International Journal of Agricultural Sustainability

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tags20

Agricultural decision support systems facilitating co-learning: a case study on environmental impacts of sugarcane production

P. J. Thorburn [a], E. Jakku [a], A. J. Webster [b] & Y. L. Everingham [c]

[a] CSIRO Ecosystem Sciences and Sustainable Agriculture Flagship, GPO Box 2583, Brisbane, QLD, 4001, Australia

[b] CSIRO Ecosystem Sciences and Sustainable Agriculture Flagship, James Cook University, PO Box 12139, Earlville BC, Cairns, QLD, 4870, Australia

[c] School of Engineering and Physical Sciences, James Cook University, Townsville, QLD, 4814, Australia

Available online: 15 Jul 2011

To cite this article: P. J. Thorburn, E. Jakku, A. J. Webster & Y. L. Everingham (2011): Agricultural decision support systems facilitating co-learning: a case study on environmental impacts of sugarcane production, International Journal of Agricultural Sustainability, 9:2, 322-333

To link to this article: http://dx.doi.org/10.1080/14735903.2011.582359

Agricultural decision support systems facilitating co-learning: a case study on environmental impacts of sugarcane production

P. J. Thorburn[1]*, E. Jakku[1], A. J. Webster[2] and Y. L. Everingham[3]

[1] CSIRO Ecosystem Sciences and Sustainable Agriculture Flagship, GPO Box 2583, Brisbane, QLD 4001, Australia
[2] CSIRO Ecosystem Sciences and Sustainable Agriculture Flagship, James Cook University, PO Box 12139, Earlville BC, Cairns, QLD 4870, Australia
[3] School of Engineering and Physical Sciences, James Cook University, Townsville, QLD 4814, Australia

Decision support systems (DSSs) are one of the ways in which agricultural scientists have attempted to make agricultural systems science more accessible to farmers and to foster innovation. Recently, there has been a shift towards more participatory processes in development and application of DSSs to enhance their end-user use. Apart from increasing adoption, these participatory processes are also likely to enhance co-learning resulting from development/application of DSSs. Learning is a valuable process in increasing sustainability of natural resource management, so the application of DSSs in a learning context can make a contribution to the global challenges faced by agriculture. We developed a framework, using concepts drawn from social studies of science and technology, describing the phases of the participatory DSS development/application process and its likely outcomes. We analysed experiences of participants in a case study exploring more sustainable management of nitrogen fertilizer in sugarcane production in an environmentally sensitive area of northeastern Australia. The data illustrate theoretical constructs underpinning the framework and learning processes within the case study. The framework and case study results demonstrate the value of participatory DSS development/application as a co-learning process, an outcome not traditionally valued by agricultural DSS developers and one that is likely to help address the challenges faced by agricultural sustainability.

Keywords: APSIM; boundary object; climate variability; Great Barrier Reef; nitrogen; science and technology studies; social learning

Introduction

Agricultural sustainability is facing substantial challenges from global change. While there are heightened requirements to maintain or increase food production as populations rise, agriculture is being confronted with climate change, continuing degradation of its natural resource base and increasing energy costs (Keating and Carberry, 2010). These challenges will require continued or increased innovation in agricultural production. The development of decision support systems (DSSs) has been one way in which agricultural scientists have attempted to facilitate innovation among farmers (McCown, 2002), to better deal with the complexity of optimizing farming systems in the face of multiple goals and constraints. In an agricultural context, DSSs are software applications aiming to represent some part(s) of the crop management and/or production system. Often they are based on models of processes in farming systems and how production and/or environmental outputs respond to different management practices, such as irrigation, fertilizer, sowing and harvesting dates, and/or climatic variability (see e.g. McCown, 2002). Given the future need for

*Corresponding author. Email: Peter.Thorburn@csiro.au

PAGES 322–333, doi:10.1080/14735903.2011.582359 ISSN: 1473-5903 (print), 1747-762X (online). www.earthscan.co.uk/journals/ijas

innovation in agricultural production, the potential for DSSs to contribute to agricultural sustainability will increase.

There has been a move to participatory action research (PAR) in the development of DSSs in an attempt to increase their impact on farm practice (Carberry *et al*., 2002; McCown and Parton, 2006), and frameworks developed to guide these interactions have focused on the individual's learning and decision making (McCown *et al*., 2009). Such work often has a goal, which may be implicit, of sustained use of the DSS to guide farming practice (Matthews *et al*., 2008), and so lack of sustained use is often seen as failure. However, agricultural DSSs are also used in group settings for more strategic analyses, for example seeking 'step changes' in farming system management (Archer *et al*., 2008), as opposed to adjustment of day-to-day practices in response to external influences (e.g. immediate past or projected climatic conditions). In these settings, there may be value in looking more to shared learning experiences rather than focusing on individual learning, decision making and DSS use (Nelson *et al*., 2002; Matthews *et al*., 2008).

There are parallels in the evolution of DSS applications in agriculture and the use of scientific knowledge for management of natural resources, notably water management. Rather than using scientific knowledge in a prescriptive manner, for example via regulation, such knowledge may make a more valuable contribution to sustainable resource management when used to facilitate learning processes among groups of stakeholders (Pahl-Wostl *et al*., 2007; Steyaert and Jiggins, 2007). Scientific knowledge can be usefully deployed through information and communication tools in these settings (Pahl-Wostl, 2007; Steyaert and Jiggins, 2007; Mostert *et al*., 2008). Much of this work has been analysed in the context of social learning (Muro and Jeffrey, 2008). Given the parallels between social learning principles and PAR approaches (Measham, 2009), there may be benefit from considering agricultural DSSs as social learning tools (Nelson *et al*., 2002; Matthews *et al*., 2008) rather than as operational tools (McCown, 2002). Their value in enhancing co-learning among groups may be increased by considering the social processes involved in the participatory approach in which DSSs use/development is embedded: That is the way in which participants share their perspectives and work together as a group to solve problems, drawing on their different kinds of knowledge (Bouwen and Taillieu, 2004).

