Beyond linear technology transfer: Examining learning environments in six sustainable agriculture participatory research projects

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Abstract. Participatory research can provide a rich collaborative learning environment in which scientists, industry and farmers can engage. Policy and funding agencies champion participatory approaches, however their implementation for advancing sustainability in agricultural production systems remains poorly understood. This paper assesses six extension projects in New Zealand which all sought to advance sustainability to identify the dynamics that influence the creation of collaborative learning environments. Evidence shows when engagement is limited, projects follow the transfer of technology model. In contrast, projects that create interactive dynamic learning environments integrate local and science knowledge in collaborative learning partnerships. The paper concludes that for sustainability to be advanced, projects must: facilitate an environment where stakeholders' expectations are clearly aired and understood; develop learning processes that are interactive and iterative and where needed challenge current practices and perceptions; and embed extension into the project from the outset.

Keywords: Participatory research, Collaborative learning, Sustainable agriculture

Introduction

It is widely recognised that modern agriculture should be managed in a way that minimises its impact on the environment (PCE 2004; Pretty 2005; Cocklin and Dibden 2006). Indeed rural communities worldwide are under increasing pressure to mitigate or prevent adverse environmental effects from agricultural practices largely resulting from agricultural intensification (PCE 2004). To combat the detrimental effects of agricultural practices, farmers are increasingly being encouraged to adopt more sustainable practices.

A transition to more sustainable agriculture is a complex issue. The complexity arises from the unpredictable and uncertain nature of the biophysical systems in which farming operates, combined with the complexity of its social, political and economic contexts (Leeuwis 2004; Pretty 2005; Klerkx, van Mierlo and Leeuwis 2012). Addressing sustainability challenges assumptions and values of current farming practice and must embrace multiple stakeholders, who often have differing perspectives on the issues and how they should be managed. How this can best be achieved is a significant challenge.

Agricultural extension built on participatory approaches can facilitate rich learning partnerships between farmers, industry and science and this is now broadly accepted as the best framework for addressing complex environmental issues (Cornwall 1993; Leeuwis 2004, Pretty 2005; Reed 2008; Neef and Neubert 2011). Academics across the sustainability, communication and extension fields embrace multiple stakeholder engagement as a way of bringing about change and argue that learning together to respond to changing circumstances, is essential for addressing complex problems like sustainability (Robinson 2004; Dale 2005; Pretty 2005; Keen et al. 2005a; Franklin and Blyton 2011; Leeuwis and Aarts 2011; Stirzaker et al. 2011).

In New Zealand, policy and funding agencies have increasingly encouraged scientists to include participatory approaches in publicly funded agricultural science research projects to connect research with its end-users (Botha 2009). This is in response to the demise of state funded agricultural extension services, and is in keeping with worldwide trends towards more client-driven research and extension.

Despite the obvious democratic appeal of the inclusive nature of participatory approaches, integrating scientific and local knowledge in research projects can be notoriously difficult to achieve (Neef and Neubert 2011; Allan et al. 2013). This was recently reinforced by a survey investigating technology transfer in New Zealand (MPI 2012) where farming respondents perceived a growing disconnect between the farming and science sectors, despite increasing interest in ways to increase the adoption of sustainable innovations and practices on the farm.

This paper is part of the author's wider PhD research, which is examining six participatory agricultural research projects in New Zealand to investigate how participatory research can advance sustainability in agricultural production systems. The paper draws from the findings of this larger body of research to explore learning environments in projects and examines their effect on advancing sustainability. The paper begins by reflecting on the key features identified in the literature that define a collaborative learning environment to advance sustainability. The research methods and six projects are described. The projects are then examined to assess how effectively they created learning environments. Finally the paper identifies four features that influenced the creation of collaborative learning environments.

Learning for sustainability

Sustainability scholars acknowledge that for future global agriculture to be equitable, sustainable and innovative, divergent stakeholders must collaborate (Pretty et al. 2010). Peer communities of scientific and lay experts have long been advocated for creating shared understandings amongst divergent stakeholders to stimulate new knowledge and new practices (Healy 1999; Bruckmeier and Tovey 2008; Leys and Vanclay 2011). Knowledge that is co-produced by scientists and farmers recognises the relevant strengths and limitations of scientific and local forms of knowledge, and fosters the integration of these knowledges when dealing with real world problems (Hoffman et al. 2007; Ingram 2010).

