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Sustainable innovation adoption barriers: Water sustainability, food production and drip irrigation in Australia

Abstract

Purpose – *This research examines impediments to the adoption of sustainable water-efficient technological innovation in agriculture. Farming is the largest water consumer and food production expansion in response to global population growth, combined with increasing droughts from climate change, threatens water and food insecurity for many countries. Yet climate smart agriculture (CSA) innovation adoption has been slow, and in this regard governments and the agricultural sector are not fulfilling their social responsibility and sustainability obligations.*

Design/methodology/approach – *Barriers to water-efficient drip irrigation (DI) adoption in Australia were investigated via 46 depth interviews with agricultural stakeholders and a survey of 148 farmers.*

Findings – *While DI water efficiency is recognised, this is not the key determinant of farmers' irrigation method selection. Complex interrelationships between internal and external barriers impede DI adoption are identified. These include costs, satisfaction with alternative irrigation methods, farmer characteristics that determine the suitability of the innovation and the extent it is incremental or radical, plus various multidimensional risks. Government support of alternative, less water-efficient irrigation methods is also a critical barrier.*

Originality/value – *A conceptual framework for understanding barriers to sustainability oriented innovation adoption is presented. Its insights should be applicable to researchers and practitioners concerned with understanding and improving the adoption of socially responsible and sustainable innovation in a wide range of contexts. Recommendations for overcoming such adoption barriers are discussed in relation to the research focus of water-efficient agriculture and encouraging uptake of DI.*

Keywords: innovation adoption barriers, climate-smart agriculture CSA, drip irrigation, water-sustainability, food production

Introduction

Corporate social responsibility (CSR) and sustainability initiatives are essential to address the many detriments of human activity, especially in relation to production (Intergovernmental Panel on Climate Change, 2014; Lioui and Sharma, 2012; Orlitzky *et al.*, 2007; United Nations Environment Programme, 2015). Production innovation is increasingly recognised as a key driver of sustainability and its associated positive outcomes (e.g. Cancino *et al.*, 2018). In this study sustainable innovation refers to new products and processes that serve both an organisation's self-interest, as well as social and environmental needs. However, the adoption of such sustainability oriented innovation often requires a paradigm shift in policies and practices (Christensen *et al.*, 2015), and particularly so in agriculture, which frequently experiences slow uptake and an array of adoption barriers (Weiss and Bonvillian, 2013). This study makes a contribution by addressing important gaps in the literature in relation to sustainable innovation adoption barriers (e.g. Sandberg and Aarikka-Stenroos, 2014), including how to overcome these in the context of climate-smart agriculture (CSA) (e.g. Long *et al.*, 2016; Senyolo *et al.,* 2018). More specifically it investigates barriers to the adoption of innovative water-efficient farming practices, which has also been recognised as a critical avenue for future research (Greenland *et al.*, 2018).

Agriculture generates many detrimental environmental and social impacts (Narula and Upadhyay, 2011; Tilman and Clark, 2014), including greenhouse gas emissions, pollution from nutrient and pesticide run-off, and soil erosion. As the largest commercial user of fresh water – 70 per cent of global consumption (United Nations World Water Assessment Programme, 2016) – agriculture has contributed to water scarcity in many regions (World Health Organization, 2015), including depleting local aquifers and salinisation (Dobbs *et al.*, 2011). This sector is also facing a production-sustainability crisis – it has been predicted that an escalating global population will increase food demand between 60 and 100 per cent by 2050 (Valin *et al.*, 2014). Food production expansion therefore threatens even greater environmental degradation, water scarcity and associated social challenges.

The biggest food productivity and sustainability opportunities lie with improving farming practices (Dobbs *et al.*, 2011). Yet governments' agricultural policies typically encourage production growth, with minimal environmental requirements (Mitchell *et al.*, 2017). To avoid potentially catastrophic consequences, any significant intensification of food output must be sustainable and socially responsible, fulfilling both production and environmental goals (Mitchell *et al.*, 2017).

The global food production-sustainability challenge is also exacerbated by climate change, which already threatens both food (World Health Organization, 2015) and water security (CDP, 2016) for many countries. Increasing droughts mean that agricultural water use can only become an even more contentious issue in the future (Vollaro *et al.*, 2015). By 2025, it is estimated that two-thirds of the world's population will face water shortages (World Wildlife Fund, 2016). Socially responsible and sustainable agricultural water management is therefore pivotal to meeting rising global food demands.

CSA technological innovations are crucial for enhancing sustainable food production while responding to climate change (Senyolo *et al.*, 2018). Sustainable water management is a well-recognised CSA innovation (Long *et al.*, 2016), and replacing flood irrigation with drip irrigation (DI) is key to reducing agricultural water consumption while increasing food production (Dobbs *et al.*, 2011). However, agriculture's slow adoption of CSA practices (Weiss and Bonvillian, 2013) impedes the response to the food production-sustainability challenge, and presents an important avenue for further research (Senyolo *et al.*, 2018). This study therefore makes practical and theoretical contributions by investigating barriers to the adoption of water-efficient CSA. It examines sustainable DI innovation adoption barriers in Australia, and assesses the applicability, or otherwise, of adoption barrier frameworks from the literature.

Contextual background and literature review

Australia

As a largely arid continent with a population of just over 24.5 million (Australian Bureau of Statistics, 2017), Australia experiences extreme water-stress. Its agriculture sector faces significant water resource challenges and irrigation is required for huge areas. While DI is acknowledged as one of the most environmentally sustainable and water-efficient approaches, less efficient, open-channel flood irrigation is the most widely used method in Australia (O'Mahony *et al.*, 2016).

Australian agricultural policies and government investment have come under criticism for not improving water efficiency. For example, over the past decade in the Murray-Darling Basin, where surface or flood irrigation is the main method, A$13 billion has been spent on water reforms with minimal impact on restoring the balance between agricultural water consumption and environmental water that supports natural ecosystems (Thompson, 2017). Australia is typical of many arid countries, in that water-efficient irrigation presents an under-utilised opportunity for improving water scarcity and agricultural sustainability.

Some classifications that estimate the pressure of irrigation on available water resources rate Australia's agricultural irrigation as having only minimal impact (e.g. Frenken and Gillet, 2012). However, such classifications are based on annual rainfall averages (Alexandratos and Bruinsma, 2012), and the country's seasonal water scarcity challenges are actually significant. This is aptly illustrated by multibillion-dollar desalination plants in Sydney, Melbourne, Perth, Adelaide and South East Queensland, which supply water to the state capital cities during droughts (El Saliby *et al.*, 2009). Desalination is also contentious, as it is not a sustainable method of water production (Knights *et al.*, 2007), with very high construction and running costs (Ferguson, 2014; Knights and Wong, 2008).

