Just-in-case to justified irrigation: Applying co-innovation principles to irrigation water management

Srinivasan M.S.[1], Bewsell D.[2,*], Jongmans, C.[1,3], Elley G.[1]

[1] National Institute of Water and Atmospheric Research Limited, Christchurch, New Zealand

[2] AgResearch Limited, Lincoln, New Zealand; *Current address. Red Meat Profit Partnership, Christchurch, New Zealand.

[3] Wageningen University, Wageningen, The Netherlands

WORD COUNT: 5496

Abstract

A pilot study, using a co-innovation approach in identifying the opportunities to improved irrigation management, is underway in five farms in an irrigation scheme in New Zealand. Through a process of co-learning, a group of on-farm and off-farm stakeholders defined the problem of on-farm water use efficiency and developed solutions to enhance farmers' ability, desire, and capacity to adopt improved irrigation practices. To enable informed decision-making, participants were supplied with current soil water demand (measured on farm) and 2 to 15 day rainfall forecasts as a daily email update. We conducted several one-on-one formal/informal meetings and annual workshops with stakeholders to evaluate the farmers' ability in integrating the updates into their current irrigation practices. Some of the key learnings are: 1. on-farm irrigation decisions are influenced by on-farm and off-farm hydrological, climatic, infrastructural, and regulatory factors, thus we need to develop a wider view to irrigation management; 2. for successful uptake, it is important to understand the external stimulants that, directly and indirectly, conflict or align with proposed practice changes; 3. introduction of stakeholders with conflicting perspectives needs to be carefully managed; 4. with co-learning, project objectives continuously evolve in response to ongoing monitoring, review and reflection on the processes, thus it is important to build flexibility into the implementation pathway; 5. when scaling out from five farms to the wider irrigation scheme, opportunities such as collective learning and reflection at end-user focused workshops may become more challenging owing to stakeholder size, thus other co-learning opportunities need to be identified.

Keywords: Irrigation, co-innovation, co-learning, stakeholder management, agricultural innovation system, water use efficiency.

1. Introduction

The limitations of science-driven technology transfer approaches in which agricultural innovation is seen as a linear process of development, dissemination and adoption become apparent in the context of complex or 'wicked' problems (Botha et al., 2014; Klerkx et al., 2012; Leeuwis & Aarts, 2011; Smits, 2002; Rittel & Webber, 1973). This lack of success has been attributed to their insufficient attention to multi-actor processes and perspectives, lack of acknowledgement of non-scientific knowledge, and not viewing innovation as a combination of technical, social, economic and institutional changes (Turner et al., 2016; Klerkx et al., 2012; Leeuwis & Aarts, 2011; Smits, 2002). Agricultural Innovation System (AIS) addresses these limitations by arguing for a holistic, transdisciplinary, multi-stakeholder approach that encourages participants to collectively identify and address problems and instigate technical, social and market changes (Botha et al., 2014; Klerkx et al., 2012).

Irrigation management in New Zealand (NZ) presents a case study for a complex problem in need of a systems approach such as AIS. On-farm irrigation management in NZ is influenced by several layers of technical, hydrological, climatic, societal, environmental, economic, regulatory and cultural factors, which individually and collectively impose controls and constraints on farmers' ability and desire to adopt efficient irrigation practices. IrrigationNZ, an industry body for irrigators in NZ, forecasts that irrigation in this country will expand from the current 0.75 million ha to 1 million ha by 2025, and urges the need for developing validated irrigation practices and tools that will enable farmers to become 'water-wise' (IrrigationNZ, 2016). They indicate that current irrigation efficiency can be improved by as much as 20% through improved irrigation practices. Historically, there has been limited success with technology transfer of irrigation management tools and practices. Uptake of technology such as soil moisture sensing to schedule irrigation has been stagnant over the last three decades (Davoren, 2015, HydroServices; personal communication), though the area under irrigation has been doubling every twelve years since 1970 (IrigationNZ, 2016). Previous technology transfer approaches have tended to be farm specific, ignoring wider issues to water management such as water limits, multiple water users and community aspirations for improved water use efficiency (WUE). Here, we define WUE as scheduling irrigations by taking into account of current soil water demand and forecast rainfall.