In this paper we briefly describe and then use concepts from social sciences, specifically the field of science and technology studies, to develop a framework that provides a new perspective on the social processes at play in developing and/or applying a DSS. In particular, the framework embraces a wider definition of 'success' of the process, by acknowledging the value of the learning achieved, irrespective of the subsequent use of the DSS. We illustrate the application of the framework through a case study of using an agricultural DSS to evaluate options for improving sustainability of sugarcane production in environmentally sensitive catchments of Australia's Great Barrier Reef.

Conceptual framework

Science and technology studies demonstrate that 'scientific knowledge is not the passive product of nature but an actively negotiated, social product of human inquiry' (Cozzens and Woodhouse, 1995, p.534) and that technology is 'a social product, patterned by the conditions of its creation and use' (Williams and Edge, 1996, p.866). There are three concepts in science and technology studies that provide a more theoretically informed understanding of DSS development and/or application; they are *interpretative flexibility*, *technological frames* and *boundary objects*. These concepts can be combined (Figure 1) to describe how they can interrelate in participative interactions for development/application of DSSs. Here we outline the three concepts and how they may interact in the process of participatory DSS development/application. A more complete description of the framework and the social concepts underpinning it is given by Jakku and Thorburn (2010a).

Interpretative flexibility means that any object can mean different things to different people, depending on contextual factors (Hess, 1997). For example, scientists' perception of a DSS may be linked to the underlying scientific concepts embodied in the DSS, whereas extension officers' and/or farmers' perception may be linked to their assessment of the utility of the DSS for addressing an issue of concern for them. Interpretative flexibility also emphasizes that there is flexibility in the interpretation and use of technologies (Orlikowski, 1992). Importantly, these different views and/or uses are equally valid.

Technological frames are the assumptions, beliefs and expectations that groups of people hold about a

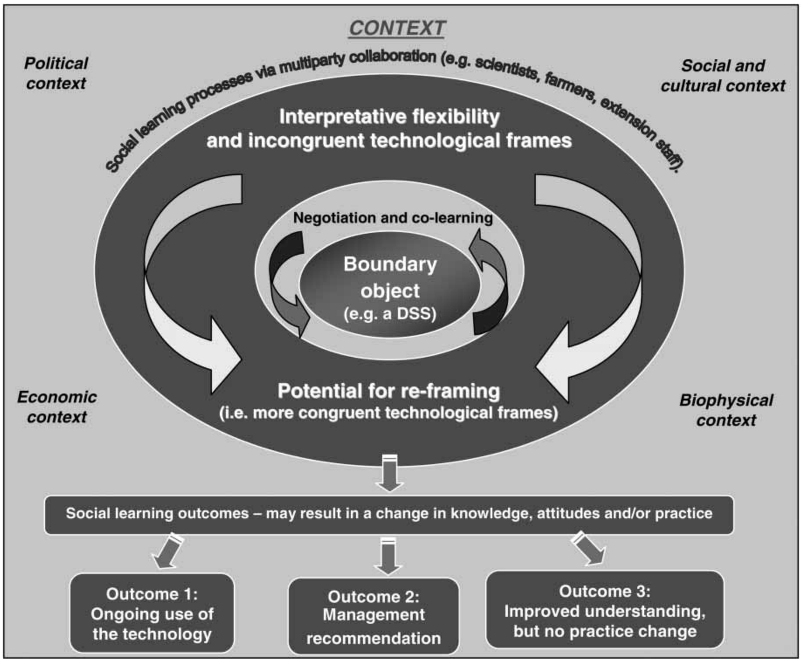

Figure 1 | Theoretical framework of the context, processes and outcomes of participatory development and/or application of agricultural DSSs (after Jakku and Thorburn, 2010a, b)

specific technology, which in turn influence the design and use of that technology. A technological frame can be considered a kind of 'mental model', which consists of cognitive elements such as an individual's goals, problem-solving strategies, etc. (Bijker, 1987). Due to the interpretative flexibility of technology, technological frames may be held in common or be disparate. When the frames of different people become similar, they are termed as being congruent (Orlikowski and Gash, 1994). Incongruent technological frames can lead to conflicts over the use and value of a technology and hence create difficulties for its application. It is hoped that participatory processes result in increasingly congruent technological frames.

Boundary objects 'are objects which are plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity' (Star and Griesemer, 1989, p.393). The concept of boundary objects has been used to describe the role of various information and communication technologies in social interactions. Harvey and Chrisman (1998, p.1693) use the concept to describe how GIS technology facilitates cooperation between scientists, policy specialists, various institutions and concerned citizens. Cash (2001) described how scientific models can act as boundary objects in agricultural extension: 'models themselves can act as boundary objects, dependent on both the participation of farmers to get inputs that reflect reality and outputs that are useful, as well as on scientists who incorporate basic research on the systems under study and the technical capacity to guide the endeavour' (Cash, 2001, p.441).

