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Abstract

Precision agriculture (PA) technologies offer a potential solution to food security and environmental challenges but, will only be successful if adopted by farmers. Adoption in China lags behind that in some developed agricultural economies despite scientifically proven benefits of PA technologies for Chinese agriculture. Adoption is dependent on farmer attitudes and perceptions towards PA technologies. An exploratory qualitative study using in-depth interviews was conducted with Chinese arable farmers (n=27) who manage commercial, family-owned farms in two Chinese provinces (Hebei and Shandong). The intent was to explore the perception of this important and growing sector of the farming community towards adoption of PA technologies. A thematic analysis revealed 5 central themes to have emerged from the data, these were: "*socio-political landscape", "farming culture", "agricultural challenges", "adoption intentions (barriers/facilitators)" and "practical support mechanisms".* All were likely to influence the level and rate of adoption of PA technologies amongst family farmers in China. The research revealed an openness to the potential of PA technologies amongst family farmers, although there was heterogeneity in the perceptions of PA technology and willingness to adopt. Improved rates of adoption will be achieved by reducing the barriers to adoption, including the need for low-cost PA applications that can be applied at small scale, improved information provision, financial support mechanisms including more accessible subsidies and credit, and reliable, regulated and affordable service provision.

Keywords: farmer perceptions, adoption motivations, China, risk, benefits, policy implications

Declarations

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1. Introduction

1.1. Overview

Precision agriculture (PA) is being implemented globally as an agricultural management strategy across many agronomic contexts and is an approach "that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production" (International Society of Precision Agriculture, no date). The use of PA technologies in particular is aimed at ensuring sustainable intensification across all aspects of agricultural production, whilst reducing its environmental impacts (Gebbers & Adamchuk, 2010; Li et al., 2020). Their utility in relation to improved food security and environmental protection has been well documented (Cheema & Khan, 2019; Gebbers & Adamchuk, 2010; Mikula et al., 2020; Phillips, 2014). PA can be viewed as a 'toolkit' from which farmers choose what they (perceive to) need (Lowenberg-DeBoer & Erickson, 2019). Although a clear definition of what technologies are included in PA is still required (Lowenberg-DeBoer & Erickson, 2019; Say et al., 2018), broadly technologies can be classified into data collection technologies, including, global navigation satellite systems (GNSS) (Stombaugh, 2018), remote sensing technologies (Wachowiak et al., 2017) and soil sampling and mapping, data processing and decision-making technologies e.g., geographical information systems (GIS) and sensor networks (Jawad et al., 2017) and application technologies, including, variable rate technologies (VRT) (Wandkar et al., 2018).

PA technologies are designed to deliver three fundamental benefits to farmers and society: 1) economic benefits through reductions in farm expenditure *via* the controlled application of agricultural inputs (Tey et al., 2017); 2) increased production levels due to targeted management of in-field (or intra-animal) variability (Schimmelpfennig, 2016) and; 3) environmental benefits through the precise application of agrichemical applications (such as fertilisers, pesticides or antimicrobials), which will also increase compliance with national/global environmental legislation (Ma et al., 2014). Uptake in low resource economies falls behind more advanced agricultural economies despite the considerable potential to increase efficiencies in production, to improve rural livelihoods and inclusion and participation in global markets (Deichmann et al., 2016; Pathak et al., 2019). There is scope for the adoption of small, low-cost PA technologies and there are examples of PA uptake in Argentina, Brazil, India and South Africa (Finger et al., 2019; Say et al., 2018). Rates of PA adoption vary considerably globally, with uptake in China recognised to fall significantly behind Europe and Australia (Chen et al., 2014; Say et al., 2018). The culmination of social, environmental, political and production pressures identify China as a country with significant potential to benefit from the adoption of PA technologies and make the country an interesting and timely example for their adoption (Li et al., 2020; Li et al., 2019).

1.2 The potential of precision agricultural technologies in China

Intensification of production has historically dominated Chinese agriculture policy (Hauptman, 2018). Chinese agricultural production is subject to interacting pressures including, *inter alia*; dwindling natural resources, environmental degradation, climate change and over-reliance on agrichemicals (Cui et al., 2014; Hauptman, 2018). Social pressures including population growth, rapid urbanisation and increasing socio-economic rural/urban divides, and changing consumer preferences (Cui et al., 2018; Qian et al., 2016).

A variety of policy initiatives have been introduced over the last 50 years to address China's food security pressures, and modernise its approach to agriculture (Zhong & Zhu, 2017). These include reducing the ecological impacts of farming by introducing a cap on fertiliser usage, (Lin, 2020). Widespread agricultural technology adoption is recognised as having a fundamental role to play in the modernisation process, and will contribute to securing China's future economic growth (Liu et al., 2013). It represents a key component of China's 13th, Five-Year Plan[1] and features in the national 863 Programme (State High-Tech Development Plan). PA is currently concentrated on large-scale commercial agricultural operations, which only account for 0.0007% of all farms in China (Clark et al., 2018). This may be in part due to lack of IT infrastructure to support PA technologies, coupled with a lack of capacity both within the industry and intended population, to exploit their potential at scale (Li et al., 2019).

1.3 Agricultural landscape in China

The Chinese agricultural landscape is characterised by the fragmentation of farmland and a preponderance of small subsistence farms (Table 1), This is a legacy of the former Household Responsibility System (HRS) that represented a move away from collective farming and gave individual households autonomy over allocated plots for substance farming, commonly known as responsibility land (Table 2 summarises key Chinese agricultural policy reforms and their impacts). Agricultural policy reforms introduced in the 1990's and early 2000's aimed to radically transform the agricultural landscape by creating formalised markets for land transfer to facilitate larger scale, commercial framing to meet food demand (Sausmikat, 2015). In creating land markets, the value of agricultural land and the agri-business sector increased, whilst also increasing the suitability of the land for the adoption of advance agricultural technologies. This provided an opportunity for some farmers to leave agricultural production and pursue alternative employment, whilst for others, renting additional land from others provided a means of producing commercially. "Family farms" in this sense are farms that are operated at commercial scale but are predominantly operated by a single family. Therefore, these farms are comprised of a family's responsibility land plus land they have

[1] China's Five Year Plans represent the countries social and economic development initiatives. During this work China was in the 13th five year planning period that covered 2016–2020.

tenanted from others. In 2016, 30.7 million ha (460 million mu) of land had been transferred in this way, accounting for more than a third of all total agricultural land area. This indicates that small non-commercial farming is diminishing and there is an observable growth in the number of larger, commercially viable "family farms" (Xinhuanet, 2020), although these still only accounting for a small proportion of total agricultural holdings (approximately 0.33%) (Xinhuanet, 2020).