1.2 Theory on learning through co-innovation

The AIS perspective promotes multi-actor processes to explore technological, social and structural needs and visions; to build trust; to agree on working procedures; and to foster capacity building, learning and (intellectual) resource management (Klerkx et al., 2012; Leeuwis & Aarts, 2011; Botha et al., 2014). Stakeholder engagement has been associated with benefits such as increased knowledge, insights, experiences, networks, resources and creativity, improved 'ownership' of the innovation, empowerment and improved livelihoods, and a way of legitimizing research and innovation projects (Leeuwis, 2004). However, it can also present challenges in terms of rules to be followed, resources required, power relations and political agendas (Leeuwis, 2004; Schut et al., 2014). Taking into consideration the context-specific nature of successful co-innovation (Neef & Neubert, 2011), the irrigation WUE case study is built on nine co-innovation principles, adapted from Nederlof et al. (2011), and described in detail in Coutts et al. (2016).

In this paper, our objective is to highlight the key learnings from applying a co-innovation approach to improving WUE on NZ farms. We have linked these learnings to the nine, adapted co-innovation principles. Through the use of co-learning we identified opportunities and barriers to improve the uptake of previously poorly used irrigation management tools and practices. Although existing literature provides relevant insights, "learning by doing remains essential in operationalizing co-innovation" (Botha et al., 2014, p. 219). Accordingly, this paper provides insight into the implications of applying co-innovation principles in an irrigation case study in NZ. Considering the length of the paper, we have limited ourselves to the co-learning among the stakeholders and have not included any of the biophysical data collected during the study.

1.3 The project

The five-year duration WUE study was initiated in 2012 in the Waimakariri Irrigation Scheme (WIS), a run-of-the-river irrigation scheme located north of Christchurch, South Island, NZ. In this scheme, irrigation practices are strongly influenced by the reliability of river flows which are currently at about 74% (Walton, 2015; WIS Executive Manager; personal communication). Irrigators tend to use a "just-in-case" approach, where irrigations are applied whenever supply is available, even when demand is low. Very few farmers use the alternative practice, deficit irrigation, which is a "just-in-time" approach, where irrigation is scheduled based on water demand, rather than supply.

The project was based on the premise that a proactive irrigation management that matches current irrigation demands against forecasted (2-6 days) rainfall would lead to desirable economic and environmental outcomes to farmers and wider society. Accordingly, the project researchers aimed to support study farmers in their irrigation decisions by providing them with customised information on current demand (measured soil moisture) and forecast rainfall. As a pilot, this study was focused on five farms (four dairy/one cropping) within WIS. They were selected because of their enthusiasm for the project and current (significant) water use. The farms are geographically scattered across the irrigation scheme (5-15 km apart from each other), and have varying soil types (varying soil water holding capacities to support crop growth), rainfall supplies and evaporative demands, and thus, varying irrigation demands. Each farm was equipped with a soil moisture sensor that measured soil moisture (a proxy to irrigation demand) at 20 cm depth and a rain gauge that measured irrigation and rainfall. Data were recorded at 10 minute interval and shared with participating farmers via a daily e-mail. Farmers were also given 24/7 access to real-time soil moisture, rainfall and irrigation data via a secure, customised website. Additionally, farmers were provided with 2-, 6- and 15-day weather forecasts that includes rainfall, air temperature, relative humidity and wind speed and direction. , enabling them to schedule irrigations based on forecast rainfall. These data were included in the daily email update. To encourage a collective approach, study farmers were provided access to data from all pilot farms, which enabled them to compare their conditions and practices against others as well as make useful observations of others' practices.

