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Science communication and engagement in adaptive farm-systems research: a case study of flexible milking research in New Zealand

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ABSTRACT

Context. The aim of farm-systems research is to test concepts in a holistic context that enables results to be as applicable as possible to commercial farmers. A downside of such research has been that it can take several seasons to be confident in the consistency of the outcomes and interpretation of the results. Scientists are often reluctant to communicate outcomes until they have clear conclusions, which conflicts with farmers' desire to see rapid answers and engage with research. **Aims.** This paper reviews a 3-year farm-systems research project investigating flexible milking strategies for New Zealand dairy farmers. The aims of this paper are to (1) examine the impact of real-time science communication in achieving farm system change, and (2) develop a framework for science communication and engagement in adaptive farm-systems research. **Methods.** The project involved farmer interviews, a farmlet experiment, a component experiment, partner farms, modelling, and a farmer reference group. We use data from sources such as e-newsletter engagement, webinar participation, web-page engagement, presentation attendance, and farmer feedback to collect insights on the impact of the project. **Key results.** The analysis highlighted that farmers do not always seek complete information and will follow a project as it evolves, particularly when it is highly topical. We propose a framework for delivering adaptive farm systems research and communication. The framework includes the critical aspects for real-time farm-systems research: credible evidence, rapid results, inclusion of farmer voices, meaningful outcomes, flexible communication channels, iterative feedback loops, and adaptable research design. **Conclusion.** Farm-systems research can be designed to communicate results to farmers as a project develops, while simultaneously using the engagement with farmers to refine the direction of the research. **Implications.** This framework can guide scientists leading multi-year farm systems projects to design, implement, and communicate the project outcomes to improve farmer engagement and adoption.

Keywords: co-development, communication, email, engagement, learning, podcast, project design, social media, webinar.

Introduction

Agricultural scientists live with the tension of controlled component science versus applied farming-systems research (FSR). While the component-focused approach enables issues or opportunities to be carefully investigated by minimising confounding variables, the relevance of component findings can disappear among the myriad of interactions occurring within farm systems. FSR therefore approaches the research challenges from a more holistic perspective (Byerlee *et al.* 1982) to 'create robust solutions and new farming systems' (Stevens *et al.* 2016). It also encompasses a focus on the needs of a defined end-user, and use of a participatory approach with farmers and other stakeholders (Petheram and Clark 1998). FSR also requires a systems-thinking approach and is multi-disciplinary (Darnhofer *et al.* 2012). The need for inclusion of all facets of the farm system, including people managing the system (i.e. farmers and employees),

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has also long been identified (Davidson 1987). However, with such dynamic interactions, capture of robust data to provide definitive research outcomes often requires multi-year projects (Luna *et al.* 1994).

The long-term and dynamic nature of FSR can present a challenge for engaging and communicating with farmers as complete results can take several years to produce. This approach has historically made scientific publication difficult because of limitations around replication and a focus on practical application (Tanaka *et al.* 2008; Cerf 2011). To some extent, the development of farm-system modelling has replaced more explorative aspects of FSR (Stevens *et al.* 2016). However, the need for farm-systems studies remains, so as to provide farmers with 'real-world' evidence of strengths and weaknesses of new systems (Scott *et al.* 2013). Working alongside farmers as research end-users is important for FSR design, refinement, and dissemination of results. Farmers are keen to see new technologies in action, and their desire for results can clash with science-driven timeframes and processes involved in research analysis (Crawford *et al.* 2007). The lag time from project initiation to analysis and write-up, especially for long multi-year studies, means that communication of results often has a significant delay. This can be an issue when farmers are engaged at the start of the study but become disengaged due to a lack of actionable knowledge, or ongoing communications from the project.

There are a range of issues facing dairy farm systems in Australasia, due to a changing climate, consumer preferences, animal care standards, and workforce expectations. This presents a challenge for conducting FSR that remains relevant and responsive to farmer needs. There is a need for new models of science communication and use of real-time information (Davis *et al.* 2021), along with use of modern communication methods not often applied in science. Therefore, the aims of this study were to (1) examine the impact of real-time science communication in informing farm-system change, and (2) develop a framework for science communication and engagement in adaptive farm-systems research. In this paper, we outline the results from a recent FSR project on flexible milking strategies for New Zealand (NZ) dairy farmers and propose a framework for science communication in FSR projects.

Case study – flexible milking strategies

The 'Flexible milking' (FM) project was conducted from 2019 to 2022, funded by the Ministry for Primary Industries (MPI) through the Sustainable Farming Fund, and co-funded by DairyNZ Inc. Flexible milking relates to variations in milking frequency other than the traditional 'twice-a-day' and well known 'once-a-day' milking strategies. The aim was for farmers and advisors to have the confidence to adopt, optimise, and support the use of reduced milking-frequency strategies, with the benefit of enhanced wellbeing and workplace attractiveness (less hours spent on farm, fewer early starts, and greater flexibility).

