfer towards it being perceived as a joint learning process, where knowledge from both the inside and outside is needed. However, this joint learning process could involve other actors as well, such as researchers, technology providers and, in the case of CropSAT, the government organisation funding the AgriDSS. PA technology requires support structures to facilitate learning, thus reducing uncertainty and supporting adoption (Eastwood, Klerkx and Nettle 2017). We would claim that there is a gap between agronomy and technology that needs to be bridged or at least narrowed if PA AgriDSS use is to be extended to wider groups of farmers to support their *enhanced professional vision* (Lundström and Lindblom 2016; Lundström and Lindblom submitted), either by already established advisors or by somebody else. Regardless of who it is, this group needs to be involved in 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 and Thornburn 2010; Lindblom et al. 2017; Rose et al. 2017).

These days PA and concepts such as Smart Farming and Future Farming offer opportunities as well as drawbacks from the user's point of view. Some argue that the role of people in analysis, planning and decision-making in farming practices is being taken over still further by machines so that the decision-making cycle will ultimately be fully autonomous, while other researchers argue that humans are still in the decision-making loop "*but probably at a much higher level of intelligence*" (Sundmaeker et al. 2016, 133). Handling large amounts of unstructured heterogeneous data requires "*a smart interplay between skilled data scientists and domain expertise*" (Wolfert et al. 2017, 79) promoting a transdisciplinary approach. It also requires a cognitively demanding ability to convert and interpret the collected data into available and meaningful pieces of information that can be acted upon, and simultaneously this information should be combined with additional historical data and many other kinds of available data and information (Sundmaeker et al. 2016; Wolfert et al. 2017). We argue that this *higher level of intelligence* in the form of *domain expertise* is aligned with other comparable situations from inside, or what Nitsch (1994) refers to as the coordination ability of farmers based on situated knowledge, and then with the experience of advisors, the outside. We claim that this kind of change in mind-set among advisors and farmers, in line with within-field variation, technology use and expectations as well as expertise, is vital to increase sustainability in agriculture.

References

Albertsson, B., K. Börling, P. Kvarmo, U. Listh, J. Malgeryd, and M. Stenberg. 2015. *Rekommendationer för gödsling och kalkning 2017*" [Recommendations for fertilisation and liming 2017]. Jordbruksverket. JO15:19. http://webbutiken.jordbruksverket.se/sv/artiklar/jo1624.html

Alenljung, B. 2008. "Envisioning a future decision support system for requirements engineering". PhD diss., University of Linköping, Sweden.

Aubert, B. A., A. Schroeder and J. Grimaudo. 2012. "IT as enabler of sustainable farming". *Decision Support Systems* 54 (1): 510-520. DOI:https://doi.org/10.1016/j.dss.2012.07.002

Black, A. W. 2000. "Extension theory and practice: a review." *Australian Journal of Experimental* Agriculture 40 (4): 493 – 502. DOI: https://doi.org/10.1071/EA99083

Dreyfus, H. L. 1972/1979. *What computers can't do – a critique of artificial reason* (revised edition). New York: Harper & Row. (This book is contained in the extended MIT Press edition (Dreyfus, 1992).

Eastwood, C. R., D. F. Chapman, and M. S. Paine, 2012. "Networks of practice for co-construction of agricultural decision support systems: Case studies of precision dairy farms in Australia." *Agricultural Systems* 108: 10-18. DOI: https://doi.org/10.1016/j.agsy.2011.12.005

Eastwood, C., L. Klerkx and R. Nettle. 2017. "Dynamics and distribution of public and private research and extension roles for technological innovation and diffusion: Case studies of the implementation and adaptation of precision farming technologies." *Journal of Rural Studies* 49: 1–12. DOI:https://doi.org/10.1016/j.jrurstud.2016.11.008

EU Scar. 2012. "Agricultural Knowledge and innovation systems in transition – a reflection paper." Brussels. http://bookshop.europa.eu/en/agricultural-knowledge-and-innovation-systems-in-transition-pbKI3211999/

European Parliament. 2016. "Precision agriculture and the future of farming in Europe Scientific Foresight Study." EPRS European Parliamentary Research Service. Scientific Foresight Unit (STOA) PE 581.892

Garnett, T., M. C. Appleby, A. Balmford, I. J. Bateman, T. G. Benton, P. Bloomer, and B. Burlingame, et al. 2013. "Sustainable Intensification in Agriculture: Premises and Policies." *Science* 341 (6141): 33-34. DOI: 10.1126/science.1234485

Hoffmann, V., K. Probst, and A. Christinck. 2007. "Farmers and researchers: How can collaborative advantages be created in participatory research and technology development?" *Agriculture and Human Values* 24 (3): 355-368. DOI:10.1007/s10460-007-9072-2

Hutchins, E. 1995. *Cognition in the Wild*. Cambridge US: MIT Press.

Jakku, E., and P. J. Thorburn. 2010. "A conceptual framework for guiding the participatory development of agricultural decision support systems." *Decision Support Systems* 103 (9): 675-682. DOI: https://doi.org/10.1016/j.agsy.2010.08.007

Kerselaers, E., E. Rogge, L. Lauwers, and G. Van Huylenbroeck. 2015. "Decision support for prioritising of land to be preserved for agriculture: Can participatory tool development help?" *Computers and Electronics in Agriculture* 110: 208–220. DOI: https://doi.org/10.1016/j.compag.2014.10.022

Kuehne, G., and R. Llewellyn. 2017. "The wisdom of farm advisors: knowing who and knowing why. " DOI: https://ssrn.com/abstract=2897232

Leeuwis, C. 2004. *Communication for rural innovation. Rethinking agricultural extension*. Oxford UK: Blackwell Science.