2. Methodology

2.1 Data collection

Individual meetings with pilot study farmers took place periodically during the irrigation season (September – April) to explore current irrigation practices, to provide training on data interpretation and irrigation scheduling, and to gain feedback on the project and support provided by researchers. Several formal and informal one-on-one meetings, email communications and telephone conversations took place with other stakeholders (irrigation scheme manager, researchers, regional regulatory authority, local catchment committee, and local and national government officials) to involve them in the project, and to obtain more information on links between on-farm water management with wider water management policies, strategies and perceptions. At the end of each irrigation season, a workshop was held to debrief on the season just finished and to plan ahead for the season ahead, with participation of pilot farmers, scheme managers, irrigation professionals, regional councils (local government bodies tasked with regulating environmental resources and outcomes) and researchers. Workshop discussions aimed to (i) develop a shared understanding of WUE and solutions, (ii) guide the development and uptake of irrigation management tools, practices and processes; and (iii) discuss the benefits, risks, barriers and opportunities in using a weather-based irrigation management. Feedback from workshops was used to review and refocus the process and information being generated and sought. To date, three such workshops have been held: Workshop 1 in May 2013; Workshop 2 in May 2014; Workshop 3 in May 2015. Each of these workshops have been held in the WIS; firstly at one of the pilot farms, then moving to a local hall as the size of the stakeholder group grew. Workshop 1 was attended by pilot study farmers, irrigation scheme managers and researchers. In addition to workshop 1 attendees, workshop 2 was attended by the regional council and members of the local catchment management committee who advise the regional council on resource management. In addition to workshop 2 attendees, workshop 3 participants included farmers from WIS but not currently part of the project, managers from neighbouring irrigation schemes and the project funders.

There were a range of data collection points within the project. Each interaction, whether individually based or in a workshop setting, provided opportunities to obtain rich descriptive data, capturing individual and collective decision making, individual and collective reaction to information and the co-innovation processes being used. During the irrigation season, individual discussions with farmers and other stakeholders were recorded in the form of notes and narratives to determine management changes, training needs and the usefulness of the co-innovation approach. At the end of each workshop a feedback sheet was used to collect data on each participant's response to the workshop. In February 2016 the project leader and the reflexive monitor reflected on the first 4 years (December 2012 – February 2016) of the project.

The biophysical data on rainfall, irrigation and soil moisture conditions present a record of irrigation practices of each participant (when and how much irrigation was applied) during the season, and thus were used at the workshops as a launching pad to initiate a discussion among stakeholders in examining the barriers and opportunities to changing irrigation practices.

3. Results

In this section, we highlight three prominent learnings from the project that distinguishes the co-innovation approach from the conventional technology transfer approach used to disseminate irrigation tools and practices in the past. These learnings were derived from review of biophysical data and reflection of processes and practices by stakeholders at the one-on-one meetings and annual workshops.

3.1 Lesson 1: Broadening the context of the initial project into an innovation space

The primary aim of the study was to improve irrigation WUE in the pilot farms through the use of weather-forecast based irrigation practices. As opposed to "just-in-case" and "just-in-time" irrigation practices described earlier, we term this as "justified irrigation" as the irrigations are justified based on current soil water demand and forecast supplies (rainfall). To ensure the problem defined and solutions identified are consistent and fit with the perspectives of the wider stakeholder community that is relevant to water management, we involved both on-farm and off-farm stakeholders in the co-innovation process. In this way we conceptualised an irrigation landscape that extended far wider than the farm (see Figure 1). Through stakeholder interactions, we mapped the controls, barriers, constraints and opportunities to irrigation management in NZ farms.

