Adoption Characteristics of Successful Technology Stacks for Emission Reduction

Sarah C. Whitnall

Marit E. Kragt

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Centre for Agricultural Economics and Development, Department of Agricultural and Resource Economics, University of Western Australia

Executive Summary

Agricultural innovations are increasingly being developed and promoted as packages, bundles or stacks of technologies, rather than standalone products. Yet most research on technology adoption focus on single technologies, leaving a gap in understanding of what drives farmers to adopt multiple, interrelated technologies. This report presents findings from a scoping review examining what characteristics of technology packages and their extension programs most likely supported successful adoption in agricultural systems.

The report draws on a systematic review of academic and grey literature on technology package adopt in agriculture following the PRISMA structure, supplemented by case studies and interviews with four academics with expertise in technology adoption.

A key finding from our work is that farmers consistently adopt packages in a stepwise, sequential fashion rather than all at once. Uncertainty about whether the full package will be profitable on a specific farm leads farmers to trial individual components first, accumulate knowledge and confidence, and progress incrementally. Technology packages that are divisible and adaptable to existing farming systems are more likely to gain traction, particularly when they allow farmers to trial components incrementally and derive standalone value at early stages. Tight complementarity between components is both a strength and weakness—it reinforces long-term value but creates risk if farmers sequential adoption means they may not see expected benefits, undermining confidence in the bundle as a whole.

Other key priorities for package development include addressing farmer-identified problems in collaborative partnerships between researchers/technology companies (providing the technical expertise), extension services (facilitating knowledge exchange), farmers (as anticipated end-users) and government agencies (ensuring a supporting regulatory environment). Packages that integrate with existing farming systems and deliver economic benefits are key motivators for sustained adoption.

For extension and outreach, several priorities emerged. First, focus initial extension on gateway technologies that require less additional skills or training and give farmers exposure to the broader package. Second, target extension towards most receptive farmer segments while being mindful that messaging around contested goals can inadvertently reinforce disengagement among some. Third, use collective action and community-based trialing to demonstrate value. Fourth, invest in long-term institutional capacity and recognise that extending complex packages takes time.

Together, these insights point to the importance of aligning package design and extension with how farmers realistically trial, evaluate, and integrate new technologies over time.

Table of Contents

1 Factors influencing the adoption of new technologies in agriculture

The adoption of agricultural innovations by farmers has been extensively researched over the past 70 years, generating a substantial body of literature across multiple disciplines including sociology, economics, psychology, and marketing (Konstantinos et al., 2025; Montes de Oca Munguia et al., 2021; Ogundari & Bolarinwa, 2018; Rizzo et al., 2024; Rogers, 1958; Ryan & Gross, 1950). Understanding what drives farmers' adoption of new technologies or practices remains central to agricultural policy, research and development, and extension efforts that aim to increase productivity, sustainability, and resilience in farming systems (Pannell & Zilberman, 2020).

Early research on adoption was driven by agricultural innovations during the Green Revolution (Feder & Umali, 1993), while more recent work focuses on sustainable agricultural practices, digital and precision agriculture, and climate-smart agriculture (see, for example, Barnes et al., 2019; Bramley & Ouzman, 2019; Fragomeli et al., 2024; Gosnell et al., 2019; Kernecker et al., 2020; Masi et al., 2022; Möhring et al., 2024; Pagliacci et al., 2020; Westermann et al., 2018). The vast body of literature provides a strong evidence base for the factors that determine the levels of adoption and the rate of diffusion. Research from around the world has consistently found that adoption is influenced by complex interactions between the farming system, farmers' socio-economic, cognitive, and behavioural characteristics, the institutional environment, and characteristics of the technology itself—including its relative advantage, complexity, trialability, observability, compatibility with the farming system and the values, experiences, and needs of adopters (Rogers, 2003) (Table 1). Most studies to date have focussed on how farmers' characteristics influence adoption (Montes de Oca Munguia & Llewellyn, 2020), and how extension, education, and outreach strategies can help to enhance uptake of innovations (Tey & Brindal, 2012). There are many research findings that suggest that targeted training is needed to increase farmers' knowledge about the innovations, and that opportunities for demonstration, peer learning, and targeting the more educated farmers will help to change behaviour (Barnes et al., 2019; Begho et al., 2022; Ren et al., 2022). However, such conclusions risk taking a "knowledge deficit" approach to adoption (Niles et al., 2016). More recent research acknowledges that institutional factors and policy alignment also play an important role to incentivising adoption (Mao et al., 2021; Pagliacci et al., 2020), and that a further focus on the characteristics of the technology itself is warranted (Montes de Oca Munguia & Llewellyn, 2020), since adoption is fundamentally dependent on the relative advantage of the technology in the farmer's specific context (Pannell & Zilberman, 2020).

Table 1: Key factors influencing farmers' adoption of new technologies

Factor	Explanation	Sample references
Farm and farmer demographics		
Education	Education generally shows positive effects on adoption. Farmers with higher education may be more open to change, and may be better equipped to evaluate and implement innovations.	(Brown & Roper, 2017; Huffman, 2020; Marr et al., 2016; Pannell et al., 2006)
Age	Age tends to have a mixed effect, with younger farmers generally being more 'tech-savvy' and interested in new technologies, but older farmers relying more on experience to embrace 'what works'.	(Amoussouhoui et al., 2024; Paustian & Theuvsen, 2017; Rizzo et al., 2024)
Farm size	Larger farms can better absorb high investment costs and spread risks associated with trialling and adopting a new technology.	(Barnes et al., 2019; Tey & Brindal, 2012)
Farm income	Farmers with higher income are better able to afford the up-front investments (e.g. infrastructure, machinery, learning) that may be required to change practices. Higher income also provides greater access to credit, which may be necessary when investing in new technologies.	(Diederen et al., 2003; Miller et al., 2017; Olum et al., 2019; Schimmelpfennig, 2016; Tey & Brindal, 2012)
Social networks	Adoption decisions can be influenced by the decisions of other farmers and nearby stakeholders, suggesting that social normative pressures are a determinant of adoption. Social networks also provide peer-to-peer learning opportunities, which has been found to facilitate information diffusion and adoption levels.	(Barnes et al., 2019; Lemay & Boggs, 2024; Pagliacci et al., 2020)

Table 1 (cont.): Key factors influencing farmers' adoption of new technologies

Cognitive and behavioural factors		
Knowledge about the innovation	How observable is the relative advantage of an innovation (e.g. in the field versus novel software)? Access to accurate, reliable, and consistent information positively influences the uptake of innovations, as helps to evaluate whether a certain innovation is beneficial to an individual landholder.	(Llewellyn, 2007; Olum et al., 2019; Rogers, 2003)
Attitudes towards innovation	A farmer's (lack in) willingness to innovate in general, and the level of trust in new technologies, will influence the uptake of innovations.	(Lemay & Boggs, 2024)
Risk perception	Risk and ambiguity aversion are important factors influencing adoption. Farmers often hesitate to adopt if outcomes are unpredictable.	(Barham et al., 2014; Chavas & Nauges, 2020; Greiner et al., 2009; Pagliacci et al., 2020)
Environmental norms	Farmers with pro-environmental attitudes are more willing to change their routines to more sustainable farming practices.	(Rizzo et al., 2024; Wensing et al., 2019)
Institutional context		
Access to advisors / extension services	Access to advisory resources and extension personnel strongly supports adoption by providing technical guidance.	(Begho et al., 2022; Chavas & Nauges, 2020; Norton & Alwang, 2020)
Government policies	Public policy interventions, including providing economic incentives, abolishing economic disincentives, and having stable, reliable policies are necessary to encourage uptake of new practices.	(Feder & Umali, 1993; Greiner et al., 2009; Möhring et al., 2024)