Leeuwis (2004) claims that in the agricultural sector, farmers need to be conversant with a broad range of knowledge. At the same time, when addressing complex environmental problems, scientists need to recognise that farmer awareness of and knowledge about local environments and dynamics must be built into decision making to ensure solutions are relevant to end-users (Baars 2010). This tacit knowledge Leeuwis (2004, p. 5) argues, is often developed 'on the spot' with close interaction between farmers, scientists and other stakeholders.

To be effective, it is argued that a collaborative learning environment must be both iterative and interactive (Roling and Wagemakers 1998; Keen et al. 2005b). It should foster equitable partnerships, develop collaborative learning opportunities, provide space for conflict resolution and collective action and enable participants to reflect on their actions and ideas (Leeuwis and Aarts 2011) to examine how these influence current practice (Andrew 2003; Keen et al. 2005b).

Research methods

Six horticultural cropping projects were investigated. All sought improved sustainable agricultural practices and the participation of scientists and farming groups. The types of farming groups that participated were different across the six projects and ranged from industry-good bodies funded by a farmer levy to voluntary groups comprised of sector farmers. Table 1 identifies the different groups and summaries the objectives in the six projects. Four projects were examined retrospectively as their funded period had finished and project management had been dismantled. Two projects were still in progress and provided opportunity for observations to be made of the project in action.

To capture the diversity of stakeholder perspectives a qualitative methodology was employed using multiple case study research. Evans (2011) argues that the empirical foundation of case study research means it is well suited to capturing the complexity of multi-stakeholder sustainability projects. Each project was researched as a separate unit, in keeping with the recommended design for multiple case study research (Hancock and Algozzine 2006; Yin 2009). Evidence was gathered from 83 stakeholder interviews, eight field and participant observations and from analysis of project documents, archival records and project and media publications. This mixed method approach provides rigour and credibility to the data and to its subsequent interpretation by the researcher (Yin 2009). Semi-structured interviews were the principal method used for investigation. Sixteen interviewees were scientists (including two science technicians), fifty were farmers, ten were from farming sector groups and seven were from policy and funding agencies. While most farmer participants had been active members of project committees, farmers from each sector outside these committees were also interviewed to examine knowledge transfer beyond the project boundary.

All interviews adhered to ethics guidelines of the University of Auckland Human Participants Ethics Committee. The majority were digitally recorded and fully transcribed. All texts from transcribed interviews, interview notes, field notes taken from observations and project documents were individually examined to identify emergent issues. The texts were coded following the protocols outlined by Saldana (2009). Two levels of coding were applied. The first identified specific words and phrases of interview participants (NVivo coding), while descriptive coding was employed for other texts. The second level of coding looked for patterns to enable larger categorises to be developed. In some cases these were further sub-categorised. These categories were then thematically analysed and grouped into larger themes so cross comparisons could be made. Similarities, differences and regularity of themes among the projects provided a rich source of evidence for the research analysis.