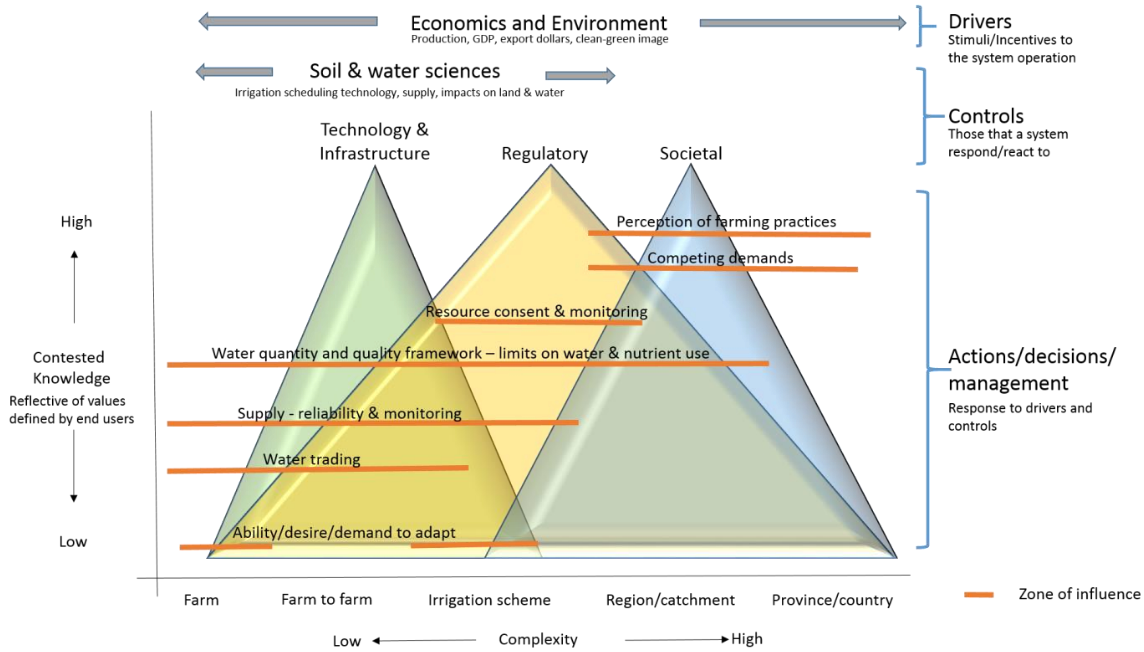

Figure 1: An overview of on-farm irrigation water management landscape in New Zealand, developed as context for the water use efficiency study being undertaken in the Waimakariri Irrigation Scheme (adapted from Srinivasan et al., 2015).

While an individual irrigation event may appear to be a stand-alone on-farm activity, the ability of farmers to implement it efficiently relies on several factors – from on-farm infrastructure to scheme and regional scale controls shown in Fig 1. These factors were identified at various stakeholder meetings and workshops. On the farm, the ability of a farmer to efficiently manage irrigation practices is primarily reliant on the availability of suitable irrigation infrastructure, access to a reliable water supply, accurate knowledge of soil properties, crop irrigation demands and access to a reliable weather forecast. Between farms, additional issues such as water trading and dynamic resource consenting rules (rules that control water abstraction and use) may influence irrigation decisions. At the irrigation scheme level, the efficiency of on-farm irrigations can be influenced by environmental limits placed on nutrient losses and water use, and the ability of schemes to reliably reticulate water to meet user demands.

At scheme, catchment and regional scales, water quantity and quality limits on resource use dictate irrigation practices. While catchment and regional-scale controls may not impact on-farm individual irrigation decisions, they can affect irrigation practice as a whole. With increasing intensity of irrigation, the risk of contamination of groundwater or surface water also increases. In some areas of NZ deterioration of water quality is already apparent (Environment Canterbury, 2016a). Therefore nutrient management has also become the domain of national and regional government, and regulatory frameworks are currently under development. In Canterbury, the location of this project, water take consents have a number of environmental conditions attached to it. These include, or are about to include if not already, improved WUE and farm nutrient management plan requirements, and self-audited management of water quality.

At regional and national scales, public perceptions about irrigation, and the demands from competing users (including from those expanding irrigation), influence irrigation practices. The clean-green image projected by the tourism industry often clashes with agricultural intensification, as the latter is perceived as polluting the clean-green environment. A recent example of such clashes can be found at RNZ (2016).

At the national scale, the science knowledge available to make informed decisions, linking cause and effect, becomes limited. For example, at farm scale, lysimeters that measure irrigation-drainage are used to link over-irrigation to the loss of water and nutrients below root zone. However, relating the impact of over-irrigation and the resulting drainage and nutrient loss at one farm, to wider catchment and regional scale water quantity and quality, is challenging. The contestability of science knowledge is very high at those large scales.

In essence, irrigation decisions and investments are made on-farm, but are informed and constrained by the wider system in which they fit. Hence, to be successful, on-farm irrigation solutions must encompass and represent the wider system, along with the constraints and opportunities it presents. Also, the solutions developed and the resulting effect of these solutions on WUE and irrigation practices should be demonstrable to both on-farm and off-farm stakeholders. This highlights the relevance of one of the nine co-innovation principles, “be aware of the wider context”.

The knowledge of the wider irrigation landscape has been very useful in including and responding to external stimulants to improve irrigation in NZ: for example, IrrigationNZ has adopted an 80% beneficial use performance target for irrigation (IrrigationNZ, 2016). Similarly, the Sustainable Dairying Water Accord requires irrigation systems to be designed and operated to minimise the amount of water needed to meet production objectives (DairyNZ, 2016). The regional regulating authority in the pilot region, Environment Canterbury, a member of the stakeholder community, have designed a Matrix of Good Management, a set of recommendations to improve irrigation and nutrient management in the region (Environment Canterbury, 2016b), which is to be implemented in 2017 under the National Policy Statement on Freshwater described in Snelder et al. (2014).