Table 1 (cont.): Key factors influencing farmers' adoption of new technologies

Technological attributes		
Complexity	Technologies that are easier to understand, are perceived as easy to use, and that reduce labour see higher adoption rates.	(Marr et al., 2016; Rogers, 2003; Rosário et al., 2022)
Trialability	The degree to which an innovation can be experimented with on a limited basis before a landholder commits to full-scale adoption.	(Pannell et al., 2006)
Perceived benefits	Farmers prioritize innovations that offer clear advantages, such as increased productivity, cost savings, or environmental sustainability.	(Dessart et al., 2019; Kuehne et al., 2017; Pannell et al., 2006; Rogers, 2003)
Economic profitability	Among other relative advantages, profitability or net economic benefit (as perceived by the landholder) is often the primary motivator for adopting a new technology or practice.	(Feder & Umali, 1993; Kernecker et al., 2020; Pannell et al., 2006; Tey & Brindal, 2012)
Compatibility, interoperability, and easy of integration	Farmers are more likely to try and adopt a new technology that align with existing farming practices and integrate seamlessly into their operations, including connecting to the different equipment, devices, and applications that are already used on the farm. Compatibility also refers to how the technology fits with a farmer's standard work patterns and preferences.	(Alvarez & Nuthall, 2006; Kernecker et al., 2020; Kutter et al., 2011; Lambert et al., 2015; Lemay & Boggs, 2024)

Whilst existing literature has generated substantial insights, most studies have examined the adoption of single technologies rather than farmers' adoption of multiple, interrelated technologies. Nevertheless, agricultural innovations are often promoted as a 'package', 'bundle', or 'stack' of technologies[1]—that is, a set of two or more technologies or practices whose combined effect may exceed the sum of their individual contributions due to complementarities between components. Empirical research that treats adoption decisions

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[1] The terms 'technology package', 'technology bundle' and 'technology stack' are used interchangeably in the literature, though 'stack' is more common in genetics and software development, and 'package' or 'bundle' more common in agricultural economics.

as independent potentially misses important interdependencies when new technologies are complementary, i.e. adoption of one practice enhances the benefit of another (Blazy et al., 2025; Oumer et al., 2025). Understanding what drives adoption of ‘bundled’ technologies is crucial for the development of new technologies and for effective extension and adoption strategies.

A few notable exceptions have examined stepwise or simultaneous adoption of multiple technologies. For example, Dorfman (1996) showed that decisions by US apple growers to adopt different sustainable production technologies cannot be evaluated in isolation from each other. Byerlee and de Polanco (1986) demonstrated that farmers followed a stepwise approach to the adoption of technological packages (improved barley varieties, fertiliser, and herbicide) in the Mexican Altiplano. The authors conclude that, while researchers may aim to develop a package of practices that exploits positive interactions between the components, adoption of the package should be a long-term goal, not the objective of direct extension to farmers. Miller et al. (2019) found that farmers in Kansas who have adopted an information intensive precision agriculture technology bundle are more likely to stay with these bundles than transition to a new technology.

These early studies demonstrate the value of examining technology adoption as a portfolio decision rather than as isolated choices. However, research on technology bundles remains limited, particularly in high-income-country contexts, and the mechanisms through which farmers make sequential or simultaneous adoption decisions across multiple technologies warrant further investigation. In this paper, we conduct a systematic review of academic and grey literature on the adoption of technology bundles in high-income agricultural settings. We supplemented the systematic search with case study analysis and consultation with four adoption experts. Results of the analysis will assist to improve the development of complementary technologies and to increase the effectiveness of extension of such technologies as a bundle.

The report is structured as follows: we first describe the systematic review methodology; next, we present key themes from the systematic review and provide illustrative case studies from agriculture and other sectors. The discussion and conclusion synthesise key lessons for the design and extension of new technology packages.

2 Systematic Review Methods

We performed an in-depth, systematic review of the academic and grey literature about the adoption of technology packages (including technology bundles or technology stacks) in high-income countries, as defined by the World Bank (2025). We considered both financial instruments and software to be technologies (for example, insurance or farm management software) and included papers about their adoption as long as these were part of a broader package.

We excluded papers that focused on smallholder farmers and settings outside of high-income countries as defined by the World Bank. We also excluded papers that were historic reviews, for example on the introduction of farming or the Colombian exchange. Papers about the adoption of single technologies were excluded, such as papers that analysed a single technology where the keyword ‘package’, ‘bundle’ or ‘stack’ appeared only as a recommendation for the technology to be included in a package/bundle/stack. We considered genetic “trait bundles” or “stacked traits” to be a single technology (e.g. new seed variety) and excluded papers analysing its adoption unless in combination with other technologies.

Following the PRISMA structure, we conducted a desktop search of academic and unpublished papers. We searched within article title, abstract and keywords the following combination: *agricultur* AND adopt* AND technolog* AND (bundle* OR package* OR stack*)*. We also added an *AND NOT smallholder** in the title only. We performed the search on 24 November 2025 in four databases: Web of Science, Scopus, EconLit and Agricola.

Figure 1 shows the systematic review process using a PRISMA diagram. We uploaded the search results into Covidence which automatically removed duplicate papers, leaving 420 papers for title and abstract screening. Two reviewers screened each paper’s title and abstract independently and met to discuss any conflicting votes on whether a paper should undergo a full paper review. At the conclusion of the title and abstract screening process, the two reviewers agreed that 367 papers were irrelevant references, and 53 papers underwent full paper review. After reading those 53 papers in full, the two reviewers agreed that 16 papers fully met the inclusion criteria. The 16 papers are summarised in Appendix Table A.1.

