Some considerations about the development and implementation process of a new agricultural decision support system for site-specific fertilization

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Abstract

Precision agriculture provides important routes toward a more sustainable agriculture. Many farmers have the necessary technology to operate site-specifically, but they do not use it in practice, and available IT systems are not used to their full potential. This paper discusses how to reduce the so-called 'implementation problem' in order to improve the ongoing development process of a web-based fertilization project in Sweden. The intention of the project is to apply a participatory design approach, and some pitfalls on starting to use this approach in the development and implementation process are identified as well as some suggestions on how to reduce them.

Keywords: learning, agricultural decision support systems, user-centered design, participatory design, human-computer interaction

Introduction

Agriculture is facing immense challenges regarding increased food production, as well as extended considerations about the environment, biodiversity, climate change and rural development among others. The overall trend in agriculture is towards a more complex, technologically-based crop production with increasing regulation and supervision regarding the use of fertilizers, pesticides and other chemicals (Rossi *et al.*, 2012), and where precision agriculture (PA) plays an important role in a sustainable intensification.

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

In order to implement PA adequately, agricultural decision support systems (AgriDSSs) are needed. A decision-support system (DSS) is a computer-based information system that supports either a single decision-maker or a group of decision-makers in making more effective decisions when dealing with unstructured or semi-structured problems. The DSS supports one or more activities in a decision process in order to complement and 'support' decision-makers rather than to replace them.

Many farmers, at least in Sweden, have the necessary machinery that could operate site-specifically with variable rate application (VRA), but do not use it in practice. Thus, available AgriDSSs seem not to be used to their full potential and researchers are discussing the so-called 'implementation problem' (e.g. Aubert *et al.*, 2012; Eastwood *et al.*, 2012; Matthews *et al.*, 2008). Various explanations for the low adoption rate have been put forward, and the benefits of usable AgriDSSs have also been stressed. An active user involvement approach is a major success factor for delivering AgriDSSs in PA that have a significant uptake by intended users, and therefore can have a substantial impact on the quality of farmers' individual and collective decision-making and learning (e.g. Aubert *et al.*, 2012; Jakku & Thornburn, 2010; Parker & Sinclair, 2001; Van Meensel *et al.*, 2012). These issues need to be addressed in order to accomplish future AgriDSSs that considerably facilitate development in agriculture, aiming for a sustainable intensification (Caron *et al.*, 2014).

The network Precision Agriculture Sweden (POS) works with a web-based AgriDSS aiming to combine Yara N-sensor data with satellite images, for computation of variable-rate application files for nitrogen fertilization. POS's development process was financially supported in 2013 and, during 2014, a high-fidelity prototype of the AgriDSS was available on the internet (http://vegetationsindex.datavaxt.se/). So far, farmers and advisors have showed a considerable interest in the prototype. In order to use the prototype, the farmer choses a certain field using Google Earth and then a vegetation index (Qi *et al.*, 1994) is computed which will be made visible in different colours on the satellite image. The prototype handles five different levels of nitrogen application, according to differences in vegetation index. The farmer states the N-application rates for the different levels of index and then the prototype computes the total need for fertilization within the field. Finally, a VRA file is produced and the file can then be transferred to the spreader by a USB memory stick. In 2015, POS aims to take the next step in the development and implementation process of this web-based AgriDSS and to adapt it further to the farmers' needs and practice.

This paper aims to investigate and discuss the 'implementation problem' as well as the pros and cons of user participation in the development and implementation of an AgriDSS for computation of variable-rate application files for nitrogen fertilization. The focus is on how to improve the ongoing implementation process, using a more participatory model for development and implementation via the application of user-centred design (UCD) approaches from the field of human-computer interaction (HCI) (e.g. Hartson & Pyla, 2012; Rogers & Sharp *et al.*, 2011). The target group for this work are researchers and other stakeholders who have noticed problems in the process of implementing new technology, such as AgriDSSs, in agricultural practice. The paper is structured as follows: the next section addresses failures and success factors of AgriDSSs. The subsequent sections introduce the field of HCI, and UCD approaches such as participatory design (PD), which then is followed by different learning perspectives on participatory AgriDSSs development and use. Then some pitfalls when starting to apply UCD approaches are identified as well as some suggestions of how to reduce these pitfalls.