Projected agricultural water use

The scope for maintaining food production in many countries, let alone increasing it, depends on the adoption of more water-efficient irrigation (Alexandratos and Bruinsma, 2012). Due to increased food production, global agricultural water use is expected to rise 30 per cent by 2030 (Dobbs *et al.*, 2011). More modest estimates predict increases of 6 to 7 per cent by 2050 (Alexandratos and Bruinsma, 2012, p. 123; Food and Agriculture Organization [FAO], 2011), but these assume significant improvements in irrigation efficiency.

The estimates of future irrigation water requirements are also often flawed, with calculations again being based on average annual precipitation without factoring in the extreme seasonal variability of climates, particularly in arid regions (Alexandratos and Bruinsma, 2012) like Australia.

Regardless of the variations in predicted global irrigation water demands, it is clear that agriculture's water consumption will increase. Encouraging the adoption of sustainable, water-efficient irrigation methods by farmers is therefore imperative. For example, the United Nations estimates that potential savings from improved water productivity in agriculture could be as high as US$115 billion annually by 2030 (United Nations World Water Assessment Programme, 2016). Furthermore, the provision of more efficient water technologies to up to 100 million farmers could generate an estimated direct total net benefit of US$100-200 billion (Dobbs *et al.*, 2011).

Drip irrigation (DI)

DI is "an important innovation in agriculture, which surpasses sprinkler and flood irrigation, and is critical in areas with limited water supplies" (World Health Organization, 2016, no page number). Using surface and subsurface dripper lines located at or below the plant roots, DI can reduce required water for irrigation by 20 to 60 per cent, and improve yields by 15 to 30 per cent (Dobbs *et al.*, 2011). DI therefore provides a primary opportunity for reducing global agricultural water consumption, while increasing food productivity. Its targeted water application minimises run-off or deeper percolation, and combined with remote technology, can significantly reduce manual labour associated with irrigation (Kalpakian *et al.*, 2014). In terms of water delivery, DI is more efficient than flood irrigation, as replacing open channels with pressurised pipes reduces water losses from evaporation and seepage (Wakeel *et al.*, 2016). Although as Ward and Pulido-Velazquez (2008) emphasised, DI must be effectively managed to avoid higher volumes of irrigation water being used in the quest for even higher yields.

Israel is the 'poster child' for the production opportunities afforded by DI. Israeli farmers pioneered fertigation, which uses DI to integrate the application of water and fertilisers. Over the past 50 years, this country's agricultural output increased 12-fold, while water consumption remained constant (Dobbs *et al.*, 2011).

Despite the benefits of DI, its adoption is not widespread across many of the regions facing water shortages (O'Mahony *et al.*, 2016). To date, there has been considerable research on the production dimensions of DI technology, but little examines it from the perspective of the intended end users, the farmers (Whittenbury and Davidson, 2009). This study therefore aims to uncover why more farmers are not using DI, including the key barriers to its adoption that must be overcome to respond to the global food production-sustainability challenge.

Innovation and sustainability

As corporate social and environmental responsibility has evolved entrepreneurship (e.g. Hoogendoorn *et al.*, 2017) and innovation in particular (e.g. Cancino *et al.*, 2018) have become increasingly recognised as key drivers of future sustainability. Corresponding investigations of barriers to CSR and pro-environmental behaviour (e.g. Laudal, 2011; Mont and Leire 2009) have also led to more focused studies on the specific barriers to sustainable innovations (e.g. Luthra *et al.*, 2014).

The literature describes how innovation occurs incrementally by modifying existing products and practices, or radically via totally new and different offerings and approaches (e.g., Reed, 2015). However, the delineation between incremental and radical innovation is often blurred, with varying degrees of radical innovation noted (e.g. Harmancioglu *et al.*, 2009). Sandberg and Aarikka-Stenroos (2014) consequently called for more research comparing radical and incremental innovations. Irrigation provides an interesting sustainability context because the degree of radical innovation is farmer-specific. For example, for a farmer with no DI experience, a switch to this method would be more radical than for another with at least some past experience. Furthermore, as DI can potentially displace established irrigation practices, as well as associated water management policies and infrastructure, it can also be considered a disruptive innovation (Christensen *et al.*, 2015).

Extensive research has sought to understand why different stakeholders adopt innovations in a variety of contexts (e.g. Arts *et al.*, 2011), with numerous innovation adoption models produced; many building on Rogers' (2003) innovation diffusion theory. Studies focusing on barriers to innovation adoption present a particularly important avenue for such research (D'Este *et al.*, 2012). As contended by Sandberg and Aarikka-Stenroos (2014, p. 1293), "as innovation barriers inhibit or diminish innovative activities, it has become increasingly important to identify and understand them".

Sandberg and Aarikka-Stenroos (2014) acknowledged the sparsity of research focusing on innovation barriers and called for further investigation. They conducted a comprehensive review of extant literature and, although not specific to pro-environmental innovation, their research presents a useful typology of innovation adoption barriers, categorised according to external and internal dimensions. The external barriers include resistance or lack of support from specific stakeholders, such as customers and government, as well as restrictive macro-environment factors such as technological turbulence, the established infrastructure and local culture; and internal barriers include restrictive mindsets, lack of competencies, insufficient resources, as well as unsupportive organisational structures.

Research specifically examining barriers to pro-environmental innovation adoption has increased (e.g. Luthra *et al.*, 2014). Some has focused on improving water security and sustainability via wastewater recycling (Bichai *et al.*, 2018; Garrone *et al.*, 2018). CSA innovation adoption barriers, in relation to food production, have also received increasing attention (e.g. Long *et al.*, 2016, Senyolo *et al.*, 2018). Yet inadequate adoption of CSA innovations remains an ongoing and serious concern (Senyolo *et al.*, 2018), and only "a limited amount of research focuses on the adoption of technologies and innovations within agricultural contexts in developed countries" (Long *et al.*, 2016, p. 16).

Barriers to sustainable innovation adoption have been reported as being consistent with the innovation diffusion literature and 'normal' technological innovations (e.g. Kemp and Volpi, 2008). However, with CSA some differences might be expected given the unique context of climate change and its significant impact on agriculture. Two notable studies specifically examined barriers to agricultural innovation adoption and focused on a broader array of CSA technology innovations (Long *et al.*, 2016; Senyolo *et al.*, 2018).

