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ANIMAL PRODUCTION SCIENCE

Selecting methods of agricultural extension to support diverse adoption pathways: a review and case studies

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ABSTRACT

This paper presents results from a review of methods of agricultural extension, including the evidence for the effectiveness of methods in supporting farm practice change, how they affect the change process, and the critical success factors involved. Agricultural scientists face challenges in aligning their research outputs to the change process on farm. These challenges are exacerbated by the funding environment for research, development, and extension (RD&E), the complexity of the adoption process and the privatisation and commercialisation of advisory and extension services. To assist scientists in navigating these challenges, a structured literature review of extension methods was conducted, examining the following: group-learning/peer-to-peer; technology development; training; information provision; one-on-one advice/coaching; e-extension; co-innovation; best management practice; and social marketing. In addition, two case studies outlining the application of combinations of extension methods in the context of feeding system challenges in the Australian dairy industry, and their effects, are described. While the evidence across the studies reviewed was strongest for the effect on adoption of small group-learning and one to one consulting, it was combinations of methods that resulted in larger effects (for example, in practice change or profitability), which was credited to how they addressed the human and social dimensions of the adoption process. Case studies of adoption in the dairy sector found that scientists influenced adoption by collaborating with the private sector, being directly involved with on-farm trials and demonstrations, and supporting group-learning approaches to help the adoption of past research. This role for scientists in adoption was enabled by investment in programs of RD&E rather than discreet research experiments, and research designs and methods that incorporated the social dimensions of adoption. This synthesis demonstrates the need for scientists to be proactive in providing guidance for farmers on where to access and source information related to their work, engage with a broad range of advisor types associated with their research field, champion in-field trials and/or demonstrations and be active participants in collaborative approaches to RD&E.

Keywords: action learning, advisory system, agribusiness, coaching, consultancy, extension methodology, group learning, farmer adoption, farmer co-learning, private-sector.

Introduction

This paper examines the evidence for the effectiveness of different methods of agricultural extension in facilitating change on farm and supporting an adoption process, whether that be in relation to technologies, practices or the application of new knowledge arising from research. There has been considerable scholarly focus over many years on understanding drivers and barriers to adoption (e.g. Vanclay 1992; Dessart *et al.* 2019) and adoption is increasingly recognised as a process of learning and uneven change, rather than a point in time event or binary decision (Pannell and Claassen 2020) and where different farmers take different adoption pathways that involve a diversity of social and behavioural changes (Montes de Oca Munguia *et al.* 2021). Central to understanding the variability in learning

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processes associated with adoption are the diversity of people (both individually and collectively), farming systems and technologies (Kuehne *et al*. 2017), as well as the institutional environment, which is the social, cultural, political, and organisational 'rules of the game' affecting change and adoption processes (Rose *et al*. 2018).

Methods of agricultural extension are interventions that are designed to support voluntary change and they are a key mechanism through which farmer diversity and the adoption context can be considered and addressed. However, the study of agricultural extension and the theories, terminology, and practices of agricultural extension is a contested and value-laden domain (Röling 2009). Divisions are based largely on differences in the underpinning theories of change (e.g. diffusion of innovation or farmer empowerment) and the extent to which the socio-political context for intervening is explicit (e.g. the power of global value chains and commercial interests in the goals of agricultural extension). The study of extension methods has also tended to be divided on these grounds, with either a focus on methods to address demand and supply side barriers to adoption (e.g. Vanclay 1992) or criticisms that methods too often 'do not take into account farmers' needs and the capacities of farmers to innovate' (Faure *et al*. 2012, p. 474; Hermans *et al*. 2021) or fail to address institutional constraints (e.g. Cook *et al*. 2021). This has left few studies explicitly examining extension methods from a comparative perspective or exploring the quality of delivery or modes of effects, with socio-political dimensions in mind. This has led to a situation where the attributes of different methods and their implementation are either not considered as a factor in the adoption process, inferring that 'anything will do' in the selection and delivery of extension methods, or that extension efforts 'succeed' or 'fail' with limited consideration of how methods were selected and delivered and by whom. Yet, it is plausible that the capacity and capability of different extension providers and the format and mode of delivery would influence the quality of such interventions, and hence the adoption process. It is therefore important to examine the evidence-base for the effectiveness of different methods so that the selection of methods in the design and delivery of adoption pathway support can be considered (Michie *et al*. 2011).

There are two additional trends that increase the relevance and importance of this study of extension methods to farm advisers, scientists, and policy makers, including the nature of scientific outputs in relation to farm adoption and the increased privatisation and pluralism of extension and advisory services. First, scientific outputs are not the inputs to farm decision-making. Whereas in Australia farmers pay a research and development (R&D) levy and are often involved in identifying problems and identifying knowledge gaps for research priorities, the experimental methods and sample used to address the questions may not be reflective of the on-farm need for knowledge, nor address how that knowledge effects practice change (Sewell *et al*. 2014). Rarely does biophysical research account for the dispositional, cognitive, or social norms associated with the farmers' diverse position on the practices to change (Dessart *et al*. 2019). This means that science outputs are not immediately adoptable and are evaluated through many filters, requiring translation, and tailoring to different needs (Sewell *et al*. 2017). The involvement of farmers in the selection and design of research and in defining likely adoption pathways can therefore be considered a pre-cursor to the consideration of appropriate advisory and extension methods.

Second, in Australia, there have been waves of evolution in the policies and strategies related to agricultural research, development and extension (RD&E), including the level of involvement of state and national governments and industry investment through to strategies of integration in RD&E functions to highly fragmented approaches where research and extension are considered discrete and separate functions delivered by different organisations often with commercial ends (Hunt *et al*. 2012, 2014). Further, the systems that support learning have been disrupted through processes of privatisation of agricultural extension (Paschen *et al*. 2017; Nettle *et al*. 2021), changes to the investment in and organisation of the agricultural innovation system (Murphy *et al*. 2013), and involvement of new actors associated with digital agriculture (Eastwood *et al*. 2019; Fielke *et al*. 2020). Scientists are not immune to the impact of these system disruptions. This has created disconnects between researchers and farmers and between researchers and advisers (Paschen *et al*. 2021). This sets an emerging context for scientists where the application of research knowledge on farm will involve diverse players and organisations rather than traditional 'extension officers' and will require collaboration and a context whereby scientists cannot devolve the responsibility for application of their research to an extension provider. The effectiveness of extension methods is therefore a shared responsibility in the innovation system. Few studies discuss the role of scientists in the selection and delivery of extension methods.

The paper, first, addresses the the following research question: which extension methods support adoption pathways and how are they effective; and second, what are the implications for the design of extension and the role of scientists?

Methods

The effectiveness of agricultural extension methods is highly contextual. This has meant that studies of extension methods and their implementation have predominately been through case studies. Further, there are few comparative studies, with a predominance of ex-post evaluations in which the design and choice of methods was not an explicit purpose in the study. To study the effectiveness of different extension methods in a range of contexts therefore requires a meta-analytical approach to assess the quality of evidence and patterns across studies. Qualitative analysis is also needed to identify common processes underpinning the effectiveness of methods across studies.

A typology of extension methods

Typologies of extension methods or approaches have been put forward by various authors over the past four decades. The food and agriculture organisation (FAO) defined eight approaches reflecting different contexts for delivering extension (i.e. general or transfer of technology approach; commodity specialised approach, training and visit approach, Participatory approach, project approach, farming system approach, cost-sharing approach, and educational institution approach; Axinn 1988). This typology was added by Bell (2015) in describing Farmer Field Schools and the Land Grant (USA) approach. Other authors have defined categories of extension methods based on the source of the approach, such as 'push' or extension-centred (supply driven), 'pull', farmer-centred or market-oriented (demand driven), and 'participatory' (Kareem and Phand 2018) or the client focus being the individual, the group, education or mass media (Gonsalves *et al.* 2005). Others distinguish the governance and organisational arrangements of extension (i.e. government, private, non-government; Davis 2008) or profit/non-profit, free/cost-recovery, multi-/single-purpose, technology-driven/need-oriented (Nagel 1997). More recently, the ethics, outcomes and means of agricultural extension has catalysed consideration of different theoretical lenses to consider the interests of which are being served in the extension process (i.e. producer-focused, interaction-focused or system-focused approaches; Rickards 2018). In Australia, a typology of extension methods developed by Coutts *et al.* (2017) focuses on nine different mechanisms that can encourage learning and change (Table 1). It is this typology that aligned most closely with the purpose of the review in that the mechanisms for learning and change need to be considered by all actors in the innovation system, irrespective of the institutional arrangements or philosophy underpinning extension interventions, although important. This framework was used to select and compare studies of extension methods and their effectiveness.

A structured literature review and meta-analysis of published studies and reports was conducted, informed by a PRISMA process for structured literature reviews (Page *et al.* 2021). Data bases searched included SCOPUS, the Web of Science Core Collection citation index, Science direct, and JSTOR. Direct searches of specialist extension journals [Journal of Agricultural Education and Extension; Rural Extension and Innovation systems (REIS) and the Journal of Extension (JoE)] were also conducted. Queries were used to retrieve the articles with the following protocols: published between 2000 and 2022; developed country focus (Australia/New Zealand; North America; UK and Europe); articles in English. Word search queries of titles, abstract and key words were conducted using the following search terms: (agricult* extension): AND (technology* adoption; adoption; demonstration) AND (adult learning and workshop) OR (training OR education) AND (nudge/nudge theory) OR (social marketing) AND (podcast; YouTube; social media; webinar; online; e-learn*; e-extension) AND (farm consult*; mentor; coach; fee-for-service) AND (boundary span*) OR (intermediary) AND (participa* action*) OR (action learn*) AND (best management practice; BMP) OR (on-line; virtual; augmented reality).