Table 1: Characterization of Chinese farms at different scales

Scale	Description	Number (households)	Percentage of farms in China	Average farm size (ha)
Small farms	Very small operations for personal food production	266.07 million	99.2%	0.41
Farm cooperatives	Collaborations between groups of family famers to increase scale to improve commercial output and economic functioning	1.39 million	0.52%	
Family farms	Farms at commercial scale (typically) managed and predominantly operated by a single family	0.88 million	0.33%	13.38
Large government/State managed farms	Typically state run farms where it is easy to adopt PA in line with emerging Chinese policy	1789	0.0007%	

Table reproduced with permission from Clark et al. (2018)

Whilst land transfer policies have been a fundamental component of China's agricultural modernisation planning (Table 2), for famers that have acquired land, it creates additional challenges and presents further barriers to PA adoption. For example, farmers are managing land to which they have no historic connection or may be farming fragmented and discontinuous plots rather than larger, contiguous management areas. This hinders the adoption of more sophisticated PA technologies that are currently designed for large continuous land areas, making application on small plots challenging (Clark et al., 2018; Kendall et al., 2017; Li et al., 2019). Moreover, the creation of land markets has aided socio-economic trends, including increased levels of rural to urban migration, allowing farmers to transfer responsibility land to others to pursue higher earning employment opportunities in cities (He & Ye, 2014; Liang & Wu, 2014; Liu, 2014). The result of which has increased ageing demographics in rural communities, reduced agricultural labour pools and increased associated labour costs.

Table 2: Historic agricultural policies and their impact

Policy	**Description**	**Impact**

Household Reasonability system (HRS)	HRS represented a move away from collective farming (team-based system) and gave individual households responsibility for their land, creating millions of smallholders. Under the HRS farmers had limited ownership rights over the land that they famed and no formal means of transferring ownership to others.	Abolishing the HRS system, increasing tenancy duration and creating land markets has facilitated land-transfer, increased the value of agricultural land and the agri-business sector, whilst also increasing the suitability of the land for the adoption of PA technologies. Although this has resulted in farmers managing land to which they have no historic connection or may be farming fragmented and discontinuous plots rather than larger management zone. (He & Ye, 2014; Liang & Wu, 2014; Liu, 2014; Qian et al., 2016).
Land tenure	Short tenures (2-3 year base) resulted in lack of stability in farming, rural poverty, high rates of rural-urban migration, and limited finical investment by farmers in their land and production methods (Gao et al., 2017). These were extended in the 1990's to increase farmer's stability improve scope for investment and prosperity through farming.	
Land transfer	In 2002, a land transfer market in China was formalised, allowing farmers to transfer land during their land lease periods, promoting the amalgamation of small farms into larger management zones.	

(Adapted from Clark et al. (2018))

1.4 Adoption motivations and the importance of stakeholder engagement

The adoption of PA technologies requires farmers to change their existing and often historic, agricultural practices. There is a broad literature that has explored the factors influencing farmer adoption of PA technologies, although much of the research conducted to date has explored drivers of uptake in developed agricultural economies, predominantly North America, Europe and Australia (for reviews see Hasler et al., 2017; Pathak et al., 2019; Tey & Brindal, 2012). Limited research has been conducted to understand the adoption trajectories of PA technologies in developing agricultural economies and to the best of the authors' knowledge, this includes research conducted with Chinese farmers to explore their attitudes towards and the factors influencing more widespread adoption in Chinese agriculture. An overview of research that has sought to identify the factors influencing farmer and landowner uptake of PA technologies is provided in Table 3 and highlights three primary groupings of factorial influences (internal, external and technology) and the geographical region where each research factor has been identified to influence adoption.

It is unlikely that farmer adoption motivations are influenced by one single factor, rather, they are driven by a combination of each of these three aforementioned influences, which are also likely to be context specific and subject to change over time. Adoption is also potentially dependent on the level of behavioural change required by the adopter, i.e., the extent to which a new technology is "disruptive" (i.e. requiring a fundamental change to their existing behaviour) or "continuous"(i.e. requiring incremental behaviour change or offering benefits that complement existing farming practice) (Hasler et al., 2017). Continuous technologies are more easily integrated into existing practices as they do not require significant behaviour change (Clark et al., 2018; Kendall et al., 2017).

118 ***Table 3: Factors influencing PA adoption***

	Factor influencing adoption	Description	Europe	North America	Australia	Low resource economies	Global perspective
Internal factors	Gender	Males are less risk adverse than females. In developing countries often female farmers are left to manage farmland whilst male farmers seek alternative employment which can exacerbate low levels of uptake.				(Mondal & Basu, 2009; Say et al., 2018)	
	Age	Older farmers are likely to be more risks adverse than younger farmers, less willing to innovate and have shorter planning horizons. They are more reluctant to engage with new technologies owing to the reduced likelihood of paying off investments reduced time periods over which they can witness benefits accrue.	(Paustian & Theuvsen, 2017)		(Daberkow & McBride, 2003)	(Adesina & Baidu-Forson, 1995; He & Ye, 2014; Liang & Wu, 2014; Say et al., 2018; Zhang et al., 2016)	(Hasler et al., 2017; Tey & Brindal, 2012)
	Education	Educated farmers more likely to meet the human capital requirements for adoption. Farmers educated to degree level are more likely to adopt such technologies as training becomes part of higher education curriculums. Younger farmers are more likely highly educated and therefore more willing to innovate.	(Paustian & Theuvsen, 2017; Reichardt & Jürgens, 2009)	(Robert, 2002)		(Say et al., 2018)	(Tey & Brindal, 2012)
	Skills and experience	Adoption of unfamiliar PA technologies requires farmers to invest in learning new skills (i.e., using information systems and interpreting data outputs). PA technologies may be perceived to be complex and difficult to use. Agricultural workers may give low prioritisation to the analysis of data over practical tasks (i.e. harvesting). Longitudinal data collection is often	(Paustian & Theuvsen, 2017; Reichardt & Jürgens, 2009)	(Adrian et al., 2005; Daberkow & McBride, 2003; Kutter et al., 2011; Robert, 2002)	(Lamb et al., 2008)	(He & Ye, 2014; Jin & Jiang, 2002; Say et al., 2018)	(Chen et al., 2014; Tey & Brindal, 2012)