Long *et al.* (2016) investigated impediments to the adoption of CSA innovations in Europe, and also concluded these were similar to adoption barriers in other innovation contexts. They identified the key adoption barriers as economic, institutional/regulatory, behavioural/psychological, organisational, consumer/market specific, as well as social. These authors presented a model, which like Sandberg and Aarikka-Stenroos's (2014) framework, involved external and internal characteristics, divided according to whether they originate from the supply (provider/manufacturers) or demand side (users/customers). The authors subsequently called for further research to validate, or otherwise, their findings in other markets.

Senyolo *et al.* (2018) similarly presented a framework defining barriers to CSA innovations in South Africa, and highlighted the importance of involving farmers early in the adoption process, via education programs to enhance their knowledge and understanding of such technologies. These authors also called for further research to better understand the barriers and drivers of sustainable CSA technology adoption, from the perspectives of both farmers and technology providers.

From the small number of studies that have examined barriers to DI adoption, lack of financial access appears to be the most common barrier (e.g. Kalpakian *et al.*, 2014). In line with this, Dobbs *et al.* (2011) reported three main barriers to DI adoption: the first is cost and the fact that DI equipment is capital-intensive and beyond the means of many farmers; the second is that many lack information about DI benefits, leading to inertia; and the third is that in many countries, water does not have a market price, often discouraging investment in improved irrigation.

This study makes a practical contribution by examining barriers to the adoption of DI and more water-efficient agricultural practice. While the focus is on Australia the barriers identified should be relevant to other countries facing similar water scarcity challenges. A theoretical contribution is also made via a new conceptual framework to help understand CSA innovation adoption barriers, which should be applicable to a wide range of innovation contexts.

Methods

Barriers to DI adoption were investigated here via a mixed-method research approach, comprising both qualitative and quantitative components.

Qualitative interviews with agricultural stakeholders

This phase of the research adopted a qualitative approach similar to Long *et al.* (2016). Qualitative research is appropriate given the exploratory nature of barriers to innovation investigation, and since CSA is a relatively new concept (Senyolo *et al.*, 2018). In this study, 46 in-depth interviews were conducted with various stakeholders involved in the supply and use of agricultural irrigation in Australia, including farmers, irrigation equipment dealers, and sales managers from a major DI manufacturer, as well as agricultural extension workers who undertake applied research to educate farmers. These interviews captured the factors influencing irrigation method selection, insights into the perceived advantages and disadvantages of DI, as well as detailed discussion of the barriers to adopting DI. They were conducted by the project research team (the authors) and audio-recorded, with verbatim comments transcribed and then analysed via thematic content analysis (Braun and Clarke, 2014). This involved reading all responses for each area of questioning and sorting the various reasons into similar themes.

Quantitative farmer survey

Long *et al.* (2016) suggested using a larger sample and a quantitative approach in future research, to effectively investigate the primary barriers to CSA innovation adoption. Thus, 148 computer-assisted, interviewer-administered telephone interviews were conducted with farmers who had purchased irrigation equipment in the previous 12 months and used different methods as their main form of irrigation: centre pivot (26), DI (39), flood (56), and sprinkler (27). The sample included small, medium and large farms from New South Wales, Queensland, South Australia, Western Australia and Victoria, and covered a range of food crops and farm types (e.g. broad acre, sugar cane, vegetables, fruit and nut trees, and other fruits). The sample therefore consisted of the main food crops in Australia that use irrigation (Frenken and Gillet, 2012), but did not include non-food crops such as cotton and flowers.

The questionnaire was developed following the qualitative research, after this exploratory phase revealed that attitudes towards DI are often influenced by the perceived performance of alternative irrigation methods. In the survey, the farmers therefore provided an overall satisfaction score for their main irrigation method. An importance-performance analysis (IPA) approach was also adopted to capture the importance of the key irrigation selection criteria identified during the qualitative phase, as well as ratings of the perceived performance of the main method along the same dimensions. The IPA approach has been widely used for evaluating perceived performance, user levels of satisfaction, as well as the importance of selection criteria (e.g. Greenland *et al.*, 2016).

The famers' likelihood of using DI in the future, and the reasons why more farmers do not use it were also captured, along with general farm and farmer characteristics, such as crop type, location, etc.

A team of experienced market research telephone interviewers administered the survey. Responses were entered directly into a data entry file and analysed via SPSS. The interviews were recorded to ensure accurate capture of responses to the open-ended questions. As in the exploratory research phase, these responses were analysed using thematic content analysis.

Results and findings

Qualitative in-depth interviews

Five broad themes of determinants influencing farmers' irrigation method selection were identified in the qualitative phase (see Figure I).

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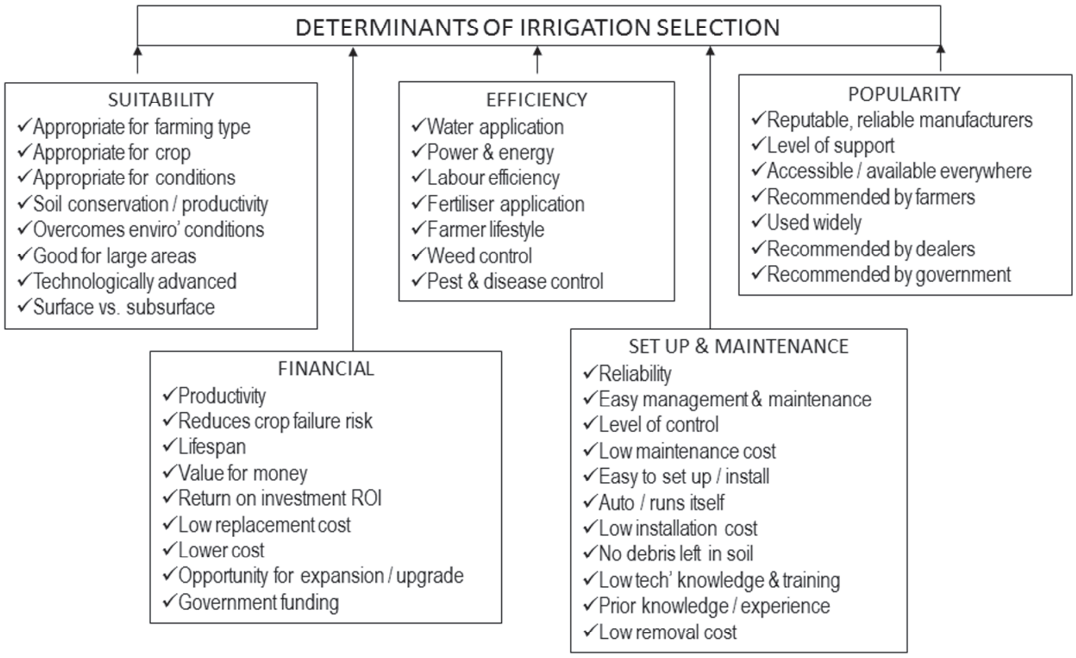
Figure I: Factors determining irrigation selection



The depth interviews uncovered numerous advantages and disadvantages of DI. The disadvantages were the same as the barriers to DI adoption given by the participants (see Table I).