Table 1. A typology of methods of agricultural extension (adapted from Coutts *et al.* (2017, pp. 89–91)).

Extension method	Primary focus
1. Facilitated groups/farmer-led groups/small-group learning (including peer-to-peer learning; farmer action groups; focus farms, discussion groups)	Provides a platform for social learning and can include focus farms, demonstrations
2. Technology development (multi-actor approach)	Collaborative approaches with farmers to address specific topics and problems such as application of a new technology or tools
3. Training	Enables the development of knowledge, skills and techniques as a foundation for change
4. Information provision	Facilitates access to relevant information
5. Consultancy (one-to-one, mentoring, coaching)	Provides individual support to make decisions about changes
6. E-extension	Uses information and communication technologies to provide information and extension support virtually/remotely
7. Co-innovation	Collaborative process that brings people together to negotiate and implement shared goals and outcomes
8. Best management-practice frameworks (BMPs)	A formalised process for self-assessing capacity and then responding to gaps or deficiencies
9. Social marketing	Aims to better understand and engage people to towards specific behaviour changes

The decision to select articles for further analysis was based on their relevance to the aim of the paper, namely, to examine the effect and impact of the application of extension methods and the process by which the effect was achieved. Articles were excluded if they were general studies of factors affecting adoption rather than with a specific focus on evaluating methods, related to early versions of decision support tools (pre-2005; to focus on internet-based decision support), or books and book chapters. Additional limits were added if many results were achieved including LIMIT-TO: farm*.

In total, 2625 articles were sourced and, following a review of the abstract for relevance, a total of 96 articles was chosen for full review (Table 2). To achieve the aim of the study, analysis of the 96 articles involved identifying the extension method(s) according to the typology of methods (Table 1), noting the type of evidence collected in evaluating the extension methods, noting the adoption impacts or changes attributed to the methods, noting interrelationships between methods, and compiling critical success factors in the delivery of the method or other insights.

In addition to the review, two case studies of the application of combinations of extension approaches in the Australian dairy industry were examined. The purpose of the case studies is instrumental (Stake 2003, p. 137); that is, to provide practical insights and deepen the understanding of the review findings in the contemporary context of Australian dairy-sector RD&E. Chosen by the co-authors as examples of effective applications of methods where scientists are actively involved, the case studies include a description of the problem context and adoption challenge, the selection and delivery of extension methods, the role of scientists and the reported impacts. Critical success factors in the implementation of the combination of methods in the cases were drawn from reflections of the co-authors in light of the literature review findings and published studies.

The research concludes with frameworks developed from a synthesis of findings from the literature review and case studies, which identifies the context conditions that are suited to different extension methods and strategies for combining methods. These frameworks can be used to assist scientists and others in the selection of advisory and extension methods.

Results

The results are presented in two sections. First, a synthesis of the findings from the structured review of extension methods is provided according to the typology of extension methods. A summary of the findings is provided in Table 2. Second, the two case studies are presented, which describe the application of combinations of extension approaches in the context of supporting adoption of grazing management systems (Tasmania) and white grain sorghum (Queensland) in the dairy industry.

Facilitated groups/farmer-led groups

Facilitated farmer groups, including farmer-led groups and demonstration/focus farms, draw on methods of peer-to-peer and participatory action learning (PAL) (Knook *et al.* 2018). Studies of the impact of farmer groups on improving adoption, farm performance and other outcomes are largely positive. While many of the reviewed studies did not control for self-selection bias (i.e. groups may involve farmers more motivated to implement change), where this was considered, group involvement was linked to increased profitability and likelihood of adoption (Hennessy and Heanue 2012; Läpple *et al.* 2013). Other studies reported increased profitability and financial returns (Bell and Allan 2000; Hansen 2015) and increased farmer empowerment (Garforth *et al.* 2003; Morgans *et al.* 2021). When combined with one-to-one advice, group involvement has been found to influence changes in farmers' attitudes, knowledge, and practices (Hansen 2015), and can support more rapid change than do other methods (Bewsell and Brenton-Rule 2019; Patchett *et al.* 2020) or does adoption among non-participants (Hansen 2015). In comparing impacts from different types of group involvement, Prager and Creaney (2017) found the levels of learning and adoption were higher for discussion groups than monitor farms, even though individual monitor farmers had greater practice change. In an investigation of demonstration farms as transformational learning spaces, Cooreman *et al.* (2021) found that facilitated dialogue as part of farm demonstrations was more likely to promote transformational learning than did those without facilitation.

The mechanisms by which group involvement influences adoption is suggested to be the development of high social capital and trust among participants and, through this, peer support and increased pro-activity to change, and better problem solving (Hansen 2015). However, it has been noted that the social and informal interactions in groups are often devalued by those investing in group-based extension (King *et al.* 2001). While the more open and flexible the approach in groups is suggested to create an environment for observing, experimenting, learning, and encouraging peers (Nettle *et al.* 2006), it was found that such environments rely on farmers having a mindset of being active knowledge creators rather than consumers of information (Prager and Creaney 2017) and the scientists involved in such groups also need to position themselves as learners and part of the shared inquiry (Sewell *et al.* 2014). The outcomes from these open group processes were noted as more difficult to measure (Sewell *et al.* 2017). In addition, the effectiveness of action learning has been found to be dependent on the presence of a variety of activities that were aligned to desired outcomes of farmers (Sewell *et al.* 2014) and the quality of facilitation with an emphasis on the mobilisation of knowledge and the reflection stage of the learning process (Dooley 2020; Cooreman *et al.* 2021; Morgans *et al.* 2021).

Table 2. Results from structured literature review of agricultural extension methods and their impact (2000–2022).

Method to support change and adoption	Context	References	The form of adoption impacts attributed to the method(s)	Noted links to other methods	Critical success factors
1. Facilitated groups/farmer-led groups/small-group learning (including: peer-peer learning; farmer action groups; focus farms, discussion groups)	Dairy	Bell and Allan (2000)	• Increased financial returns • Increased profitability • Increased likelihood of adoption • Change in attitudes toward practices • Increased knowledge and skills • Accelerated adoption • Change in social acceptance of change • Increased farmer empowerment	[5] [Consultancy] [4] [Information provision] [3] [Training]	• Encourage a research culture that is participatory and practice-relevant • Involve multiple actors in knowledge exchange • Involve friends and families in knowledge exchange activities • Find ways of communicating with farmers in existing formal or informal networks • Invest in trained facilitators • Recruit 'peer champions' • Prescribed approaches may reduce farmer autonomy • Some farmers won't participate in group-learning (risk of exclusion)
	Red meat	Bewsell and Brenton-Rule (2019)			
	Sustainable agriculture	Cooreman *et al.* (2018, 2021)			
	Dairy	Dooley (2020)			
	Land managers	Garforth *et al.* (2003)			
	Dairy	Hansen (2015)			
	Dairy	Hennessy and Heanue (2012)			
	Water pollution	Inman *et al.* (2018)			
	Cropping	King *et al.* (2001)			
	Dairy	Läpple *et al.* (2013)			
	Livestock farming	Lyon *et al.* (2010)			
	Dairy	Morgans *et al.* (2021)			
	Dairy	Nettle *et al.* (2006)			
	Red meat	Patchett *et al.* (2020)			
	Beef cattle	Prager and Creaney (2017)			
	Dairy	Roche *et al.* (2015)			
	Nitrogen use	Robertson and Vitousek (2009)			
	Livestock farming/pasture management	Sewell *et al.* (2014, 2017)			
2. Technological development/multi-actor approaches (including: precision farming, digital agriculture)	Conservation agriculture	Brown *et al.* (2022)	• Increased linkages among farmers, researchers, advisers • Increased advisory capacity in new areas • Improved farm decision making • Increased knowledge and skills of farmers • Increased knowledge flows between technology providers and farmers • New roles for scientists in co-ordination, facilitation, and networking	[1] Facilitated groups [3] [Training] [5] Consultant	• Engagement of technology developers, farm advisers, scientists, and farmers in joint exploration • Personal over impersonal sources more valued • A problem-solving process/joint commitment
	General farming	Caffaro *et al.* (2020)			
	Viticulture	Calliera *et al.* (2021)			
	Broadacre cropping	Carberry *et al.* (2002)			
	Cropping/plant breeding	Dawson and Goldberger (2008)			
	Dairy	Eastwood *et al.* (2019)			

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Table 2. (*Continued*).