In a participatory process, a DSS may act as a boundary object, by creating a temporary bridge between the various people involved in its development and/or application, while remaining flexible enough to be used by the different parties for their own purposes. The co-learning that the DSS-as-boundary object can facilitate involves a re-framing of beliefs, assumptions and expectations regarding the problem (i.e. more congruent technological frames), which allows the parties involved in this process to arrive at an increasingly shared understanding of the problem. Acknowledgement of this co-learning potential of the DSS-as-boundary object helps one to manage interpretative flexibility and deal with differences in technological frames within the participatory development of DSSs. Obviously any technology, including a DSS, is conditioned by and embedded in its external social, cultural, political, economic and biophysical contexts (Figure 1), which must be considered during these interactions.

The framework also highlights three social learning outcomes, which may result if there is a change in knowledge, attitudes or practices during the participatory DSS development or application process (Figure 1). Outcome 1 may be acceptance by potential users of the value of ongoing use of the DSS, which may necessitate further cycles of negotiation and co-learning to, for example, make the software more user-friendly. This corresponds to more classical participatory DSS development. Once the DSS is ready for routine use, emphasis shifts from co-learning to making the DSS available for ongoing use by farmers and their advisors.

However, the cycles of co-learning can lead to a more detailed understanding of the problem and its context and thence to a new and widely applicable management practice that becomes a routine management recommendation, independent of the DSS (i.e. Outcome 2). In this situation, the DSS may be seen as having been more applied than developed.

Finally, the parties involved may find that their understanding of the problem has improved, but there is no reason to change current practice (Outcome 3). This outcome may occur because better understanding of the problem has led to the acceptance, especially by the farmers involved, that there is no opportunity for, or no relative advantage associated with, changing the current management practice. If some parties, for example the scientists, disagree with this view, the technological frames are obviously incongruent.

Case study

The case study examined the experiences of a group of farmers, extension officers and scientists who collaborated to utilize a DSS to explore opportunities for reducing environmental losses of nitrogen (N) from sugarcane farms. A description of the context of the study, the formation of the Group, explorations with the DSS conducted by the Group and outcomes follow.

Context

The health of corals in the Great Barrier Reef, lying off the northeastern coast of Australia, is under threat from land-based pollutants, including N. This is particularly so in the region off Tully (18.0°S, 145.8°E), and N losses from sugarcane are of concern in this region (Bainbridge *et al*., 2009). However, sugarcane production relies on large applications of N fertilizer and there may be conflict between management practices designed to reduce losses of N and those designed to maximize productivity. The N cycle in cropping systems is complex, with many interactions between soil biology, soil hydrology, plant growth and climate. As a result, experimental approaches to N fertilizer management can be very expensive and may not produce definitive answers. DSSs can describe interactions in the N cycle and have been found useful in helping define more sustainable N management practices in sugarcane production (Thorburn *et al*., 2005). Informal discussions between Tully sugarcane farmers and scientists led to the initiation of this case study.

Approach

The case study comprised 10 sugarcane farmers and three local sugarcane industry representatives[1] from the Tully region, and three scientists from outside the region. The Group met five times from November 2004 until March 2006, with interactions progressing through the following phases:

1. Defining the ‘problem’ to be addressed by the Group and perceptions of potential solutions (i.e. farm management option) to the problem.
2. Describing and gaining trust in the DSS’s capacity to predict sugarcane production in Tully.
3. Defining the boundaries of the analyses (i.e. specifying soils, farming systems, economic parameters, etc.).
4. Analysing the potential outcomes of the management options.
5. Final review of the case study.
6. Interviews with individual Group members about their experiences and learning during the case study.

The first three phases were completed during the initial meeting. At first, Group members were surveyed about their perception of the problem and the potential solutions to be explored. Results of the survey were collated immediately, discussed by the Group and agreement reached on the path forward. Given the scope of the informal discussions prior to the study, the scientists had prepared information describing the DSS and its capacity to predict sugarcane production in general and specifically in the Tully region. The boundaries of the analyses were negotiated, trading off between the level of detail that the local Group members thought was desirable and the limitations of the DSS and the time available in which to undertake the analyses.

Phase 4 was undertaken over the next three meetings. Simulation results (described below) were presented by the scientists and discussed. Discussions centred on the 'meaning' of the analysis results to all the Group members. These discussions identified 'problems' with the results, and alterations and/or extensions to the scenarios that defined the simulations done before the next meeting.

The final review (Phase 5), which included discussion about future actions, started in the second last meeting and was the main topic for the last meeting.

After the conclusion of the Group's interactions, semi-structured, in-depth interviews (i.e. Phase 6) were conducted with nine members of the Group (including farmers, industry representatives and scientists) to collect 'rich' data (Maxwell, 1996) on their experiences, with a particular focus on the social learning processes occurring within the Group. Questions focused on participants' perceptions of N fertilizer management, the simulation studies undertaken during the Group's interactions and the potential impact the Group's conclusions had on participants' future practices. The data were analysed with a particular focus on both (1) the science and technology studies theory embodied within the framework (Figure 1) and (2) the social learning processes the case study involved.

Problem and possible solutions

Local members of the case study Group wanted to find potential ways to improve their N fertilizer management to reduce environmental impacts and cost of production while maintaining or improving productivity. Sugarcane production at Tully is inversely related to annual rainfall and the local 'mental model' was that low growth in years of high rainfall was caused by N being leached from the soil. Hence, maintaining production might be achieved by applying additional N fertilizer in 'wet' years. However, losses of N fertilizer to the environment may be greater in these years. So the 'net outcome' of different management strategies was not clear. There was also concern about the best way to manage the different soils occurring in the region.