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Table I Primary DI advantages and adoption barriers / disadvantages, in order of frequency of mention (Based on 46 depth interviews with agricultural stakeholders)

Advantages of DI	DI adoption barriers / disadvantages
Less water used or wasted	Installation/upfront setup cost
Higher yield – improved productivity/quality	Running cost – power
Less fertiliser used, or wasted	Maintenance costs
Uniform targeted fertiliser delivery	Maintenance complexity
Uniform targeted water delivery	System management required
Less power and energy used	More complex/technical
Better return on investment	Lack of knowledge
Less labour required	Reluctance to change
Automation, can run the system remotely	Not suitable for some crops/conditions
Better monitoring	
Better farmer lifestyle	Water quality and blockage issues
	Other irrigation methods preferred
	Lack of confidence in drip irrigation
	Can't see subsurface irrigation lines

The deeper discussion afforded by the qualitative research also revealed more deep-seated reasons determining the uptake of DI, as well as some of the psychological factors. While water efficiency was the most frequently mentioned advantage of DI, for many this was not considered to be an important enough factor to motivate farmers to switch from alternative irrigation methods.

These interviews also provided insights on why the agricultural sector has been slow to adopt CSA innovation (e.g. Mitchell *et al.*, 2017; Weiss and Bonvillian, 2013). For example, given the array of factors affecting the success of crops, many of the participants considered farmers to be wary of new practices, as well as those promoting such changes. One of the stakeholders explained: *"Farmers are sceptical of people who are trying to sell them new things, particularly those who do not share the same risks and uncertainties".*

Another barrier to the uptake of DI innovation is the famers' experiences of using alternative irrigation methods and the perceived performance of these. Reluctance to adopt DI was often grounded on preferences for traditional irrigation methods, with acceptable levels of satisfaction associated with these. One of the participants clarified: *"The big issue is to convert farmers to drip when they've been using something else successfully for years".*

The popularity of alternative irrigation methods, including recommendations by other farmers, opinion leaders and other key stakeholders is particularly influential. Most farmers rely on the support and guidance of others when making irrigation decisions, particularly given the significant financial investment involved and the ever-present risk of crop failure. Since a majority of farmers use alternative methods, the comparatively low popularity of DI is another barrier to its adoption. Furthermore, if a farmer goes against the norm, there is a perception that they would risk not receiving government subsidies and support should things go wrong.

Government policy emerged as a key influencer of farmers' irrigation preferences, and highlighted why more farmers do not use DI. In Australia, both the federal and state governments have invested in improving traditional pre-existing open-channel, flood irrigation water delivery and distribution infrastructure, as well as water recovery, rather than promoting and encouraging the adoption of more water-efficient irrigation methods. Such investment has focused on enhancing traditional irrigation methods via solar-power, modern information communications technology, as well as automated gates and valves that integrate sensors, and flow meters. Australian farmers, with minimal investment from their own resources, subsequently have access to an open-channel irrigation network they can monitor via their own personal computer. Such policy has therefore improved the farmers' levels of satisfaction with the traditional irrigation method, so the motivation for adopting more water-efficient DI is lacking.

Quantitative farmer survey

Farmers' satisfaction with their regular irrigation method was measured using a 5-point scale where 1=extremely dissatisfied and 5=extremely satisfied. While the differences between mean scores were statistically significant at the 0.05 level, all methods received positive satisfaction ratings. Satisfaction was highest for DI at 4.51 amongst the farmers who used this method as their main form of irrigation, compared with 4.38 for open-channel flood irrigation, 4.15 for sprinkler, and 4.00 for centre pivot.

Importance of the determinants of irrigation method selection identified in the qualitative phase (see Figure I), as well as perceived performance along the same dimensions, were also measured using 5-point scales. A summary of the IPA results is presented in Figure II for the five main determinants, identified in the qualitative phase. In order of importance these are suitability, financial, efficiency, setup and maintenance, and popularity. In terms of the main irrigation method's performance, DI outperformed the others at the *.001* significance level for both suitability and efficiency; while flood irrigation performed best on the financial, setup and maintenance, and popularity dimensions. These IPA results are consistent with the overall satisfaction scores, with performance scores of around 4 out of 5 for all irrigation methods. Notable gaps between the importance and performance scores are for DI in terms of financial, and for flood irrigation in terms of efficiency.

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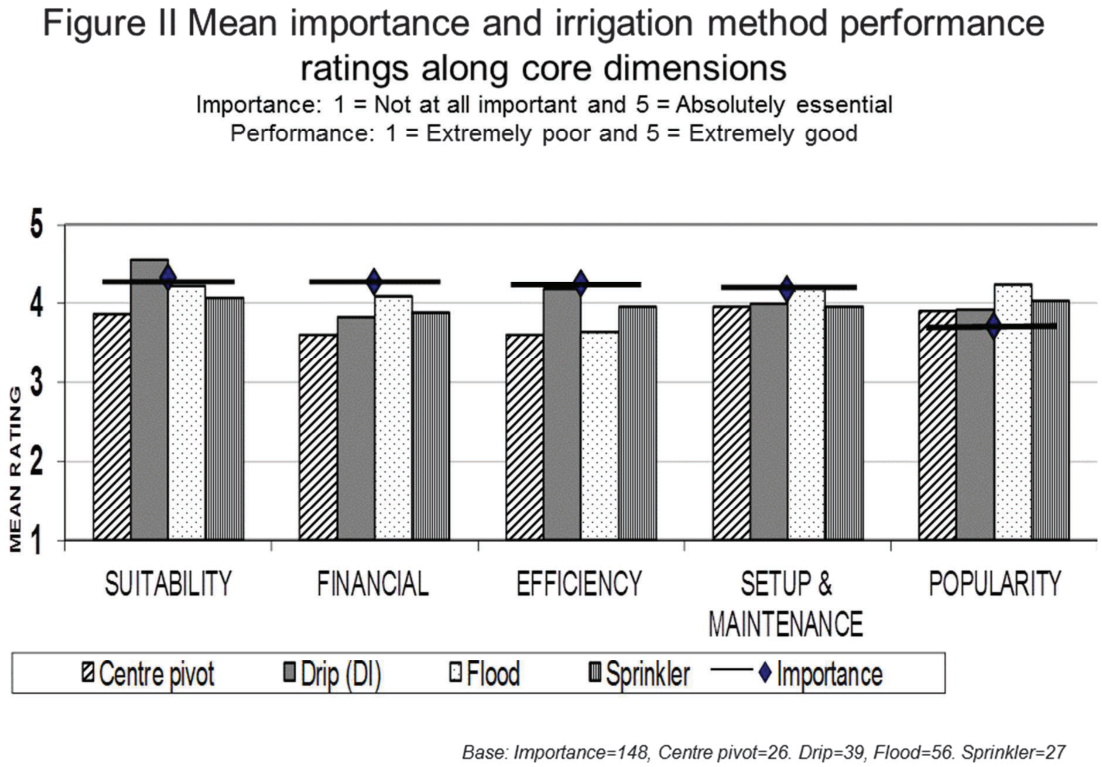
Figure II Mean importance and irrigation method performance ratings along core dimensions (Based on a survey of 148 Australian farmers)