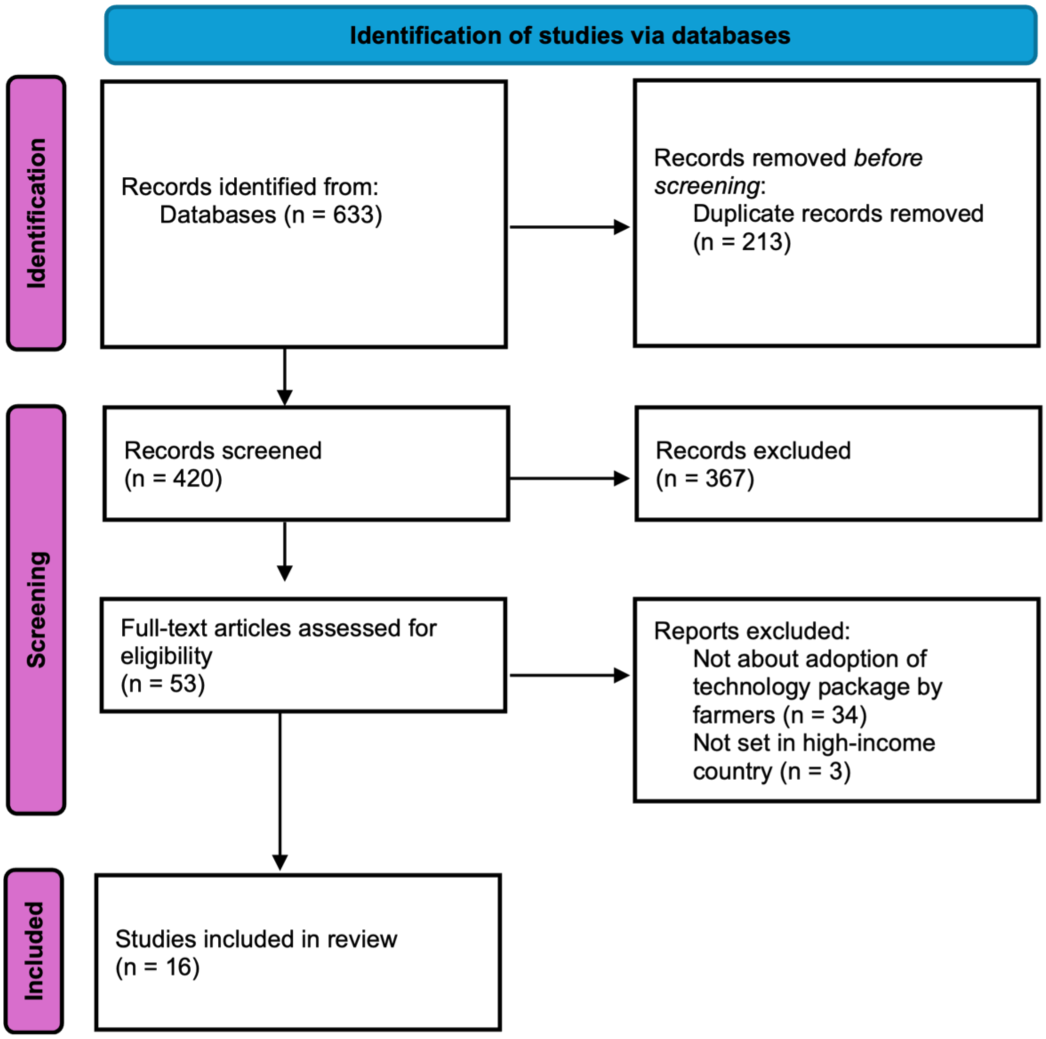

Figure 1: PRISMA diagram of the systematic review

We supplemented the systematic review with semi-structured interviews with four academics with deep expertise in technology adoption in agricultural systems. Each interview followed a common structure: we presented key findings from the scoping review for comment and discussion, and invited them to draw on their own research experience to identify key lessons relevant to the development and roll-out of new, packaged, technologies.

3 Key themes from systematic review on adoption of technology packages

3.1 How is technology package adoption different from adoption of a single technology?

Overall, there are many similarities between technology package adoption and single technology adoption, including the characteristics of farmers more likely to adopt, and characteristics of the technology or technology package that tend to facilitate adoption.

The main difference is divisibility and sequential adoption. Across many contexts and packages, farmers tend to adopt components of the package in a "stepwise" or sequential fashion, rather than immediately adopting the package in its entirety (Leathers & Smale, 1991; Schimmelpfennig & Ebel, 2016; Griffin et al., 2017; Miller et al., 2019). While not included in systematic literature review, Byerlee & De Polanco (1986) and Aldana et al. (2011) also found similar patterns of sequential adoption.

When deciding to adopt a new technological package, farmers face uncertainty about whether the package will be profitable on their specific farm. Sequential adoption allows farmers to experiment with an individual component before committing to a full, more expensive package (Leathers & Smale, 1991; Schimmelpfennig & Ebel, 2016). This provides farmers with information about the costs, returns, risk, and effectiveness of the technology package, reducing uncertainty through experience. Theoretical models show that this behaviour is rational, even under the assumptions the farmer is risk neutral, their expenditure is unconstrained, and that adopting the package in its entirety is the most profitable option (Leathers & Smale, 1991; Aldana et al., 2011).

Ryan and Subrahmanyam (1975) also argue that sequential adoption of components is a rational choice for a farmer with limited cash. By starting with practices that require "minimal change" and have high profit-to-cost ratios, farmers can accumulate the cash needed to adopt more complex parts of the package later. This explanation suggests that a constrained farmer will adopt the choice which has the highest profit per dollar of expense, while an unconstrained farmer will adopt the choice which has highest profits (Leathers and Smale, 1991).

That said, there is also strong evidence that farmers tend to persist in the same technology package over time (Banerjee & Martin, 2009; Griffin et al., 2017; Miller et al., 2019).

Persistence is typically highest among nonadopters and adopters of the complete package. The biggest hurdle is adopting one component of the package—after that, it is easier to encourage sequential adoption of the other components, particularly when they are part of a package where joint adoption produces synergistic benefits (Griffin et al., 2017; Miller et al., 2019; Canales et al., 2020). Technologies like precision soil sampling or yield monitors are more likely to be adopted because they provide the data necessary to inform "downstream" technologies like variable-rate application (VRT) (Griffin et al., 2017; Miller et al., 2019).

Complementarity among package components is both a driver and complicating factor for package adoption. Complementarity means using one component increases the value of adopting another, meaning adopting the full package is the more valuable outcome (Lacy, 2018; Canales et al., 2020; Yu et al., 2012). It can also create a logical and reinforcing sequence of adoption (Griffin et al., 2017; Miller et al., 2019). However, tight complementarity creates risk: farmers who adopt part of a tightly coupled package may not see the expected benefits, which can undermine confidence in the package as a whole (Dorfman, 1996; Leathers & Smale, 1991).

3.2 What farmer demographics are most important in explaining adoption of technology packages?

Formal education is strongly and positively associated with package adoption (Thomas et al., 1990; Dorfman, 1996; Rajendran et al., 2016; Schimmelpfennig, 2016; Lacy, 2018; Canales et al., 2020). The assumption is that more educated farmers have learned or are inherently better able to manage complex information, allowing them to use complex technologies. Education can also directly enhance a farmer’s skills required to operate sophisticated software or technology packages.

The other connection to education is that better-educated farmers may be more likely to realise the potential benefits of increased mean profits and greater sustainability in the long run, where other farmers may perceive the package as increasing risk (Dorfman, 1996). While not in the systematic review, Aldana et al. (2011) found that compared with less educated farmers, those with tertiary education tend to learn faster from their own experience and took fewer years to adopt stacked GM seed varieties.

Age and experience in farming have mixed effect on package adoption. Several papers (Lambert et al., 2015; Lacy, 2018; Canales et al., 2020; Reints et al., 2020) found that farmer age was negatively correlated with package uptake, consistent with younger farmers typically have longer career planning horizons, giving them more time to recover the initial investment in technology. But more importantly, younger farmers tend to be less resistant to modifying existing routines and may be more willing to invest in learning about new systems compared to the older generation. Other papers found no significant evidence that age affected package uptake (Thomas et al., 1990; Banerjee & Martin, 2009; Schimmelpfennig & Ebel, 2016). Fleischer et al. (2011) also found that farmers with more years in farming were more likely to adopt complicated technology packages.

Several papers found evidence that suggested farmers with limited time available for developing new skills were less likely to adopt new technology packages. Dorfman (1996) found farmers working more hours off farm are less likely to adopt, consistent with them having less time to learn about new technologies. Similarly, Lacy (2018) and Canales et al. (2020) found off-farm income reduced adoption speed. Reints et al. (2020) found that farmers who had a higher share of income from avocado production (suggesting specialisation) were more likely to adopt advanced packages for avocado production. However, Alvarez & Nuthall (2006) note that farmers who have off-farm employment can expose farmers to new technologies, broaden their perspectives on management and increase their willingness to adopt technology.

The effect of farm size varied across studies, but most found that larger farms tend to adopt multiple technologies (Yu et al., 2012; Lambert et al., 2015; Rajendran et al., 2016; Schimmelpfennig & Ebel, 2016; Canales et al., 2020). As is the case with single technologies, larger operations can spread the high fixed costs of complex bundles over more units of production (acres or animals), reducing the per-unit cost of adoption. Larger farms also have greater capacity to manage risk, for example by dedicating portions of their land to small-scale trials and experiments—trialability being an important theme in the general technology adoption literature (Rogers, 2003; Pannell et al., 2006). Lacy (2018) found nonlinear association between farm size and adoption: the relationship is positive at smaller farm sizes but turns negative beyond a threshold farm size. Reints et al. (2020) found no effect of farm size and Dorfman (1996) found inconclusive effects of farm size on package adoption. Fleischer et al. (2011) found that farm size had a significant negative effect on adoption of high-technology packages; larger farms were more likely to choose low-technology field crops with minimal irrigation.