There were three broad strategies for improving N fertilizer management identified by local Group members. Firstly, they were interested in varying N fertilizer rate: what is the optimum rate and does it vary between years? They were also interested in the benefits of applying N fertilizer in split applications (e.g. half the amount applied at two times). 'Splitting' involves extra effort and cost compared to a single application and so, in the scientists' experience, is generally not seen as a convenient or profitable option by farmers. However, the farmers maintained that splitting was a viable management option. Thirdly, local Group members considered that seasonal climate forecasts might be useful for identifying wet years and the time to apply more N fertilizer.

Boundaries of the analyses

Agreement was reached on the soil types to be included in the simulations, representing a range of textures (fine to very coarse) that the local Group members thought was important, but limited to specific soil types the scientists felt could be reliably parameterized for the model. A regionally representative cropping system was defined for the simulations: sugarcane was planted in early August, crops harvested mid-season (mid-September) for five years (giving four ratoons) and N applied (all or first split) six weeks after planting or harvest.[2] The second application of N, if applied, was six weeks after the first.

Analyses with the DSS

The APSIM-sugarcane cropping systems model was the DSS used by the Group because of its capabilities for simulating N dynamics in sugarcane systems (Thorburn *et al*., 2005). Data from soil surveys and local experiments (Hurney *et al*., 2003) were used to parameterize the DSS.

The simulations were divided into two groups: tactical and strategic.

Tactical simulations

The tactical simulations were a detailed presentation of sugarcane yields and environmental N losses in each of the years 1998–2004 (Figure 2). These specific years were chosen as the local participants remembered climatic conditions of each, which varied across those years (including much wetter than average and much drier than average seasons) and resulted in contrasting crop yields. Simulations focused on the response of yields and N losses to increasing N fertilizer application rates for the different soil types. The effect of splitting N applications was also considered. The tactical simulations were used by the Group to: (1) understand the DSS's capabilities and limits; (2) fine-tune DSS

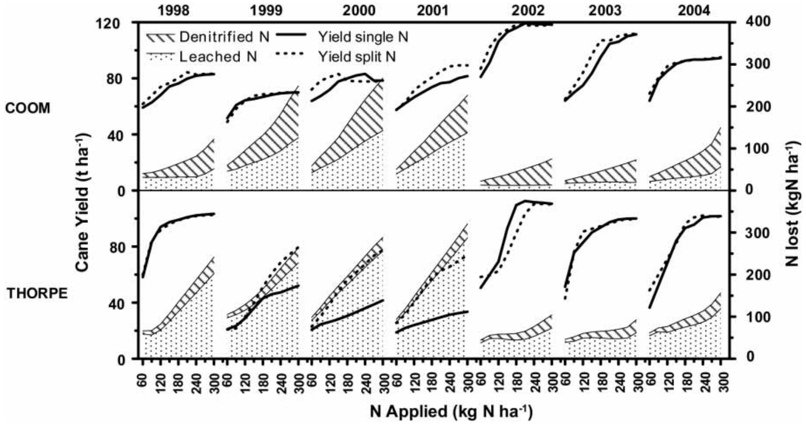

Figure 2 | Simulated responses in sugarcane yield (solid line) and nitrogen lost to the environment via leaching (stippled area) or denitrification (hatched area) in response to increasing N fertilizer applications across seven years in two soil types (Coom – fine textured; Thorpe – coarse textured; Cannon *et al*., 1992). All results have a single application of N fertilizer applied 42 days after harvest. Yields simulated for split application (dashed lines) of N fertilizer, 50 per cent of fertilizer applied 42 days after harvest and the remainder applied 42 days later, are also shown

parameterization to better reflect local experience (some of which was documented by Hurney *et al*., 2003); and hence (3) gain trust in the DSS's capabilities.

The tactical simulations showed that:

- crop yields in wet years (1999–2001) were lower than in dry years (2002–2004);
- responses in yield to high N fertilizer applications (i.e. at rates above those recommended) did not vary substantially between wet and dry years (Figure 2), except in the coarse soil; and
- the effect of splitting N applications was variable, giving greatest benefits in wetter years, especially in the coarse textured soil.

The second result, that extra N did not increase yields in wet years in all but the coarse soil, was contrary to the local Group members' 'mental model'. The result occurred because radiation, and hence growth and demand for N, is lower in wet years. It was only in the coarse textured soil, where low organic matter reduces the amount of N that can be mineralized and become available for the crop in times of high N

Table 1 | **Nitrogen fertilizer management strategies for sugarcane production simulated over 40 years**

Management strategy	Amount of N fertilizer	Single or split application	Condition[1]
Constant management			
C1	150	Single	Always
C2	150	Split	Always
Variable management			
V1	75	Single	September SOI phase is consistently positive
V2	150	Split	September SOI phase is consistently positive
V3	(i) 75 late-October, and	Conditional	(i) September SOI phase is consistently positive, and
	(ii) 75 early-December		(ii) Rainfall between mid-October and mid-December <300 mm

[1]SOI = Southern Oscillation Index.

losses, that additional N fertilizer or split applications gave higher yields.

Strategic simulations

The strategic simulations presented longer-term predictions, over 40 years from the early 1960s. This time period was specified by the farmers as being relevant to their memory and covered a range of decadal climatic cycles. The strategic simulations concentrated on predicting the long-term yield, profitability and environmental N losses as a function of different management strategies. The strategies focused on 'rules' for splitting N fertilizer applications based on seasonal climate forecasts to 'manage risk' of N losses: that is, if a 'wet season' was forecast, then less N fertilizer could be applied or the conventional amount of N could be 'split' or a lesser amount could be initially applied followed by more later in the season should the actual rainfall be less than forecast (and crop yield potentially be higher). A 'wet season' was defined by rainfall totalling 300 mm during the period between the two potential times for fertilizer application (late October and early December). The Southern Oscillation Index (SOI) phase system (Stone and Auliciems, 1992) was used to provide a seasonal rainfall forecast. If the SOI phase at the end of September was *consistently positive* there was a 74 per cent chance of rainfall exceeding the median (389mm) during October to December. 'Control treatments' included in the simulations were N fertilizer consistently applied either at one time or split. Thus there were five different management systems simulated (Table 1).