The likelihood of using DI in the future relates strongly to whether farmers use it as their main irrigation method (see Table II). That is, 90 per cent of farmers currently using DI said they would definitely use it, while a clear majority of those using alternative methods have indicated they definitely would not. For example, 82 per cent (46 out of 56) of flood irrigators indicated they definitely would not use DI in the next 12 months.

INSERT AROUND HERE
Table II Likelihood of DI usage in the next 12 months (Based on a survey of 148 Australian farmers)

	Main irrigation type currently used				Total n=	Total %
	Centre pivot	*DI*	*Flood*	*Sprinkler*		
Definitely will not use	17	3	46	17	83	56
Probably will not use	5	0	4	3	12	8
Possibly	0	0	1	0	1	7
Probably will use	2	1	2	3	8	5
Definitely will use	2	35	3	4	44	30
TOTAL	26	39	56	27	148	100

When asked the main reason why more farmers do not use DI in Australia, 46 per cent of the respondents cited financial aspects, particularly the fact that it is too costly to install, operate and maintain; while a further 26 per cent cited suitability of DI for certain crops or farm conditions as the main adoption barrier. Among those farmers using alternative irrigation methods (not DI), the prevalence of perceived financial barriers was generally greater (50 per cent), with a lower 23 per cent citing suitability as the main barrier to adopting DI. Although among the farmers using drip as the main irrigation method, suitability was cited by most as the main barrier, followed by finance. Other reasons for not using DI were mentioned by less than 10 per cent of the farmers.

Discussion

While DI is not suitable for all crops and conditions, Australia's water scarcity challenges suggest that a more favourable disposition towards DI might be anticipated from farmers and agricultural stakeholders. However, this research has revealed that while efficient agricultural water use is deemed important, it is not the primary concern for many Australian farmers. Indeed current policy in Australia means that water efficiency is not the key determinant of irrigation method selection. If farmers are to be encouraged to switch to more sustainable DI, the importance of adopting more water-efficient irrigation needs to be imparted, including reassurance that DI use will not increase any of the perceived multidimensional risks. Government policy and recommendations from agricultural stakeholders have a critical role to play in this regard.

Numerous impediments to DI adoption were identified in this study's qualitative phase, and further quantified in the survey. Further analysis was guided by the existing literature, which provided useful frameworks for helping to classify and understand such dimensions. For example, Long *et al.* (2016) developed a classification of adoption barriers relating to a broad range of CSA technological innovations. Many of these are applicable to this study's specific DI context in terms of economic, institutional/regulatory, behavioural/psychological, customer/market specific, as well as social barriers. Furthermore, their division of barriers into supply and demand related characteristics is also relevant to this study. As illustration, DI manufacturers could encourage adoption by improving farmer knowledge of this method, and by ameliorating the high initial setup costs by offering flexible payment options.

Sandberg and Aarikka-Stenroos's (2014) classification of innovation adoption barriers into external and internal dimensions was also useful for analysing the barriers for DI identified in this study. There are many external factors here, including the abovementioned economic, market and environment considerations that do not support the uptake of more sustainable irrigation options. For example, restrictive external barriers are evident in terms of the popularity of, as well as recommendations from stakeholders for alternatives, as well as ongoing government investment in the improvement of open-channel irrigation. Similar technological turbulence was therefore also observed in this study's findings, with the government-improved flood irrigation technology and infrastructure promoting greater reliance on and preference for alternative irrigation methods rather than water-efficient DI. The lack of general support for DI is a major impediment to its uptake, which reiterates the findings of Caliyurt (2005) who examined the impact of government policy on agricultural practices and found that policies unsympathetic to more sustainable and socially responsible farming practices often discourage their diffusion and adoption.

Numerous internal factors were also identified here, as influencing DI adoption. Access to resources, particularly funding, was the most frequently mentioned barrier to DI adoption among Australian farmers, consistent with research into CSA adoption barriers in other countries (e.g. Long *et al.*, 2016; Sandberg and Aarikka-Stenroos, 2014; Senyolo *et al.*, 2018). Although for DI there was a unique link between farmer finances and government irrigation investment policy. The Australian Government also regularly supports farmers with subsidies and bail-outs, leading to perceived risk associated with DI innovation adoption that might be viewed as going against mainstream policy; many farmers are therefore wary of making radical changes to their irrigation practices.

Inertia and a restrictive mindset, in terms of not wanting to move away from traditional farming practices due to perceived multidimensional risks, was also strongly evident as a barrier for DI adoption. While all sectors face risks stemming from unpredictable economic and market aspects, Australian agriculture often experiences far greater uncertainty due to climatic and environmental conditions.

Lack of familiarity and knowledge of the innovation is another internal barrier recognised in other CSA innovation adoption studies (e.g. Senyolo *et al.*, 2018). This is an aspect that is particularly complex in the context of DI, where competency is dependent on the farmer's background and experience. For example, while some of the farmers in this study used an alternative method as their main form of irrigation, they also regularly used DI. Switching to DI as the main irrigation method may therefore represent incremental innovation for one farmer, but radical innovation for another. This may explain why those farmers familiar with DI conveyed different reasons from those not currently using it, about why uptake of it is low. For example, famers using DI suggested its suitability for certain crops or farm conditions as the main barrier, while those not using it perceived the main barrier to be financial, particularly in relation to installation and maintenance costs.