Attracting and retaining quality staff is a challenge faced by most NZ dairy farmers (Eastwood *et al.* 2020), and is a challenge globally (Malanski *et al.* 2021). Its importance is recognised by the dairy industry commitment to build great workplaces for NZ's most talented workforce (DairyNZ 2022). Internationally, there is a need to focus on work organisation, job desirability, and workforce productivity in agriculture (Malanski *et al.* 2021). Improving hours of work, both the amount (e.g. reducing occurrence of 60+ h weeks) and timing (e.g. avoiding 4 am starts; Edwards and Kuhn-Sherlock 2021), will increase the competitiveness of dairy relative to other workplaces offering more conventional hours. Milking requires significant labour inputs and data from a survey of 500 farms in 2018 highlighted that milking typically accounted for 16–24 h per person per week at peak lactation (range depended on herd size and dairy type; Edwards *et al.* 2022*a*). Traditionally, cows in NZ have been milked twice-a-day (TAD), with 10 and 14 h milking intervals. This means that if milking takes an average of 2 h, and the goal is to finish by 5 pm then a 5 am start to the morning milking is required, and, for many NZ herds, milking takes significantly longer than 2 h (Dela Rue *et al.* 2020). The milking schedule is therefore an obvious starting point for reducing the length of the working day and increasing dairy workplace attractiveness. A survey indicated that milking three times in 2 days (3-in-2) was used on about 12% of NZ dairy farms in the 2017/18 season (Edwards 2021), and annual data are shown in Fig. 1. However, many NZ farmers did not have the confidence or knowledge of how to determine whether a FM strategy was a good farming decision for their individual circumstances. The 3-year FM project was initiated to understand the information needs of NZ farmers, collect credible information, and co-develop and communicate knowledge related to implementing FM.

The project was run over the 2019/20, 2020/21 and 2021/22 dairy seasons. It involved the following three main phases: needs analysis and knowledge creation, farmer co-development of information, and communication. A major focus of the project was on communication and engagement with farmers (Fig. 2). The main methods used in the project to communicate with farmers and sector stakeholders included email list, website and social-media content, print articles, presentations, radio interviews, webinars, podcasts, and peer-reviewed articles. These communication and engagement activities are further described in the next section, and the major activities in each year of the project are outlined below.

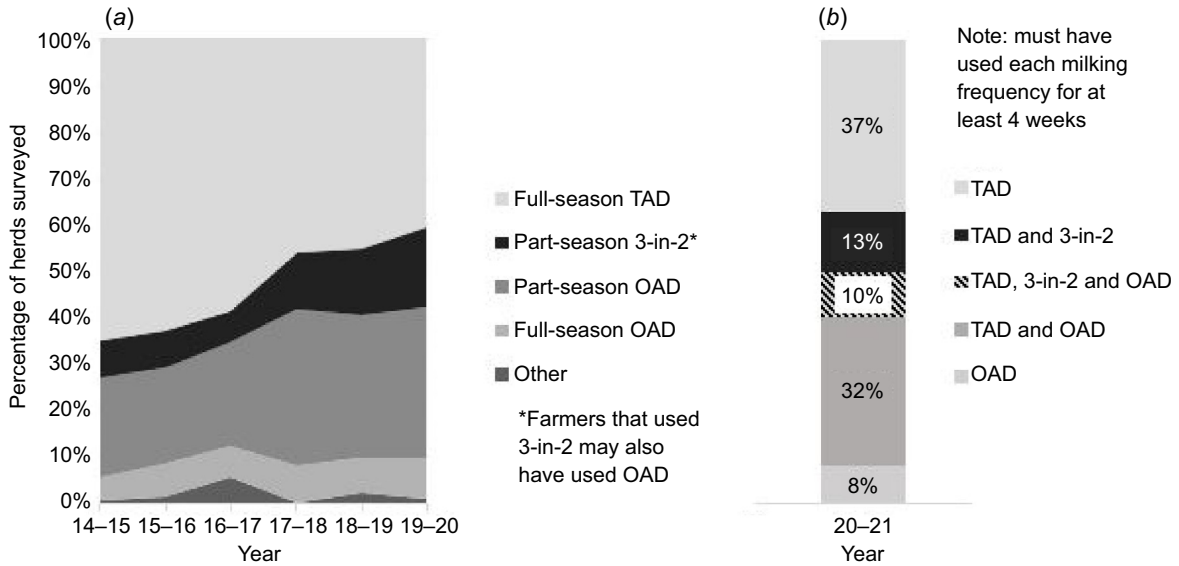

Fig. 1. Percentage of herds milked twice-a-day (TAD), three times in 2 days (3-in-2), or once-a-day (OAD) by season. Data sourced from (*a*) DairyNZ Animal Husbandry Consults 2014/15 to 2019/20 and (*b*) Fonterra in 2020/21. Source: Edwards (2021).