Table 1. Synopsis of the projects

Project/Participants	Project Objectives
Crop Science for Maori East Cape North Island (6 year project) CRI scientists working with the East Coast Organic Producers (ECOP) Trust	Identify how Maori communities could make the transition from extensive agriculture to intensive organic horticulture. This involved establishing a reciprocal learning network providing scientific, education, and extension services to enable ECOP Trust to develop and implement 'best' organic vegetable farming practices.
Kabocha Squash Rot Gisborne, Manawatu, Hawkes Bay (3 year project) CRI scientists working with the squash industry group (Horticulture New Zealand), squash farmers and pack-house owners.	Assess factors that influenced the extent of storage rot in Kabocha squash (buttercup) fruit lines. Scientists aimed to develop a model of weather influences on squash growth and yield that would assist with defining multi-factor influences on fruit yield and maturity.
Potato Aphid Project Canterbury (3 year project) CRI scientists working with the Potatoes New Zealand (Horticulture New Zealand) and potato farmers	Develop a resistance management strategy to delay or prevent the development of aphid insecticide resistance in potatoes, with the intention of maintaining future options for pest control and potato quality. In addition it sought to determine 'best practice' for the control of aphids and viruses in potato crops, and provide up to date information on aphid flights and infestation of potato crops to growers.
Walnut Blight Project Canterbury (3 year project) Scientists working with Walnut farmers from the Walnut Industry Group	Optimise the timing of copper-based sprays and understand and transfer to growers best practice around blight management. The overall objective was to develop an environmentally benign agent for blight control to reduce grower reliance on copper-based sprays.
The Wheat Calculator Canterbury (3 year project) CRI scientists working the arable industry good body – FAR (Foundation for Arable Research) and wheat farmers	Examine and quantify the effects of arable and vegetable growing practices on nitrate leaching. Project participants were involved in the development of a 'user-friendly' software package called the Wheat Calculator which provides information on how different wheat cultivars respond to nitrogen and irrigation. The calculator aimed to increase farmer profitability by increasing yields and reducing farm inputs and improving environmental outcomes by limiting the detrimental effects of nitrate leaching into groundwater.
Precision Agriculture Projects (LandWise) 2003-2006, 2008-2009 LandWise (a voluntary farmer extension group) working with LandWise farmers, researchers, arable and vegetable industry partners	To co-ordinate on-farm research and development, primarily in the vegetable and arable cropping industries. The projects focused on soil health, minimum tillage and irrigation efficiency and investigated farmers' engagement with advanced technology (Precision Agriculture), including RTK-GPS guided mechanical weeding, GPS controlled spraying, GPS contouring, data and zonal management.

The six projects each sought to answer specific questions to develop more sustainable farming practices or technologies through the creation of new knowledge or tools, which could then be applied to, or adopted by, the farming sectors. As all projects were participatory, farming and science stakeholders were expected to jointly engage in the research. The projects therefore provided a valuable source of empirical evidence to investigate if and how they developed collaborative learning environments to advance sustainability.

Results

Collaborative projects

Collaborative research provided a trans-disciplinary space where farmers and scientists could learn from each other by learning together, project tensions could be aired and different knowledge and perspectives could be exchanged and integrated into project decision making. Learning environments developed when this occurred. The collaborative nature of the engagement led to an open sharing of knowledge between science and farming participants. This was consistently evident in the Walnut and Precision Agriculture projects, while in the Wheat Calculator and Crop Science for Maori projects, collaborative learning environments emerged as the project progressed. A walnut grower described the collaborative nature of their relationship with the scientists by saying, 'We were engaged with the researchers all the way'.

Farming groups sought outcomes that were relevant to farming practice and they expected this to be clearly evident in the project's aims and experimental design. In the Walnut and Precision

Agriculture projects, the farming groups sought to have a significant contribution to project planning and implementation. Scientists' research was jointly planned to ensure it remained cognisant of farming practice and science and farming objectives were aligned. Farmers undertook fieldwork employing scientific methods or principles with or without the scientists' input. Project participants openly shared information and were willing to learn from any mistakes, as a walnut grower explained, 'When there is collaboration between farmers and scientists there is this whole sort of let's share knowledge and an openness to learn from mistakes'.

Although farming groups in the Precision Agriculture and Walnut projects initiated, coordinated and drove the research, they still created a network of stakeholders each bringing their own varied expertise to the table. The intense involvement with the research, enabled farming groups to understand and accept project failures, such as the unsuccessful transfer from the laboratory to the orchard of an environmentally benign bio-control to replace copper spraying in the Walnut project. The Precision Agriculture projects farming group manager explained why farmers accepted any failures,

> We have a policy of telling everyone our failings as well as our successes. We had some really resounding failures and we told everybody about them so the next person didn't go and have the same failure...if farmers are on a journey they don't mind failures, because it's just a thing on the way to a bigger goal.