Unique to this study was the detailed investigation of the relevance of satisfaction and perceived performance of alternative technologies as barriers to the adoption of new technologies. The four most common irrigation methods in Australia (flood irrigation, centre pivot, DI and sprinkler) all had reasonable user satisfaction scores, and were all rated as performing reasonably well across the dimensions determining irrigation selection. This likely adds to the inertia to switch irrigation methods, and helps explain the small proportion of farmers using alternative methods who indicated they would use DI in the next 12 months.

Organisational structure is another internal barrier to innovation adoption that was recognised in both Long *et al.*'s (2016) and Sandberg and Aarikka-Stenroos's (2014) frameworks. While this dimension did not clearly arise for DI in this study in the context of farms, it may be relevant in future research specifically investigating the barriers to DI among different farm types.

The interplay between internal and external barriers was strongly evident in the context of DI in this study, unlike in Sandberg and Aarikka-Stenroos's (2014) research where separate models were developed for the external and internal barriers.

Framework for understanding barriers to sustainable innovation adoption

The classification of innovation adoption dimensions as external or internal to an organisation is reminiscent of business situation analysis, which is a commonly used strategic planning approach (e.g. Armstrong *et al.*, 2015; Reed, 2015). This categorises factors that influence businesses according to their perceived distance from the organisation. Reed (2015, p66) described 'remote' external environment dimensions as political, economic, socio-cultural, technical, environmental (natural/physical), and legislative. These are often referred to in business literature by the PEST and PESTEL acronyms (e.g. Aldehayyat *et al.*, 2011). Nearer external environmental dimensions relate to more marketing-specific concerns such as supply and distribution. The classification of internal components of the business environment relates to specific organisational characteristics and capabilities, such as size (e.g. financial, staff, network), structure, skills and values. This business situation analysis framework has been adapted in a new model depicting the barriers to sustainable innovation adoption identified in this research (see Figure III).

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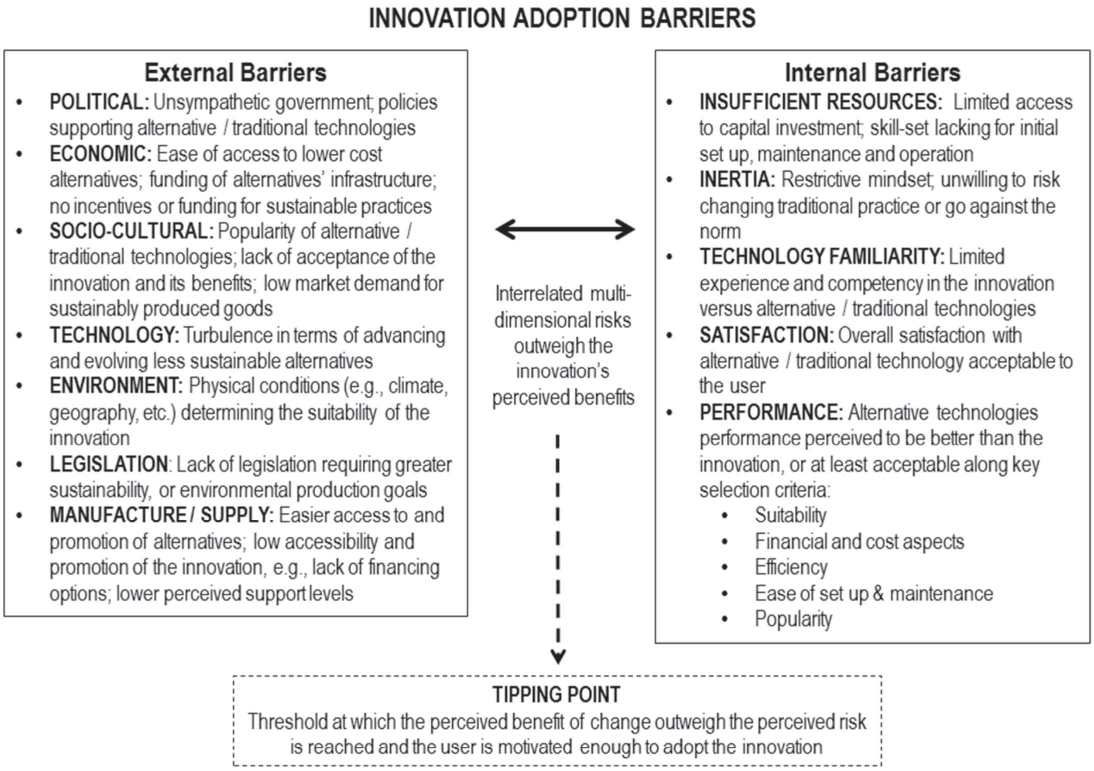
Figure III Barriers to the adoption of sustainable innovation



The strong interplay between the internal and external barriers, as observed in this study for DI, is acknowledged in this model. For example, the decision to adopt sustainable technology innovations requires potential users to perceive more associated benefits than risks. Only once a critical tipping point is reached will potential users be motivated enough to seriously consider change and the adoption of such sustainable innovations.

Conclusion

Even though CSA innovations offer a solution to the global food production-sustainability challenge, their adoption has been slow. To reduce the risk of future food and water insecurity due to increased production, the agricultural sector, and its stakeholders, must prioritise water-efficient irrigation and fulfil their social responsibility and sustainability obligations. DI has the most potential for improving food productivity without increasing water scarcity, yet its use in many countries including Australia, where water resources are limited and water challenges are increasing, is limited. Researching the barriers to DI adoption is therefore essential to help understand and alter this situation.

Through an adaptation of approaches used by other innovation researchers, this study has uncovered barriers that inhibit the adoption of water-efficient DI among Australian farmers. Its mixed-method approach proved successful in identifying a range of explicit and implicit barriers. The survey component provided useful data, including quantifying irrigation method selection criteria, as well as farmers' satisfaction and performance ratings of alternative irrigation methods. The qualitative in-depth interviews revealed the complex decision-making surrounding the adoption of new agricultural practices in Australia. This includes the interrelated, multifaceted range of risks many farmers face, highlighting that DI adoption among Australian farmers will only occur when the perceived benefits of adoption outweigh such risks.