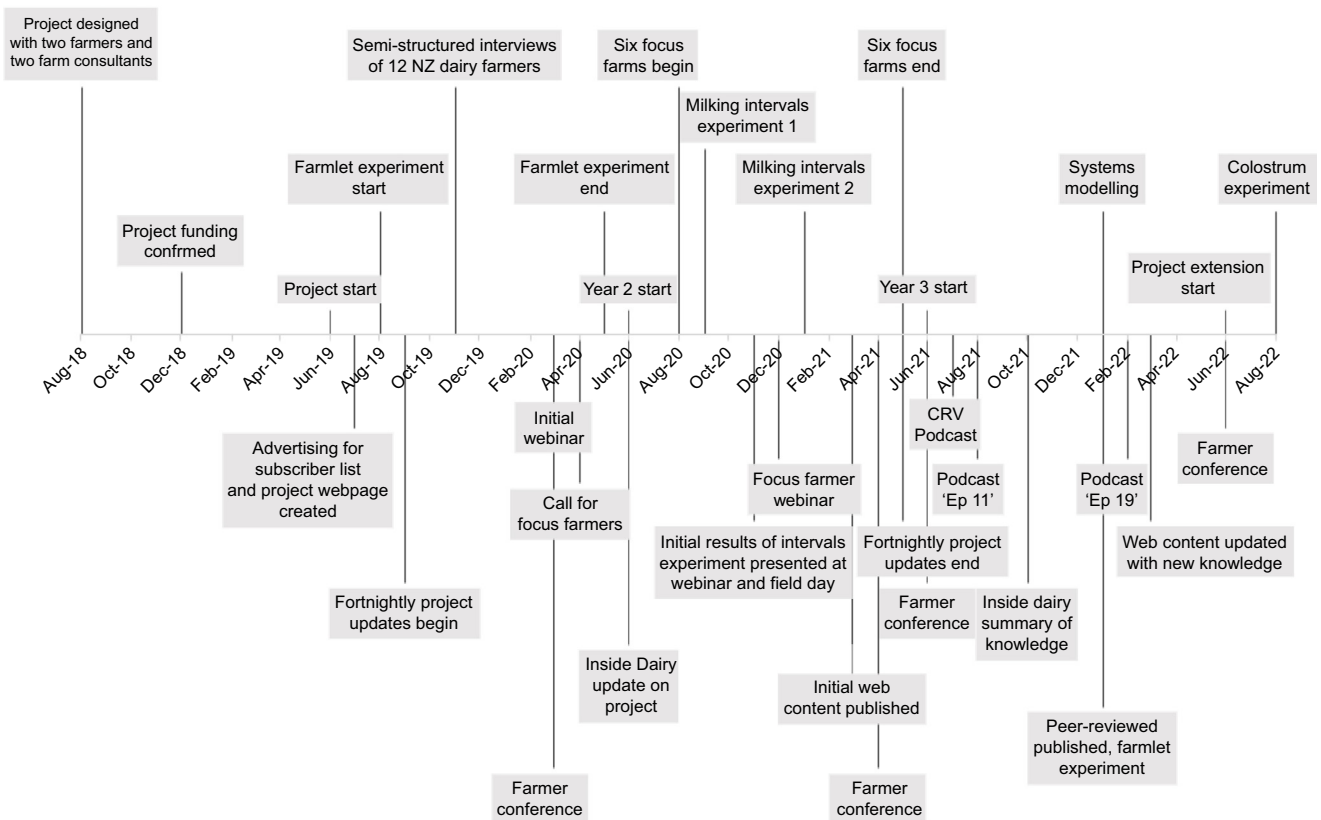

Fig. 2. Outline of major 'Information creation' and 'Communication' activities in the flexible milking project.

Year 1 (2019/20)

The first year of the project focused on understanding the information needs by learning from farmers already using FM strategies to help guide development of resources and information. Major activities included the following:

- A seven-person reference group consisting of farmers and rural professionals formally established to provide input

into project design. The group was selected by the DairyNZ project team from people interested in FM, and was initiated in 2018/19 to gain support and input for the funding application.
- Twelve farmer interviews conducted to understand adoption triggers, barriers, and information gaps. These farmers had used a range of approaches (full season 3-in-2, part season 3-in-2, and variable interval milking, where a range of intervals are used on a weekly basis) for the previous 1–3 years.
- Farmlet experiment conducted at the Lincoln University Research Dairy Farm (Lincoln, New Zealand), evaluating the impacts of adopting FM at the following three time points: full-season (100% of the lactation), after 39% of the lactation (after 1 December) or 74% of the lactation (after 1 March) relative to TAD were tested.
- Project communications were initiated, including fortnightly email updates to a subscriber list during the farmlet experiment, an in-person presentation during a farmers forum mini-conference, a webinar where results-to-date were presented along with learnings from the farmer interviews and a written summary of knowledge gained to-date published in the traditional farming media (magazines and newspapers).

Year 2 (2020/21)

In the second year, activities centred around focus farms where FM strategies were being implemented. Major activities included the following:

- Commercial-focus farms, with a range of farm-systems data being captured, including milk production and animal health, reproductive performance, and farm finances. Additionally, sleep/fatigue, wellbeing, and hours worked of some of the farm teams were captured.
- Fortnightly email updates focused on results from the focus farms.
- Component experiment conducted to investigate the effect of different intervals used with milking three times in 2 days on milk production.
- Increased number of project communication activities, with an additional two webinars, in-person farmer presentations and articles in traditional farming media.

Year 3 (2021/22)

Main activities in the third season included the following:

- Modelling to predict the outcome of different combinations of milking intervals and within-season change points. These scenarios were identified from farmer questions in Years 1 and 2.
- Disseminating the information gathered in the project (particularly from the focus farms) via traditional farming media, farmer field-days, farmer, and stakeholder conferences.
- Additional funding was also secured for an experiment to investigate postpartum changes in milk composition (management of colostrum), which was a question that had not been able to be answered during the project.

Materials and methods

In this paper, we use a mixed-method approach to data collection and analysis. To track longitudinal engagement with the project, we examined interaction with different information channels over time. The primary data sources are listed below. DairyNZ human ethics processes were followed during this project.

Engagement with website content, podcasts, and webinars

A key channel for communicating results from the project was through the DairyNZ website. Engagement with the content created for this website was followed through analytics of unique page views (termed 'views' through the remainder of this paper) and clicks using Google Analytics™. Three webinars were also delivered at different stages of the project, conducted live and recordings were posted on the DairyNZ YouTube™ channel and website. 'Update 1' in March 2020 focused on the season-to-date results from the farmlet experiment and learnings from farmer interviews, 'Update 2' in November 2020 reviewed project results, including the completed farmlet experiment and partial results from the component experiment, and 'Update 3' in December 2020 involved four of the focus farms outlining their experiences mid-way through the season. Engagement was tracked through web views, and time spent watching the content. Two 'Talking Dairy' podcasts were created in the final year of the project; 'Episode 11: better workplaces through flexible milking' was released 24 August 2021, and 'Episode 19: flexible milking case study and research' was released 2 February 2022. Engagement with these podcasts was tracked by recording downloads and average consumption length (% of episode people listened to).