Positive relationships developed between people, not between institutions and farming sectors. While these relationships developed naturally in the Precision Agriculture and Walnut projects where farmers' science expertise and experience of working with scientists enabled them to maintain an equal footing, in the Crop Science for Maori project they developed over time. Past experiences of the community having been research subjects, rather than research partners resulted in these community participants starting from a low level of trust towards the scientists. This affected their willingness to engage in collaborative activities despite being jointly engaged in setting objectives. Relationship building was slow, as one researcher explained, 'It was probably three years into the programme before we started to actually get some community feedback'. However, the Crop Science for Maori project showed that initial impediments to relationships can be overcome with time, through dialogue, listening, facilitation and mutual understanding, so relationships can mature and stakeholder apprehensions and tensions can be aired and resolved. As one scientist said, 'You have to drink a lot of tea'. In addition, scientists learned that linear approaches to learning were unsuccessful. Traditional teaching platforms initially adopted by the scientists, such as science seminars and workshops, were poorly attended, so were replaced by field activities to enable farmers and scientists to collaboratively engage.

Reconciling science and local knowledge can be challenging in applied projects. Facilitators often aided this knowledge integration. In the Wheat Calculator project, a facilitator was needed to act as a 'boundary crosser' (Veitch et al. 2007) between the scientists and the farming community, to overcome initial science resistance to simplify their pre-existing science research model into a farmer friendly tool to manage nitrogen input. While the project was collaborative from the outset, the facilitator transformed the project into a trans-disciplinary learning space by linking the science and farming stakeholders. This enabled the Sirius wheat simulation model to be developed into a decision support tool for farmers to manage nitrogen and irrigation inputs.

<u>Learning in collaborative projects</u> Farmers' intense engagement with the research resulted in deep levels of learning for individual participants who actively engaged in the projects. Learning was more than just the uptake of a technology or skill, as a wheat farmer explained, 'It's changed my thinking…having been around in the early stages of the project. I think about the consequences of certain actions'. A walnut grower described the gains from their involvement with the project, when she stated, 'We have got smarter about what we're doing. The knowledge base just wasn't there to do that six years ago'. While a Landwise farmer explained the value of integrating different knowledge and being intensely involved in decision-making.

> Because we are using science and using research organisations and our own skills we are basically saying, you show me something better than this. We are doing absolute best practice and we are doing research to check it out… We won't always get our way, we won't always get what we would like, but at least if we are part of making the decisions, we will probably manage it ok.

While collaborative projects created valuable learning among active participants there were limitations. A focus on technology development limited wider learning about the complexities of the innovation system. This was particularly evident in the Crop Science for Maori project. In this project scientists needed to understand and be receptive to Maori protocols, perceptions and traditional/local Maori knowledge (*matauranga*) and where possible to integrate this knowledge into the project's research. However, the initial focus on growing kumara overlooked the importance of understanding the market for organic kumara. Growers' cultural perspectives valued large kumara, however the highly valued urban restaurant market sought small kumara and growers' produce was unable to be sold. It was only when growers and scientists looked beyond the technology (i.e. production of organic kumara) and connected with an organic buyer that they could align the project's technology development and the growers' cultural perspectives with market demands.

In addition, while farmers learnt about environmental consequences of farm practices, learning was focussed on the paddock or farm scale and economic benefits of the technology to the farm business were made prominent. Researcher observation and interview analysis showed that a focus on the technology development at the paddock scale largely ignored the wider complexities of the biophysical system in which the farm system operated to examine the consequences of actions beyond the farm gate at the landscape level.

<u>Extension in collaborative projects</u> In collaborative projects where farming groups were actively engaged in project planning, extension was embedded into the project design from the outset. In the Walnut, Wheat Calculator and Precision Agriculture projects, facilitators not only ensured project delivery remained relevant to end-users, they also facilitated the flow of information back and forth between project participants and their wider farming community.