Method to support change and adoption	Context	References	The form of adoption impacts attributed to the method(s)	Noted links to other methods	Critical success factors
	Sustainable agriculture	Halbleib and Jepson (2015)			
	General farming	Harden *et al.* (2021)			
	Broadacre cropping	Hochman and Carberry (2011)			
	Livestock production	Ingram *et al.* (2020)			
	Dairy	Kenny and Regan (2021)			
	Livestock	Knierim *et al.* (2019)			
	Dairy	Macken-Walsh (2019)			
	Cropping	Stitzlein *et al.* (2020)			
3. Training	Resource constrained farmers	Akobundu *et al.* (2004)	• Increased access to formalised sources of knowledge and information • Increased awareness of advantages and disadvantages of change • Better timing of farming operations • Increased activity in efforts to solve problems • Improved planning on farm • Increased referral to expertise • Better decisions on farm • Increased linkages between advisers and researchers to farmers • Increased milk quality • Increase in changed practices • Increased compliance (when accompanied by incentives) • Improved awareness and knowledge	[8] [Best-management practice] [4] [Information provision]	• Must be associated with follow up • Impact can decline without continual focus • Learning design is an important aspect of impact • Choice of trainer • more than 1 person on the farm/family completing the course (e.g. employees)
	Farm family health	Brumby *et al.* (2009)			
	General farming	Caffaro *et al.* (2020)			
	Farm Health and safety	Coman *et al.* (2020)			
	Farm health and safety	Cryer *et al.* (2014)			
	Farm health and safety	DeRoo and Rautiainen (2000)			
	Pasture improvement	Dillon *et al.* (2016)			
	Pesticide reduction	Goodhue *et al.* (2010)			
	Sustainable agriculture	Halbleib and Jepson (2015)			
	Broadacre cropping	Hochman and Carberry (2011)			
	Nitrogen management	Lawrence *et al.* (2000)			
	Land Management	Klerkx and Proctor (2013)			
	Pasture improvement	Lloyd *et al.* (2009)			
	General farming				

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Table 2. (*Continued*).

Method to support change and adoption	Context	References	The form of adoption impacts attributed to the method(s)	Noted links to other methods	Critical success factors
		McKenzie *et al.* (2018)			
	Farm health and safety	Rautiainen *et al.* (2008)			
	Farm health and safety	Svennefelt and Lundqvist (2020)			
	Wool producers	Thompson and Reeve (2011)			
4. Information provision	General farming	Bamka *et al.* (2020)	• Increased awareness and knowledge • Quality information resources are highly valued • Meet different needs of farmers	[4] Information provision [7] [Best Management practices]	• Practical rather than conceptual presentation • Tailored to different audiences/ segmentation • High-quality resources: relevant, accurate, accessible
	General farming	Caffaro *et al.* (2020)			
	Rangeland's farming	Coleman *et al.* (2017)			
	Biodiversity	Rollins *et al.* (2018)			
	General farming	Vedeld *et al.* (2020)			
	Cropping	Widderick *et al.* (2006)			
5. Consultancy (one-to-one advice, mentoring, coaching)	Climate adaptation	Cobon *et al.* (2021)	• Increased adoption • Tailored advice • Farmer empowerment (with coaching)	[1] [Facilitated groups] [4] [Information provision] [7] [Best-management practices]	• Trust, credibility, and empathy in the advisory relationship is more important than whether an adviser is from the public, private or not for profit sector • Scientists can collaborate or partner with trusted advisory services
	Cropping	Eanes *et al.* (2019)			
	Livestock farming	Fisher (2013)			
	General farming	Herrera *et al.* (2019)			
	Cropping	Ingram (2008)			
	Dairy	Klerkx and Jansen (2010)			
	Cropping	Kuehne *et al.* (2019)			
	Cropping	McRoberts and Rickards (2010)			
	Dairy	Nettle *et al.* (2018)			
	General farming	Nettle *et al.* (2021)			
	Livestock farming	Sobotta *et al.* (2016)			
	Environmental sustainability	Sutherland *et al.* (2013)			
	General farming	Vrain and Lovett (2020)			

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Table 2. (*Continued*).

Method to support change and adoption	Context	References	The form of adoption impacts attributed to the method(s)	Noted links to other methods	Critical success factors
6. e-extension	General farming	Anastasios *et al.* (2010)	• Increased knowledge and skills • Increased reach • Increased access to information • Increased flexibility and options for accessing information and learning • Changed practices	[4] [information provision] [3] Training	• Can achieve broader reach with mixed approaches to ICT (Information and Communication Technologies) • Can be part of discussion/learning tools
	Red-meat/livestock sector	Brown and Bewsell (2009)			
	Dairy	Michels *et al.* (2019)			
	General farming	Chivers *et al.* (2021)			
	Dairy	Hesse *et al.* (2019)			
	General farming	Ivey and Myer (2019)			
	Environmental literacy	Leitão *et al.* (2022)			
	Climate adaptation	Reardon-Smith *et al.* (2015)			
	Horticulture	Stock (2020)			
	Organic horticulture	Stone *et al.* (2012)			
	Nitrogen management	Stewart (2015)			
	Dairy	Winder *et al.* (2018)			
	Cropping	Wright *et al.* (2018)			
7. Co-innovation	Climate adaptation	Bartels *et al.* (2013)	• Farmer-scientist learning • Practice adoption; enhance social learning • increase resilience to challenges and uncertainties • Enhance management skills and decision-making abilities • Develop new knowledge	[1] [Facilitated groups] [2] [Technological development]	• Commitment to joint exploration by scientists, farmers, and others • Address institutional dimensions as part of the change process • Quality facilitation and innovation brokering
	Sustainable agriculture	Berthet and Hickey (2018)			
	Sustainable agriculture	Bruges and Smith (2008)			
	Greenhouse-gas (GHG) emissions	Burbi *et al.* (2016)			
	Sustainable agriculture	Del Corso *et al.* (2015)			
	Agricultural research projects	Ingram *et al.* (2020)			
	Climate adaptation	Knook *et al.* (2018)			
	Climate adaptation	Knook and Turner (2020)			
	Sustainable agriculture	Smithers and Furman (2003)			

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Table 2. (*Continued*).

Method to support change and adoption	Context	References	The form of adoption impacts attributed to the method(s)	Noted links to other methods	Critical success factors
	Environment	Taylor and Van Grieken (2015)			
	Private–public sector partnerships	Titterton *et al.* (2011)			
	Pastures	Turner *et al.* (2016)			
	Climate services	Vedeld *et al.* (2020)			
8. Best-management practices (BMPs)	US farmers	Baumgart-Getz *et al.* (2012)	• In combination with other methods, increased adoption • Increased awareness and knowledge • Authoritative information	[3] Training [4] [Information provision] [1] [Facilitated groups]	• Relies on the quality of resources and inclusion of business and practical implementation steps • Combine with other methods
	Viticulture	Calliera *et al.* (2021)			
	Nutrient management	Daxini *et al.* (2019)			
	Farm nutrient management	Emtage and Herbohn (2012*a*)			
	Farm nutrient management	Emtage and Herbohn (2012*b*)			
	General farming	George *et al.* (2019)			
	Horticulture	Merhaut *et al.* (2013)			
	Dairy	Rahelizatovo and Gillespie (2004)			
	Environmental practices	Tamini (2011)			
	Pastures	Turner *et al.* (2020)			
9. Social marketing	Water quality	Barnes *et al.* (2013)	• Target approaches that will work with different groups (wider reach/engagement)	[4] [Information provision] [1] [Facilitated groups]	• Careful design and testing of nudges/ budges
	Water use	Chabé-Ferret *et al.* (2019)			
	Food technology	Ferrari *et al.* (2019)			
	Agri-environmental schemes	Kuhfuss *et al.* (2016*a*, 2016*b*)			
	Dairy (lameness)	Main *et al.* (2012)			
	Environmental management	Mills *et al.* (2017)			
	Water quality/land use	Peth *et al.* (2018)			

There were exceptions to the positive outcomes reported from group-learning. Poorer outcomes were reported where groups were formed by external bodies with imposed or expert-chosen objectives and topics or where there was a lack of involvement of landholders in project design (Robertson and Vitousek 2009) or the use of groups as part of socio-political agendas (Cook *et al.* 2021). Prescriptive programs struggled to simultaneously encourage farmer-led processes (Prager and Creaney 2017). The need to consider group extension approaches as embedded in the wider advisory landscape was emphasised by Inman *et al.* (2018) who noted that some farmers believe that group-learning cannot be tailored to their individual farm-specific circumstances.

While scientists may consider farmer groups to be largely outside their sphere of professional work, the evidence of the importance of group-learning in the adoption process suggests that this assumption needs to be reconsidered, and time spent. In studying a participatory research project involving scientists and farmers, Lyon *et al.* (2010), observed that initially 'farmers weren't sure participation was worth their time, while scientists, didn't think it would serve their careers' (p. 555). Yet this and other studies found that farmers' learning was promoted when they participated in a learning community with agricultural scientists (Sewell *et al.* 2014) and enabled the interests of both researchers and farmers to be met (Lyon *et al.* 2010). This suggests that scientist are missing out on being part of the adoption story if they are not engaged in these processes, including the influence to participating farmers' networks, where Wood *et al.* (2014) found that farmers exchanged new scientific knowledge from interactions with scientists in facilitated groups, within their wider networks. Scientists' involvement in groups therefore provides an opportunity for farmers to engage with the science, and interactions with scientists helps span the worlds of science and farm decision-making (Sewell *et al.* 2014, 2017). Further, facilitated groups and farmer-led groups are also a key foundation for other methods, including technological development/multi-actor approach (Method 2) and co-innovation (Method 7).