Engagement with email communications

An important communications channel for the project was an email list, to which farmers and other sector stakeholders could subscribe. The email list was advertised on the project website and at early project events such as webinars, and the subscriber list rapidly increased to peak at 552 subscribers. Of the subscribers, 75% were farmers, and 25% rural professional and other stakeholders. Among the farmers, there was a range of farm owners (40%), sharemilkers/contract milkers (42%), farm managers (11%), and other (7%). There were

subscribers from all NZ dairying regions, with Canterbury/North Otago being the largest group (26%), and 3% of subscribers lived outside of NZ. The cadence of emails varied across the project timeline; in the first year, fortnightly updates were sent during experimental periods to provide 'real-time' information about trial results. In the second year, fortnightly emails were sent to provide updates from the focus farms as well as *ad hoc* communication of experimental results. In the third and final years, emails were sent less frequently, only when there were major project updates, with the final email being sent in May 2022. Interaction with the email list was assessed by using ClickDimensions™ to analyse 'open rates' (how many emails were opened) and 'click-to-open rates' (how many weblinks within emails were opened).

Surveys of the email subscribers

Surveys were undertaken at the start and end of the project to assess the knowledge farmers and rural professionals had of FM, and the main barriers they saw to its use on farm. A baseline survey was conducted with email list subscribers from 12 November to 2 December 2019. Respondents were able to indicate whether they were a farmer, rural professional (e.g. farm consultant or vet), or 'other'. Relevant demographics were collected including region, herd size, preferred information sources, and previous experience with FM. Respondents were asked about their perspective on whether FM had a positive or negative impact on people on farm, milk production, farm profit, animal health, and reproduction. Additionally, respondents were asked which of these five areas they wanted more information on. They were asked questions related to their knowledge and confidence to implement or advise on aspects related to FM. The final survey was conducted between 5 May and 2 June 2022. Respondents were asked to select whether they were a farmer, rural professional, or other stakeholder. Questions mostly matched those asked in the initial survey, with the addition of questions about the project delivery methods.

Results

The impact of the project activities on farmer engagement, and the ability of the project team to adapt to the needs of farmers based on feedback, was measured using a range of data. Below we outline the results related to main categories of dissemination.

Co-development of project activities and messaging with farmers

A co-development approach underpinned most of the project. A 'reference group' was created to connect the project team with engaged farmers and stakeholders. This group helped co-design the specific treatments to be investigated in the farmlet and component experiments. This flexibility in design was built into the original project proposal. Interaction with, and feedback from, farmers on important topics for the project to investigate was also undertaken through discussion groups, farmer conferences, and question and answer sessions in webinars. These insights were incorporated in the scenarios in the modelling phase, and in the development of website resources. Questions raised by farmers also resulted in an additional experiment being funded in 2022/23 to investigate postpartum changes in milk composition to improve guidance of colostrum management in FM systems. Farmer feedback also led to the development of web pages to fit the following themes:

- *What is it?* This 'Milking intervals' page provided an explanation of FM, along with other milking intervals, so that farmers could compare the approaches and understand the relative strengths (see dairynz.co.nz/milking/milking-intervals/)
- *Should I do it?* This 'Flexible milking' page provided background information to help farmers decide whether it was right for them and their system (see dairynz.co.nz/flexible-milking)
- *How do I do it?* For those who have decided to implement FM, this 'Implementing flexible milking' page was based mostly around the questions sourced from farmers and stakeholders during the project. This resource was highly flexible in development, and was informed by the initial email survey, farmer interviews, and focus-farmer experiences. Initially, this resource was planned as a booklet, but feedback from the initial email survey showed that a web-based resource would better match farmer information seeking behaviour (see dairynz.co.nz/going-flexible)
- *How does it work on farm?* An overview was provided of the focus farms as case studies (see dairynz.co.nz/flexible-farms)
- *What is the evidence?* The 'Flexible milking research' page outlined the project itself and was used to store project updates before being incorporated into the aforementioned resources (see dairynz.co.nz/3in2)

In addition, results were presented to farmers at 25 farmer/industry events (including annual conferences such as the South Island Dairy Event and Farmers Forum) and 17 articles published in the traditional farming media. Also delivered were six webinar or Facebook live events (via DairyNZ-run Facebook groups), three podcasts, one radio interview, and three international presentations.

Surveys of farmer and rural professional needs

Initial survey

There were 92 responses to the initial survey of the 274 email subscribers at that time, a 34% response rate. Of the

respondents, 83% were farmers, and the remainder was rural professionals (RPs) or other sector stakeholders. Respondents (reported as farmers; RPs) wanted to know the impact of FM on production (84; 81%), reproduction (53; 81%), profit (63; 87%), animal health (58; 75%), and people on farm (57; 87%). This indicates that RPs have an interest in the wider systems implications of FM, while farmers are primarily focused on the impacts on milk production. Additionally, farmers may have been more confident on benefits for aspects such as animal health and people, but unsure about milk production impacts. Overall, respondents perceived the greatest negative impact of FM to be on milk production, while the greatest positive impacts were to animal health and reproduction (Table 1).

Respondents said they would look for information on the DairyNZ website (67%), through talking to other farmers (58%), talking to a rural professional (42%), or using social media (17%). Most (74%) of respondents agreed that they were confident to make decisions related to the use of FM; however, only 55% felt that they had flexibility with their milking times.

Final survey

There were 46 responses to the final survey (35 farmers, six rural professionals, two sector stakeholders, three international), from over 550 subscribers at that time, an 8% response rate. Survey participants were asked the following: 'In the last three seasons, where have you accessed information on flexible milking?'. Participants could select more than one option. The most common source was the DairyNZ website (89%), print media (52%), talking to other farmers (48%), webinars (33%), podcasts (28%), social media (26%), and rural professionals (24%). All other options rated lower than 20%. Compared with the initial survey, respondent perceptions of the impacts of FM were more positive about impact on people (98% positive compared with 60%). The results showed limited change in perceptions across the other aspects; however, perceptions on the impacts were already favourable in the initial survey (Table 1). More respondents agreed they had enough knowledge to decide whether FM made sense for their farm (51% in 2109; 95% in 2022), and more agreed that they were confident to make decisions about FM (74% in 2019; 95% in 2022; Table 2). The proportion of respondents who agreed that they had 'limited flexibility with their milking times' reduced from 26% to 9% from 2019 to 2022, more agreed that they were confident with pasture management (71–97%), and more agreed that they knew when in the season to use FM (48–95%; Table 2).