The Precision Agriculture, Walnut and Wheat Calculator farming groups stimulated conversation in their wider membership to challenge current practice. This enabled learning by individuals within the project, to move out beyond the project boundary. New knowledge, which emerged from the research, was communicated to farming communities through a variety of platforms involving farmer to farmer and scientist to farmer learning. Activities included fielddays, paddock walks, farmer mentoring and annual grower conferences. Key messages from projects were communicated in farming literature, such as the walnut group's *Walnut Growers' Manual* and LandWise's *A Guide to Smart Farming* (Bloomer & Powrie 2011), which both encapsulated the learning from the groups' science research projects. Farmers who had been actively engaged in project fieldwork were willing to share their knowledge. They viewed this sharing as mutually beneficial, as one farmer from the Precision Agriculture projects explained, 'We are not in my view a threat to each other, we are usually an enhancement to each other'.

Established farming groups such as LandWise and the Wheat Calculator's Foundation for Arable Research (FAR) provided support throughout the duration of the project and beyond its funded period. In addition they importantly connected the project with industry, science, policy and regulatory players.

Linear projects

Projects that were heavily weighted towards science outcomes saw scientists largely control and manage the research and they typically proceeded in a linear fashion with scientists undertaking the field research in relative isolation from the farmers. This was evident in the Potato and Squash projects.

In the Squash project, the farmer group was engaged in trial design; however the technically complicated nature of the research prevented collaborative field engagement between scientists and farmers. Farmers relied on the research to provide a predictor tool to identify crops vulnerable to rot but variability in the collected data prevented this from happening. Since science outcomes dominated, the project struggled with the twin demands of producing rigorous scientific evidence while remaining relevant to farmers. The failure to produce a predictor tool led to the squash farmer group questioning their investment in science, and contributed to their withdrawal from funding further science research.

Active farmer engagement in the Potato project was also limited. With minimal farmer input in research planning and implementation, there were few opportunities to collaboratively develop best practice for the control of aphids and viruses in potato crops. As a potato farmer explained, 'Well [the scientist] did all of it, basically I didn't do it. I provided the place, I might have been there two times when he emptied the traps'.

<u>Learning in linear projects</u> Where changes to practices were sought as a project outcome, farmers needed to deeply engage with the research to build trust in the science participants and develop confidence in the reliability of any collected data. Where there was limited farmer engagement in the research, the resultant uptake of project outcomes was minimal. While seed potato growers were willing to adopt simple technologies, such as using a new spray, they were

less willing to change management practices, such as when and how often they sprayed. A farmer described his hesitancy in changing his farming routines when he stated:

> I am not sure we would change our programme from what we were doing, it will move us towards it perhaps, with more confidence in time, but you don't go and change a programme overnight on one set of trial work.

Farmer resistance was further enhanced when changes were perceived to pose a risk to the security of the farming business, as a potato farmer stated, 'I said to [scientist's name], if we get virus, will you pay the bill?'.

Furthermore when a project's focus was on the technology development, the wider conditions needed to support farmer uptake were often ignored. Seed potato growers would not consider changing their spray routines without assurance that laboratory facilities would be available to carry out analysis with results communicated to the farmer in a timely manner. Farmers were also not prepared to change practice during the project to then find structural support offered in the project, such as laboratory facilities and monitoring tools, would be withdrawn when the project finished. In the Wheat Calculator project, there was also concern over who would fund ongoing calculator updates to accommodate new wheat varieties. Collaboration is required to ensure these issues are heard and resolved so projects do not stall.

<u>Extension in linear projects</u> In science-dominated projects, extension followed a linear path. It was typically viewed as technology transfer and scheduled in the final year of the project after scientists had obtained their results. Facilitators were rarely utilised. One scientist discussed this linear approach to extension when he stated,

> I always thought there wasn't enough information to do any extension so you had to do the science first, so I tried to put as much as I could into the science to get the information out.

Extension activities adhered to traditional teaching platforms, such as a scientific seminar followed by a field excursion. Ironically, one scientist described these events as, 'Death by PowerPoint', as he claimed there was minimal opportunity for farmer interaction. One potato farmer recalled his frustration at attending an event when he stated, 'Why on Earth would they [the scientists] think that I would be remotely interested in the DNA structure of an aphid?'.