Agricultural decision support system – identified failures and success factors

Many researchers have viewed the development of new AgriDSSs as possibilities for providing scientific knowledge and information to farmers with the aim of increasing sustainability and facilitate innovation (Fountas *et al.*, 2005; McCown *et al.*, 2009; Thornburn *et al.*, 2011). During the last 30 years, research has produced a large number of AgriDSSs, but most of them have not been used appropriately in practice (e.g. Aubert *et al.*, 2012; Eastwood *et al.*, 2012; Matthews, 2008; McCown, 2002; Rossi, *et al.*, 2014). Aubert *et al.* (2012) claim that factors influencing the adoption of innovations are tightly linked to work practices that are more complex than just the mere perspectives of technology acceptance or diffusion of innovations, while Fountas *et al.* (2005) point out that time requirement, lack of technical knowledge and cost are the most important impediments in the implementation of PA. One central issue is the fact that researchers often focus on one specific area or problem, while the farmers must have a holistic view of the crop production with a wide range of problems (Rossi *et al.*, 2012). Van Meensel *et al.* (2012) also point out that some AgriDSSs are too complex, and terminology and functions are not adapted and are irrelevant to the intended users and their activities. The AgriDSSs are often developed as a result of technology push instead of a request grounded in a defined problem or an expressed need. Thus, there is an obvious gap between research and practice (Mackrell *et al.*, 2009) that McCown *et al.* (2009) define as a 'gap of relevance' which has to be bridged, or at least decreased.

Concerning the 'implementation problem', various explanations for the low adoption rate of AgriDSSs have been put forward, ranging from individual characteristics of farms, farmer's age and education level, resource availability, ease of use, experienced usefulness to farmer's risk management attitude (Aubert *et al.*, 2012; Pierpaoliet *et al.*, 2013) as well as high costs in investment and learning (Kutter *et al.*, 2011). Two reasons that are explicitly stressed are how well the farmers perceive the PA technology as 'useful' and its 'ease of use' (Aubert *et al.*, 2012; Pierpaoliet *et al.*, 2013). Lack of relevant standards and poor compatibility between different equipment, have for instance strong influence on the ease of use. Another reason identified for the 'implementation problem' is the normative way of developing new technology without considerations of the actual needs of the end-users (McCown, 2009). In other words, there seems to be a lack of knowledge concerning farmers' daily practices. Most existing research on farmers' work practices is based on rationalistic assumptions rather than empirical data from practice studies in real-life settings, though there are exceptions (e.g. Bradford, 2009; Lindblom & Lundström, 2014; Lindblom *et al.*, 2013, 2014).

Nevertheless, a well-designed AgriDSS is a useful tool for the ongoing transfer of scientific knowledge and 'best practices' within the field of agriculture. Parker and Sinclair (2001) claim that the single unifying predictor of success or failure of an AgriDSS is the extent to which users are involved and participate in design and development processes. Moreover, Jakku and Thorburn (2010) as well as Van Meensel *et al.* (2012) stress the importance of participatory approaches for the successful development of AgriDSSs as well as the role and relevance of social learning by the stakeholders involved in the participatory AgriDSS development process. From this perspective, the lack of UCD and PD approaches is the core of the identified 'implementation problems' of most DSSs.

Reducing the 'implementation problem' via the application of user-centred approaches

In order to reduce the 'implementation problem' as well as the inter-related 'gap of relevance', the authors argue that the design of AgriDSSs need to be user-centred, since humans undergo activities in a context and the varieties in people's context make the design of interactive systems challenging. The field of HCI is characterized as; '…a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them' (The ACM SIGCHI group, 1992). HCI research offers a large amount of interesting user participation approaches, showing user involvement to be a critical factor in successfully developing IT systems in general (Harris & Weistroffer, 2009). UCD is an approach within HCI aiming to develop and adapt the IT system based on the users' needs, rather than forcing the users to change their behaviour to accommodate to the system (e.g. Hartson & Pyla, 2012; Rogers *et al.*, 2011). The result of employing a UCD approach when designing and developing an AgriDSS is a more efficient, satisfying and usable experience for the user, which is likely to increase user acceptance, learnability and confidence of the system (Hartwick & Barki, 2001). Similarly, a more radical approach to UCD is the 'Scandinavian model' of PD emerging within the system development field among a group of Scandinavian researchers who focused on the democratization of working life (Marti & Bannon, 2009). PD as a design approach is characterized as attempting to actively engage all users and stakeholders (they all are seen as equal partners) in the design process in order to ensure that the product designed fulfils their needs and is useful. PD stresses the importance of processes and procedures of design and is more responsive to their stakeholders' and users' cultural, emotional, and way of working practices and learning (e.g. Bjerknes *et al.*, 1987). In summary, UCD and PD approaches have the vision of insuring high usability, i.e. adapting the system to the end users' and stakeholders' needs and goals which increase the possibility of satisfied users and AgriDSS success significantly. The final AgriDSS is not an end in itself; rather the system is a means towards the end of providing good usability and user experience, and for supporting the actual tasks for the intended users.