In terms of the type of information provided during the project, and the cadence of updates (Table 3), respondents were most positive about the amount of FM-related information that now exists (66% strongly agreed), the provision of 'on-the-go' interim results (53% strongly agreed). When asked whether they felt engaged with the project across the 3-year period, only 20% strongly agreed (61% selected agree), and when asked whether results from the trials were useful to them, 30% strongly agreed (52% selected agree). However, the feedback was still overwhelmingly positive (strongly agree + agree) for all questions listed in Table 3.

Qualitative feedback from the final survey regarding the project content and communications covered a range of themes. The first related to the delivery of 'credible research' on FM, with links to a university in the experiments providing greater credibility with farmers. One respondent noted the following: 'Good to have some controlled research on a farm practice that a lot of us have been doing for a while. Gave us more confidence to further tweak the milking times to become more staff friendly'. Respondents also noted value from 'farmer feedback' mixed with the credible research. There was also a call for more evidence of impacts in a range of regions and farm systems throughout NZ. While the experiments were conducted on a research farm in Lincoln, Canterbury, the focus farms were situated in a range of regions, including Southland, Otago, Canterbury, Taranaki and Waikato. The regularity of updates was identified as a highlight, with one respondent noting that 'The regular updates were extremely informative and well presented. Enabled you to be part of the journey'. A final theme related to ongoing uncertainty about implications for people on farm, with perceptions that FM reduces employee productivity due to variable schedules, and that it is difficult under arrangements such as contract milking.

Table 1. Respondent answers in Surveys 1 (2019) and 2 (2022) to the following question: 'Do you believe flexible milking has a positive or negative impact on the following aspects?' (% of total responses, rounded to nearest whole number) Data are presented as results from 2019, with those from 2022 in parentheses.

Item	Highly negative	Negative	Neutral	Positive	Highly positive
Animal health	0 (0)	1 (2)	19 (18)	59 (53)	21 (27)
People	1 (0)	11 (2)	28 (0)	45 (36)	15 (62)
Production	0 (2)	21 (18)	54 (53)	21 (24)	4 (2)
Profit	0 (2)	9 (9)	43 (42)	44 (40)	3 (7)
Reproduction	0 (0)	2 (0)	28 (33)	57 (45)	12 (22)

Table 2. Participant responses in Surveys 1 (2019) and 2 (2022) to a range of statements related to implementing flexible milking (% of total responses, rounded to the nearest whole number); data are presented as results from 2019, with those from 2022 in parentheses.

Statement	Not sure or N/A	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree	Agree	Strongly agree
I feel I have enough knowledge to decide whether flexible milking makes sense on my farm	0 (0)	4 (0)	25 (0)	20 (5)	28 (45)	23 (50)
I feel confident to make decisions about using different milking intervals	0 (0)	1 (0)	9 (0)	15 (5)	53 (55)	21 (40)
I feel I have very little flexibility with my milking times	0 (0)	21 (24)	34 (54)	17 (12)	21 (2)	5 (7)
I feel confident with pasture management using flexible milking	3 (0)	3 (0)	11 (0)	13 (3)	44 (59)	27 (38)
I feel confident about when during the season I can best use different milking times	2 (0)	5 (0)	24 (0)	21 (5)	29 (54)	19 (41)
I feel confident I can manage mating while using flexible milking[A]	– (0)	– (0)	– (21)	– (24)	– (32)	– (13)

[A]Question on mating was asked only in the 2022 survey.

Table 3. Participant responses to a range of statements related to information provided during the project (% of total responses, rounded to nearest whole number) from survey conducted with email subscriber list in 2022 (Survey 2).

Statement	Not sure or N/A	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
I feel there is more information available to make informed decisions about flexible milking than three seasons ago	0	2	2	2	27	66
Being able to follow farmers adopting flexible milking approaches (pilot farmers) and hearing their experiences was very useful to me[A]	2	0	2	13	40	42
I enjoyed the 'on-the-go' interim results rather than waiting for a rigorous analysis at the end of the project[A]	4	0	0	4	38	53
I felt engaged with the project across the three seasons[A]	2	0	0	16	61	20
Project communication was highly engaging (e.g. use of email/web/print/online/events)[A]	2	0	0	5	52	41
Results from the two experiments (farmlet study and timing of milking trial) were very useful to me	2	0	0	16	52	30
The project answered many of my flexible milking related questions	2	0	0	5	57	36
The results from this project were rapidly available[A]	2	0	0	2	62	33

There were 44 responses to most questions.
[A]There were 45 responses.

Engagement with email communications

During the project, 552 people subscribed to the email list, and a total of 16 643 emails was sent, an average of 30 emails per subscriber (Fig. 3). The numbers of email sent through the project were 2343 (2019), 9330 (2020), 4567 (2021). Overall, 9057 emails were opened at least once, corresponding to a 54% open rate. Additionally, 1437 emails had click-to-opens, a 16% click-to-open rate, which is considered high for DairyNZ-sent emails (overall average 2.8%).

Engagement with website content, podcasts, social media, and webinars

Of the pages on the DairyNZ website, the most popular was the page 'Implementing flexible milking', where farmer-sourced questions were presented. From August 2020 to August 2022, this page was viewed 7625 times, with people spending an average of 6 min 17 s on the page (Fig. 4). Statistics for the other pages were 'Flexible milking' (4531 views, 2 min 53 s average time), 'Milking intervals' (3904 views, 1 min 29 s average time), 'Flexible milking research' (3774 views, 4 min 21 s average time). The webpages also had different engagement profiles over time, as illustrated in Fig. 4. Practical information, such as the information on the 'Implementing flexible milking' page, appeared to have had greater ongoing engagement.