		required, requiring staff retention or at least acquisition of new staff with appropriate skills. Trained and skilled agricultural workers may be limited in rural areas.				
	F**arm size**	Larger farms are more likely to adopt PA technologies owing to increased levels of awareness and ability to absorb costs and associated risks. Some PA technologies (i.e. variable rate technologies and remote sensing) are likely to be unsuitable for small farms	(Kutter et al., 2011; Reichardt & Jürgens, 2009) (Paustian & Theuvsen, 2017; Schimmelpfennig & Ebel, 2016; Winstead et al., 2010)	(Adrian et al., 2005; Daberkow & McBride, 2003)	(He & Ye, 2014; Mondal & Basu, 2009; Wainaina et al., 2016)	(Hasler et al., 2017; Tey & Brindal, 2012)
	Farmer values and needs	Innovation characteristics and the extent to which they reflect farmer values and meet their individual needs is an important predictor of engagement and adoption.	(Kernecker et al., 2020)			
	Land ownership	Land ownership increases farmer security and promotes willingness to invest in new technologies and management practices. Farmers that own their land are more likely to manage land in a more favourable way tenanted land and this has been identified to incentivise PA adoption.		(Robert, 2002)	(Dean & Damm-Luhr, 2010; Gao et al., 2017)	(Hasler et al., 2017)
	Risk and benefit perceptions	The primary benefits of PA may be difficult for the farmer to quantify. Perceived risk within rural communities for negative impacts to rural communities and erosion of traditional agricultural practices, cultures, and socio-demographic composition.	(Reichardt & Jürgens, 2009)	(Plant, 2001)	(Hansen & Gale, 2014)	

		New technological innovations are likely to be perceived as being riskier than traditional practices.					
	Resources and access to credit	Access to credit can stimulate the adoption of high cost innovations and speed up the adoption process.			(Hudson & Hite, 2003)	(Wainaina et al., 2016; Wossen et al., 2015)	(Hasler et al., 2017)
	Involvement in external groups (i.e. cooperatives)	Farmer involvement with external groups such as cooperatives, advisory councils and associations provide a source of information and knowledge exchange and can stimulate interest in new technologies and farming methods and encourage trail and adoption.			(Robertson et al., 2012)	(Ju et al., 2016; Tey et al., 2014)	(Hasler et al., 2017)
	Regulations	By making adoption mandatory. regulations prompt adoption and can accelerate the process.					(Hasler et al., 2017)
	Observability and trialability	Benefits need to be observed and experienced by farmers, which supported through trail in order to improve acceptance. Evidence also suggests that observability of use to peers is also an important motivator of adoption.		(Heiniger et al., 2002; Kernecker et al., 2020)	(Hayman et al., 2007; Kuehne et al., 2017)	(Zhang et al., 2016)	(Hasler et al., 2017)
	Support	The quality of support given throughout the purchase acquisition through to implementation process has a significant influence on adoption and sustained use of a technology. Support is required at the point of purchase (identification of suitable technologies) but is also required to continue to beyond purchase and training, education and after care service to adopted technologies.		(Lamba et al., 2009; Weber & McCann, 2015)	(Kuehne et al., 2017; Robertson et al., 2012)		(Hasler et al., 2017)
External factors	Information and knowledge exchange	Quality and quantity of information and support offered to farmers is important driver of adoption, PA technologies are complex and typically require	(Busse et al., 2014; Reichardt & Jürgens, 2009;	(Daberkow & McBride, 2003; Plant, 2001; Watcharaananta	(Jochinke et al., 2007)	(Chang & Tsai, 2015; Sausmikat, 2015; Say et al., 2018) .	

		consultation. Those with past experience of engagement with agricultural consultants are more likely to adopt, Farmers that obtain information from farm dealers, crop consultants, university extension, other farmers, trade shows, the internet, and/or news media were more likely to adopt complex innovations. Different sources of information are important at different stages of the adoption process i.e. mass media is important in the awareness phase whereas technical know-how provided by service providers important in the decision-making process. Farm advisory specialists and agronomy advisors can be limited in availability and/or lack knowledge and training in specialist approaches and are therefore unable to provide adequate support to farmers.	Winstead et al., 2010)	pong et al., 2014)			
	Compatibility with existing systems and production methods	Compatibility within existing technology is important particularly for more advanced PA technologies. Incompatibility of software and hardware from different PA manufacturers is shown to be a barrier for adoption.	(Reichardt & Jürgens, 2009)	(Adrian et al., 2005; Hudson & Hite, 2003)		(He & Ye, 2014)	(Hasler et al., 2017)
	Technology task- fit	PA technologies are predominantly computer-based applications and therefore require proficiency or a minimum comprehension of these technologies. There is a role for adapted PA approaches that apply the principles of PA but in a low technology context for small holder farmers.	(Busse et al., 2014; Reichardt & Jürgens, 2009)	(Adrian et al., 2005; Aubert et al., 2012; Batte & Arnholt, 2003; Daberkow & McBride, 2003; Kutter et al., 2011; Watcharaananta	(Jochinke et al., 2007; Robertson et al., 2012)	(Galindo et al., 2012; Li et al., 2020; Tey & Brindal, 2012)	(Hasler et al., 2017)

			pong et al., 2014)			
	Cost (i.e. financial investments)	Capital costs associated with PA technologies can be high and can carry greater risks than more traditional management approaches. High costs of PA technologies may disproportionately favour larger farms. Additional costs associated with extension services required to interpret data and formulate management plans can be prohibitive. Moreover, whilst the costs are clear, the financial benefits of PA technology can be difficult for farmers/landowners to quantify and there is mixed evidence on the profitability of PA technologies.	(Kutter et al., 2011; Reichardt & Jürgens, 2009; Robert, 2002)	(Heiniger et al., 2002; Hudson & Hite, 2003; Plant, 2001)	(Hansen & Gale, 2014)	(Chen et al., 2014; Tey & Brindal, 2012)