Technological development (multi-actor approach)

Greater interaction among scientists, technology developers, farm advisors and farmers, or 'multi-actor' approaches, have been recommended to co-develop decision support tools with farmers and to support the implementation challenges of precision and digital agriculture (Douthwaite *et al.* 2001; Hochman and Carberry 2011; Eastwood *et al.* 2019). The close cooperation of practitioners with developers in co-design processes has been found to be crucial to ensuring that new agricultural innovations are successfully developed with farmers' needs, values, knowledge, and experiences in mind (Kenny and Regan 2021). Further, interactions among farmers and between farmers and scientists has been shown to generate new ideas in farming, and hence is key to the innovation process (Sewell *et al.* 2014). In smart-farming contexts, the absence of effective interaction and knowledge flows among these groups has been associated with poorer outcomes, yet such interactions have proved difficult to support (Knierim *et al.* 2019). Farmers' variable interest in being engaged in the research and development process has been identified as an issue (Dawson and Goldberger 2008; Lyon *et al.* 2010); however, multi-actor approaches, when combined with training, were found to improve farmers' ability to access and use precision-agriculture and climate-forecasting tools (Halbleib and Jepson 2015; Stitzlein *et al.* 2020; Harden *et al.* 2021) and farmers perceived that direct links with researchers were of greater benefit than was access to decision support models alone (Carberry *et al.* 2002). In this study, farm advisers are suggested to have an important role in leading 'what-if' discussions with farmers and in helping in the interpretation of data and outputs of models (Carberry *et al.* 2002).

Another reported advantage of multi-actor approaches to technological development is in building relationships, trust and social capital among end-users, scientists, and developers (Sewell *et al.* 2014; Calliera *et al.* 2021; Brown *et al.* 2022), contributing to greater knowledge and skills among all participants and generation of new ideas (Sewell *et al.* 2014). Scientists are often called on to lead or contribute to these approaches (Ingram *et al.* 2020), expanding their professional profile into roles as coordinators and facilitators. With increasing expectations that scientists will engage more with pathways to have an impact (Röling 2009), scientists will need to be more engaged in the technological development process. How scientists can be supported, along with farmers and advisers, to play this role is an area needing to be addressed in the R&D policy. Greater collaborative actions between all stakeholders in multi-agency partnerships, where learning is mutual and co-constructed, is a recommended response (Sewell *et al.* 2014).

Training

The impacts of training on practice change and adoption indicate mixed results. In the field of farm safety-training interventions, some studies have reported limited effects or increases in occupational fatalities following the completion of programs. This was attributed to the short-term nature of the training, a lack of on-going support and that stakeholders and the media devoted less attention to the topic following the program (De Roo and Rautiainen 2000; Rautiainen *et al.* 2008; Cryer *et al.* 2014; Svennefelt and Lundqvist 2020). There was some evidence that accompanying training with financial incentives (in this context, reduced insurance premiums) influenced training participation (Rautiainen *et al.* 2005). In other contexts, training was found to have a positive effect on attitudes and commitment towards change in pasture improvement (Lloyd *et al.* 2009), increased awareness and understanding in nitrogen management (Lawrence *et al.* 2000), and was a precursor to further participation in learning among resource-limited farmers (Akobundu *et al.* 2004). Farmers who undertook agricultural training on mastitis management were 10 times more likely to monitor milk quality through milk recording than were those who had not (Dillon *et al.* 2016). Additionally, those farmers in contact with an extension service and who participated in a dairy discussion group were seven times more likely to practice milk recording (Dillon *et al.* 2016), and the combination of education, extension and milk recording reduced somatic cell count (SCC) by 25% for the average herd (Dillon *et al.* 2016).

The importance of follow-up to training was a common theme. Follow-up included individualised farm visits and on-going engagement or multiple contacts with participants after training. Follow-up to training was found to improve the timing of farm operations and increase active effort to solve on-farm problems and improved planning (Akobundu *et al.* 2004). The use of demonstrations alongside training and follow-up was shown to reduce pesticide use (Goodhue *et al.* 2010). Learning design was also found to be a factor in the success of training efforts. Specifically, to ensure that the practical and procedural (or action-based) knowledge of farmers was the focus in training efforts rather than a conceptual orientation, which is more common among scientists (Thompson and Reeve 2011). This was found to be particularly relevant in the field of pest management (Halbleib and Jepson 2015). The choice of trainer was also found to be important, with formal personal sources of information and farmers' associations and consultants suggested as being important to involve (Hochman and Carberry 2011). One study reported the importance of inclusion of advisers and researchers with farmers in training (McKenzie *et al.* 2018). Involving others in the family or farm team in training was also found to be important in increasing knowledge and retention of knowledge in farm family health (Brumby *et al.* 2009).

While scientists may not be directly involved in training design, ensuring that the information conveyed from research is tailored to meet the practical needs of farmers is an important consideration for scientists (Sewell *et al.* 2014). Whereas scientists tend to focus on knowledge related to the 'what and why' of scientific principles, farmers seek 'know how' or practice knowledge (Klerkx and Proctor 2013), an area where scientists can place more effort.

Information provision

In a study of the efficacy of newsletters and brochures to facilitate adoption of herbicide-resistance strategies, Widderick *et al.* (2006) found that farmers who received a newsletter had greater knowledge of the situations causing herbicide resistance and expressed a greater concern about it. In another study, best management practice guides on management of invasive species were found to be highly valued sources of information, with detailed information on current best practices in one authoritative document of value for time-poor farmers (Coleman *et al.* 2017). However, the decision of whether to invest in a comprehensive best management practice guide was dependent on the urgency and risk from future invasion (Coleman *et al.* 2017). Offering tailored information with other methods such as financial incentives and intensive support was found to be effective; however, more specific tailoring to different segments of the population was needed with varying rates of adoption arising from different farm sizes, the future goals of farms such as succession intention and whether farmers were members of interest groups (Rollins *et al.* 2018). Further, the relevance, accuracy and format of information was noted as vital for farmers in the use of weather and climate services (Vedeld *et al.* 2020), pasture mixes (Sewell *et al.* 2017), alternative grazing regimes (Lyon *et al.* 2010), nitrogen management (Stuart *et al.* 2018) and carbon farming (Ingram *et al.* 2016).

There is an increasing use of digital tools to create and share information (Bamka *et al.* 2020) and in the context of sharing information about the perceived usefulness of smart-farming technologies, a positive indirect association was found between farmers' exposure to formal personal sources of information such as farmers' associations or training and the intention to adopt (Caffaro *et al.* 2020). The curation of information is therefore an important role in science communication (Llewellyn 2007) to which scientists can place greater effort, alongside their engagement with different networks where trusted sources of information are used by farmers.

Consulting (one-to-one advice, mentoring, coaching)

The provision of one-to-one advice to farmers has been associated with increased adoption in a range of studies. Farmers' use of paid advisors was found to be a factor in the partial or full adoption of no-till cropping methods in Australia; however, farmers using multiple till practices were those less likely to employ a paid advisor (McRoberts and Rickards 2010). In a study of farmers' contacts with advisory services relating to environmental concerns in the EU, advisory contact was positively related to the adoption of innovations, the number of information sources used and the adoption of farm risk-management measures (Herrera *et al.* 2019). The association between one-to-one advice and practice change has increased the interest of government and industry bodies in Australia to explore ways to support or subsidise farmers access and use of one-to-one advisers without farmers paying directly for this service (Klerkx and Jansen 2010; Nettle *et al.* 2021). However, the effectiveness of one-to-one advice has been found to be dependent on the extent of trust, credibility and empathy between the farmer and adviser within the advisory relationship (Kuehne *et al.* 2019). These attributes were shown to affect the quality of knowledge exchange, particularly in the context of facilitating farmers' transformation to more sustainable best management practices (Ingram 2008) and where trust in government is low (Fisher 2013). Further, it has been found that farmers and advisers hold different opinions about what is effective in the advisory service provided. In one study, farmers considered that advisers were useful in providing information about grants and held relevant knowledge; however, their level of trust in the advice, the continuity and clarity in advice and how this compared to local evidence were also important attributes in advisory services valued by farmers; yet, these were areas advisers did not always acknowledge or appreciate (Vrain and Lovett 2020).

The type of advisory model used was found to be an important factor in the effectiveness of one-to-one services. In a study of the application of coaching models to support livestock farmers' understanding of GHG emissions and improving profit, 79% of participants either intended to, or had already made changes because of participating, which was a 9% higher level of intention to change than reported in traditional adoption programs in the industry. Other changes included a 43% increase in skills post-coaching and an overall reduction of 19% in GHG emissions intensity (Sobotta *et al.* 2016). Coaching models work with farmers' own knowledge and local context while supporting their autonomy, and coaches can operate as intermediaries between farmers and researchers (Cobon *et al.* 2021). One study reported that advisors and advisory organisations often fail to consider these functions (Herrera *et al.* 2019) and hence the advisory context (the organisation and the interests of advisers) can be an important factor in the effectiveness of the one-to-one approach (Nettle *et al.* 2018). For instance, in one study, crop advisers were most likely to recommend practices associated with soil health that were directly related to crop production (e.g. higher yields and lower inputs) rather than to other benefits to the environment (Eanes *et al.* 2019). It is argued that if advisers do not buy-in to the importance of sustainability, then the link between the provision of advisory services and sustainability outcomes is weakened (Sutherland *et al.* 2013).