Social media (such as Facebook™, Twitter™, Instagram™, YouTube™, and LinkedIn™) were used throughout the FM project to promote webpage, webinar, and other content. These platforms provided much greater reach for the project content; for example, a post on the DairyNZ Facebook™ page

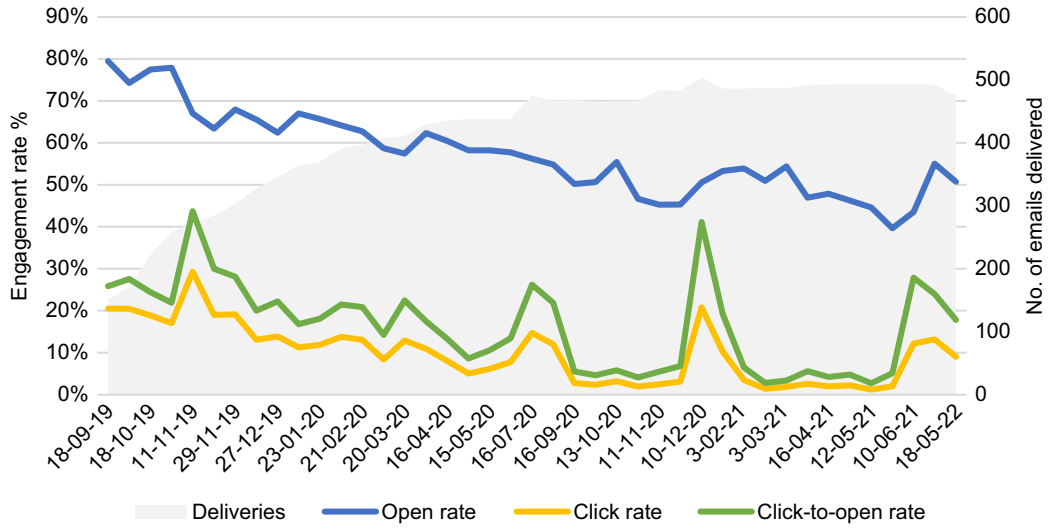

Fig. 3. Email send statistics for overall deliveries (emails sent), open rate (% of sent emails opened), click rate (click-throughs as a % of total deliveries), and click-to-open rate (click throughs as a % of unique opens) from 18 September 2019 to 18 May 2022.

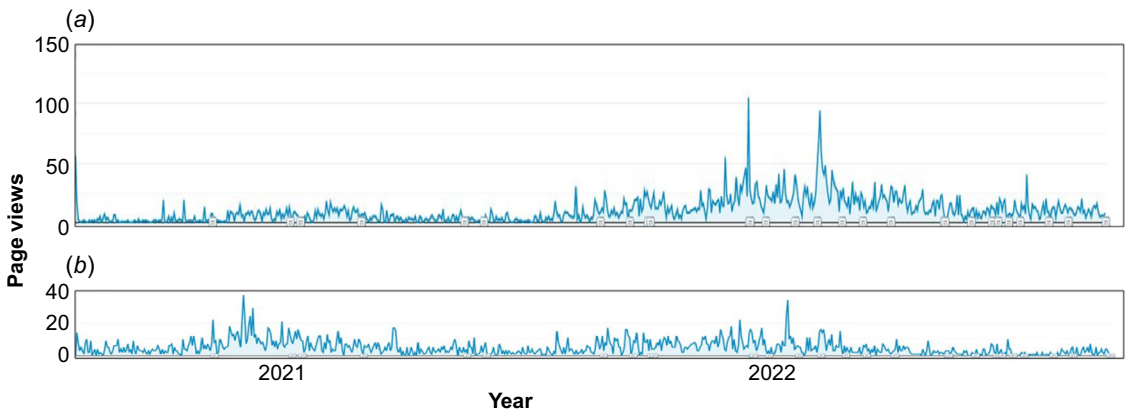

Fig. 4. Engagement profiles of project web pages over time. (*a*) Presents views of the 'Implementing flexible milking' web page; (*b*) presents views of the 'Flexible milking research' web page.

on 29 December 2020 resulted in 756 clicks through to video content and an overall reach of 19 589 by August 2022. Reach represents the total users with potential contact, on the basis of the network of those who have commented on, or 'liked', the post.

Two major articles were also published in the DairyNZ 'Inside Dairy' magazine (June 2020, October–November 2021), which is being delivered bi-monthly in print form to every dairy levy payer. While readership of print media is difficult to track, each Inside Dairy issue is also available online and views were tracked. The October–November 2021 issue had 1049 views by August 2022; however, most (750) of these views were in October 2021, 90 views in November 2021, and an average of 23 views per month through to August 2022. This highlights how publishing the magazine online results in a high number of views soon after it is released, but that this view rate rapidly degrades.

Two podcasts were published on the DairyNZ 'Talking Dairy' channel. The downloads for Episode 11 and 19 (described earlier) were 307 and 685 in their first 7 days, and 824 and 1049 in their first 30 days respectively. This compares with the last 20 'Talking Dairy' podcasts which had an average of 483 and 790 for their first 7 and 30 days respectively. Episode 11 had 2097 downloads, making it the most downloaded podcast of all episodes on that channel by August 2022. On average, people listened to 94% of the 25 min episode, the highest of all podcasts on the channel. Episode 19 had 1797 total downloads by August 2022 (fourth-most downloaded episode) and an average consumption length of 85% of the 39 min episode (fifth-highest for all episodes).