119 Source : Author compiled

Research has been conducted to develop PA applications and evidence their benefits for Chinese agriculture (see for example (Gao et al., 2017; Han et al., 2019; Huang et al., 2018; Jihua et al., 2014; Peng et al., 2014; Zhao et al., 2017)). However, there is limited social research conducted in China that specifically explores the factors influencing the adoption of PA technologies, the extent to which existing factors apply in the Chinese agronomic, policy and cultural context. This research therefore adopted an interpretivist approach, using in-depth qualitative interviews to explore the views of Chinese family farmers, generate nuanced understandings of their perceptions of, and attitudes towards, PA and identify the factors that promote or inhibit adoption. The qualitative approach permitted a comparative exploration of factors and concepts that have been shown to influence uptake globally (Table 3) and explore the extent to which these have relevance to family farms in the Chinese context. Adoption of technologies, particularly where current levels of adoption are low, requires the inclusion of stakeholders in the research and development process (Galindo et al., 2012; Raley et al., 2016). This ensures that technologies align with the needs, priorities and preferences of end-users, avoid any unintended consequences, and increase adoption (Clark et al., 2018). Therefore, understanding the factors influencing adoption from the end-user perspective is important for scientists, researchers, educators and agricultural extension services provider who are designing, trailing and suppling PA to Chinese family farmers. It also has wider relevance to those with an interest in developing agricultural economies and small-scale farming. This will support the development of PA approaches and the design of initiatives that promote widespread uptake (Wossen et al., 2015).

Three primary research aims were identified for exploration in the qualitative study:

1. To identify current agricultural challenges and the corresponding solutions from the perspective of Chinese farmers;
2. To understand Chinese farmers' perceptions of, and attitudes towards, different PA technologies and;
3. To explore the barriers to, and facilitators of, Chinese farmers' adoption of agricultural technologies and services.

Methodological Approach

2.1 Research development

Qualitative in-depth interviews were chosen for their ability to explore participant experiences. This method is suited to exploratory studies and the method is recognised to have cross cultural validity (see Kendall et al. (2017) (Lofland & Lofland, 1971)). Whilst the approach does not allow for the generalisation of findings to wider populations, it does provide the opportunity to deeply engage with potential end-users and to unpick the factors that motivate, support, or inhibit adoption (Bryman,

155 2016). An initial discussion guide informed by the literature and theories of technology adoption was
156 developed. The study protocol was also informed by exploratory qualitative research conducted by the
157 lead authors with Chinese farmers and Chinese agricultural policy makers, with both used to develop
158 an understanding of contextual issues for more detailed exploration (Kendall et al., 2017). Interviews
159 were semi-structured and conducted in English and simultaneously translated into Mandarin or the
160 local dialect. A semi-structured approach provides both focus on core topics and flexibility based on
161 participant responses, and is particularly useful when multiple researchers are conducting interviews
162 to ensure consistency (Bryman, 2016). Ethical approval for the project was granted by Newcastle
163 Ethics Committee (March 2018).

164 A discussion guide was piloted to check accuracy, the suitability of the question areas and
165 comprehension of meaning and timings, with 10 Chinese farmers located in the Beijing region in
166 November 2017[2]. The pilot revealed that participants found it particularly difficult to discuss in any
167 detail, commonly available PA technologies owing to their limited awareness and experience of these
168 technologies. Pilot interviews were dominated by discussion of demographics, farming practices and
169 agronomic challenges. In order to ensure construct validity, these findings were used in conjunction
170 with the study aims (Yin, 2014) to prepare a revised (final) discussion guide for data collection (April
171 2018). The discussion guide focused on several key concepts identified within the literature to
172 potentially impact adoption of agricultural technologies, including: the challenges faced by family
173 farmers in China, their level of existing technology adoption, perceived level of technology adoption
174 readiness and potential mechanisms to support PA technology adoption amongst family farmers.
175 Contextual demographic farm information was collected by questionnaire prior to commencing the
176 interview. The final discussion guide contained five broad question areas (Table 4).

177

[2] Separate ethical approval was obtained for the pilot work (July 2016).

178 ***Table 4: Discussion guide content; family farm managers***

Section	Section title	Questions (broad focus)
1	Your farm and agricultural policy in China	• Changes to land and crops. • Duration of time on land lease. • Support or benefits received from cooperative.
2	Farming practices and challenges	• Changes (over the last 10 years) and challenges to farming practice. • Strategies to address challenges and additional needs.
3	Technology adoption	• Perceived technology readiness (Rogers, 1962). • Current level of technology adoption. • Adoption motivation(s). • Benefits/risk factors preventing adoption. • Required improvements to support adoption.
4[b]	Mechanisms to support technology uptake	• Agricultural policies, • Financial incentives, • Agronomic services, • Knowledge exchange, • Agricultural extension • Others
5	Summary/ wind down	Opportunity to review and add to the discussion.

179 [a] Available from corresponding author on request.

180 [b] Denotes additional section of questions added post pilot.

181

182 Question probes were included to prompt further inquiry, and interviewers were encouraged to
183 investigate interesting lines of enquiry verbally. Prompt cards were used as discussion aids,
184 specifically in sections 3 and 4 of the discussion guides (technology adoption and mechanisms to
185 support uptake). The cards were particularly useful in helping to familiarise participants with a range
186 of technologies from simple to more advanced PA technologies e.g., Remote sensing, GNSS and
187 VRT). All materials were translated from English to Mandarin and back translated. Each interview
188 lasted approximately one hour. All interviews were recorded *verbatim* and were translated from
189 Mandarin to English for analysis.