Yu et al. (2012) claimed that the productivity of bundled complementary technologies can be greater than the productivity of technologies used in isolation. Because the technologies are expensive, the packages were more likely to be adopted by the largest farms who subsequently had the largest productivity advantage—compared to smaller farms using a smaller number of technologies. Hence, bundled complementary technologies were a source of increasing returns to scale in hog production.

3.3 What characteristics of the extension program affect adoption?

Agricultural extension considers the ways in which trials, demonstrations, education and information influence adoption. Surprisingly, relatively few of the papers reviewed reported explicitly on extension program characteristics, and where they did, the findings were more mixed and context-specific than those for farmer demographics or technology attributes.

Access to extension services, training, and information were consistently important for adoption. In the review by Rajendran et al. (2016), extension services, training, and engagement with farmer associations, particularly when factoring in location-specific advice, were positively associated with adoption of sustainable agricultural practices across studies. Reints et al. (2020) found that access to free public resources aided adoption.

Financial incentives also help the speed and extent of package adoption. Both Lambert et al. (2015) and Canales et al. (2020) found that cost-share payments were positively associated with package adoption. High capital costs is a consistent barrier to adoption (Lambert et al., 2015; Schimmelpfennig & Ebel, 2016; Reints et al., 2020; Canales et al., 2020), and cost sharing helps reduce this burden on farmers. Canales et al. (2020) also found that favourable market and growing conditions created windows during which farmers were more willing to invest in new technologies and outreach efforts were more effective.

4 Case studies

4.1 Integrated Pest Management

Integrated pest management (IPM) is a well-documented example of a technology package where the value of any individual component depends on how it interacts with the broader system. The IPM package is a bundle of complementary practices—biological controls, habitat management, targeted chemical use, monitoring protocols, and cultural practices like crop rotation—whose combined effect on pest suppression, input costs, and yield stability exceeds any single practice's effect (Vargas et al. 2016).

Thomas et al. (1990) assessed how farmer and farm characteristics, information sources, and IPM beliefs affect the number of IPM practices adopted by Texas cotton growers. They found farms who had adopted the full IPM package had higher yields than non-adopters, providing an economic signal that can reinforce uptake over time. Adoption of (some or all) IPM practices was strongly associated with farmers' education, gross farm income, and beliefs about the benefits of IPM. Farmers who rated interpersonal communication (private consultants, extension group meetings, individual contacts, contact with extension and university professionals) as important were more likely to adopt IPM practices. A barrier to adopting the IPM package was its requirement for active, judgement-based pest management, in contrast to the routine pesticide schedules of conventional farming. The study did not report on characteristics of the rollout that may have influenced uptake, limiting conclusions about what extension approach could be most effective in this context.

Vargas et al. (2016) documented the effectiveness of the Hawaii Fruit Fly Area-Wide Pest Management (AWPM) Program in suppressing fruit fly populations below economic thresholds while reducing the use of organophosphate insecticides. By coordinating adoption across many farms through collaborative partnerships between federal, state, and academic institutions, the program reduced fruit fly populations by 83-95% across major agricultural regions. Adoption was supported by a comprehensive educational outreach program, hands-on visits to farmers, and school curricula. The package provided clear economic and sustainability benefits to participants through reduced use of insecticides, higher grower revenue and market access.

These studies highlight complementarity as a strength and weakness of the IPM package. Area-wide adoption is more important for IPM than other technology packages because adoption has limited value in isolation, e.g. adopting field sanitation on your farm has little effect unless neighbouring farms also adopt. Collective action and outreach targeting farming communities rather than individual producers led to its successful adoption in Hawaii in particular (Vargas et al., 2016).

4.2 Precision agriculture

The precision agriculture (PA) technology package includes a spectrum of technologies: yield monitoring, yield mapping, satellite and/or electromagnetic soil mapping, equipment auto-guidance systems, automated section control, and variable rate technology (VRT) for fertilisers, seeds, and/or chemicals. Drawing on several quantitative papers on grain farmers, mostly in the United States, this case illustrates patterns of sequential adoption, farm and farmer characteristics that influence uptake, and lessons for designing technology packages.

PA uptake follows the sequential, stepwise path typical of technology package adoption. Part of the success of PA adoption is access to simpler, lower skills technologies. Schimmelpfennig & Ebel (2016) found that yield monitoring, essentially standard equipment on new equipment, served as the entry point into the PA package for many U.S. corn producers. Over time, producers incrementally adopted one new technology at a time and progressed toward more information-intensive ones like VRT (Schimmelpfennig & Ebel, 2016; Griffin et al., 2017; Miller et al., 2019).

Several barriers explain why PA adoption remains partial and slow despite potential gains. Lambert et al. (2015) and adoption experts highlighted the knowledge and skill demands of information-intensive technologies as a major friction point for complete package adoption (adoption expert, personal communication, 2026). For PA, the data management work required to extract value from yield maps or soil data are high, and some farmers are not interested in investing in these skills. Risk also plays a significant role: not only about whether a technology will perform on a given farm, but operational risk around adopting specialised equipment that might be difficult to service at critical times.

Non-adoption or partial adoption can, in fact, be cost-effective outcomes. One of the interviewed adoption experts highlighted cases where farmers invested in yield and soil mapping and then, rather than progressing to VRT, restructured their paddocks to keep zones of similar characteristics together. By changing farm practices through field layout rather than through VRT, farmers can achieve similar outcomes despite not adopting the complete package (adoption expert, personal communication, February 2026). This is made possible through the PA technology package being separable: farmers can partially adopt, pause, and diverge. For researchers and extension services designing new technology packages, this case study offers a few key lessons. Farmers take advantage of the modular, divisible nature of the PA technology package that allows for sequential, partial adoption.

Low knowledge burden at entry helped familiarise farmers with the broader technology package. Finally, technology package adoption is heterogeneous and depends on how well it aligns with a farmer's skills and interests, and how readily it integrates with the current farming system.

4.3 Outside agriculture: Restaurant owners adopting Point of Sale, inventory management and online ordering

Restaurant owners are somewhat similar to agricultural producers because they are independent operators within a larger industry, making decisions for their own business. Like farmers, restaurant owners operate with limited capital, time constraints, and high sensitivity to operational risk, making them a useful comparison for understanding technology package adoption outside agriculture. A common technology package in this context typically comprises of complementary systems of point-of-sale (POS) hardware, inventory management, payroll and accounting integration, online ordering and delivery, analytics and demand forecasting (Ko, 2020; Alt, 2021). While these systems are modular, they are also interdependent, for example inventory tracking only functions effectively once sales are already digitised.

Several characteristics facilitated adoption of this package among independent restaurant owners. The modular design allowed for sequential adoption, with owners able to start with one component and scale up over time. Returns were clear: adopters report reduced shrinkage, labour savings, closer monitoring of profit and loss, better insight into consumer preferences, less time spent on administrative work, and improved consumer loyalty and satisfaction (Ajdini & Datta et al., 2025). Subscription-based pricing replaced large fix costs with payments more compatible with the cash flow constraints typical of restaurants. The main lessons for agricultural package adoption are that sequential adoption preferences, capital constraints, and importance of complementarity are consistent drivers of adoption across sectors.

The franchise model offers a contrasting example where franchisees are effectively enforced to adopt an entire package of standardised equipment, supply chain contracts, IT systems and operating procedures and training. This removes the sequential adoption dynamic seen among independent operators but substantially reduces risk and uncertainty for owners through a system of proven, pre-integrated components with observable outcomes from nearby franchisees (Perrigot et al., 2023). Ongoing centralised support, training, manuals, and IT administrators further facilitate uptake (Ajer & Hustad, 2015). The main lesson for agricultural package adoption is that where contract farming or vertical integration creates a similar degree of coordination and standardisation, rollout of a technology package is considerably more straightforward. It also illustrates the value of ongoing dedicated support.