This study's findings suggest that a simple rating of the perceived importance of barrier dimensions alone is unlikely to reveal the relevance of more implicit drivers of decision-making with regard to irrigation method selection. For example, in the survey the importance that farmers attach to the popularity of an irrigation method, including stakeholder recommendations, relative to other selection criteria was rated comparatively as the least important determinant. Yet the influence of stakeholders, particularly government policymakers, emerged in the qualitative phase as a key determinant, if not the most significant factor influencing the chosen irrigation method. It would appear that government agricultural policy and its current focus on open-channel water delivery via more traditional, less water-efficient methods strongly influences farmers' irrigation preferences. The financial investment required by farmers that use this less water-efficient irrigation approach is lower, thereby reducing the appeal and ultimately the adoption of DI. This also potentially explains why water efficiency was not the primary irrigation method selection criterion.

Both pro-environmental innovation and business literature proved useful in this study for analysing DI adoption barriers. Many of the external and internal barriers identified here reflected the typologies presented in extant innovation barrier models, which were developed from research examining a range of innovations. However, by focusing specifically on the CSA DI context, this study has provided new insights. For example, the suitability of an innovation based on the specific user context is not something that features prominently in other models, yet it proved an important determinant for DI adoption. This study also revealed comparatively high levels of satisfaction with more traditional irrigation methods, which lessens the appeal of adopting new approaches. In line with this, the farmers' level of prior experience with DI often dictated whether this innovation represented an incremental or more radical shift in agricultural practice; with the latter conveying greater risks.

In Australia, sustainability does not appear to be the key driver of water-resource-related policies. Its government response to water scarcity challenges has instead included investment in desalination plants, which are not only resource-intensive, but create significant negative environmental impact (Elimelech and Phillip, 2011). It would therefore seem that a paradigm shift is required for sustainability to be integrated into such policies, which must include sustainability goals outside of those relating to water delivery and food production output. Without policy change including broader recognition of sustainable development goals, it is unlikely that adoption of the DI will significantly increase.

Researchers, organisations and other stakeholders that recognise the need for water sustainability initiatives should lobby government and the agricultural sector to encourage change. Manufacturers and consumers can also encourage best practice farming by demanding food sourced and produced in a sustainable, water-efficient manner.

In conclusion, while this study has focused on DI adoption in Australia, many of the observations and innovation barriers identified should transcend contextual boundaries. The new barriers to the adoption of sustainable innovation framework should therefore be useful in informing sustainability-innovation-related research, policies and practices elsewhere. Future research might adopt the same mixed-method approach to test the applicability of this framework to other CSA innovations, as well its relevance to wider production innovation and sustainability contexts.

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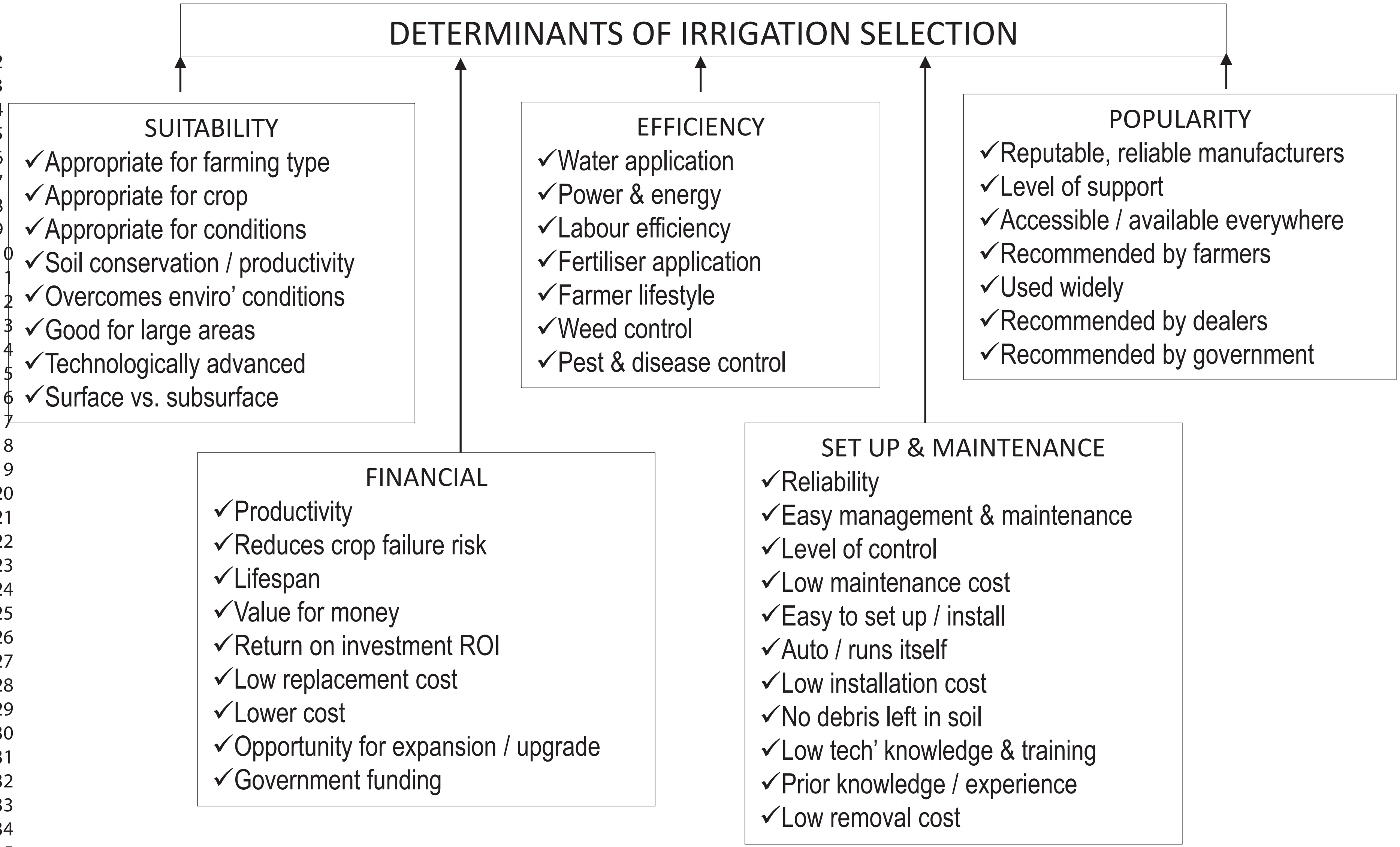
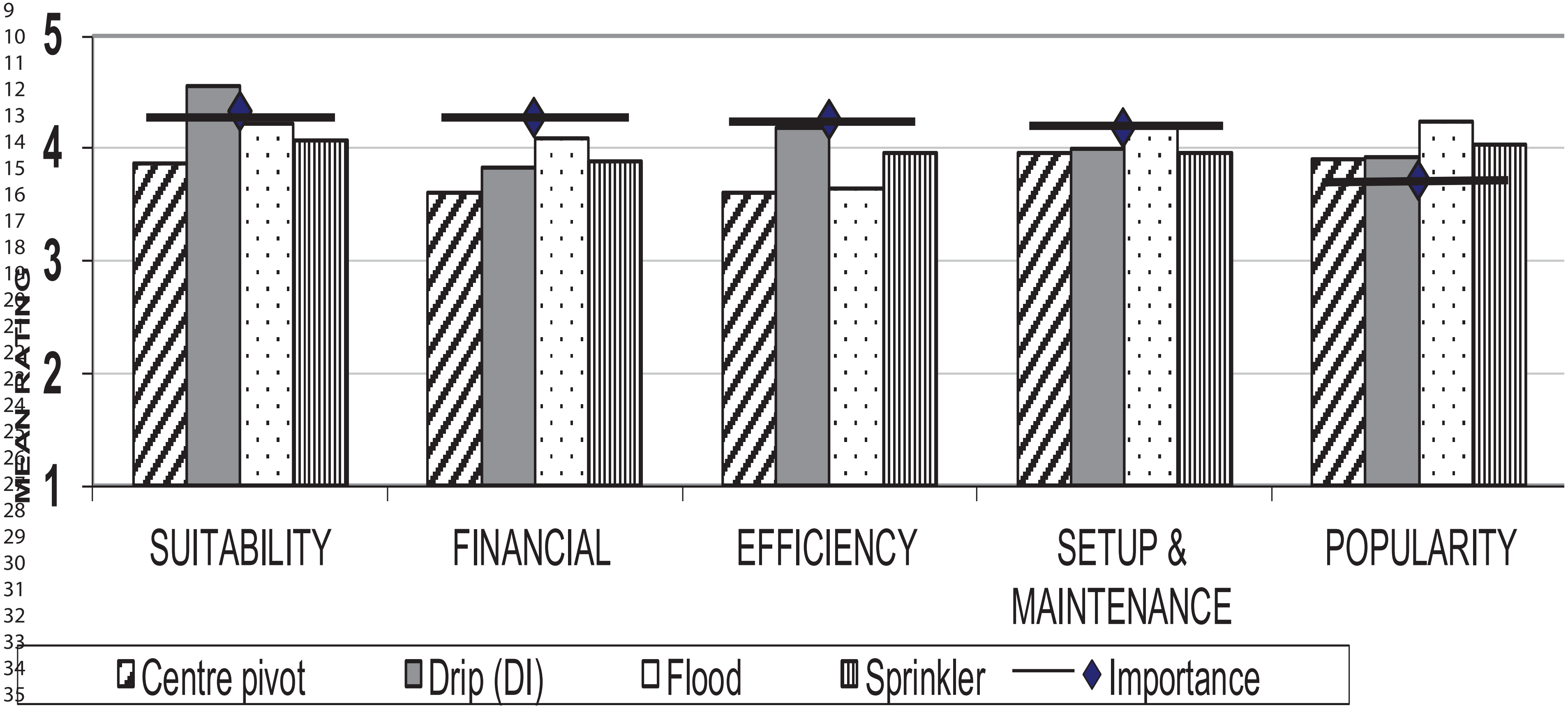