Overall, a positive, long-term interactions between an adviser and a farmer were found to be more important in engendering trust than whether the advisory service provider was from the public, private or a charitable service (Sutherland *et al.* 2013). In the Australian context, all advisers then should be considered part of the knowledge system (Nettle *et al.* 2021) and, given the importance of advisers in adoption, scientists need to understand the advisory landscape and make efforts to communicate and collaborate with the range of trusted advisory services in adoption efforts.

E-extension

There is increasing farmer acceptance of the use of information and communication technologies (ICT) for accessing relevant knowledge and engaging in extension programs. In one study, a large proportion of organic producers that accessed an e-extension platform with webinars, videos, information/e-newsletters, and broadcasts, supported changes in practices in some instances (Jenkins *et al.* 2019), and in another, podcasts and videos were found to have far greater acceptance and use since the COVID-19 pandemic (Chivers *et al.* 2021). Farmers favour a wide range of information delivery channels; however, the development and introduction of ICTs should be planned and evaluated with the users, implying that local knowledge systems, a focus on experiential knowledge and working in conjunction with local organisations and advisers is needed with e-extension methods (Anastasios *et al.* 2010; Chivers *et al.* 2021).

One application of e-extension is in on-line or E-learning. In a study of the use of a feed-management learning package for meat and wool producers, E-learning based on videoconferencing was found to be effective with small-group, interactive sessions with practical 'homework' tasks rather than large group, face-to-face workshops (Brown and Bewsell 2009). The shorter, repeated sessions increased reflection and decisions to try the suggested actions. Having access to an 'expert' was also an important aspect of success. Similarly, Hesse *et al.* (2019) found that micro-learning courses were popular and effective in colostrum management on dairy farms, creating feelings of confidence and accuracy in work performance and in establishing standing operating procedures. Little difference was found between the efficacy of online training, hands-on training, or a combined approach in training dairy farmers to successfully administer pain control (Winder *et al.* 2018) with the on-line trained groups rating their technical knowledge slightly lower and taking longer to complete the course, yet on-line training was considered most useful for motivated producers who lacked access to hands-on training.

Another area of application of e-extension is in the development of Apps, virtual experiences and video demonstrations and podcasts (Chivers *et al.* 2021). In a study examining the use of smart phone Apps in dairy herd management, Michels *et al.* (2019) concluded that the benefits of App use should be clearly visible and the handling of Apps as simple as possible to ensure Apps are attractive for farmers, irrespective of farmers' educational background and knowledge. In a pest-management application, webinar conversion to YouTube videos were the most frequently watched videos from all videos produced (Wright *et al.* 2018). In a cropping application, sugar cane growers and agronomists were receptive to the use of the web-based virtual world Second Life™ platform for modelling virtual conversations between characters (avatars) which integrated relevant climate information and industry-recommended management practices in practical farm decision-making scenarios that were used as 'discussion support' tools to improve farm climate-risk decision-making (Reardon-Smith *et al.* 2015). Other studies noted increased engagement of farmer audiences through digital gamification for improving awareness of Natural Resource Management (NRM) issues (Leitão *et al.* 2022) and the use of Instagram (Stock 2020) and Facebook, WhatsApp, and Twitter in extension programming (Mueller *et al.* 2018). Scientists can engage in these platforms to increase the awareness of their work and work with e-extension providers to develop content and channels relevant to farmer needs.

Co-innovation

Co-innovation approaches in agriculture involve shared problem solving across organisations and/or among farmers, commercial parties, government, advisers, researchers and often consumers or other stakeholders (Fielke *et al.* 2018). This requires formal or informal collaboration and iterative processes of coordination, co-design, and co-creation of solutions. The outputs of co-innovation can either be new business models or value chains, new products and services or changes in practices. There are many similarities in the features of co-innovation methods and facilitated groups (Method 1) and technological development or multi-actor methods (Method 2). Whereas facilitated groups are often farmer-to-farmer oriented and technological development often farmer-to-scientist oriented, the co-innovation method is often directed to pre-commercial stages of the innovation cycle, where defining the problem and deciding on options or pathways for addressing problems is less well defined and where a wider range of stakeholders outside farmers, advisers and agricultural scientists are involved (such as other science disciplines, commercial companies, and consumers). However, it is recognised that there is often little difference among the three methods in the underlying learning processes involved. One of the challenges in reviewing the studies of the impacts from co-innovation approaches is that multiple terms have been used so that co-innovation is described under titles of 'participatory extension programs' (Knook *et al.* 2018) or 'participatory (action) research (PAR)' or 'PAL' and involving facilitated groups (Method 1) and multi-actor approaches (Method 2).

Focusing on the evidence around co-innovation involving a wide range of stakeholders, participatory approaches broadly have been found to provide formal opportunities for researchers to positively interact with farmers in a transparent and effective way (Burbi *et al.* 2016). For instance, in climate-change adaptation, a climate learning network involving farmers, agricultural extension specialists, researchers, and climate scientists found that dialogue among researchers and practitioners can enhance agricultural adaptation to climate change (Bartels *et al.* 2013) and higher rates of adoption of climate-change mitigation practices (Knook *et al.* 2020). Similarly, Titterton *et al.* (2011) found that farmers' knowledge and intuitive understanding of the need to adapt to changing weather patterns were significant when part of learning projects with scientists, and Del Corso *et al.* (2015) found that group deliberation and the exchange of arguments in learning processes helped disseminate new technical knowledge, enlarge the range of individual experiences, and change the normative frameworks for action in water use. In another study, innovation platforms with producers allowed farmers to contribute directly to extension-program design (Brown *et al.* 2022). However, in these studies, while the processes were found to influence the questions of scientists, changing the roles of scientists and farmers was more difficult, whereby farmers were often passive listeners to information and scientists as expert presenters, rather than involved in joint exploration and inquiry (Sewell *et al.* 2014; Berthet and Hickey 2018).

Some authors note that co-innovation is more recently being applied to promote policy objectives, such as in public-good and environmental schemes; however, the application to policy goals can be contradictory in principle and problematic in practice (Bruges and Smith 2008; Knook *et al.* 2018). Successful co-innovation approaches are described as having built high levels of trust and confidence among participants (Smithers and Furman 2003) and directly engaging with socio-cultural dimensions and institutional arrangements affecting participation (Knook and Turner 2020; Paschen *et al.* 2021). For instance, farmer participation has been found to be reliant on the institutional arrangements of programs such as the source of funds, trust in, and goal-orientation of government funding agencies; cost-sharing arrangements; the degree of social recognition involved, the role of local and regional level intermediaries, and economic relationships between growers and their processors, contractors and suppliers (Taylor and Van Grieken 2015). Farmer participation was also found to be conditioned by perceptions of the risks of that participation to their local institutions of economic and social cooperation, and what it means to be a 'good farmer'. It has been suggested that agricultural extension design could be significantly improved by more directly and explicitly engaging with these risks through dialogue and mutual inquiry (Sewell *et al.* 2017). Co-innovation approaches are also considered to require a conducive policy and institutional environment to produce a more transformative ambition (Turner *et al.* 2016) and successful co-innovation approaches have been found to hinge on deliberate institutional design (Vedeld *et al.* 2020). While involvement in co-innovation processes may appear distant from the core work of agricultural scientists and farm advisers, Ingram *et al.* (2020) noted that facilitation of multi-actor groups and innovation brokering are increasingly considered as core competencies in agricultural innovation, and involvement of scientists in these processes, essential.

Best management practices (BMPs)

Studies of the adoption of best management practices (BMPs) suggest that high-quality best management practice guides are useful to farmers (Baumgart-Getz *et al.* 2012) but were not, on their own, effective in practice change. However, in combination with other extension approaches, stronger results were realised. For instance, membership of advisory clubs was found to have a statistically significant positive effect for farmers adopting environmental BMPs (Tamini 2011). A study of the adoption of nutrient management plans found social pressure and perceived ease of adopting were strong predictors of intentions to adopt BMPs (Daxini *et al.* 2019). Because farmers were found to express differing levels of trust in different organisations, different strategies to encourage adoption of recommended management practices were suggested to differing groups of farmers and involving a variety of organisations who are able to meet with and provide advice to landholders (Emtage and Herbohn 2012*a*, 2012*b*).

The importance of farmer involvement in establishing BMPs has also been highlighted in contexts including BMPs to deal with climate risks (George *et al.* 2019) and water quality (Merhaut *et al.* 2013). Farmer involvement in developing the guidelines and how they were communicated increased trust by farmers and ensured that BMP guides contained practical inputs concerning business and operational issues along with science. Additional methods such as on-site visits and direct on-farm recommendations increased understanding of issues and significantly increased the implementation of appropriate BMPs (Merhaut *et al.* 2013) as did meetings with advisers, attendance at seminars (Rahelizatovo and Gillespie 2004) and involvement in demonstrations and field-scale projects with 'model growers' where multiple practices integrated into whole-farm management are displayed (Hopkins *et al.* 2007). The role of farm data in farmer learning and monitoring and tracking progress toward BMPs has also been identified as an emerging consideration in the design of BMP programs (Turner and Irvine 2017; Sumner *et al.* 2018).