3.2 Lesson 2: Learn from each other and be flexible and adaptive when implementing co-innovation

Co-learning has been central to the study. All stakeholders - researchers, irrigation scheme managers, and pilot-study farmers - have been learning from interactions and through reflection on on-farm biophysical data and observations. Biophysical data provide a ’stake-in-the-ground’ for discussion at the workshops, and enable a means of understanding the decision making on farm, as well how the decision making at a scheme or region level has an impact on decisions on-farm.

Researchers co-learning with farmers: The project was originally aimed at assisting farmers in scheduling irrigations based on current irrigation demand and forecast weather. However, researchers have adapted the information provided throughout the project as they have learnt from other perspectives represented. For example, at the start of the project a soil moisture sensor was installed at 20 cm below surface (coinciding midway to 40-cm root zone) so that soil moisture conditions could be measured and irrigations could be scheduled accordingly. However, interactions at Workshop 1 indicated that drainage resulting from over-irrigation (applying more water than the top soils can hold) and poorly-timed irrigations (irrigating before a rainfall event or when soil moisture is high) was important, as the regional authority have been mandating farmers to store as much as 80% of applied irrigation in the soil and allow only 20% of irrigation as drainage. However, farmers were given no specific procedure or tool to measure irrigation-drainage, nor were any practices recommended to prevent drainage. At Workshop 2, the discussion thus focussed on drainage estimation to enable stakeholders to understand the process and ways of preventing irrigation “wasted” as drainage. At that workshop, farmers also expressed interest in knowing the monetary value of their drainage, which became the theme of Workshop 3. We chose, for every hectare of irrigated land, an arbitrary monetary value of $1.50 per mm of rainfall-drainage and $2 per mm of irrigation-drainage. At Workshop 3, we presented these number to the stakeholders and there was a general agreement that these numbers are reflective of actual numbers. Cumulated at farm scale, the monetary benefits proved substantial, at Workshop 3 researchers and stakeholders sought tools that could allow monitoring and managing irrigation and drainage together in real time. At Workshop 3, researchers introduced the use of a profile soil moisture sensor in place of single point soil moisture sensor used at 20 cm depth. The profile soil moisture sensor measures soil moisture at eight depths along the soil profile, at every 10 cm interval over the top 80 cm soil profile. This has enabled researchers to provide farmers with information on irrigation demand and drainage at the same time. Farmers could schedule their irrigations using the soil moisture at the top 20 cm and monitor the drainage by reviewing the soil moisture levels at 80 cm depth following the irrigation. Pilot study farmers were given real-time, 24/7 online access to these data and were individually trained in December 2015 and January 2016, to use the new data to schedule irrigation.

Irrigation scheme manager co-learning with farmers: The weather forecast that the farmers receive via daily email update provides 2, 6 and 15-day weather forecast (rainfall, temperature, humidity and wind speed and direction). Because of the unique weather conditions of NZ, it is generally considered that any forecasts past 48 hours are less reliable and often changeable over a very short period of time (hours). Following the first year of this project, the irrigation scheme took notice of accuracy of 2-day weather forecasts and reduced their irrigation water request lead time from 48 to 9 hours, to allow the pilot study farmers to use the best weather forecast available when ordering their irrigation water from the irrigation scheme.

Farmers co-learning with other farmers and researchers: At Workshop 1, when farmers were queried on their use of weather forecasts, the general response was that forecasts were important at the start and end of the irrigation season ("shoulder season") and were less important during the peak season when irrigations are applied regularly and frequently with no regard to weather forecast or demand (a just-in-case irrigation practice). At the third workshop (Workshop 3), after collecting data for over three years and observing farmers' behaviour, the researchers presented biophysical data that showed evidence for substantial irrigation-drainage during the peak season, most of which resulted from untimely irrigations (e.g., irrigation on previously wet soil, irrigation immediately preceding a rainfall event) and the complete absence of irrigation-drainage during the shoulder season. This information provided an opportunity for farmers to reflect on their irrigation decisions and decide whether it was appropriate to change their irrigation management during peak season. In December 2015, during a one-to-one meeting with a pilot study farmer, he indicated that based on the data supplied in the project he had skipped a few irrigations even when his neighbors continued to irrigate. This suggests that reflection on practices in this case actually to some extent influenced behaviour. This also reflects the co-innovation principle regarding flexibility. One of the key drivers of irrigation decisions during peak season is poor reliability of supplies. This has not changed over the course of the project so farmers may not wish to change their irrigation practices, even though they have been shown that irrigation-drainage occurred during the peak season. However, with new profile soil moisture probe, they have options to reconsider the amount of irrigation applied.