5 Discussion

5.1 Lessons for package development

The technology packages described in our source papers typically address clear, ‘real world’ environmental or economic challenges, such as fruit fly management packages in Hawaii and integrated soil-moisture and accounting tools in Australia. This may seem like common sense, but the importance of addressing a ‘real’ challenge as perceived by the intended adopters when developing a technology package cannot be underestimated. Through reviewing the academic literature and consultation with adoption experts, several important design principles emerged.

Lesson 1: Successful packages involve farmers and address farmer-identified problems. Technology and technology packages are more likely to be adopted if research and development (R&D) aligns with the practical realities of farming and is tailored to the intended user, rather than creating ‘fad’ technology looking for a solution (Tingey-Holeyoak et al, 2021). To achieve this, move towards R&D structures that involve farmers throughout the process. R&D will ideally involve collaborative partnership between researchers/technology companies (providing the technical expertise), extension services (facilitating knowledge exchange), farmers (as anticipated end-users) and government agencies (ensuring a supporting regulatory environment) (Vargas et al, 2016; Lee et al., 2022). Deep knowledge about farmers’ preferences, needs, and work patterns can only be built into a new technology if those farmers are involved in its design. Farmer involvement also helps extension services improve their messaging and outreach strategy.

Lesson 2: Create packages that accommodate sequential adoption. Farmers want divisible packages that allow them to test individual components before committing to the whole package. R&D and package development should be structured to support a stepwise adoption path, identifying "gateway" technologies that build the necessary skills for more complex components later.

Lesson 3: Create packages that integrate with broader farming systems. Ensure that systems are designed to integrate with existing equipment to enhance usability. Technologies are more easily adopted if they are "plug-and-play" and require minimal specialised training or skills to operate (Miller et al, 2019). Market segmentation or systematic benchmarking of existing innovations can help to identify which design characteristics (e.g., user-friendliness, transparency, and product-level sensory capability) are most valued by producers to inform the development of more stable, integrated tools (Tingey-Holeyoak et al, 2021).

5.2 Lessons for extension and outreach programs

Effective outreach programs for technology packages cannot use a "one-size-fits-all" approach, and extending a package is inherently more challenging than extending a single technology. The literature and adoption experts point to four priorities.

Lesson 4: Focus initial extension on “gateway” technologies within the package. While researchers and developers might promote technologies as a complete package (Leathers and Smale, 1991), farmers frequently adopt them stepwise to manage risk and uncertainty. This is rational behaviour: sequential adoption allows farmers to "experiment" with sub-components, reducing uncertainty before committing to a full, expensive package. Extension might encourage "gateway" or “first-step” technologies that provide immediate standalone value and generate the data needed for more advanced "downstream" technologies (Lambert, 2015; Schimmelpfennig, 2016). That said, adoption experts caution against “patch merchants”—advocates who push one technology when value is conditional on adopting the other components, risking disillusionment if farmers fail to see the expected benefits (adoption expert, personal communication, 2026).

Lesson 5: Target extension efforts towards the most receptive farmer segments. Outreach is most cost-effective when it identifies and targets the most receptive audiences rather than putting effort into those who are unlikely to adopt the technology (Dorfman, 1996). From the systematic review, outreach and extension is best focussed on younger, better-educated farmers who operate larger farms, as these groups tend to show a higher propensity for adopting complex or management-intensive bundles. Outreach efforts are most effective during periods of favourable markets and growing conditions, during which farmers are more willing to invest in new technologies (Canales et al., 2020). Adoption experts suggested two distinct groups worth targeting (adoption expert, personal communication, 2026). The innovative and influential adopters who are well known in the community and whose opinions on a technology hold weight in the farming community. The second are farmers who are not particularly known as innovators but hold positive attitudes towards the benefits and goals of the package and are more likely to adopt (Thomas et al., 1990). Identifying these farmers requires deliberate effort. For farmers with negative attitudes, adoption is more likely to be triggered by significant economic benefits, for example larger profits or market access. Adoption experts cautioned that the messaging around packages associated with contested goals such as emissions reduction can inadvertently reinforce negative perceptions among farmers who feel the goal is unachievable on their farm or who feel disconnected from the broader policy agenda. Meeting farmers where they are and framing the package in terms of their own operational priorities is more likely to reach this disengaged group (adoption expert, personal communication, 2026).

Lesson 6: Leverage collective action, social learning and community-based trialling. Collective action makes ‘unobservable’ innovations visible and lowers the transaction costs involved in learning about new technologies and packages. Government-driven extension programs and farmer grower groups can establish platforms for communication where farmers can share experiences—early adopters of the package build common knowledge about its success and reduce uncertainty for nonadopters (Canales et al., 2020). Interpersonal communication (field demonstrations, face-to-face visits) is significantly more influential than printed materials in changing technology beliefs and facilitating adoption (Thomas, 1990; Vargas et al, 2016; Reints et al., 2020). Experts emphasise trialability should not be understood as a single trial—one trial on one farm in one season is heavily dependent on local and environmental conditions that will not accurately represent the range of farmers’ experiences. Community-based trialling across multiple sites within a farming region and farmers sharing their experiences generates more robust and credible conclusions than single demonstrations (adoption expert, personal communication, 2026).

Lesson 7: Invest in institutional capacity for long-term adoption. Adoption of complex packages is slow, and extension programs must be designed with realistic time horizons (Griffin et al., 2017). Experts highlight the decline of public extension as a growing challenge in Australian agricultural technology adoption, and its partial replacement by private consultants raises questions of cost, access and continuity (adoption expert, personal communication, 2026). Electronic communication tools partially offset the reduced advisory workforce but cannot fully substitute for sustained, trusted, face-to-face relationships that are most effective for guiding farmers through multi-year adoption of complex packages. Investing in the right people and tools to extend this package over a long time horizon will be critical to achieving high levels of adoption.

6 Conclusion

This paper examined how agricultural technologies that are developed and promoted as ‘packages’ (also called ‘bundles’ or ‘stacks’) are adopted in high-income agricultural systems. Through a systematic review of academic and grey literature, supported by case study analysis and consultation with adoption experts, the study assessed how characteristics of farmers, technologies, and extension approaches interact when adoption decisions involve multiple, complementary components rather than a single technology.

A key finding from our work is that successful adoption of technology stacks depends less on promoting fully integrated solutions and more on designing and extending technologies in ways that align with (a) farmers’ decision-making context and (b) adoption as a sequential, path-dependent process. Technology packages that are modular, interoperable, and adaptable to existing farming systems are more likely to gain traction, particularly when they allow farmers to trial components incrementally and derive standalone value at early stages. Complementarity between components can strengthen long-term value, but only when supported by sustained extension, clear economic signals, and institutional capacity that recognises adoption as a long-term process. Together, these insights point to the importance of aligning package design and extension with how farmers realistically trial, evaluate, and integrate new technologies over time.