BMP guides are a common output from agricultural research; however, researchers need to be engaged in additional processes to see BMPs effectively applied. This will include involving farmers and advisors in designing guides, aligning best-practice recommendations with the ease and level of social acceptance of practices and ensuring that interactive approaches are used to explore complex or uncertain practices in demonstrations and group-learning settings with farmers (Lacy 2011) and explore novel approaches in collecting data associated with the application and impact from BMPs.

Social marketing

Social-marketing approaches focus on addressing the psychological and behavioural dimensions of practice change and adoption mainly through the use of tools and techniques of social comparison. Commonly applied in agricultural environmental schemes to promote positive choices to desirable behaviour change, various studies have explored the strengths and weaknesses of nudges (non-financial and non-regulatory tools) to shift people's behaviour without closing options or changing economic incentives, or budges (tools which restrict or eliminate choice; Barnes *et al.* 2013). Marketing approaches, including incentives and demonstrations, are also part of the suite of methods (Heiman *et al.* 2020). Applying the concepts can be complex. For instance, in a study comparing the voluntary adoption of water-quality management techniques, both 'budging' and 'nudging' were found to be needed but the mix of approaches may differ on an individual basis and regulations created both divisions and alliances towards attitudinal acceptance and resistance (Barnes *et al.* 2013). In this study (Barnes *et al.* 2013), influencing social norms through group sharing of information and demonstrations that raise the visibility of individual farmer practices was suggested to make acceptable behaviour more explicit and to reduce a victimisation culture from environmental schemes. While nudging was found to have a preventive effect on fertiliser use (Peth *et al.* 2018), social comparison was a disincentive to change, indicating that social comparisons might work for one group but not for others. In a systematic review of the evidence on green nudging (i.e. environmentally focused) interventions, Ferrari *et al.* (2019) found that almost all studies on farmers provide evidence that 'green' nudging can be effective. This is supported by other studies involving nudges to reward individual participation and conveying information on other farmers' pro-environmental practices (Kuhfuss *et al.* 2016*a*, 2016*b*).

The short-term impact of nudges has been raised as an issue if nudges do not allow for farmers to internalise values and build new habits, such as in environmental management (Mills *et al.* 2017). The mixed evidence between the role of social comparison highlights the potential for negative effects from poorly designed nudges (Chabé-Ferret *et al.* 2019) and, more generally, challenges with undertaking 'controlled' intervention studies (Main *et al.* 2012).

While scientists may be hesitant in engaging with social marketing to promote the relevance of their research to different farmer groups, scientists can consider the principles and reflect on the signals that farmers would need so as to consider changing practices and the extent to which social comparisons can be beneficial.

Across the studies of extension methods, it was the application of combinations of methods that were a common feature in successful adoption outcomes. The following section reports on two case studies from the Australian dairy industry that describe the design of extension approaches using multiple methods and their effect.

Case studies of the application of combinations of extension methods

So as to deepen the understanding of the review findings in the contemporary context of Australian dairy RD&E, and to provide practical insights from combining extension methods, two case studies of extension projects are presented. Feeding-system projects from Queensland and Tasmania were selected to reflect the different organisational arrangements for dairy RD&E across Australia. Organisational arrangements can influence the selection of extension methods as there are different levels of co-investment and different structures and capacity available for extension. Projects where there was involvement of scientists, where there had been investment in research, development and extension in the topic area over time and in which the co-authors had direct experience were additional criteria in the selection of cases. Finally, projects involving interesting combinations of methods and where effects and impacts are reported influenced the selection of projects as cases. Critical success factors in the implementation of the combination of methods in the cases were drawn from reflections of the co-authors in light of the literature review findings and published studies associated with the cases.

Case study 1: how extension methods influenced uptake of white grain sorghum (WGS) for silage on Queensland dairy farms

Context

In Queensland, strong social norms exist among dairy farmers around the growing and feeding of corn silage to dairy cows due to its high-yielding, high-quality and fast-growing nature. However, corn silage is becoming an increasingly high risk and expensive crop to grow with farmers absorbing reduced margins and feed gaps. Faced with increasing price of inputs, water requirements and the varying effects of weather on crop quality and yield, farmers and researchers were considering alternatives. Studies funded by the dairy industry found heat-treating (popping) of white grain sorghum (WGS), when compared with red grain, provided improved starch digestibility in ruminants (Anstis 2015). This initial laboratory research led to further studies into the unique characteristics of grain sorghums, which explored planting, harvesting and ensiling methods. WGS silage was found to produce silage yields and quality similar to those of corn silage, at a third of the cost under much harsher conditions (Anstis *et al*. 2019). Traditionally only grown for grain production, dairy farmers took particular interest in the research and innovation of WGS grown for silage and the benefits it provided during periods of tighter margins. Complimenting the research and demonstration studies, a range of extension methods was considered by the Queensland Department of Agriculture and Fisheries (QDAF) dairy team Chataway *et al.* (2010), including participatory technology development, facilitated groups, information provision, e-extension and consulting. These methods informed ongoing research and stimulated widespread farmer adoption of WGS as a lower-risk silage option.

Extension methods

The strong industry norms of corn production for silage, along with regional variability in the level of uncertainty and risk associated with the production and management of a new feed source, required the QDAF dairy team to think carefully about how farmers could be best supported to consider and manage a significant change in feed source. A participatory technology-development approach involving a range of stakeholders was put in place in 2017 to improve the knowledge base (Method 2). Extension officers facilitated engagement between researchers and seed company representatives to consult on alternative grain varieties as well as with silage contractors and specialists to help assess harvesting practicality, ensiling methods, and ensiling duration on the feed quality. Further, nutritionists offering consulting services (Method 5) were involved in assessing dairy cow rations that balanced and maximised the the potential of the grain silage. The relationships developed through this multi-actor approach encouraged a diversity of farmers to become engaged in considering WSG silage. Silage contractors and seed representatives shared information about WGS silage with their extensive networks. The private contractors and consultants had existing long-term trusted relationships with farmers, and their one-on-one consulting with farmers expanded the support to farmers beyond that provided by QDAF extension officers. The collaborative approach also provided timely feedback from advisers and companies about their farmers' successes or concerns, which were then compiled and conveyed to more farmers in e-extension publications and social media messaging (Method 6) to help promote WGS use and highlight seasonal challenges.

The establishment of four demonstration sites on farms (Method 1) enabled existing discussion groups, other interested farmers and farm input and service providers from across the region to learn from the experiences of farmers and hear more about the results of research trials. This iterative and interactive effort among researchers, extension officers, farmers, farm-input providers, and services/consultants to develop a feeding system around WGS silage became a co-innovation effort over 2–4 years (Method 7), although this was not planned at the outset. The development of harvesting and ensiling methods and feeding management was refined among researchers, extension staff and farmers over a 2–3-year period, where confidence and skills were learnt, and the practice continues to be implemented where conditions suggest.

By working directly with different farm-input providers, specialists and farm services, the QDAF team found that more farmers and a wider diversity of farmers visited the demonstration sites beyond those usually involved in QDAF discussion groups. The service providers were sharing information with their clients and referring farmers to the research and the farm demonstrations as well as assisting their clients implement the change.

Adoption outcomes

The implementation and inclusion of WGS as a silage in dairy cow rations has increased substantially on Queensland dairy farms. Of the five (5) discussion groups of QDAF that involve over 30% of the industry, multiple farms in each group are now regularly growing WGS for silage (Anstis *et al.* 2019). An annual competition is now run among the groups for the highest yielding WGS silage crop. A winning farmer outlined that when timed correctly, three cuts were taken of the WGS, yielding over 50 t of dry matter per hectare (t DM/ha) annually, compared with that of corn (15–20 t DM/ha). In drier seasons or lower-rainfall areas, social norms are shifting, with greater acceptance of lower risks of the WGS than of corn silage and with farmers either completely replacing corn silage or planting a 50/50 split to spread financial and feed gap risk. Seed companies also report adoption and use of WGS, where demand for seed nationally is outstripping supply annually.

Critical success factors

The purposeful involvement of a range of stakeholders that have a role in the change to WGS silage was critical to the research, development and extension process. The engagement of industry specialists and contractors in the early stages of research provided researchers with access to the most relevant sorghum varieties to trial and increased their understanding of the management considerations in moving from laboratory and plot research to field sites. The involvement of their specialist peers in the research and extension activities increased the credibility of QDAF researchers with these stakeholders and the wider industry, which was vital given the novelty of the feed source. With strong social norms around production of corn silage, farmers were hesitant in the trialling of WGS; however, the one-on-one support of trusted long-term industry contractors built their confidence in taking this risk. Furthermore, the ongoing education and relationships built between QDAF scientists and industry specialists widened the reach of extension to different regional areas. As seed specialists and harvest contractors travel across regions supporting farmers in their day-to-day decision-making and planning, WGS for silage production could be discussed in their frequent visits, creating allies for the extension process. The involvement of these stakeholders was not a once-off engagement, rather there has been a shared commitment to learn and to connect farmers with the best information and support possible, an alliance that continues and has operated for over 5 years and remains a community of informed industry stakeholders.