3.3 Lesson 3: Network development and increased engagement with co-innovation

Over the course of the project a network of farmers and other stakeholders has been built within the irrigation scheme through the provision of the daily emails. At the beginning of the project in December 2012 the daily update was sent to the farm owners/managers of the five pilot study farms.

The daily update is now being sent to 25 individuals every day, and each recipient could see the irrigation practice occurring at every pilot study farm. All the recent additions to the list were made on the request of recipients. As the pilot study farmers share their experience with their neighbours and peers at informal gatherings, the daily updates have gained more recipients.

In addition, over the course of the three workshops, more people have been added to the network, contributing knowledge and experience; for example, an exchange in workshop 2 where one pilot study farmer with 20 years of farming experience, shared with another his experience with managing soil drainage, saying "if you keep growing grass longer, drainage will decrease because increased organic matter leads to increased water retention/storage". The workshops have helped to develop an understanding of the irrigation management issue and built trust amongst the project participants. The workshops have also been a forum for hearing, sharing and understanding multiple views to water management. The trust that has been built during the process has enabled additional stakeholders to be bought into the project, particularly representatives from the regional council.

4. Discussion

The co-innovation process has been leading to significant learning and observable irrigation practice changes among the stakeholders. Changes in irrigation scheduling from the start to date as well as changes in the project focus and description are evidence for those changes. Widening the stakeholder community to include both on-farm and off-farm stakeholders allowed us to understand the scope and complexity of on-farm irrigation decisions and to identify structures and external stimulants and controls that influence WUE at farm scale. These observations correspond to those reported in van Mierlo et al. (2013) on the application of an innovation system perspective in Dutch poultry subsectors, and reaffirms the importance of acknowledging the multi-level and multidisciplinary character of innovation highlighted by other researchers (e.g., Turner et al., 2016; Geels, 2002; Smits, 2002). The presence of regional council representatives (Environment Canterbury) at workshops 2 and 3 provided legitimacy to the irrigation practice among the end-users, through recognition of the environmental benefits of their practices, and reinforced through further initiatives by councils to request presentations about the project to other regional water management groups. However, such inclusions had to be done very carefully. Being mindful of contrasting and conflicting ideas is considered integral to stakeholder participation (Neef & Neubert, 2011; Cornwall, 2008; Leeuwis, 2004). We did not introduce the regulatory authority as a stakeholder at Workshop 1, because sufficient trust needed to be established between researchers, the pilot study farmers and the wider irrigation scheme. Our experiences correspond to those reported by Schut et al. (2014) who emphasized the need for context-sensitive research strategies in competing claims situations. Hence, much attention was paid to decide on the right moment and time of involvement and potential side effects of research actions.

The co-innovation process also saw changes, mainly resulting from reflexivity, to the roles of the researchers and other stakeholders. Stakeholders continually reflected on the process and pathways towards system change, and this led to changes in roles. Researchers moved between being a fully independent science knowledge holder and supplier in a technology transfer approach, with co-innovation, donned the roles of broker and facilitator. The relationship between researchers and other stakeholders moved beyond informative to co-learning and capacity building, and such transitions have been described by Schut et al. (2014) as changes in dynamics of boundary arrangements at the researcher-stakeholder interface. This mandated a reconceptualization of researcher roles towards knowledge co-creation, network building, brokerage and entrepreneurial activities, roles that have been observed in other similar studies (Hermans et al., 2013; Klerkx et al., 2012; Wieczorek & Hekkert, 2012; Leeuwis & Aarts, 2011). Similarly, the pilot farmers by having conversations with other farmers in the scheme enhanced the dissemination of the WUE message.