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Appendix Table A.1: Summary of papers included in the systematic review

Paper	Location	Study objective	Study Design	Analysis Method	Data Collection Method and Sample	Items in technology package	Characteristics of target population that contributed to adoption	Characteristics of target population that did not affect or prevented adoption	Percentage of target population adopting / not adopting	Characteristics of technology package that contributed to adoption	Characteristics of technology package that prevented to adoption	Characteristics of rollout that contributed to adoption	Characteristics of rollout that prevented to adoption	Notes
Thomas et al., 1990	USA	To assess how farmer and farm characteristics, information sources, and IPM beliefs affect the number of IPM practices adopted by farmers, and the impact of adoption/nonadoption on yields.	Quantitative	Multiple linear regression to measure the effects of personal and farm characteristics on (a) growers' ratings of the importance of pest management information provided by information sources, and (b) growers' beliefs about IPM. Logistic regression to assess the effects of personal and farm characteristics, information sources, and IPM beliefs on number of IPM technologies adopted.	Telephone survey of a random stratified sample of cotton growers in Texas in February 1985. N=722 cotton farmers.	IPM package, with a specific focus on scouting fields, using information from pheromone traps to help determine insect populations, and preservation of beneficial insects by selectively using insecticides.	Education and gross farm income is positively associated with the number of practices adopted. Producers who strongly believed in the benefits of IPM and importance of economic thresholds of pest damage were significantly more likely to adopt IPM practices.	Age and farm size had a largely insignificant effect on IPM uptake.	Full adoption: 36%. Components adopted between 46-90%. Didn't adopt any component: 6%.	Sustainability: IPM reduces dependency on chemicals and helps reduce development of pesticide resistance. Economic: Farms that adopted the package had higher yields compared to nonadopters.	Greater decision making: IPM requires more periodic assessments and variable time windows for pesticide application compared to "chemical routinism".	Farmers who rated interpersonal communication (private consultants, extension group meetings, individual contacts, contact with extension and university professionals) as important were more likely to adopt IPM practices.	Farmers who rated printed materials as important were no more likely to adopt IPM, negligible effect.	

Paper	Location	Study objective	Study Design	Analysis Method	Data Collection Method and Sample	Items in technology package	Characteristics of target population that contributed to adoption	Characteristics of target population that did not affect or prevented adoption	Percentage of target population adopting / not adopting	Characteristics of technology package that contributed to adoption	Characteristics of technology package that prevented to adoption	Characteristics of rollout that contributed to adoption	Characteristics of rollout that prevented to adoption	Notes
Leathers & Smale, 1991	N/A	To present a theoretical, behavioural model that explains why farmers often adopt components of a technological package in a sequential or "stepwise" fashion rather than all at once.	Theoretical	Bayesian model using backward induction to identify optimal choices under uncertainty.	N/A	Applied to a simple package of a new seed variety and a commercial fertilizer but can be generalised to other packages.	Experience: to learn more about the package, the farmer may choose to adopt a component rather than the whole package, even when the package is more profitable. Uncertainty is reduced through experience. Even under assumptions of risk neutrality and unconstrained expenditure, sequential testing is rational because of the resolution of uncertaint	Adoption patterns will differ from individual to individual within a region because of differences in the Bayesian priors of individuals.	N/A	If farmers can learn about the whole package by buying only a part of it, there will be an information incentive to buy the part rather than the whole.	None.	Information about the effectiveness of the techniques, costs, returns. High confidence in this information e.g. from extension agents and neighbouring farmers, will lead to faster adoption of the entire package.	Uncertainty that the information provided is not valid for a particular farm.	

							y concerning farm-specific impacts.							
Dorfman, 1996	USA	To investigate interactions between decisions to adopt or not adopt multiple sustainable production technology bundles and identify farmer and farm characteristics that explain adoption patterns.	Quantitative	Multinomial probit model using Gibbs sampling.	USDA's National Agricultural Statistics Service (NASS) 1991 Fruit and Nut Chemical Use survey of apple growers from 8 U.S. states. N=625 apple farmers.	Improved irrigation techniques, IPM practices, defined as using at least three IPM techniques on their orchards. Considered four bundles: neither, IPM only, improved irrigation only, or both.	Farmers with higher education levels were more likely to adopt entire bundle, but less likely to adopt improved irrigation only.	Farmers working more hours off farm are less likely to adopt, consistent with them having less time to learn about new technologies. Farm size is inconclusive.	Full adoption: 9%. IPM only 60.4%. Irrigation only 1.4%. Didn't adopt any component: 29%.	None.	Significant negative correlation between IPM and improved irrigation: IPM adopters are less likely to adopt improved irrigation.	N/A	N/A	
Banerjee & Martin, 2009	USA	To identify factors affecting the adoption of GM cotton, including use of conservation tillage.	Quantitative	Binary logit models to explain adoption of GM cotton as a function of farmer demographics, farm characteristics including if they grew GM cotton in the previous year, if they no tilled in the previous year, and if they used conservation tillage equipment.	USDA's Agricultural Resource Management Survey (ARMS), specifically the 2003 survey of cotton producers. N=537 cotton farmers in BH model, N=898 cotton farmers in BHS model.	GM cottonseed, conservation tillage	Using GM cotton in the previous year positively correlated adoption in the study year. Farms with a higher percentage of acreage in cotton positively correlated with GM adoption.	Regional variation. Education negatively correlated with adoption at the 10% level. Labour expenses, cotton acres, highly erodible land indicator, refuge size, yield, tenure, gross farm income and age	Full adoption not stated. 15-30% used conservation tillage, 65% BH, 86% BHS. Didn't adopt any component not stated.	None.	Use of conservation tillage did not significantly affect adoption of GM cotton, despite expected synergies.	N/A	N/A	Notes limitation of using cross-sectional data, estimated effects are not causal.

				Two models for two definitions of GM cotton: BH=either Bt or HR, BHS=either Bt, HR, or SG.				were not correlated with GM cotton adoption.						
Fleischer et al., 2011	Israel	To examine the choice of crop, irrigation, and cover as a bundled decision by farmers and to test whether these bundled decisions are sensitive to climate variables.	Quantitative	Cross-sectional discrete choice modelling, specifically a multinomial logit model, estimated using maximum likelihood estimation.	Face-to-face survey among a stratified sample of farmers across geo-climate zones, conducted between January and March 2003. N=303 cropping farmers.	Crop choice (field crops, vegetables, fruit orchard), cover (no cover, net cover, greenhouse) and irrigation system (little or no irrigation, drip irrigation, sprinkler irrigation)	More years of experience positively associated with adoption of fruit orchard bundles. Farmers with larger government-allocated water quotas were more likely to adopt bundles involving sprinklers, rather than water efficient drip irrigation.	Farm size had a significant and negative effect on adoption of high-technology bundles; larger farms were more likely to choose low-tech field crop with minimal irrigation.	Full adoption: N/A. Different bundles had adoption between 7-35%. Over 95% of farmers in the sample used irrigation, and 31% used a cover. Less than 5% didn't adopt any component.	Adapt to different climate conditions: Warm temperatures encouraged greater adoption of fruit orchard with irrigation bundles. Covers were adopted to prevent wind damage.	Cost: Some components are expensive e.g. drip irrigation.	N/A	N/A	
Yu et al., 2012	USA	To propose and illustrate a tractable statistical strategy to identify the complementarity or substitutability among technology	Quantitative	Construct an expected probability that a subset of technologies will be adopted under the hypothesis	Survey of hog farmers subscribed to National Hog Farmer Magazine in 1995, 2000, and 2005. N=not stated.	Six hog production technologies: Artificial Insemination (AI), Split Sex Feeding (SSF), Phase Feeding (PF), Multiple Site Production	Large farms are more likely to adopt high-dimensional (4-6) technologies.	Smaller farms use fewer technologies.	N/A	N/A	N/A	N/A	N/A	As the number of technologies considered increases, they are more likely to be compleme