Conclusions

Scientists and extension practitioners worked together to apply a combination of extension methods to support farmers in considering and implementing a new feed source in the face of uncertainty and risk. The central design feature of the QDAF dairy team response to support feeding-system change was to combine the methods of participatory technology development (a multi-actor approach) with peer learning about WGS silage, over multiple seasons. The approach drew on processes of co-innovation, involving the mobilisation of the contacts and networks the dairy team had into the farm services sector, including seed suppliers, contractors, nutritionists and consultants. This networking strategy provided the basis from which more traditional methods of extension were linked, including group-learning/demonstration sites, information provision and e-extension, further supporting refinement of research. While there was an underlying interest from farmers in seeking alternatives for summer silage production, the evidence from this case indicated that it was the networked, multi-actor approach that enabled relationships to be built so that sharing, trialling and implementation of the alternative feed source was understood and adopted by many farms. Other extension methods complimented this approach to support farmers in their ongoing inquiries and uptake of WSG silage on their farms. Throughout, scientists have been present and have incorporated feedback in real time to refine research outcomes and recommendations.

Case study 2: grazing management support in Tasmanian dairy systems

Context

Grazing management in temperate, pasture-based dairy systems has been underpinned by decades of research. This research has provided the technical basis for extension, including training (courses) (Method 3), based on ‘best management practices’ (Method 8), field days and discussion groups (Method 1). In examining the impact from previous extension programs (Turner and Irvine 2017), the Tasmanian Institute of Agriculture (TIA) Dairy RD&E team found that there were different learning processes involved in groups of farmers who were ‘advanced’ pasture managers when compared with groups of farmers with limited adoption of recommended practices or who were new to management or farm ownership. Farmers with advanced pasture management were found to have previously engaged in and benefited from intensive coaching based on stepwise learning, problem solving and applying best management practices. In contrast, less experienced farmers had not participated in coaching and found it difficult to apply the best management practices or adapt their management to seasonal conditions.

The incorporation of a coaching method (Method 5) as part of the training and small-group approach (Methods 3 and 1) was developed to support farmers who had limited adoption of recommended practices. The approach combined a focus on ‘best management practices’ (Method 8) with observation and adaptive decision-making about grazing management across a season.

Extension methods

‘Pasture coaching groups’ (combining Methods 1, 3, 5 and 8) were formed on a regional basis within the Dairy on PAR project in 2015 (Turner and Irvine 2017). Participants were recruited through advertising, targeting those with less experience in grazing management, an interest in improving pasture utilisation and an interest in being involved in a 12-month small-group learning process. Each group comprised six to eight farmer participants and one TIA extension advisor, taking the role of coach. The groups met 8–10 times during a 12-month period, with each participant hosting a meeting on their farm at least once. The coaching program covered a sequence of foundational grazing management topics, incorporated pasture measurements and calculations, and emphasised planning for seasonal changes in pasture growth and expected management changes required to adapt to the seasonal changes. The pasture coach worked through the topic of the meeting using the host farm as the example and facilitated discussion about how pasture measurements and calculations could be applied to upcoming pasture management decisions.

Adoption outcomes

Fifty-three farmers participated in pasture coaching groups between 2015 and 2018. Evaluation data collected from surveys before and after participation and interviews with participants indicated that implementation of all recommended pasture management practices significantly increased in frequency, with increased farm productivity (Flight *et al.* 2019). Key practice changes were a 74% increase in the use of leaf stage in setting grazing rotation length, and a 54% increase in use of a plate metre to regularly measure pasture growth. Modelling studies indicated that the value to farmers from moving from low to imperfect grazing management knowledge on dairy farms is AUD$363/ha.year (Beukes *et al.* 2018). Capacity building in foundational pasture management practices has been shown to not only increase pasture consumption (Beukes *et al.* 2018) but support future business growth (Turner and Irvine 2017).

Critical success factors

Evaluating and learning from past extension efforts enabled the development of more effective extension methods for a group of farmers that struggled to implement change from the existing approaches. The small groups were more conducive to learning and the consistent and regular coaching sessions and the hands-on approach throughout a season supported farmers to gradually gain the knowledge and skills needed to apply recommended practices, when required. The interaction between the group members and between the members and the coach also built confidence to adapt recommendations and make changes that were suitable for their own farm businesses.

Conclusions

Continually adapting extension approaches to better meet the learning needs of different groups of farmers is important, requiring investment in evaluation and in social research to examine and propose extension methods more relevant to specific learning challenges. In this case, combining three common extension methods into one targeted ‘package’ was highly effective in supporting change. Whereas one-to-one coaching or consulting is more commonly recognised as effective for addressing individual challenges in implementing new practices; in this case, the small-group coaching approach where the group facilitator was ‘coach’ was found to provide the impetus for participants to seek further individual support. While not replacing the need for BMP guidelines, this case provided evidence that even well established science, translated into best-practice guidelines are not enough on their own to support their implementation on farm. While scientists were at arms-length from these pasture coaching groups, being involved in such small-group learning environments would help scientists to re-contextualise or re-imagine ways to translate and communicate science to better support on-farm application and problem solving.

Discussion: selecting and combining agricultural extension methods

From the literature review and case studies, methods of agricultural extension were found to have different strengths and weaknesses in supporting change as well as attributes that influenced the quality and impact of their implementation (Table 2). While few studies compared methods directly or controlled for self-selection bias, qualitative analysis in the studies provided evidence of the ways in which different methods supported the change process, as well as the interrelationship between methods and the context conditions such as the topic or practices in focus, the target population and the socio-political or socio-organisational context. Patterns in the combinations of methods to support change were identified in the literature and the two case studies, reflecting different extension strategies. These strategies were labelled as stacking, linking, or networking of extension methods.

- *Stacking*: where multiple methods are used within a single project or intervention and they are combined as a cohesive package or offer to farmers. The goal of stacking strategies is the reinforcement of learning and the targeting of support to a learning need. Stacking strategies involve tailoring the methods to the learning journey for people;

providing the environment and tools for change. For instance, in combining small-group learning with training and coaching or individual advice (Hansen 2015; Sobotta *et al.* 2016; Bewsell and Brenton-Rule 2019), combining e-extension and training (Hesse *et al.* 2019) or combining facilitated groups/demonstrations and BMPs (Merhaut *et al.* 2013). Case study 2 combined small-group learning, BMPs and training with coaching, to better meet the needs of a target group of farmers. Stacking strategies tend to be delivered by a single organisation, such as in Case study 2, rather than involving collaboration with, or referral to, other organisations.

- *Linking*: where there are multiple points of engagement for farmers to be supported in change and farmers can access and select their preferred means of support. The goal of linking strategies is to meet a diversity of interests, needs and engagement with a topic for change and to generate awareness or need for change. Rather than combining or packaging methods to a target population, linking strategies involve the coordination and alignment of a range of methods that provides an environment in which farmers can engage in a way that suits them. Linking strategies can involve multiple organisations that specialise in an extension approach (e.g. providing one-to-one or specialist advice or formal/accredited training) and that cooperate with industry to provide support to farmers. Linking strategies need leadership to foster a collective and coordinated response. Examples of linking strategies included linking training to information resources and other technical support from the industry (Dillon *et al.* 2016), linking information provision to separate advisory services (Coleman *et al.* 2017) and linking demonstrations to training and external follow-up (Goodhue *et al.* 2010). Case study 1 involved the QDAF dairy team linking with multiple advisory organisations (across seed supply, agronomy, silage contracting, animal nutrition) to share information about WGS silage, which, in turn, led to farmers being able to access this information and find the advice they needed. These advisory organisations then linked farmers to the demonstration sites and other avenues for learning about WGS silage.
- *Networking*: where different organisations create formal or informal collaborations or networks (Kelly *et al.* 2017) to cross-reference or refer farmers to the services that can meet their needs and support change most effectively. The goal is to focus collective efforts to align with the different preferences or interests in a topic of change and to achieve wider reach to a farming population by leveraging the associations that people from different organisations have with different farmers. For instance, in developing cross-organisation networks for application of BMPs (Emtage and Herbohn 2012*a*, 2012*b*), providing access to a range of external expertise following group-learning (Brown and Bewsell 2009), and accessing different interest groups to tailor information (Rollins *et al.* 2018). Case study 1 involved the development of a network and collaboration among scientists, extension workers, milk companies and commercial and advisory organisations, which, on one hand, provided farmers with a variety of access points for information and experience with WSG silage and, on the other hand, provided scientists and advisers with a strong feedback and learning mechanism to continually update and improve the information available for farmers.

The combination of extension methods and the relevance of different strategies will depend, first, on the attributes of the context for adoption, such as the level of uncertainty, complexity and risk involved for farmers in change. This context relates to whether the benefit from change is assured, how long it will take to see benefits from change and the perceptions to the level of exposure to different risks and vulnerabilities that change may bring, personally, socially, financially or environmentally. Second, the goals of adoption will also influence the choices, such as the target populations and level of ambition for change. Table 3 presents a framework that synthesises the relative strength of each method (1–9) in different contexts of change distinguished by the level of complexity and uncertainty involved in change (A–C). This framework can assist farmers, scientists, advisors, and policy makers in considering methods that could address the variation in adoption drivers across landholders, enterprises, and practices (Rolfe and Gregg 2015; Rolfe *et al.* 2021) and can be used to consider the enabling environment for change such as which methods better account for the influences of trusted people and peers (Larsen *et al.* 2018) and which organisations hold or need to build greater trust (Rose *et al.* 2018).