Mean and 50th percentile simulated yields were higher with consistent splitting of N fertilizer (strategy C2, Table 1) than a consistent single application (C1) in both soil types (Figure 3), as expected from the tactical simulation results (Figure 2). Yields with the variable strategies (V1–V3) were also lower than with consistent splitting, although the difference between this latter strategy and the variable splitting strategy (V2) was small (Figure 3). With the variable strategies, 'wet seasons' were forecast by the SOI in seven years but only eventuated in four (Figure 4). Conversely, there were three years with 'wet seasons' when the SOI forecast did not favour above median rainfall. This 'mismatch' between the strategy and the seasonal rainfall limited crop growth in some years in the simulations. N losses were lowest with consistent splitting of N fertilizer (C2) in both soil types (Figure 3). This result is consistent with the yield data, as sugarcane crops contain considerable amounts of N, so there is less N available to be lost to the environment in larger crops. The profitability (data not shown) of the variable strategy (V2) was similar to or greater than that of the other strategies as income from higher yields offset or exceeded the additional cost of the second fertilizer application.

Final review

The Group considered whether there were any future practical actions (e.g. on-farm trials and changes to local recommendations) that should be taken in the region regarding the N management strategies examined. The local Group members' general feeling was that, even though they accepted the simulation results that splitting N fertilizer *every year* was the most sustainable system, the inconvenience involved in splitting was not worth the benefits identified in the simulations. Their original interest in examining splitting was, essentially, based on the hope that it would provide more dramatic improvements in sustainability. As one participant commented:

> I thought we might be able to get much better, from an environmental point of view, and an economic point of view, utilization of nitrogen.

As described below, there was some general interest in considering splitting in years where the SOI phase was 2 during the harvest season: The less frequent inconvenience might be acceptable for the possible benefits. But there was no consensus among local Group members on this issue.

Analysis of case study participants' experiences

The participants' comments illustrate the elements of the framework. For example, the range of expectations the participants initially held about the possible direction of the study illustrates the various technological frames that shaped their expectations of the study:

> . . . I was curious to see how you could use the nitrogen application part of . . . it, which I understand we probably all have our own ideas through experience, about putting on nitrogen in different wet years and dry years, and things like that. (Farmer)

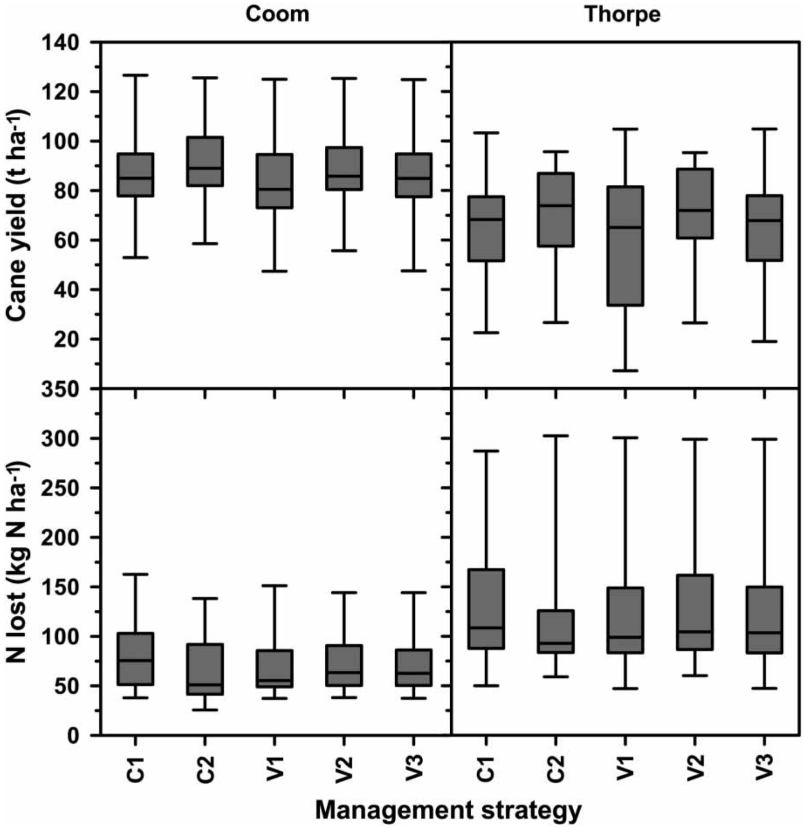

Figure 3 | 'Box and whisker' plots (showing minimum, maximum, median, lower quartile and upper quartile information for groups of data) of simulated long-term sugarcane yield and N losses in five different management systems (described in Table 1) for two soil types (described in Figure 1)

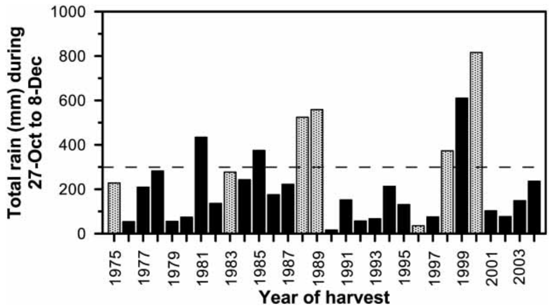

Figure 4 | Total rainfall at Tully from 27 October to 7 December (the 'window of opportunity' for applying nitrogen fertilizer in the simulations) in the years simulated in the case study. Years when above median rainfall was forecast from the SOI in September are indicated by the stippled bars and the horizontal line shows the median rainfall for that time