190 ## 2.2 Recruitment and sample

191 Data were collected in two primary locations, Hebei (Shijiazhuang) and Shandong (Zibo). These
192 represented regions in the North China Plain predominated by family farms and where local project
193 partners had demonstration sites. Recruitment and translational support were also provided by the
194 project partner NERCITA. Purposeful sampling was adopted to identify "family farmers" that would
195 be able to talk with experience in relation to the study aims (Palinkas et al., 2015). Selection criteria
196 ensured that participants were, 1) part of the farming community in Hebei (Shijiazhuang) and
197 Shandong (Zibo); 2) were the principle farmer of their land (i.e., farm manger); 3) had at least one
198 year's farming experience within these locations, and; 4) their farm was classified as a 'family farm'
199 (i.e., operating at a commercial scale but managed and primarily operated by a single family).

Consistent with the exploratory nature of the study the final sample consisted of N=27 arable farmers across the two study locations. All participants were remunerated for their time and contribution to the research, this was in line with local practice. Consistent with methodological recommendations, interviews were conducted until data saturation was reached (Bryman, 2016).

2.3 Data analysis

Field notes were taken by the lead researchers (HK, BC) during and after the interviews were conducted. These included thoughts on the interview content and reflections on the interview and the research process itself. Thematic data analysis was supported by qualitative analysis software Nvivo (NVivo, 2016), and followed a three-stage process. First, interview transcripts were open-coded (Glaser & Strauss, 1971) and an initial coding framework was developed by the lead author (HK). Second, the coding framework was refined. Three members of the research team (HK, BC and SJ) independently coded a selection of the transcripts and compared codes against the framework. This inter-coder reliability process followed three iterations until there was agreement that the categories within the framework reflected the data. The third stage of analysis involved three members of the research team coding the full data set into the coding framework (HK, BC and SJ). Overarching themes emerging from the data were discussed and finalised.

Results

Overview

Twenty-seven interviews were conducted from 12th-19th April 2018 (n= 16 farmers with one of these also acting as research hub manager/farmer in Zibo, Shandong Province; n= 11 farm managers in Shijiazhuang, Hebei Province) (Table 5). The sample comprised of 18 males and 9 female participants (age range from 41 to 67 years). Participants had a median of 30 years farming experience (range between 3 and 50[3]). The median farm size was ~13 ha (200 mu) and ranged from ~ 0.7 to 93 ha. One farmer (participant 10) had moved to the Shandong region to establish an ecological farming business, although this was not typical of the sample. The remainder farmed responsibility land alongside land that had been transferred from other farmers. For most farmers, increases in farm size through land transfer had occurred within the last decade. Two farmers specialised in horticulture in greenhouses in addition to arable farming. Farmers planted staple crops, predominantly wheat and maize with a small proportion also planting soybean, a lower yielding but higher market value crop. A small number of farmers had diversified into the production of fruits and vegetables for which higher market values could be obtained.

[3] Data on years farming experience was not provided by 2 participants.

231 ***Table 5: Participant Characteristics***

Participant number	Location	Gender	Age	Experience (years)	Education level	Total Farm size ha (mu)	Number of years at increased farm size	Crops
1	Shandong	Female	52	30	Upper secondary education	20 (303)	2 years	Wheat, maize and Chinese yam
2	Shandong	Male	56	35	Primary education	13 (200)	5 years	Wheat and maize
3	Shandong	Male	67	45	Primary education	16 (240)	5 years	Wheat and maize
4	Shandong	Female	49	17	Lower secondary education	2 (30)	5 years	Wheat and maize
5	Shandong	Female	52	30	Lower secondary education	3.3 (50)	8 years	Wheat and maize
6	Shandong	Male	52	20	Lower secondary education	23.3 (350)	3 years	Wheat, maize and Chinese yam
7	Shandong	Female	-	-		16 (240)	21 years	Wheat and maize
8	Shandong	Male	41	18	Upper secondary education	3 (50)	3 years	Wheat and maize
9	Shandong	Male	63	45	Upper secondary education	5 (75)	7 years	Wheat and maize
10	Shandong	Male	51	3	Higher education (college)	42 (628)	3 years	Wheat, maize, watermelon, Chinese yam and green onion
11	Shandong	Female	45	8	Upper secondary	3.3. (50)	8 years	Wheat and maize

					education			
12	Shandong	Male	53	21	Higher education (bachelor's degree)	0.6 (10)	20 years	Greenhouse: cucumber, tomato, green onion, aubergine, Chinese yam and watermelon
13	Shandong	Male	61	40	Primary education	7 (105)	4 years	Wheat and maize
14	Shandong	Female	49	40	Lower secondary education	5.7 (85)	3 years	Wheat and maize
15	Shandong	Female	45	10	Upper secondary education	17.3 (260)	12 years	Wheat and maize
16	Shandong	Female	48	30	Lower secondary education	23.3 (350)	7 years	Wheat and maize
17	Hebei	Male	50	20	Upper secondary education	13.3 (200)	2 years	Wheat, maize and soybean
18	Hebei	Male	55	20	Upper secondary education	10 (150)	-	Wheat and soybean
19	Hebei	Male	55	10	Higher education (master's degree)	28 (420)	9 years	Wheat and maize
20	Hebei	Male	53	35	Upper secondary education	2.6 (40)	Over 10 years	Wheat, maize, soybean and grape
21	Hebei	Male	43	20	Upper secondary education	34.2 (513)	26 years	Wheat, maize, soybean and peanut

22	Hebei	Male	64	50	Upper secondary education	13.3 (200)	8 years	Wheat, maize and soybean
23	Hebei	Male	58	30	Upper secondary education	13.3 (200)	3 years	Wheat, maize and soybean
24	Hebei	Male	59	-	Higher education	1.3 (20)	-	Grape, peach and vegetables
25	Hebei	Male	61	40	Upper secondary education	8.3 (125)	-	Wheat
26	Hebei	Female	58	30	Upper secondary education	26.7 (406)	Over 10 years	Wheat and maize
27	Hebei	Male						

Note: Some missing data where participants did not fully complete the demographic questionnaire.