Use of co-innovation meant that the stakeholders needed to remain flexible in their practices as well as perception of problem and process. Project objectives were continuously revised in response to ongoing monitoring, evaluation, and reflection on the processes in the workshops, which captures elements of reflexive monitoring, as outlined in van Mierlo et al. (2010). During the course of the project, the definition of WUE expanded from water quantity management (irrigating right amount at the right time) to water quantity and quality management (irrigating right amount at the right time, and minimising drainage and associated nutrient loss from root zone). This broadened the scope and focus of the project. Our findings support previous work from Leeuwis & Aarts (2011) and van Mierlo et al. (2010) who argued that project flexibility can foster collective identification and utilization of 'perceived windows of opportunity', which increases the potential to reach what Röling (2009) refers to as 'science-for-impact'.

As a part of the pilot study, the recipients of daily email updates are allowed access to biophysical data from the participating farms. Discussions during the workshops indicated that farmers, in addition to the data from their own farm, frequently took notice and interest in irrigation activities occurring at other farms, which helped with co-learning among farmers. However, as we scale out from pilot farms to wider irrigation scheme and beyond, such a "shared-data" approach may become less practical, potentially hampering the learning among the stakeholders. It would be interesting to explore how this potential co-learning and self-organisation can be sustained within the increased complexity associated with scaling up and out, as has been identified by Hermans et al. (2013) and others.

5. Conclusions

The co-innovation process reinforces that decisions, controls and drivers for on-farm water use and management intersects with the values and perspectives of off-farm stakeholders, particularly those linked to environment, economy and regulations. The co-innovation process has helped researchers to develop a wider view of the complex problem of WUE, which is a significant shift from technology transfer approach. This wider view of the system has allowed researchers to effectively respond to the impacts of external stimulants that influence water use on farms. Because of the on-going learning that occurs during the co-innovation process, stakeholders have to be flexible enough to adapt to the information provided and respond accordingly. Within the irrigation scheme, farmers and the scheme managers are responding to the daily updates provided by changing their irrigation behaviour and practice, both on-farm and at the scheme levels. Stakeholders involved in the project recognised the need to manage water better, and are engaged in learning about WUE. However, some of the learnings could not be immediately put into practice owing to external factors (e.g., farmers inability to reduce irrigation frequency and the resulting irrigation drainage during peak irrigation season owing to poor supply reliability). Such learning highlights the importance of capacity building as part of innovation and the innovation process.

References

Botha, N., Klerkx, L., Small, B., & Turner, J. (2014). *Lessons on transdisciplinary research in a co-innovation programme in the New Zealand agricultural sector. Outlook on Agriculture*, 43(3), 219-223. http://dx.doi.org/10.5367/oa.2014.0175

Cornwall, A. (2008*). Unpacking 'Participation': models, meanings and practices. Community Development Journal*, 43(3), 269-283. http://dx.doi.org/10.1093/cdj/bsn010

Coutts, J., Botha, N., Blackett, P., White, T., Park, N., & Turner, J. et al. (2016). *Application of nine principles that underpin co-innovation in practice.* In *12th European International Farming System Association*. Newport, UK.

DairyNZ. (2016). Sustainable Dairying: Water Accord. Dairynz.co.nz. Retrieved 29 February 2016, from http://www.dairynz.co.nz/environment/in-your-region/sustainable-dairying-water-accord/

Environment Canterbury. (2016). Introduction to the MGM Project. Ecan.govt.nz. Retrieved 18 March 2016, from http://ecan.govt.nz/get-involved/mgmproject/Pages/intro-mgmproject.aspx

Environment Canterbury. (2016). *Water Quality. Ecan.govt.nz*. Retrieved 21 March 2016, from http://ecan.govt.nz/advice/your-water/water-quality/Pages/Default.aspx

Geels, F. (2002). *Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy*, 31(8-9), 1257-1274. http://dx.doi.org/10.1016/s0048-7333(02)00062-8

Hermans, F., Stuiver, M., Beers, P., & Kok, K. (2013). *The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. Agricultural Systems*, 115, 117-128. http://dx.doi.org/10.1016/j.agsy.2012.09.006

IrrigationNZ. (2016). *Economy - Smart Irrigation. Smart Irrigation*. Retrieved 27 February 2016, from http://smartirrigation.co.nz/smart-irrigation/why-is-it-good-for-new-zealand/economy-communities/

Klerkx, L., van Mierlo, B., & Leeuwis, C. (2016). Evolution of systems approaches to agricultural innovation: concepts, analysis and interventions. In I. Darnhofer, D. Gibbon & Dedieu, *Farming systems research into the 21st century: The new dynamic* pp. 457-483. Dordrecht: Springer Netherlands.