For webinars, by August 2022, 'Update 1' had 1168 total views on YouTube™, and an average view duration of 7 min 58 s (12.4%). It was originally streamed live at 7 pm in

March 2020, with 89 participants, then posted online. A post-session survey of the live audience, with 30 responses, rated the webinar 8.5/10 (zero poor, 10 excellent). Comparatively, 'Update 2' has had 416 total views on YouTube™, and an average view duration of 7 min 5 s (12.4%). 'Update 3' has had 562 total views on YouTube™, with an average view duration of 8 min 53 s (16.2%).

Predominant themes of the qualitative feedback from the 'Update 1' webinar were as follows: 'Ability to interact/ask questions', 'Scientific approach', 'Clarity and ease of understanding', 'Relevant information', and 'Good use of interactive webinar technology'. The first webinar was broadcast early in the project, and participant suggestions for project activities included comparing profit among farms, more data on specific milking frequencies such as '10-in-7', more in-depth information for those experienced in the approach, and making the start time earlier in the evening. The overall research design and use of webinars were considered effective by participants, with one suggesting to 'present more of the DairyNZ research projects in a similar way'.

Discussion

Assessing impact of the communication and engagement approach

The data showed that there was a high level of engagement with the project through the first 2 years when there were regular updates. The first year, focused on a farmlet experiment, connected with farmers primarily via a webinar, print articles, and the email group. The cadence of updates was regular, and farmers could see how differences among treatments evolved during the season. In the second year, much of the communication related to the focus farmers, and this provided a peer-to-peer voice for farmers through the email distribution list, webinars on specific topics, and presentations at in-person farmer events. The website, print media and webinars were the most popular forms of communication for those on the email distribution list. The third year involved greater extension of the key project messages by using a wide range of communication approaches such as podcasts, conference presentations and media. By the end of the project (June 2022), farmers noted that they had more information to make informed choices than they did 3 years ago (Table 3). They were also positive about how the project delivered interim and 'on-the-go' results and insights. However, it should be noted that the response rate for the final survey (8%) of email subscribers was lower than that for the initial survey (34%). This low response rate may have influenced this feedback if respondents were more engaged with the project, therefore potentially more positive about its impact. Overall, data collected showed reducing interaction with email communications over time, and this could be related to much of the data-collection activity happening in the first 2 years. This suggests that providing novel information over the period of the project is required to continue to add value to the audience.

Lessons related to the form of communication used in farm-systems research

The data captured in this project provide insight into effective communication channels for long-term research projects. The range of communication approaches used allowed messaging from the FM project to reach farmers who prefer specific information sources such as print, social media, internet content. The webpage content was vital, not only to provide meaningful content for farmers, but also as a place to direct listeners to during-radio interviews, presentations, and podcasts. Web traffic showed that 'how to implement' topics had most ongoing engagement (Fig. 4). Also notable is the difference in ongoing engagement for print versus online communication. Webinars provided an example of this ongoing engagement, with some immediate real-time interaction with farmers during the live webinar, and subsequent question and answer sessions. The webinar recording then serves as an ongoing resource when uploaded to a website, and, in the FM project, this provided much greater reach for the key messages. However, webinar viewing data highlighted that most of those viewing such recordings do not watch the whole webinar (e.g. 12.4–16.2% viewing time for the three FM webinars) and therefore these viewers will be missing part of the messaging. The podcasts had much longer engagement (94% and 85% consumption for Episode 11 and 19 respectively), signalling that more complex messaging may be best delivered through the podcast format.

Communication through the Inside Dairy magazine saw a large peak in views when released (via a PDF or Flippingbook™ available online) but quickly lost traction. Most views of such magazine content online are driven through social media at the time of release, and once this ends, the content appears difficult to discover. Through the early part of the project, such as, for example, in the first webinar, farmers asked to hear from other farmers who were implementing the FM practice. Farmers also wanted to see a range of examples with regional and farm-system diversity. This was subsequently delivered in Year 2 of the project. Peer-based learning, and accessing information from a wide range of opinions, has been shown to be highly valued by farmers when making management decisions (Morgans *et al.* 2021). The FM project also created a form of community of practice (O'Kane *et al.* 2008; Eastwood *et al.* 2012) where farmers, scientists and rural professionals could interact around the FM topic as a boundary object (Klerkx *et al.* 2012).

Decision-making with imperfect information

In the first 2 years of the FM project, a goal was to get information to farmers as soon as possible. The email distribution list had a high level of engagement (measured through email opens and web-link click-to-opens) and farmer feedback indicated that this was due to on-the-go information such as updates from the past fortnight in experiments and focus farms. The feedback also showed that farmers found the emerging information engaging and useful for their decision making for FM adoption. Adoption of major farming-system changes often does not follow a linear profile (Kuehne *et al.* 2017). There are a range of pathways that farmers may follow that can involve awareness building, trialling, adoption, non-adoption, or dis-adoption (Montes de Oca Munguia *et al.* 2021). Within this, farmers are constantly dealing with imperfect information and uncertainty in decision-making (Chavas and Nauges 2020; Eastwood and Renwick 2020). Therefore, the provision of interim (and possibly imperfect) results from FSR may conflict with values of scientists more than it does for farmers. The different timelines for data analysis are also illustrated by the fact that research publications from the project were becoming available only at the end of the 3-year project (e.g. this current paper; and Edwards *et al.* 2022*b*).