Emergent themes

Five central themes emerged from the data "socio-political landscape", "farming culture", "agricultural challenges", "adoption intentions (barriers/facilitators)" and "practical support mechanisms". These themes were representative of a mix of internal/external and technological factors that were all likely to influence the level and rate of adoption of PA technologies amongst family farmers. The findings are discussed under these theme headings and linkages between the respective themes explored and supported by illustrative quotes from participants that have been adjusted to correct English whilst maintaining meaning.

Figure 1: Emergent themes, sub-themes and linkages

INSERT FIGURE 1 HERE

Socio-political landscape

Societal and political influences were shown to shape Chinese agriculture and influence the awareness and adoption of PA technologies amongst participants. Despite policy directives aimed at modernising the nations approach to agricultural production, including those aimed at increasing production efficiencies and reducing the environmental impacts of production, limited consideration was given to the wider environmental impacts of agricultural production by participants. There was limited reflection given to the personal responsibilities of farmers to reduce the environmental impact of farming. Farmers were production orientated, welcoming opportunities to increase farm scale and intensify production to counter low market values for yields. All participants had benefitted from the opportunity to transfer land, noting this to have increased the scale of their production significantly over the last decade.

Participants recognised that *'in practical terms it [acquiring land through transfer] is not that easy'* (participant 19). Competing Chinese government policy agendas were identified to affect farming communities with implications recognised for the rate of land transfer, farm size growth and impact upon prosperity that could be derived from agricultural production. In parallel with the need to increase agricultural productivity and sustainability, the Chinese government is committed to reducing the environmental impacts of agricultural production by significantly reducing the countries usage of agri-chemicals alongside mitigating the degradation of the nation's forests (a consequence of a result of rapid population growth). Many respondents noted government policies aimed at forest conservation and the restoration of forest ecosystems that have been initiated (e.g., Sloping Land Conversion Program (SLCP) and the National Forest Protection Program (NFPP)) (Bennett, 2008; Rodríguez et al., 2016; Wenhua, 2004). Through the SLCP scheme, public payments are available to rural households to convert agricultural land to

‘ecological forests’ (for timber production), ‘economic forests’ (orchards or forests with medicinal value) or to grassland:

> *“Our country wants farmers to cultivate forests, so they won’t have as many fields to cultivate [crops]” (participant 22)*

> *“You are not able to expand it [farm land]. You know... look at my geographic location, now it is all covered with trees, [I] cannot transfer anymore [land].” (participant 25)*

Participants located in Shijiazhuang noted the impact of these schemes on their ability to increase farm size, with many farmers choosing to convert land to forest conservation, as the subsidies received were greater than profits that could be made from agriculture. This reduced land availability increased the costs of land available for transfer and, was noted to contribute to the fragmentation of farm plots. This policy initiative was identified to be a primary factor preventing farmers from increasing farm size and scale of production. Farm scale was noted to be a significant barrier to the suitability, applicability and likely adoption of PA technology on farm.

> *“You can earn more than 1000 yuan for planting trees on 1 mu [of land] but only 100s of yuan for crops.” (participant 26)*

Farming culture

Despite increased farm size, farmers maintained a traditional low level of mechanisation and operated. short-term management plans for their farms, with none exceeding five years, possibly attributable to the short length and informality of land transfer contracts. Most farmers demonstrated productionist orientations and were driven primarily by the need to increase the profitability of their farms, in direct response to market challenges. Economic drivers and incentives to increase farming profits were important motivators behind decisions made on farm, including decisions regarding the adoption of PA technologies. Decisions to increase land ownership and the scale of farm operations via land transfer were driven by the need to increase profitability given the broad recognition that *“you earn very little in agriculture” (participant 23).* A small proportion of farmers had diversified production, producing speciality produce that commanded higher market values. The diversity of crops grown across the regions was identified to present challenges to technology design and logistical challenges in relation to delivering agri-extension support services.

> *“Farmers just grow crops that have a higher market value. So this may, bring a big challenge to agricultural extension services. Because the crops planted in this region might vary…so for agricultural extension and service providers, it means that there isn't a uniform technology that can be provided. It's quite fragmented” (participant 27)*

Farmers only made links to the production efficiencies and economic benefits of PA technologies with limited consideration of the potential environmental co-benefits. There was limited evidence of

active environmentally regenerative farm and land management practices and equally limited recognition of the potential role that PA could play in helping farmers to improve the environmental impact of agricultural production and meet incoming national legislation and agri-chemical usage targets. Participants showed limited awareness of future policy initiatives and legislation, including the cap on agrichemical use and conversely reported significant increases in their usage, necessitated by the need to guarantee yields to improve economic prosperity from farming.

Agricultural challenges

Various interlinked challenges acted as barriers to PA adoption but also represented opportunities for the development of PA applications to address farmer needs. Challenges were linked to economic, socio-demographic, political, landscape-related, infrastructural and environmental factors. Low economic returns combined with steadily increasing input and labour costs were further confounded by difficulties in accessing markets. The socio-demographic composition of rural communities had changed in recent decades, as a direct consequence of significant economic growth in urban conurbations, which had resulted in considerable rural-urban migration of younger members of the community for educational and employment opportunities. Others had used land transfer legislation as an opportunity to rent responsibility land and had sought higher paid employment in cities.

> *"it's not worth it to farm just 1 or 2 mu of land. The younger generation would just leave the village and find jobs outside, especially the men…So, of course young people don't want to farm… Farming is hard and you can't make much money out of it" (participant 23).*

> *"It takes time and investment to achieve high levels of mechanization. Now we face many challenges in terms of land transfer…Given another 10 to 15 years, it would be easier to gather farmland because few people of the next generation will engage in farming." (participant 19)*

The average age of farmers, as well as the scarcity of agricultural workers, increased the cost of labour, particularly at peak periods of the agricultural calendar (i.e. harvest).

> *"The changes have been huge. I have engaged in agriculture for over 30 years. A prominent change in the past ten years has been the increase in labour costs. Seed costs as well" (participant 19)*

Environmental challenges were primarily associated with climatic uncertainties. Many reported drought impacts due to limited underground water supplies, inadequate well facilities and the reliance on inefficient and outdated irrigation methods, which are exaggerated by inefficient irrigation solutions. Lodging of crops in conditions of rain, hail and wind was also reported as resulting in significant crop loss, exacerbated by a lack of space for, and the cost of, storing crops.