Discussion

As discussed earlier, proponents of participatory approaches claim that participatory research should foster a learning environment that integrates science and local knowledge into project decision-making. The above results from the analysis of the six projects in this research, supports the view that participatory research can stimulate rich collaborative learning environments. However, traditional linear, top-down approaches were still evident. Four features were identified that influenced the creation of collaborative learning environments in sustainability projects.

Influence of the farming group.

The importance of social networks in fostering change in the agricultural sector is widely recognised (Phillips 1985; Ridley 2005; Kroma 2006; Sligo and Massey 2007). Furthermore, sustainability requires collective learning and action (WCED 1987; Pretty and Ward 2001; Pretty 2003; Robinson 2004; Dale and Onyx 2005). In this research, collaborative learning environments developed where farming groups played a pivotal role in project planning and implementation.

Proactive farming groups such as Landwise, FAR and the Walnut Industry Group built farmer awareness and acceptance of issues, and stimulated conversations about environmental issues. These proactive farming groups ensured project objectives and activities remained cognisant of farming practice and they acted as boundary crossers between the scientists and their farming community. They were also importantly connected with wider players in the innovation system including commercial industry stakeholders. This was critical in the Wheat Calculator project where fertiliser representatives advised farmers on nitrogen and water applications.

Furthermore, the connection proactive farming groups had with their grassroots membership provided for members' voices to be heard and reflected in the project research. These farming groups took project learning beyond project participants out to their wider farming communities, a process referred to as social learning (Leeuwis and Pyburn 2002, Reed et al. 2010). These groups also sustained project learning beyond the funded period of the project.

While the connection farming groups had with their grassroots membership ensured members' voices were heard and reflected in issues they supported, this also constrains the issues that groups support. In industries, such as potatoes, where margins are small, and squash, where risks are high, growers often had a short-term focus and preferred to support issues that were perceived as critically important, visible, and had immediate economic benefit. Sustainability issues do not always align well with these preferences.

Alignment of science and farming objectives

Farmers, scientists and policymakers reasons for supporting or engaging in applied participatory projects were not always aligned. This presented significant challenges for collaborative research. In a science culture that favours and rewards publications, citations and commercial intellectual property, scientists can be torn between the demands of their institution to do publishable research and the practical needs of farmers. This dilemma was more intense for scientists engaged in long-term community based participatory research where commercial benefits were negligible, as in the Crop Science for Maori project. Intangible outcomes that result from participatory engagement, such as the development of shared understanding among diverse participants, which was central to the Crop Science for Maori project, did not easily fit into the requirement for tangible quantitative measures such as findings of evidence-based research. Furthermore, applied research often required science to be narrowly focused and easily communicated to meet farmers' needs, so did not always meet the statistical rigour required by international publications or research institute's biometricians, and therefore risked being seen by science institutions as less important than fundamental research.

Furthermore, scientists claimed the instability in New Zealand's science system, and the need for them to change their research focus to secure funding, limited their ability to develop long-term relationships with farming sectors. Almost all of the scientists interviewed in this research were no longer working in the same field in which they worked when they participated in the projects. The Squash project illustrated how funding pressures led to overly complicated science being shoehorned into an applied project. When this occurred the project struggled with the competing demands of the scientists whose approach to research was based on collecting objective and statistically robust information and the farmers who sought practical knowledge and tools to support their farming practice. Klerkx et al. (2012) argue that institutional change may be needed to facilitate innovations. Certainly this research shows how the institution and culture of science places significant personal and professional pressure on scientists undertaking applied research.

Effect of power dynamics

Participatory projects rely on equitable relationships to facilitate an exchange of ideas between stakeholders (Kesby et al. 2007). The farming sectors in this research did not view themselves as beneficiaries of science research, but rather as active participants in it. They sought to engage with scientists to answer questions that were relevant to their farming practice. Science knowledge was to complement not replace experiential local knowledge. Farmers sought a collaborative partnership beyond their financial support. While the potato farming group may have tolerated minimal active farmer involvement in the Potato project, a practice the farmers referred to as 'rent a farmer', they learnt from the experience and were adamant they would no longer fund applied projects where they were marginalised.