Implications for farming-system research design

This study highlighted several implications for FSR projects. Adopting a variety of processes to enable integration of farmers helped ensure project findings, and the method of engagement was meaningful for the wider farmer population. One example was the original project design, which mapped out the major steps in the project but left space for farmers to influence the specific design. Adding in a study on colostrum management was one example where farmer questions during the project could be answered by altering the project design. There were opportunities to improve this further with targeted co-design and iterative feedback loops with farmers as end-users (Toffolini *et al.* 2020; Eastwood *et al.* 2022). To help facilitate this, a process of reflexive monitoring can be established, where project implementation is regularly reflected on, possibly with a specific role in the team for this skill set (Fielke *et al.* 2017; Jones *et al.* 2019). Participation can range from a stakeholder reference group, through to full participatory extension (Murphy *et al.* 2013; Knook and Turner 2020).

Science-based data are needed to underpin FSR projects; however, the concept of sufficiently credible data may have different meanings for farmers from those of scientists. In the FM project, the engagement data showed that information from focus farms was sufficiently credible for farmers to build confidence in the application of research in a farming context. Of particular interest to farmers was that the milk production loss was minimal for a 3-in-2 milking intervals, which reduce the length of the working day. Experimental data, such as potential reductions in milk production associated with FM compared with TAD milking (Edwards *et al.* 2022*b*), have value in providing independent evidence on key adoption triggers for farmers. FSR projects therefore need sufficient farmer input in the design phase, or early stages of the project, to ensure that expensive experimental work is focused on collecting data on these adoption triggers (Rose *et al.* 2018). An additional benefit of including farmers in the design phase is that it can improve the alignment of project communication with the information needs and preferred delivery methods of farmers. A gap in knowledge identified through this study was the potential unintended consequence of sharing preliminary results. There is a risk that final results may prove interim data and messaging to be incorrect, yet the interim messaging could still be imbedded in online and print communications and therefore cause confusion. This could affect the reputation of research organisations and/or the FSR process. Being clear when interim results are being presented may help alleviate this risk.

A framework for FSR communications

The insights outlined above are useful for the design of future FSR projects. Limited information has been published on communication and engagement in farm-systems research, rather the focus has been on design of the research itself (Packham 2011; Scott *et al.* 2013). Previous studies on this topic have proposed frameworks for engagement related to FSR (Le Gal *et al.* 2011; Davis *et al.* 2021). However, these frameworks do not account for the various factors related to communication and iterative design with farmers. In Table 4, we suggest the important factors for communication and engagement with farmers on the basis of experiences during the FM project. The seven factors identified involve credible evidence, rapid interim results, inclusion of farmer voices, meaningful end-user outcomes, flexible and modern communication channels, feedback loops for iterative design, and adaptable research design.

Limitations and further research

Some of the insights presented in this paper will be context specific, as the questions and interest farmers had in FM would result in different engagement than would some more complex farm-system challenges such as nutrient management or methane emissions. However, the principles in the framework for science communication and engagement (Table 4) should have broad relevance in FSR projects. Another potential influence in this study was the role of the Covid19 pandemic occurring during most of the project. The switch to online communications through this period may have led to greater engagement with webinars and online information sources, as has been highlighted in

Table 4. Framework for science communication and engagement in adaptive farm-systems research.

Factor	Description
Credible evidence	A core feature of FSR is that the information presented is backed by credible science. Perceptions of what constitutes credible data may differ between scientists and farmers, but key elements include well constructed experiments in a context that resonates with farmers. Focus farms fit with this approach, but may need to be backed up by more controlled studies.
Rapid interim results	Often major FSR projects start with some fanfare and awareness building. Rapidly providing interim results where information is provided as it is collated, at a cadence that matches the activity in the project, builds farmer engagement and maintains momentum. Farmers are used to making decisions with imperfect information.
Inclusion of farmer voices	A strength of FSR is the potential for research alongside farmers, for example, focus farms. This represents a significant opportunity to incorporate those farmer's voices in the project communications, and into the detailed design of experimental treatments.
Meaningful end-user outcomes	The information should be carefully targeted at the needs of farmers (end-users). This requires specific effort into understanding end-user needs. Results also need to consider spatial and temporal relevance; for example, they need to be conducted at a scale that relates to farmer needs. If there are regional differences, then these differences need to be incorporated in the study design.
Flexible and modern communication channels	While print media are still valuable for broad exposure, they have a short lifespan. Webpages continue to be accessible, although the information can go out of date over time. Webinars, short topical videos, and podcasts match the way new generations of farmers want to access information. They are particularly effective if boosted through social media. Social media boosting can also be used to direct people to web-based resources. Performance of different communication channels needs to be monitored during the project, to provide feedback on the most effective communication tools and strategies.
Feedback loops for iterative design	FSR projects should build in opportunities to capture insights from farmers, to understand what is working well and also what specific information gaps farmers have.
Adaptable research design	In multi-year projects, the research needs to be adaptable to change direction on the basis of questions that arise. If the research has good feedback loops, it also needs flexibility in the design to incorporate and act on the feedback.

other studies (Chivers *et al*. 2021). During the FM project, the quality of online communication tools, and the engagement with these approaches, increased and caused a shift in communication methods. Further research is warranted on whether there has been a defined and permanent change in the preferred information-access channels of farmers. Research is also needed to understand farmer definitions of sufficiently 'credible' science, whether these definitions are changing over time, and to determine how FSR needs to be designed and communicated in the future.

Conclusions

In this study, we conclude that farm-systems research projects need to incorporate reflexivity and adaptability to actively engage with farmers in 'real-time'. This needs to balance with funding structures, as many projects are required to be highly pre-planned and milestone-driven to secure funding initially. Alternatively, project milestones need to be written in a way to allow for such flexibility. In projects such as this, different forms of information are required to accelerate the adoption of a 'proven' practice. These forms must include both science-driven data on key questions, such as effects on production and animal health, and farmer voices on the practical application of the approach. This mix of information can help farmers gain the confidence to move forward on their adoption journey.

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Data availability. The data that support this study will be shared upon reasonable request to the corresponding author.

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