"One of the biggest problems is irrigation. Suppose there was a heavy rain in the fields, I don't need to irrigate for a period of time. But when you discover it needs irrigating, the crops are already in drought.' (participant 19)

"One of worst natural disasters here is of course the wind, and also the hail, hailstones…usually the wheat, wheat suffers the most from hail." (participant 24)

"The biggest problem is not having space for crop storage. When the weather is bad, the crops get wet and turn bad. It's rather problematic." (participant 21)

Land reforms have resulted in many farming larger farms and land that they had no historic connection, often a collection of variable small holder plots fragmented across villages. This reduced the suitability of many precision farming technologies (typically designed for larger continuous areas):

"On my farm, I have 50-mu chunks or 40-mu chunks. But for theirs [other farmers], many fields are fragmented, 1 mu over here and 1 mu over there. That's impossible to work on.' (participant 23).

Land fragmentation occurred because of responsibility land farmers being unwilling to rent their land to others (commonly referred to as 'nail houses') or farmers adhering to policy pressures and cultivating their land for alternative purposes e.g. converted to forestry or grassland. Rapid farmland expansion created additional problems linked to the ability to invest in adequate infrastructure, such as storage for harvested crops, and more efficient methods of irrigation as noted. There was an underlying perception that investments made on farm were not recouped in profits and short-term tenancies resulted in a reluctance to invest in farm infrastructure and supported a culture of intensification. Further challenges, such as the placement of transport infrastructure, were beyond farmers control and impacted their ability to increase farm size and the potential suitability of PA technologies were reported.

"We are confined by the landscape. 600 mu is the upper bound. We have high speed roads running along the south and the north border of the farm. There is not much space to expand." (participant 19)

Adoption intention (barriers/facilitators)

Farmers showed a willingness to consider technological solutions to the agricultural challenges faced. Intention to trial and subsequently adopt PA technologies was shaped by five factors (sub-themes) discussed below.

Awareness

Awareness and adoption of PA technology varied according to individual farmer attributes and PA applications. Farmers with formal agricultural education showed greater awareness and engagement with PA technologies and were incentivised to keep up to date in technology developments. Formally

educated farmers had a broader knowledge of PA applications and understanding of the suite of PA technologies available. Interestingly some farmers perceived themselves to be more innovative than their behaviours revealed.

One farmer reported that proximity to a demonstration farm had given them first-hand experience of PA applications. However, adoption of PA was not sustained beyond the duration of the demonstration project. The majority of farmers in the sample were aware of Global Navigation Satellite Systems (GNSS) although none owned machinery on which this was enabled. Regional promotion had resulted in the widespread awareness and adoption of some PA applications, for example UAV's were used for spot spraying of pesticides, with awareness generated through regional promotion initiatives as a resource efficient means of agri-chemical application. Participants considered this technology to be inexpensive and financially accessible for most small-scale farmers. Awareness of more advanced PA technologies, such as remote sensing and hyperspectral imaging, was extremely limited amongst participants. Where farmers demonstrated an awareness of these technologies, information was gained through informal peer-based networks, facilitated by widespread adoption of smart phones (e.g. farmers' group chat *via* WeChat[4], cooperative membership and peer networks) and television, rather than through more formal mechanisms such as research institutes, companies or agronomy services providers.

> *"I have seen drones [UAV's] used for pesticide applications but I haven't used them in my field… [I use] tractor… for ploughing and planting seeds" (participant 22)*
>
> *"Actually, I knew of it [UAV's] a long time ago."*
>
> *(Interviewer: where do you get the information? what format was this information in?)*
>
> *"Some information was via my smartphone, sometimes this was posted by my friends' in their moments on WeChat, and I also watch television programmes that have provided me with information"*[7] *(participant 10).*

Engagement

Awareness had not translated into engagement via trial or adoption for most PA technologies. Farmers relied predominantly on traditional farming machinery that were rented through machine cooperatives. The cost of technology and low profitability of farming were the primary reported barriers to trial and adoption. Farmers were unsure about where to access technologies and the availability of formal mechanisms for information provision (i.e., agronomists) beyond the information and technologies that were promoted by government sponsored annual training

[4] WeChat is a Chinese message, social media and payment app that is widely adopted across China (approximately 1 billion users).

programmes and demonstration projects. There was a perceived absence of local agricultural extension agents.

The use of UAV's for agrochemical applications was an exception with adoption common, particularly amongst farmers in Hebei. This region had been a government sponsored demonstration area where UAV's had been promoted for time and labour efficiencies. Promotion had been effective in initiating farmer engagement. Participants considered UAVs to be affordable (comparable to other technologies) and easy to implement requiring limited operator skills or training. For other technologies, uptake had not extended beyond trials within demonstration projects, with cost cited as the primary barrier to long-term adoption alongside the lack of commercial service providers.

> *"Drone spraying here is used when the crops sprout. It's used in winter, autumn and in spring. Maize as well, it's sprayed after sprouting." (participant 23)*
>
> *"That drone, I have two".*
>
> *(Interviewer: Do you provide drones to other farmers?)*
>
> *"Yes". (participant 25)*

In the absence of commercial service providers, there was evidence of collaboration and informal rental markets emerging via peers for those that could not afford to invest directly in technologies. For example, one farmer (participant 19) had adopted laser land levelling technology on his own farm and, in the absence of a company/agronomy service provider, had established a company providing this service to farmers in his region. However, this level of innovation was not typical:

> *"I have been doing laser levelling for four years, I am the first in Hebei… When I went to the United States for an agricultural inspection in 1992, I had the impression that on the irrigated land there, the water flowed neatly. When I encountered this problem, I spoke to someone and later found out about laser levelling. Then I searched it online and found that there was a company named Tianbao selling laser levellers in China at that time. [….] The company is in Beijing. I bought two levellers from this company and have used them in my experimental field." (participant 19)*

Perceived benefits

The perceived benefits centred around PA's potential for economic advantages through the reduction of inputs (e.g., time, labour and seeds and agrochemicals) whilst simultaneously increasing yield. Improvements to crop quality were considered to increase profits via the market appeal and value of products. PA technologies were recognised as time saving, reducing labour expenditure and allowing farmers to engage in alternative farm management activities at appropriate times. For example, drip irrigation was recognised to improve efficiency, allowing farmers to quickly respond to variations in weather and soil moisture. Broader factors that might influence adoption were mentioned, although economic benefits dominated discussions.