> . . . I suppose [his expectation for the project] was to learn about climate forecasting and how it might be used and the various tools that are available and for nitrogen management. (Extension officer)

There was evidence that the DSS gained credibility with local participants, to varying extents. Some participants were enthusiastic about the DSS:

> You know the APSIM modelling was very impressive. It sort of introduced me to that and to me I think that is a very powerful tool. (Farmer)

> It [the nitrogen modelling] was very informative. That really appealed to me and sent a big message home. (Farmer)

However, other participants expressed concerns about the accuracy of simulation results, as the DSS had not been applied and validated in the region before:

> I think more research is needed, though, there's no doubt about that. . . . [DSSs] are all well and good, but they need to be tested. (Farmer)

In these participatory simulation exercises, it is evident that the DSS acted as a boundary object. The participants explored their assumptions about N fertilizer management and gained a better understanding of the N cycle and the consequences of different N management scenarios in that environment:

> I was just fascinated with the different responses of the soil types. Sort of say, okay what about this scenario? [The scientists] could put it into [the DSS] and got one result and change a few parameters and you come out with totally opposite results. (Farmer)

> It [the DSS] did help. . .for those extreme years I'm talking about. . . . Yeah . . . the examples that were given, it did show the response curve to nitrogen, and things like that, when this happens and that happens. So . . . we all pretty well knew that this was happening, but how much? (Farmer)

In these responses, it is obvious that the farmers were interested in different aspects of the simulations, illustrating both the interpretive flexibility that underpinned interactions during the case study, and the role of the DSS as a boundary object, adapting to needs of the different people (farmers in this case) interacting with it.

At the conclusion of the case study, there remained a degree of incongruence among the technological frames of the case study members. Some of the participants did not see any need to change what they had been previously doing as a result of their involvement in the case study:

> . . . I thought that there would be something in it but I think farmers today are very responsible in what they do and I don't think anybody wants to waste our nitrogen and input for our crops. It's very costly and if you don't have control and manage your business well, you will not survive. . . . I think I have been responsible [re: N management] all along, even before the project. I always tried to manage as best as possible and as far as nitrogen, I think all my life I've tried to use as least as possible and tried to be productive. (Farmer)

> I don't think I've learnt much more, but I've been [managing nitrogen], you know, pretty right till now. I don't think there's much further I can improve it. (Farmer)

Others saw no opportunity for change:

> . . . I am concerned about and confused about [managing nitrogen] still, in that it would seem from a water quality perspective, nitrates are the ones that are getting targeted and from this project I saw significant limitations in what growers can actually do about it. So even at best practice, I didn't get a strong feel that we were going to solve the problem. (Extension officer)

The reactions of these three participants are consistent with Outcome 3 of the framework (Figure 1). However, for others there were clear take-home messages on how they should manage N fertilizer, consistent with Outcome 2:

> What got my attention first was that during the wet years . . . his modelling [was] indicating that if I had split my fertiliser [on my fields with coarse textured soils] I would have been up another . . . 15 tonnes a hectare, from 65 up to about 80 tonnes. So that really got my attention. (Farmer)

> . . . We were looking at [recommending] a lower rate in those wetter conditions. That's one of the things we're planning. (Extension officer)

> It was very clear to me that [for] nitrogen in [coarse textured] soils . . . the management is critical. (Extension officer)

The participatory approach to this simulation exercise provided an opportunity to gain insights into others' perspectives and was designed to help facilitate a common learning experience, which was important for making the technological frames more congruent. The learning that results from the simulation is evident in some of the responses listed above. It is also highlighted by two of the participating scientists:

> . . . The idea that you want to move to congruency is something that is important to be able to do. . . . It's difficult to put your finger on it. I think it's about understanding . . . where the other person is coming from . . .

> . . . I think we got some credibility that outsiders could walk in and [show] . . . that we had insights into the [local cropping system] . . . that were valuable and perhaps a bit different to what they had. . . I suppose I had the more detailed knowledge of the biophysical system and [we used that knowledge to address] what [the farmers] wanted to achieve, and so I could say, well, do you think this would work . . . well let's test that and come back . . . [I] was almost a facilitator between the biophysical science, [that in] this case was embodied in the [DSS] . . . , and the specifics of [the farmers'] environment and the ideas that they had for management.

> Perhaps I purposely tried to be . . . a facilitator and not inject too much of my own ideas into it, because otherwise it wouldn't be grower driven.

But, there was also learning among peers:

> That was good, the interaction, to hear [Farmer] talk about what he does up there [on his farm]. And what [Farmer] does, I can't do. And probably what I do, [Farmer] can't do. But it's interesting, you learn from that. (Farmer)

This analysis shows how, through interactions around the DSS, farmers, extension staff and scientists collaborated and learnt from each other, in spite of the diverse types of knowledge they held about the DSS function or the N management strategies addressed in the study. The collaboration was made possible because of the respect demonstrated for the range of contributions that different parties brought to the process. The iterative nature of the participatory DSS application process helped build trust between the stakeholders, to facilitate sharing of knowledge and co-learning.