DETERMINANTS OF IRRIGATION SELECTION
SUITABILITY
✓Appropriate for farming type
✓Appropriate for crop
✓Appropriate for conditions
✓Soil conservation / productivity
✓Overcomes enviro' conditions
✓Good for large areas
✓Technologically advanced
✓Surface vs. subsurface
EFFICIENCY
✓Water application
✓Power & energy
✓Labour efficiency
✓Fertiliser application
✓Farmer lifestyle
✓Weed control
✓Pest & disease control
POPULARITY
✓Reputable, reliable manufacturers
✓Level of support
✓Accessible / available everywhere
✓Recommended by farmers
✓Used widely
✓Recommended by dealers
✓Recommended by government
FINANCIAL
✓Productivity
✓Reduces crop failure risk
✓Lifespan
✓Value for money
✓Return on investment ROI
✓Low replacement cost
✓Lower cost
✓Opportunity for expansion / upgrade
✓Government funding
SET UP & MAINTENANCE
✓Reliability
✓Easy management & maintenance
✓Level of control
✓Low maintenance cost
✓Easy to set up / install
✓Auto / runs itself
✓Low installation cost
✓No debris left in soil
✓Low tech' knowledge & training
✓Prior knowledge / experience
✓Low removal cost

Figure II Mean importance and irrigation method performance ratings along core dimensions

Importance: 1 = Not at all important and 5 = Absolutely essential
Performance: 1 = Extremely poor and 5 = Extremely good



Base: Importance=148, Centre pivot=26. Drip=39, Flood=56. Sprinkler=27

Table I Primary DI advantages and adoption barriers / disadvantages, in order of frequency of mention (Based on 46 depth interviews with agricultural stakeholders)

Advantages of DI	DI adoption barriers / disadvantages
Less water used or wasted	Installation/upfront setup cost
Higher yield – improved productivity/quality	Running cost – power
Less fertiliser used, or wasted	Maintenance costs
Uniform targeted fertiliser delivery	Maintenance complexity
Uniform targeted water delivery	System management required
Less power and energy used	More complex/technical
Better return on investment	Lack of knowledge
Less labour required	Reluctance to change
Automation, can run the system remotely	Not suitable for some crops/conditions
Better monitoring	
Better farmer lifestyle	Water quality and blockage issues
	Other irrigation methods preferred
	Lack of confidence in drip irrigation
	Can't see subsurface irrigation lines

Table II Likelihood of DI usage in the next 12 months (Based on a survey of 148 Australian farmers)

	Main irrigation type currently used				Total n=	Total %
	Centre pivot	*DI*	*Flood*	*Sprinkler*		
Definitely will not use	17	3	46	17	83	56
Probably will not use	5	0	4	3	12	8
Possibly	0	0	1	0	1	7
Probably will use	2	1	2	3	8	5
Definitely will use	2	35	3	4	44	30
TOTAL	26	39	56	27	148	100