Some recent successful examples of active user-involvement in the design process of AgriDSSs are the work by Jakku and Thorburn (2010) as well as Van Meensel *et al.* (2012). Jakku and Thorburn (2010) highlight the importance of involving stakeholders as active participants throughout the whole development process. A central issue in their paper is the changed view on the agricultural innovation process, stressing the importance of viewing agricultural innovations as complex interactive processes of co-learning and negotiation, in which social learning practices are fostered. Moreover, Van Meensel *et al.* (2012) identify some success factors in the PD development approach of an AgriDSS named Pigs2win. The aim of Pigs2win was to develop an AgriDSS that is scientifically sound, usable in practice, and supported by the pig sector in the actual region. Critical success factors were flexibility, perceived usefulness, accessibility, credibility, maintenance and adaptability, and focus on the intended users. Central issues for the success of the participatory approach during the whole development process are: (1) selection of appropriate stakeholders and high level of transparency to the stakeholders; (2) constructive collaboration among stakeholders, which resulted in active involvement and a consensus of common goals for the AgriDSS; and (3) a flexibility in the development process, respecting the available time and scope, but accepting adaptation during the process and not following an *a priori* detailed road map (Van Meensel *et al.*, 2012). As a result of using a PD development process, the stakeholders identified 14 outcomes that the DSS should be able to handle properly, which then were implemented in 12 features in Pigs2win. The result is an AgriDSS that allows for identifying farm-specific sub-optimal KPIs (key performance indicators), and assessing aggregate economic and environmental effects of improving these KPIs. The authors stress that the AgriDSS does not provide any direct advice on what concrete decision to make. This means that the actual decision is left for the intended user (advisor) to do, but the AgriDSS provides information on the KPIs that is useful in supporting the activities of pig farming via technological support.

Moreover, Thorburn *et al.* (2011) emphasize that, apart from increased adoption and acceptance of the developed AgriDSS, PD approaches seem to enact co-learning as a result of the development process. They stress that learning is a valuable process in increasing sustainability in agriculture, so that the application of AgriDSS in a social learning context may make a contribution to the global challenges faced by agriculture. They point out that the value of participatory development processes of AgriDSS as a co-learning process, is an outcome that traditionally has not been appreciated enough by AgriDSS developers and one identified issue that is likely to tackle the challenges faced by agricultural sustainability.

Participatory design as a social learning process and agricultural decision support system as a social learning tool

In order to bridge the gap of relevance between research and practice, there is a need to change the perspective from 'knowledge transfer' to 'learning' (McCown, 2009). Hence, the AgriDSS should be designed as a system to support farmers´ learning instead of a system for knowledge transfer of predefined (scientific) knowledge. There is an increased focus on the need for a social learning perspective in AgriDSSs, and sustainable agriculture in general. Social learning has the potential to be the common ground in future, integrated initiatives. Thorburn *et al.* (2011) point out that much of the focus in the development process of AgriDSSs has been on the individual's learning and decision-making and such approaches have had an implicit goal of sustained use of the AgriDSSs to guide farming practices. However, AgriDSSs are also used in group settings for more strategic analyses of changes in the farming management systems, e.g. the Pigs2win project. They stress the intended value in looking more to shared learning experiences rather than focus on individual learning, decision-making and the actual use of the AgriDSSs. Furthermore, they point out that such knowledge may make a more valuable contribution to sustainable resource management when used to facilitate learning processes among groups of stakeholders. In other words, scientific knowledge can be usefully embedded in AgriDSSs in these settings.