		bundles with many components, specifically avoiding the "curse of dimensionality" that limits traditional pairwise analysis.		that the technologies are independent and compare to observed probabilities. Significantly higher probability indicates the technologies are mutually complementary.		(MSP), Early Weaning (EW), and All In/All Out (AIAO).								ntary with one another, even if subsets are substitutes when viewed in isolation.
Lambert et al., 2015	USA	To analyse adoption patterns of precision agriculture technologies, identify natural technology bundles, and determine how farm structure and farmer characteristics affect adoption.	Quantitative	Multiple Indicator Multiple Causation model and principal component analysis to identify bundles of technologies based on their use by producers. Logistic regression to correlate adoption of identified bundles with farm and farmer characteristics.	Mail survey of cotton farmers in 13 US states in 2013. N=739 cotton farmers.	Yield monitors, grid soil sampling, zone soil sampling, soil electrical conductivity, digital map use, aerial imagery, satellite imagery, soil survey maps, handheld GPS devices, decision aid COTMAN.	Adoption of technology bundles was more likely for cotton growers managing relatively larger operations that used a variety of information sources to learn about precision farming. These producers tended to irrigate, practice crop rotation, and participate in federally	Older operators less likely to adopt.	Adoption of all ten technologies very rare. The most common bundle (yield monitors and grid soil sampling) used by 2.1%. Yield monitor with GPS 22% managed cotton acres. Grid soil sample 22% of managed cotton acres. Soil survey maps 12% of managed cotton acres. Didn't adopt any component not stated.	None	Perception that technologies were too expensive or complex to manage decreased the likelihood that packages were adopted.	Cost-share payments showed higher propensity for adoption.	None	

							funded working land conservation programs. Higher farm income saw greater technology adoption.							
Rajendran et al., 2016	Global	To review and synthesize recent research on the factors that influence the adoption of bundled sustainable agricultural practices (SAPs).	Systematic literature review	Vote counting method to sort empirical findings into three categories (significantly positive, significant negative, or non-significant) to identify factors affecting adoption.	Comprehensive search of platforms (Scopus, Google Scholar, and references in selected journals) using specific keywords related to adoption (adoption/uptake/affectation/application) and sustainable bundles (IPM/organic farming/soil conservation /good agricultural practices). N=24 papers on farmers.	Sustainable bundles (integrated pest management/organic farming/soil conservation measures/good agricultural practices)	Higher formal education, farming experience tend to be positively correlated with adoption. In most cases, farm size and area under cultivation were positively associated with adoption.	Negative association between labour availability and adoption of SAPs, suggesting opportunity costs of labour favour other non-agricultural activities. Tendency to adopt declines if land right lacks security. Age mixed.	N/A	Adoption increases when the bundle is seen as superior in environmental impact, yield, and economic returns. Bundles perceived to minimize risks associated with conventional practices are more likely to be adopted. Economic motivations fundamental, profitability determine sustained use.	None	Extension services, training, and engagement with farmer associations. Factoring in location specific advice, e.g. group discussion in local farmer association enables one to share with and learn from those who know and appreciate local peculiarities.	None	Includes papers in low-income and subsidence settings.
Schimmelpfennig & Ebel, 2016	USA	To examine sequential path of PA technology adoption, what factors affect adoption,	Quantitative	Probit model to estimate factors affecting adoption, and an OLS regression	USDA's Agricultural Resource Management Survey (ARMS), specifically the 2010 corn survey. N=1507 corn farmers.	Yield monitors, yield mapping, guidance systems, GPS soil mapping, and variable rate technology	Farm size positively correlated with adoption. Higher education positively	Age insignificant.	Advanced package adoption: 8-9%. Up to 48% for yield monitor, lower for other components.	Complementarity. Yield monitoring and guidance systems are plug and play without	Advanced hardware is expensive, high capital costs. Complexit	N/A	N/A	

		and whether there are cost savings when technologies are adopted together.		to explain factors affecting variable production costs. OLS regression corrected for self-selection bias.			correlated with adoption, with the effect increasing as the technological sophistication of the bundle increased. Farmers already using GMO or soil testing were more inclined to adopt PA tools.		Didn't adopt any component unclear, less than 52%	any additional knowledge required. Standardisation, many new combines include yield monitor.	y of some parts, requires new knowledge and skill. More advanced packages did not guarantee cost savings beyond the costs already saved through implementing an intermediate package.			
Vargas et al., 2016	USA (Hawaii)	To document the effectiveness of the Hawaii Fruit Fly Area-Wide Pest Management (AWPM) Programme in suppressing fruit fly populations while reducing the use of organophosphate insecticides.	Qualitative	Descriptive	N/A	Field sanitation, protein bait application techniques (BAT), male annihilation techniques (MAT) using male lures, and sterile fly and parasitoid releases.	None	None	Not stated. But package was considered highly successful. There were more than 2747 participants, including 682 farms and over 6500 hectares under management.	Package was economically viable, environmentally sensitive and sustainable, allowing growers to reduce use of insecticides. Expected to increase grower revenue and market access. Complementarity among package items e.g. field sanitation improved	Field sanitation is effective but laborious, a deterrent for some farmers.	Collaborative partnerships between federal, state and academic institutions. Comprehensive educational program (the "1, 2, 3 Programme") that used workshops, websites and school curricula to encourage adoption. Hands-on educational outreach to farms.	None	In four major agricultural areas, fruit fly infestation was reduced by 83-95%. This was accompanied by a reduction in the use of insecticides. Saw an increase in the number of commercial farms and existing farms adding

										efficacy of baits, lures, and biological control agents.				crops that had previously been phased out due to fruit fly problems. Cost-benefit analysis found the programme will create as much as 32% ROI over 15 years.
Griffin et al., 2017	USA	To determine the precision agriculture technologies that farmers adopt and patterns of transitioning from one PA bundle to another i.e.the sequence of technology adoption.	Quantitative	One-step Markov chain to estimate the transition probability i.e. probability of being in technology bundle j given the farm was in technology bundle i in the previous year.	Face-to-face surveys of farmers in Kansas in 2015 with retrospective questions on adoption, appended to electronic databank including detailed farm-level agronomic and financial information from 1973 to 2015. N=348 farms.	Yield monitoring, variable rate application of inputs, and precision soil sampling.	The most likely path from a non-user to user of all three technologies involves the sequence of: nonadopter to YM to YM+PSS to YM+PSS+PR, stepwise. When all three information-intensive technologies were adopted, farmers tended to persist with that bundle	Technology familiarity, farmers tended to persist in the same bundle of technology over time. This is particularly true for nonadopters (94% probability of still having no technology next year).	Full adoption: 23%. Components adopted between 0-20%. Didn't adopt any component: 33%.	Complementarity, one technology like YM provides data necessary to inform the use of another (variable rate application). High adoption of YM is partially due to their standard inclusion on most new combine harvesters since 2005.	"Information-intensive" technologies provide additional information but the user must invest additional time and resources to develop skills which acts as barrier, compared to "embodied knowledge" "plug-and-play" technologies that do not require additional skills to	N/A	N/A	Recommend being aware of the persistence of slow adoption of PA technologies and allow programs to be available long enough to achieve desired adoption rates and conservation goals.

							(99% probability of continuing).				realise value of the technology.			
Lacy, 2018	USA	To assess farmers' adoption of four weed resistance management practice (RMP) groups and evaluate complementarity of these groups, given rise of weed resistance to herbicides.	Quantitative	Principal component analysis for grouping technologies. Multivariate probit models to estimate adoption probabilities as a function of farmer and farm characteristics. Complementarity test using maximum likelihood estimation and percentile bootstrapping.	Iowa Farm and Rural Life Poll, annual survey of approximately 2000 Iowa farmers. Use data on farmers who responded to every question on the 2013 survey and provided their highest earned degree in either the 2011 or 2015 survey. N=726 farmers.	11 RMP methods grouped into four categories. Chemical intensive: multiple timings and modes of action. Labor intensive: mechanical weeding, hand weeding, forage, cover crops. Capital intensive: tillage, high planting rates. Biological intensive: crop rotation, alternative herbicide-resistant cultivars.	Farmers with more formal education were more likely to adopt chemical and biological intensive RMPs. Male farmers more likely to use chemical and biological intensive RMPs than female farmers. A higher percentage of household income from the farm and larger farms increased chemical RMP adoption. The presence of a spouse increased likelihood of using chemical	Older farmers were less likely to adopt labour, mechanical and capital intensive RMPs. Once farms were too large, probability of adoption dropped. Dependence on off-farm income decreased time-intensive RMP adoption, suggesting less time available to invest in skills. No evidence that farms with more family farm labour adopt more technologies.	Full adoption: 39% use a combination of all four RMP groups. Components adopted 15%-92% depending on the practice. Didn't adopt any component: 1.1%.	Practices are mutual complements. Farmers use one RMP until the marginal cost of increasing its intensity exceeds the marginal cost of introducing a second practice. Bundles are used more frequently than independent selection would predict, indicating they work more effectively together.	None	N/A	N/A	Theoretical model looks at the cost minimization problem facing a farm with a target output. Each technology can be used at varying intensities subject to positive but diminishing marginal products. With rising marginal cost of intensity of use, eventually the marginal cost of an additional increase in intensity of use of the first technology rises above the marginal cost of using the second technology