Collaborative learning challenges scientists to share problem identification, goal definition and solution development with stakeholders outside science. This involves more than just farmer 'participation' in projects. Ziegler and Ott (2011) caution against the support for participatory approaches being driven by a blind adherence to the participation dogma, which obliges people to collaborate. This research identifies that when participatory research is employed in projects to advance sustainable agriculture, it must facilitate the meaningful integration of science and local knowledge into project decision making. To achieve this, the building of trust between scientists and farmers needs to be a consistent and collective objective.

However the creation of project learning environments was also affected by power dynamics within the different farming sectors. Where a farming sector was highly competitive, such as in the squash and potato sectors, which were highlighted by relationships dominated by grower contracts, the sharing of information between farmers was often fraught. In the Potato project, engagement was seen as a threat to a farmer's competitive advantage and collective activities were viewed with suspicion. The collective requirement of participatory research was undermined by the sector's culture of secrecy. While highly competitive players could collaborate as occurred in the Squash project, this could never have facilitated the creation of collaborative learning environments as farming stakeholders put boundaries around the information they were willing to share, a feature not evident in the projects that successfully created learning environments.

Emphasis on project-focussed technology development

Buhler et al. (2002) contend that the policy framework strongly influences the way research is conducted. Interviewees from across the science, farming and even policy sectors were concerned that an increased focus on providing measurable evidence of innovation adoption encouraged linear approaches. Critiques of diffusion research and extension have found a focus on technology development and transfer can lead to extension that is bureaucratic and hierarchically structured (Jones & Garforth, 1997) with non-adoption by end users seen as 'aberrant behaviour' that can be rectified by skilled technology transfer (Barr and Carey 2000, p. 6). Furthermore it can promote a top-down approach to communication (Vanclay & Lawrence, 1995; Leeuwis 2004), and can ignore broader changes in innovation systems that may need to be implemented to support knowledge transfer (Klerkx et al. 2006; Klerkx et al. Leeuwis 2012). This research shows that an overemphasis on project focussed technology development undermines learning about the complexities of both the innovation and the biophysical systems.

The Crop Science for Maori and Wheat Calculator projects showed that their initial focus on technology development overlooked obstacles in the wider innovation system and they struggled to make progress. However, when these projects created collaborative learning environments they developed opportunities for participants to address the wider complexities of the innovation system around the demands of the value chain, and institutional barriers that were limiting the integration of science and local knowledge to advance sustainable agriculture.

In all projects, the focus on the technology development at the paddock scale, limited opportunities for learning about landscape level complexities of the biophysical system in which the farm system operated. This led to an overemphasis on the economic benefits of the technology to the farm business, rather than a broader picture, which included wider environmental benefits. Bruges and Smith (2007) identify that when farmers' economic objectives are dominant in applied projects, opportunities for deeper environmental learning are not fully exploited. Hoffman et al. (2007) claim that to focus at the paddock scale and on immediate economic benefits limits farmers' ability to respond to and manage change in complex systems.

Conclusion

For applied science research projects to advance sustainability, this research shows that project stakeholders must embrace a collaborative learning approach. This recognises the various strengths that multiple stakeholders can bring to the collective process and integrates their different knowledge into project planning and implementation.

To enable a meaningful transition towards more sustainable agriculture, projects must focus on the process of collaboration. To achieve this they must facilitate an environment where stakeholders' expectations can be clearly communicated and understood; where learning partnerships are fostered in an iterative and collaborative process that integrates scientific and local knowledge and where needed, challenges current practices and perceptions; and where extension is central to the project from the outset not just tacked on at the end to attempt the transfer of information or technologies.

There are significant challenges ahead particularly in regards to thinking beyond the paddock or farm scale and beyond the boundaries of the project to discuss landscape level issues and to understand and address the wider complexities in the innovation system. Changing paradigms to more sustainable agriculture is challenging, however this research shows that individual projects that create a collaborative learning environment can make important steps on the overall journey to sustainable agriculture.

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