However, the ability to then implement the strategies will depend on the institutional arrangements for RD&E, including the existing collaborations between organisations or the level of autonomy that scientists and others have to work with people outside their organisation. Whereas the strengths and weaknesses of the individual extension methods highlighted through this review can be applied to combine methods to build on the strengths and compensate for weaknesses of individual methods, it is the strategies of stacking, linking and networking that underpin the process by which the methods support change. Table 4 summarises the main features of these three strategies and the considerations for applying the strategies. These strategies are not necessarily discrete, as evidenced by Case study 2, in which both linking and networking strategies were involved. Decisions to combine strategies are influenced by two main drivers. First, the need to bring in different or additional expertise, which relates to the institutional arrangements of extension and, second, whether the goals in supporting change relate to depth of engagement (i.e. the learning journey) or reach (i.e. the target population). Stacking strategies, which focus on the learning journey, can be

Table 3. A framework for assessing the relative strength of extension methods (1 through 9) according to the attributes of the context for change (A, B or C), derived from the review and case study findings.

Extension methods (1–9)	A	B	C
	The farm-practice context and impact from change is known and uncontested	The farm-practice context and impacts from change are known, yet there are complexities and uncertainties in implementing change	There is complexity, uncertainty or long time-frames in changing farm practices or in knowing the impacts from change
1. Facilitated groups/peer learning	Moderate	Strong	Strong
2. Technology development	Moderate	Strong	Strong
3. Training	Strong	Moderate	Weak
4. Information provision and access	Strong	Moderate	Moderate
5. One-on-one/consultancy (coach)	Strong	Strong	Weak
6. E-extension	Strong	Moderate	Weak
7. Co-innovation	Weak	Moderate	Strong
8. Best management practice	Strong	Moderate	Weak
9. Social marketing	Strong	Moderate	Weak

supported by linking strategies when the expertise to support change needs to be diversified beyond that provided by a single organisation. In reverse, when a linking strategy is providing great reach via multiple organisations but limited change because a learning journey for different groups has not been mapped, a stacking strategy would be considered. Similarly, linking strategies could be bolstered by networking strategies when there are new learning challenges and when the cross-fertilisation of ideas, experiences and expertise is needed to understand and support change and where this is not supported well enough in the coordination of current expertise alone.

While the individual methods and the strategies are implicitly aligned with different theories of change, these frameworks (Tables 3, 4) could assist researchers, extension policy makers and extension program managers to transcend theoretical debates to frame extension strategies through the lenses of the change context and the socio-political context of the institutional arrangements for extension.

A key finding of this review is that rather than 'anything will do' when it comes to extension methods, a considered approach in the selection of methods is required. Further, extension methods are not transferred in a generic process of 'scaling-up or out' (Wigboldus *et al*. 2016; Sartas *et al.* 2020), rather, they can be combined and adapted to suit the people, places, and times where support to change is needed. Such considerations are the professional practice of those involved in agricultural extension, which in the current environment of Australian RD&E, extends to scientists. The review has identified influence points for scientists in the adoption pathways of farmers in coordinating efforts with the private sector; being directly involved with on-farm trials and demonstrations; and supporting group-learning approaches that support the integration of knowledge from past research into farm practices. This role for scientists can be enabled by investment in programs of RD&E and in research designs and methods that incorporate the social dimensions of adoption. However, this will require scientists to be proactive in curating their work toward the business and practical needs of farmers as well as collaborating with a range of organisations to tailor this information to a variety of channels. It will require scientists to engage with a broad range of advisors that may be loosely associated with their research field, and it will require that scientists champion actively supporting field trials and/or demonstrations and be active participants in leading and brokering collaborative approaches to RD&E. Expected benefits for scientists from the time spent on generating and supporting these activities is the shared attribution to the returns from RD&E investment. This role represents an engaged-research model for scientists, a model that arguably cannot be considered discretionary.

Conclusions

The paper has presented results of a review of the application and effectiveness of nine types of extension methods and considered the application of combinations of methods in two case studies, to produce a framework for the selection of methods in different change contexts. While the strongest evidence for the effectiveness of methods in the extent, reach and time to change was toward small-group learning and

Table 4. The features of different strategies when combining agricultural extension methods.

Item	Strategies when combining extension methods		
	Stacking	**Linking**	**Networking**
Description	• Multiple methods are combined within a single project or intervention, providing a cohesive package or offer to farmers • The combination of methods provides a learning journey for participants	• Multiple methods are linked to provide multiple points of access and engagement on a topic and to suit different preferences	• Multiple methods are supported by the collective effort of a network of organisations • Organisations cross-refer farmers to the resources and organisations that can meet their needs most effectively
Goals	1. Reinforcement of learning/addressing multiple stages of learning 2. Targeting of support to a learning need	1. Meet a diversity of interests, needs and engagement with a topic 2. Generate broad awareness or need for change 3. To coordinate and align information and services so that farmers can engage in a way that suits them	1. To leverage the associations that people from different organisations have with different farmers to achieve wider reach to a farming population 2. Align the interests of farmers and different organisations in a topic of change 3. To access different expertise that is required to support a change goal
Examples from the literature review	• Combining small-group learning with training and coaching or individual advice (Hansen 2015; Sobotta *et al.* 2016; Bewsell and Brenton-Rule 2019) • Combining e-extension and training (Hesse *et al.* 2019) • Combining facilitated groups/demonstrations and BMPs (Merhaut *et al.* 2013)	• Linking training to information resources and other technical support from the industry (Dillon *et al.* 2016) • Linking information provision to separate advisory services (Coleman *et al.* 2017) • Linking demonstrations to training and external follow-up (Goodhue *et al.* 2010)	• Developing cross-organisation networks for application of BMPs (Emtage and Herbohn 2012*a*, 2012*b*) • Providing access to a range of external expertise following group-learning (Brown and Bewsell 2009) • Accessing different interest groups to tailor information (Rollins *et al.* 2018)
Examples from the case studies	• Case study 2 (small-group learning, BMPs, training and coaching) • Targeted to better meet the needs of a specified group of farmers • Delivered by a single organisation	• Case study 1 (multiple advisory organisations sharing information and then providing this and advisory support to farmers • Advisory organisations linked farmers to the demonstration sites and other avenues for learning	• Case study 1 (a network and collaboration providing farmers with a variety of access points for information and tailored advice on all stages of the change • The collaboration provided scientists and advisers with a strong feedback and learning mechanism to continually update and improve the information available for farmers
When to apply the strategy	• When farmers need a 'next-step' to consolidate a change • When there is a group of farmers with different needs in being able to change or with different motivations on a topic • When the relationship between farmers and the delivering organisation needs strengthening	• When the reach of a single organisation to a population of farmers is constrained for any reason • When the expertise to support change lies outside a single organisation • When there is a willingness for organisations to cooperate to provide consistent messages and support to farmers • There is leadership in coordinating the extension response • There is farmer trust in the organisations in which extension methods are linked	• When there is shared interest across organisations in the agenda for change • When there is willingness to learn together with farmers and share and provide expertise to support the change • When the on-farm outcomes are the driver for collaboration and not the attribution • When there is a developing level of trust between organisations to collaborate on the extension goal

provision of direct advisory or coaching services, the overall evidence across the studies suggested that combinations of methods, with a focus on addressing farmer needs and supporting a journey of change, were key to a greater impact. Providing information alone, which is based on a knowledge-deficit model of change, proved weakest.

This paper has contributed to knowledge of the role of extension methods in the farm change process and considerations in selecting methods, which includes explicit acknowledgement of the human, social and institutional dimensions of change, and consideration of who is involved or excluded, which interests are served and whose outcomes are prioritised. Rather than reinforcing a fixation on methods, or inferring that methods are value-free, it is hoped that the review has highlighted the importance of factoring in the context farmers face in making change and provides a different way of thinking about designing extension interventions, a process that can be supported by opening up the extension process to involve and include all innovation system actors and from an early stage.

Overall, the findings present a challenge to the agricultural innovation system in that for extension methods to be effective and a 'fit' for the challenges facing agriculture, then they are not science or policy driven, but locally designed, involve the building of trust and access to networks, and ultimately rely on an interactive, iterative, and adaptive agricultural innovation system where farmers and not scientists or commercials firms are viewed as the primary source of innovation.

There are some limitations to the review. First, it is possible that the systematic review, based on specified terms for extension methods, missed pertinent studies. Second, the interpretation of the overall strength of small-group learning and one-on-one advisory services cannot exclude the possibility that more studies have been conducted on those methods than on others. Third, the synthesis frameworks derived from the review findings and case studies need to be tested in practice and it is possible that it may prove difficult to use or not be specific enough to be practical in all situations. More research is recommended to consolidate the evidence base for the effectiveness of different extension approaches, including comparative studies.

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