							intensive RMPs.							, indicating a range of output where the farmer is using both the first and second technology. The implication is that large farms or farms with intense use of technologies will be more likely to use multiple technologies rather than a single one.
Miller et al., 2019	USA	Building on Griffin et al., 2017, determine adoption patterns for embodied knowledge vs information intensive technology bundles and patterns of transitioning from one bundle to another, and test whether transition probabilities have	Quantitative	One-step Markov chain to estimate the transition probability i.e. probability of being in technology bundle j given the farm was in technology bundle I in the previous year.	Face-to-face surveys of farmers in Kansas in 2015 to 2017 with retrospective questions on adoption, appended to electronic databank including detailed farm-level agronomic and financial information from 1973 to 2015. N=545 farms.	Embodied knowledge: automated guidance, automated section control and lightbar. Information intensive: yield monitors, yield monitors with global navigation satellite systems, and precision soil sampling. Variable rate bundles combined with either EK and/or II.	Stepwise adoption of new technology. Two separate paths to adopting variable rate: (i) adopted EK, followed by II, and then VR or (ii) adopted II, followed by EK, and then VR.	Technology familiarity, farmers tended to persist in the same bundle of technology over time. This is particularly true for nonadopters.	20% adopt VR and most have adopted EK and II before VR so approx. 20% full adoption. At least one EK component:80%. At least one II component: 60%. Didn't adopt any component not stated.	Complementarity, one technology like YM provides data necessary to inform the use of another (variable rate application). EK technologies require no additional skills to benefit from value. YM/YMGNSS standard equipment	"Information-intensive" technologies provide additional information but the user must invest additional time and resources to develop skills which acts as barrier, compared to "embodied knowledg	N/A	N/A	Overall slowing in the rate of adoption of PA technologies over time.

		changed over time.								on new combines.	e" "plug-and-play" technologies that do not require additional skills to realise value of the technology.			
Canales et al., 2020	USA	To analyse drivers of adoption timing for continuous no-till, cover crops, and variable rate application and to examine complementarities between these conservation practices.	Quantitative	Duration analysis to determine factors that affect the speed of adoption of conservation practices, including demographic factors, market factors, weather variables, years of practice exposure, adoption of other practices.	Face-to-face surveys of farmers in Kansas in 2013-14 with retrospective questions on adoption. N=176 cropping farmers.	Continuous no-till (CNT), cover crops (CC), variable-input application of inputs (VRA).	Producers previously adopted soil conservation practices were more likely to adopt additional complementary practices. Farmers who adopted conservation crop rotation also adopted CNT and CC faster than farmers without a crop rotation. CNT adoption sped up adoption of CC. Self-identifying as an	Dependence on off-farm income reduced adoption speed, potentially indicating limited time available for developing new skills required for these practices. Older age delayed adoption, potentially due to shorter planning horizons. Farmers motivated strictly by profits adopted CNT at slower rates. Speed of VRA	Full adoption not stated. CNT 61%, CC 40%, VRA 28%. 66% of farmers adopted at least one of the three practices. Didn't adopt any practice: 34%.	Interconnectivity in the adoption of conservation practices, indicating complementarity. CNT practices adopted at a faster rate in areas where the most benefits from the practice can be realised i.e. drier areas.	Higher initial capital costs of VRA slowed adoption among smaller farms with lower income.	Cost-share or incentive payments for implementing conservation practices saw faster adoption of CC practices. Accumulation of knowledge within the farming community over time reduced individual adoption lags for CC and CNT. Favourable market conditions or growing conditions associated with higher adoption speeds. The exception	None	Recommends education, outreach and extension efforts. Recommends cost share for some of the practices to accelerate adoption of other complementary practices to reduce risks for farmers and increase the cost-effectiveness of conservation programs through the intensification of conservation on

							innovator significantly sped up adoption of all three practices. Higher education and younger age were associated with faster adoption. Larger farm size and higher income sped up adoption of VRA.	adoption not affected by adoption of crop rotation, CNT or CC.				was market conditions for CNT, a practice which can cause yields to decline in the short-run, so higher crop prices could mean sacrificing higher short-term revenues.		farms. Recommends promotional efforts intensified when adoption conditions (weather and markets) are favourable and farmers are more likely to engage in conservation practices as a trial.
Reints et al., 2020	USA	To identify bundled water efficient technologies and management practices used by avocado growers in California, and to determine which farmer and farm characteristics contribute to their adoption.	Quantitative	Logit/multinomial logit to determine factors affecting adoption of technology and technology bundles, plus Kohonen Self-Organising Maps and multiple correspondence analysis to determine commonly used bundles.	Survey of avocado growers in Southern California in 2012-2013, 71 questions, conducted via email, mail and direct interviews in grower meetings. N=123 avocado farmers.	Water audit, soil moisture by feel, soil moisture by gypsum block, soil moisture by tensiometer, irrigation using calendar, irrigation using CIMIS, management of tree canopy, and pressure compensating sprinklers.	Farmers who placed high importance on and frequently used corporative extension were significantly more likely to adopt. Farmers who had a higher share of income from avocado production (suggesting specialisat	Age, older growers were significantly less likely to adopt more complex bundles. Irrigation complexity, e.g. irregular block shapes, step slopes and difficult topography, reduced adoption of advanced bundles.	More advanced bundle adoption: bundle 2 (34.95%) and bundle 3 (36.58%). Bundle 1, least advanced bundle, had 12.19% adoption. Didn't adopt any component: 16.26%.	Free public resources like CIMIS and professional water audits removed financial barriers to entry.	More advanced bundles requires higher human capital and specialised training.	N/A	N/A	Recommends extension.

							ion) were more likely to adopt advanced packages. Education mixed to slightly positive.	Owner operated, farm acres had no effect.						
Tingey-Holyoak et al., 2021	Australia	To explore water productivity improvements and improvements in irrigation decision making achieved by bundling smart agricultural technologies and water accounting models.	Mixed methods	Desk-based review and key actor interviews, producer survey and participant-based case study.	Desk-based analysis, semi-structured face-to-face interviews, mail surveys with follow up phone calls, and on-site direct monitoring and accounting data collection. 9 expert interviews (farmers, irrigation managers, agricultural business owners, industry consultants and government representatives), 110 farmer surveys, and 1 participatory case study farm.	Farm accounting software (e.g. Xero, MYOB), soil moisture probes, on-site weather stations, remote sensing data, real-time alerts and costed forecasting.	Not stated	Producer survey found many non-existent or informal systems of accounting are being used, creating challenges for embedding additional innovations.	Full adoption N/A. Forecasting data from BoM used by most farmers. Formal accounting systems: 43%. Budgeting/planning: 43% use basic budgeting.	Improved farm-level, focused irrigation decision-making and water productivity by linking water-related costs to decisions in real-time including energy market costs, weather forecasting and agronomic indicators. High preference for iPhone or iPad applications.	Existing bundles lack integration with current practices. Existing bundles lack user-friendliness and applicability at farm level.	N/A	N/A	Case study example of engaging with producers on current practices, the issues they face and what solutions may work. Not about bundle rollout.

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