Luff, P., J. Hindmarsh, and C. Heath. 2000. *Workplace Studies*. Cambridge MA: University Press.

Lundström, C., and J. Lindblom. 2016. "Considering farmers' situated expertise in using AgriDSS to foster sustainable farming practices in precision agriculture." Paper presented at the *13th International Conference on Precision* Agriculture (ICPA), St Louis, USA, July 31-August 3.

Lundström, C., and J. Lindblom. (submitted). "Considering Farmers' Situated Knowledge of Using Agricultural Decision Support Systems (AgriDSS) to Foster Sustainable Farming Practices: The Case of CropSAT." Submitted for journal publication.

Lindblom, J., C. Lundström, M., Ljung, and A. Jonsson. 2017. "Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies." *Precision Agriculture* 18: 309–331. DOI: 10.1007/s11119-016-9491-4

McCown, R. L., P.S. Carberry, Z. Hochman, N. P. Dalgliesh, and M. A. Foale. 2009. "Re-inventing model-based decision support with Australian dryland farmers: Changing intervention concepts during 17 years of action research." *Crop and Pasture Science* 60 (11): 1017-1030. DOI:10.1071/CP08455

Mackrell, D., D. Kerr, and L. von Hellens. 2009. "A qualitative case study of the adoption and use of an agricultural decision support system in the Australian cotton industry: The socio-technical view." *Decision Support Systems* 47 (2): 143-153. DOI: https://doi.org/10.1016/j.dss.2009.02.004

Matthews, K. B., G. Schwarz, K. Buchan, M. Rivington, and D. Miller. 2008. "Wither agricultural DSS?" *Computers and Electronics in Agriculture* 61 (2): 149-159. DOI: https://doi.org/10.1016/j.compag.2007.11.001

Nitsch, U. (1994). From diffusion of innovations to mutual learning: the changing role of the agricultural advisory services. Uppsala: U. Nitsch.

Pannel, D. J., G. R. Marshall, N. Barr, A. Curtis, F. Vanclay, and R. Wilkinson. 2006. "Understanding and promoting adoption of conservation practices by rural landholders." *Australian Journal of Experimental Agriculture* 46 (11): 1407-1424 DOI: https://doi.org/10.1071/EA05037

Pierpaoli, E., G. Carli, E. Pignatti, and M. Canavari, 2013. "Drivers of precision agriculture technologies adoption: A literature review." *Procedia Technology* 8: 61-69. DOI: https://doi.org/10.1016/j.protcy.2013.11.010

Power, D. J. 2002. *Decision support systems: Concepts and resources for managers*. Westport Connecticut: Quorum Books.

Prost, L., M. Cerf, and M. H. Jeuffroy. 2012. "Lack of consideration for end-users during the design of agronomic models: A review." *Agronomy for Sustainable Development* 32 (2): 581-594. DOI: 10.1007/s13593-011-0059-4

Rose, D. C., W. J. Sutherland, C. Parker, M. Lobley, M. Winter, C. Morris, S. Twining, C. Ffoulkes, T. Amano, and L. V. Dicks. 2016. "Decision support tools for agriculture: Towards effective design and delivery." *Agricultural systems* 149: 165-174. DOI: https://doi.org/10.1016/j.agsy.2016.09.009

Rossi, V., F. Salinari, S. Poni, T. Caffi, and T. Bettati. 2014. "Addressing the implementation problem in agricultural decision support systems." *Computers and Electronics in Agriculture* 100: 88–99. DOI: https://doi.org/10.1016/j.compag.2013.10.011

Qi, J.G., A. Chehbouni, R. Huete, Y. H. Kerr, and S. Sorooshian. 1994. "A modified soil adjusted vegetation index." *Remote Sensing of Environment* 48 (2): 119–126. DOI: https://doi.org/10.1016/0034-4257(94)90134-1

Schlindwein, S. L., F. Eulenstein, M. Lana, S. Sieber, J.-P. Boulanger, E. Guevara, S. Meira, E. Gentile, and M. Bonatti. 2015. "What Can Be Learned about the Adaptation Process of Farming Systems to Climate Dynamics Using Crop Models?" *Sustainable Agriculture Research* 4 (4): 122-131. DOI: http://dx.doi.org/10.5539/sar.v4n4p122

Sundmaeker, H., C. Verdouw, S. Wolfert, and L. Pérez Freire. 2016. “Internet of Food and Farm 2020” In *Digitising the Industry - Internet of Things connecting physical, digital and virtual worlds*, edited by Vermesan, O., and P. Friess, 129-151. Gistrup/Delft: River Publishers.

Thorburn, P. J., E. Jakku, A. J. Webster, and Y. L. Everingham. 2011. “Agricultural decision support system facilitating co-learning.” *International Journal of Agricultural Sustainability* 9 (2): 322–333. DOI: http://dx.doi.org/10.1080/14735903.2011.582359

Turban, E., J. E. Aronson, J. E. Liang, and R. Sharda. 2007. *Decision support and business intelligence systems* (8th Ed.). Upper Saddle River, New Jersey, USA: Pearson, Prentice Hall.

Wolfert, S., L. Ge, C. Verdouw, and M.-J. Bogaardt. 2017. “Big Data in Smart Farming – A review.” *Agricultural Systems* 153: 69-80. DOI: https://doi.org/10.1016/j.agsy.2017.01.023