Generally speaking, the parallels between social learning principles and PD approaches are obvious, and it may be beneficial to consider AgriDSSs as social learning tools, and not only as operational tools (Thorburn *et al.,* 2011). Their potential value in enhancing co-learning among stakeholders in agriculture may be increased by considering the social processes involved in the participatory approach in which AgriDSS use is embedded, i.e. the way in which participants share their perspectives and work together as a group to solve problems, drawing on their different kinds of knowledge (Thorburn *et al.*, 2011). Concerning the learning perspective, Thorburn *et al.* (2011) stress the value of focusing more on shared learning experiences than the actual use of an AgriDSSs. They also emphasize that such knowledge may make a more valuable contribution to sustainable farming practices when used for facilitating learning processes among groups of stakeholders. The role of AgriDSS as an enabler of co-learning is mostly present during the design and development process, but once the AgriDSS has been implemented, emphasis shifts from co-learning to routine use. Thus, it may be beneficial to consider AgriDSSs as social learning tools, and not only as operational tools. Their potential value in enhancing co-learning among stakeholders in agriculture may be increased by considering the social processes involved in the practices in which AgriDSS use is embedded (Thorburn *et al.*, 2011). To conclude, PD approaches and social learning processes share some common characteristics; stressing the importance of understanding the contexts in which the activities take place, getting to know the people involved, establishing a dialogue of mutual sharing of different perspectives, and working together to reach common goals.

Some beginners' pitfalls in participatory design and some suggestions on how to reduce them

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

The development and design process of the POS network AgriDSS for calculation of variable-rate application files has begun and a high-fidelity prototype was presented during 2014. User participation to this point has been very limited, and the ambition is to introduce user-participation in the upcoming iterative development, evaluation and implementation process. POS intends to apply a PD approach in order to avoid the 'implementation problem' as well as the 'gap of relevance'. In so doing, a group of relevant stakeholders consisting of end-users such as farmers, advisors and some researchers will be recruited, and they will meet on a regular basis. Furthermore, the initial project members have also identified the need for a user advocate/facilitator who aims to act as an intermediate link/coach between different participants in order to create a common ground and reach consensus within the newly established development team. Although the intention of introducing aspects from a PD approach is beneficial, for the development team, there are some identified pitfalls to consider:

- Non-familiarity with addressing usability work and specific work activities and processes in PD.
- General lack of knowledge concerning UCD methods, and PD methods in particular.

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

Although the above list, at first glance, may be discouraging, it serves as an initial step to reduce the pitfalls, given the fact that they are identified and made explicit. The list provides a good starting point for the forthcoming evaluation and development process. Some actions that are being considered to reduce the pitfalls are:

- Inviting an external expert in usability work to introduce PD to POS members, aiming to reach acceptance for the PD approach by an introduction workshop. With a long experience of 'the implementation problem' of new technology, the aim is that POS will begin to use this approach in future development processes.
- Recruiting farmers and advisors as end-users that are considered as early adopters and 'willing and able' to participate in this kind of PD project.
- Choosing a user advocate, with responsibility for mediating between end-users and designers/developers that will lead the PD work activities. The central question is who that will be? Should the user advocate be an external consultant or should somebody from POS be responsible for this role and learn through apprenticeship during the PD process?
- Planning for the future evaluation and development work will be performed together with all members in the PD team, focusing on evaluating the prototype and also identifying and developing additional, needed functionalities.
- Fitting the developed AgriDSS into the existing farming system context, for example, farmers´ plant production system or governmental system for extension services.
- Establishing a long term connection with a usability expert in order to manage conflicting collected user data and user opinions as well as functioning as a guide/coach in the development/learning process.

Conclusions

The intention is that the PD approach presented above will initiate a turning of the tide for POS´s future developmental work with PA technology, such as the exemplified AgriDSSs, in order to reduce 'the implementation problem'. This way of working makes it easier to bridge the gap between theory and practice. The involved stakeholders in the POS project may reach an increased understanding of 'the implementation problem' through a co-learning process. To conclude, the authors believe that a PD approach when developing an AgriDSS will lead to innovative and more applicable farm management practices which increase sustainability in agriculture.

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