Discussion

The case study illustrated the complex process in participatory interactions for DSS application, as described in our framework (Figure 1). The participants clearly entered the Group with a range of expectations and engaged in different issues in the simulations undertaken with the DSS. Thus the participants possessed a range of technological frames both at the commencement and during the study. Participants also expressed interpretative flexibility over the DSS: A scientist clearly commented on the 'biophysical science . . . embodied in the [DSS]', whereas comments from the farmers and extension staff referred to the DSS as a 'tool'. The DSS, APSIM, acted as a boundary object, allowing the farmers and industry representatives to examine different management strategies for achieving their goals, while the scientists were able to expand the environments under which the DSS was applied with some credibility. Our case study demonstrated that credibility is central to the effectiveness of boundary objects, as has been observed in other studies of boundary objects (Cash, 2001) and agricultural DSSs (Carberry *et al*., 2002; McCown, 2002; Matthews *et al*., 2008). There was some degree of agreement on the practical implications of the simulation results for local N fertilizer management among participants, particularly regarding management of the coarse textured soils, but there was disparity in participants' assessment of the relative benefits of implementing these results. Thus, there remained a degree of incongruence in the participants' technological frames. Boundary objects often facilitate discussion that does not necessarily lead to consensus (Sundqvist *et al*., 2002). There was clearly no move to continue the use of the DSS to undertake further analyses, nor universal agreement for regional implementation of the simulation results, an outcome commonly considered as negative in terms of the 'problem of implementation' for DSSs (McCown, 2002; McCown and Parton, 2006). However, the case study had clearly changed the way many of the participants viewed the local sugarcane production system and, in some cases, its optimum management. Thus, in terms of co-learning, the case study was successful.

Although this case study focuses on the environmental impacts of cropping, our framework has broader relevance. Jakku and Thorburn (2010b) examine the framework through a case study on optimizing irrigation management, in which the DSS was used following the case study for day-to-day management (i.e. Outcome 1, Figure 1). The processes described by the framework are consistent with those employed by Archer *et al*. (2008) in a DSS-based study evaluating options for maximizing production of 'green' electricity within an agricultural value chain. While there was no ongoing use of the DSS in that study, consensus was reached to maintain the current production system (i.e. Outcome 3, Figure 1). Another example is the investigation of climate change in Barrow, Alaska (Lynch and Brunner, 2007). There, quantitative climate analyses were central to community members (and scientists) gaining an understanding of the potential impacts of climate variability and change, and developing a range of policy options for increasing the resilience of the community. These analyses may have acted as a boundary object, allowing extensive local experience of climate variability impacts to be connected to future changes in climate. Drawing upon traditional and local knowledge, as well as climate science, indicates the interpretative flexibility at play in the interactions.

This case study, and our framework (Figure 1), illustrates that using a DSS as a boundary object can help break down the barriers between disparate stakeholders as observed by others (Nelson *et al*., 2002; Walker, 2002; Matthews *et al*., 2008) and encourage co-learning between those involved, despite the diverse perceptions held by the stakeholders of a DSS or the issue being considered. These ideas are consistent with many social learning principles (Bouwen and Taillieu, 2004; Pahl-Wostl *et al.*, 2007; Steyaert and Jiggins, 2007; Mostert *et al.*, 2008) in integrated water resource management (IWRM). However, there are differences between our case study and social learning in an IWRM context. Analyses of social learning in IWRM focus on agreement being reached among stakeholders involved (Muro and Jeffrey, 2008), which is only one outcome in our framework. Many of the IWRM studies have been conducted in a regulatory and formal governance environment where some form of 'agreement' is necessary. In our case study and others (Carberry *et al.*, 2002; Nelson *et al.*, 2002; Archer *et al.*, 2008), the DSS is clearly being applied in a voluntary environment where all stakeholders are free to agree or disagree as they see fit. Thus, while the concepts in our framework have strong similarities to those used in IWRM (e.g. Figure 2 of Pahl-Wostl, 2007) it possibly represents a broader conceptualization of the benefits of participatory application of DSSs.

Acknowledgements

We acknowledge funding from the Australian sugarcane industry and Australian Government through the Sugar Research and Development Corporation. We also thank the collaborators who participated in the study, and gave freely of their time in the interviews. We also thank many colleagues who have contributed useful comments during development of the framework, including Dr Geoff Inman-Bamber, Steve Attard and especially Dr Toni Darbas of CSIRO.

Notes

1. The industry representatives were two industry-funded extension staff (one of them was also a sugarcane farmer) and a member of a representative body for Australian sugarcane farmers.
2. Analyses of early- and late-season harvest times and different delays between harvesting and fertilizer application were also undertaken, but are not described here as the general results were similar to those of the mid-season harvest.

References

Archer, A. A., Thorburn, P. J., Hobson, P. A., Higgins, A. J., 2008, 'Evaluating alternate strategic options for agricultural value chains', *Journal on Chain and Network Science* 8, 131–141.

Bainbridge, Z. T., Brodie, J. E., Faithful, J. W., Sydes, D. A., Lewis, S. E., 2009, 'Identifying the land-based sources of suspended sediments, nutrients and pesticides discharged to the Great Barrier Reef from the Tully–Murray Basin, Queensland, Australia', *Marine and Freshwater Research* 60, 1081–1090.

Bijker, W., 1987, 'The social construction of Bakelite: towards a theory of invention', in: W. Bijker, T. Hughes, T. Pinch (eds), *The Social Construction of Technological Systems*, Massachusetts Institute of Technology Press, Cambridge, MA, 159–187.

Bouwen, R., Taillieu, T., 2004, 'Multi-party collaboration as social learning for interdependence: developing relational knowledge for sustainable natural resource management', *Journal of Community and Applied Social Psychology* 14, 137–153.