Leeuwis, C., & Aarts, N. (2011). *Rethinking Communication in Innovation Processes: Creating Space for Change in Complex Systems. Journal of Agricultural Education and Extension*, 17(1), 21-36. http://dx.doi.org/10.1080/1389224x.2011.536344

Leeuwis, C., Leeuwis, C., & Ban, A. (2004). Communication for rural innovation. Oxford: Blackwell Science.

Nederlof, S., Wongtschowski, M., & van der Lee, F. (2011). Putting Heads Together. Agricultural Innovation Platforms in Practice. Amsterdam: KIT publishers.

Neef, A., & Neubert, D. (2010). *Stakeholder participation in agricultural research projects: a conceptual framework for reflection and decision-making. Agric Hum Values*, 28(2), 179-194. http://dx.doi.org/10.1007/s10460-010-9272-z

Rittel, H., & Webber, M. (1973). *Dilemmas in a general theory of planning. Policy Sci*, 4(2), 155-169. http://dx.doi.org/10.1007/bf01405730

RNZ. (2016). Tourism industry wants 5-year ban on irrigation schemes. Radio New Zealand. Retrieved 21 March 2016, from http://www.radionz.co.nz/national/programmes/morningreport/audio/201793032/tourism-industry-wants-5-year-ban-on-irrigation-schemes

Röling, N. (2009). *Pathways for impact: scientists' different perspectives on agricultural innovation*. *International Journal of Agricultural Sustainability*, 7(2), 83-94. doi:10.3763/ijas.2009.0043

Schut, M., Klerkx, L., Rodenburg, J., Kayeke, J., Hinnou, L. C., Raboanarielina, C. M., Bastiaans, L. (2015). *RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. Agricultural Systems*, 132, 1-11. doi:10.1016/j.agsy.2014.08.009

Schut, M., Van Paassen, A., Leeuwis, C., & Klerkx, L. (2013). *Towards dynamic research configurations: A framework for reflection on the contribution of research to policy and innovation processes. Science and Public Policy*, 41(2), 207-218. doi:10.1093/scipol/sct048

Smits, R. (2002). *Innovation studies in the 21st century. Technological Forecasting and Social Change*, 69(9), 861-883. doi:10.1016/s0040-1625(01)00181-0

Snelder, T., Rouse, H., Franklin, P., Booker, D., Norton, N., & Diettrich, J. (2014). *The role of science in setting water resource use limits: case studies from New Zealand. Hydrological Sciences Journal*, 59(3-4), 844-859. doi:10.1080/02626667.2013.793799

Srinivasan, M. S., Elley, G., & Bewsell, D. (2015). *Co-innovation for water management in New Zealand. GLP News*, (11), 16-18.

Turner, J. A., Klerkx, L., Rijswijk, K., Williams, T., & Barnard, T. (2016). *Systemic problems affecting co-innovation in the New Zealand Agricultural Innovation System: Identification of blocking mechanisms and underlying institutional logics. NJAS - Wageningen Journal of Life Sciences*, 76, 99-112. doi:10.1016/j.njas.2015.12.001

Van Mierlo, B., Janssen, A., Leenstra, F., & Van Weeghel, E. (2013). *Encouraging system learning in two poultry subsectors. Agricultural Systems*, 115, 29-40. doi:10.1016/j.agsy.2012.10.002

Van Mierlo, B., Regeer, B., Van Amstel, M., Arkesteijn, M., Beekman, V., Bunders, J., De Cock, T. (2010). Reflective monitoring in action. A guide for monitoring system innovation projects. Retrieved from https://www.wageningenur.nl/en/show/Reflexive-Monitoring-in-Action.htm

Wieczorek, A. J., & Hekkert, M. P. (2012). *Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy*, 39(1), 74-87. doi:10.1093/scipol/scr008

Acknowledgements

We would like to acknowledge the Ministry of Business, Innovation and Employment for funding the Primary Innovation project (CONT-30071-BITR-AGR) through a Biological Industries Targeted Research grant.