Cannon, M. G., Smith, C. D., Murtha, G. G., 1992, *Soils of the Cardwell-Tully Area, North Queensland*, CSIRO Division of Soils Report 115. CSIRO Division of Soils, Canberra.

Carberry, P., Hochman, Z., McCown, R., Dalgliesh, N., Foale, M., Poulton, P., Hargreaves, J., Hargreaves, D., Cawthray, S., Hillcoat, N., Robertson, M., 2002, 'The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation', *Agricultural Systems* 74, 141–177.

Cash, D., 2001, 'In order to aid in diffusing useful and practical information: agricultural extension and boundary organizations', *Science Technology and Human Values* 26, 431–453.

Cozzens, S., Woodhouse, E., 1995, 'Science, government, and the politics of knowledge', in: S. Jasanoff, G. Markle, J. Petersen, T. Pinch (eds), *Handbook of Science and Technology Studies*, SAGE Publications, London, 533–553.

Harvey, F., Chrisman, N., 1998, 'Boundary objects and the social construction of GIS technology', *Environment and Planning A* 30, 1683–1694.

Hess, D., 1997, '*Science Studies: An Advanced Introduction*', New York University Press, New York.

Hurney, A. P., Berding, N., Grace, D., 2003, '*Assessing Clonal and Nitrogen Interaction on CCS of Sugarcane in the Wet Tropics*', Final Report SRDC Project BSS180 [available at www.srdc.gov.au/ProjectReports/ViewReports.aspx?ProjectNo=BSS180].

Jakku, E., Thorburn, P., 2010a, 'A sociological analysis of the participatory development of agricultural decision support systems', in: W. Proctor (ed.), *Integrated Mission-Directed Research: Experience from Environment and Natural Resource Management*, CSIRO Press, Canberra, 95–113.

Jakku, E., Thorburn, P. J., 2010b, 'A conceptual framework for guiding the participatory development of agricultural decision support systems', *Agricultural Systems* 103, 675–682.

Keating, B. A., Carberry, P. S., 2010, 'Emerging opportunities and challenges for Australian agriculture', *Crop and Pasture Science* 61, 269–278.

Lynch, A. H., Brunner, R. D., 2007, 'The importance of context in climate change impacts assessment: lessons from Barrow, Alaska', *Climate Change* 82, 93–111.

Matthews, K., Schwarz, G., Buchan, K., Rivington, M., Miller, D., 2008, 'Wither agricultural DSS?' *Computers and Electronics in Agriculture* 61, 149–159.

Maxwell, J., 1996, '*Qualitative Research Design: An Interactive Approach*', SAGE Publications, Thousand Oaks, CA.

McCown, R., 2002, 'Changing systems for supporting farmers' decisions: problems, paradigms, and prospects', *Agricultural Systems* 74, 179–220.
McCown, R. L., Parton, K. E. A., 2006, 'Learning from the historical failure of farm management models to aid management practice. Part 2. Three systems approaches', *Australian Journal of Agricultural Research* 57, 157–172.
McCown, R., Carberry, P., Hochman, Z., Dalgliesh, N., Foale, M., 2009, 'Re-inventing model-based decision support with Australian dryland farmers. 1. Changing intervention concepts during 17 years of action research', *Crop and Pasture Science* 60, 1017–1030.
Measham, T., 2009, 'Social learning through evaluation: a case study of overcoming constraints for management of dryland salinity', *Environmental Management* 43, 1096–1107.
Mostert, E., Craps, M., Pahl-Wostl, C., 2008, 'Social learning: the key to integrated water resources management', *Water International* 33, 293–30.
Muro, M., Jeffrey, P., 2008, 'A critical review of the theory and application of social learning in participatory natural resource management processes', *Journal of Environmental Planning and Management* 51, 325–344.
Nelson, R., Holzworth, D., Hammer, G., Hayman, P., 2002, 'Infusing the use of seasonal climate forecasting into crop management practice in North East Australia using discussion support software', *Agricultural Systems* 74, 393–414.
Orlikowski, W., 1992, 'The duality of technology: rethinking the concept of technology in organizations', *Organization Science* 3, 398–427.
Orlikowski, W., Gash, D., 1994, 'Technological frames: making sense of information technology in organizations', *ACM Transactions on Information Systems* 12, 174–207.
Pahl-Wostl, C., 2007, 'Transitions towards adaptive management of water facing climate and global change', *Water Resources Management* 21, 49–62.
Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D., Taillieu, T., 2007, 'Social learning and water resources management', *Ecology and Society* 12, Article 5.
Star, S., Griesemer, J., 1989, 'Institutional ecology, "translations", and boundary objects: amateurs and professionals in Berkeley's museum of vertebrate zoology 1907–1939', *Social Studies of Science* 19, 387–420.
Steyaert, P., Jiggins, J., 2007, 'Governance of complex environmental situations through social learning', *Environmental Science and Policy* 10, 575–586.
Stone, R., Auliciems, A., 1992, 'SOI phase relationships with rainfall in eastern Australia', *International Journal of Climatology* 12, 625–636.
Sundqvist, G., Letell, M., Lidskog, R., 2002, 'Science and policy in air pollution abatement strategies', *Environmental Science and Policy* 5, 147–156.
Thorburn, P. J., Meier, E. A., Probert, M. E., 2005, 'Modelling nitrogen dynamics in sugarcane systems: recent advances and applications', *Field Crops Research* 92, 337–352.
Walker, D., 2002, 'Decision support, learning and rural resource management', *Agricultural Systems* 73, 113–127.
Williams, R., Edge, D., 1996, 'The social shaping of technology', *Research Policy* 25, 865–899.