"We can see the advantages of the machines…I want all machine operations including seeding, pesticide spraying and harvesting in line with the field size. They can improve farming efficiency. I've been looking for GPS so that I can make the field banks straight." (participant 20)

Wider land management and environmental benefits of PA were not considered, including the potential of PA to reduce pesticide, fertiliser and herbicide application. The primary focus on farm profitability, and the lack of consideration of the wider environmental and land management benefits aligns with the issues explored within the theme 'farming culture', particularly the productivity focused identities and the short-term orientation of family farmers in China.

Perceived risks

The perceived risks associated with the adoption of PA technologies represented a barrier to adoption. Although there was some appreciation of the potential benefits that PA could deliver, the capital investment that such technologies require, and the perceived lack of cost/benefit information to support decision-making of adoption represented important risks,

"Just the investment is big… Too much investment." (participant 6)

"Nothing could be done without money…I couldn't use the new technology if I don't get loans." (participant 22)

"I want [to adopt]. But I have no money. We don't have things like this here. Drones [UAV's] are quite advanced here." (participant 26)

Participants were aware of government subsidies to support adoption. However, access was limited by: farm size, whether subsidies covered the full cost of adoption, the prescribed nature of subsidies issued to landowners and not managers (i.e., to the owners of responsibility land and not for land rented), and only permitted farmers to purchase technologies that were approved by the government.

Concerns were raised about the performance and reliability of technology and whether it could deliver the claims made. For example, many farmers with UAV's highlighted issues with battery life and size, chemical holding capacity and concerns around chemical evaporation.

"So the bottleneck now is, for drones [UAV's], we need a breakthrough regarding the battery issues…The battery life sucks; so far the bottleneck hasn't been resolved. Apart from that…the battery takes up the space, right…adds to the weight, so the loading capacity suffers" (participant 10).

Farmers had limited awareness about the sourcing and appropriateness of more advanced PA technologies. Many had not observed or trialled these technologies so benefits were difficult to quantify. Farmers were concerned about their ability to learn new systems, operate machinery and interpret data, and did not consider there to be adequate practical support available to aid the integration of technologies into existing practice. Farmers questioned their ability to financially

benefit from technology adoption, based on demographic factors including age and the reduced likelihood of intergenerational succession as a consequence of migration trends.

"It [UAV's] is surely is great if I knew how to use it.' (participant 21)

(Interviewer: Have you ever thought of buying one yourself?)

"Maybe. But it's not suitable. I'm old'" (participant 26)

Concerns were also expressed about the potential for mechanical failure, lacking the knowledge and skills to fix machinery or having this available locally, and the unforeseen costs that this might incur.

"of course, there are risks…for example, like mechanical malfunction… things like that." (participant 10)

Openness towards technology and level of adoption readiness varied. Some farmers demonstrated characteristics from which they could be considered 'innovators' (Rodgers 1962), specialising in production methods including ecological farming and greenhouse horticulture (in addition to arable faming) (participants 10 and participant 12) and developing close relationships with those developing technologies (laser land levelling) to address farming problems (Participant 19). Others perceived readiness to adopt did not align with their actual level of engagement with technology. Many perceived themselves to be 'innovators' characterised by taking an active role in understanding new technologies and willing to try innovations despite unproven benefits and with some risk that adoption might be unprofitable (Clark et al., 2018; Rogers, 1962). However, this was contradicted by their (low) level of engagement with technology and limited awareness and knowledge of both established and emerging PA technologies. Farmers did not want to be early adopters, yet were aware of the risks of being left behind and were persuaded to adopt technologies after the benefits of technologies have been proven (Rodgers, 1962). These farmers were less likely to adopt technologies that required significant change to their existing practice and were more likely to consider adopting technologies that could be incorporated easily into their existing farm management practices.

" would use the new technology when I see others use it [first]. If you wait to see the benefits, everybody would like to use it for sure. I am willing to try new technologies." (participant 21)

"The one I bought [UAV] was a decision made from seeing others use it; that's why I bought one for myself as well" (participant 1)

Adoption mechanisms

Farmers were enthusiastic about being involved in the research and development of technologies. Whilst "co-production" has been advocated in scientific communities (Clark et al., 2018; Cui et al., 2014), farmers expressed difficulties engaging with researchers beyond expected attendance at annual government training initiatives and supported visits to demonstration farms. Despite willingness to engage, farmers had limited knowledge of how best to engage and consequently reported waiting for

information and technologies to reach them. Information was shared informally, *via* peer-based networks including hearing and seeing neighbours adopting new approaches. Participants recognised the need for more professional and effective platforms for information exchange; including a role for local extension agents, to provide more comprehensive and targeted information and build trust.

> *"Policy support. The government has invested a lot of money to build high-quality farmland, and I think there should be policy in place to guide the process. I think it would be great if the policy can promote the use of land levelling and soil quality improvement in this region." (participant 19)*

Participants expressed a need for policy to address the economic barriers that prohibit on-farm investment. Flexibility of government subsidies to include a wider range of technologies, reducing the limitations on farm size, as well as private low-interest borrowing options to support investment in technologies were commonly cited.

> *"We have subsidies for growing quality seeds and the crops-farming. But the subsidies only go to owners of the land, not to the people who actually farm the land." (participant 21)*

From a policy perspective, farmers appreciated the fundamental role played by land reforms although suggested improvements to accelerate this, including: more formalised mechanisms for recording land transfer; improvements to contractual arrangements to increase farmer tenancy stability, and; facilitating long-term farm management planning and policy interventions to reduce land fragmentation.

Discussion and policy implications

This study found Chinese family farmers to be open to the potential of PA technologies, although heterogeneity in farmer perceptions of PA technology, willingness, and readiness to adopt were apparent. Awareness and use of the PA technologies was shown to be influenced by a combination of internal (i.e., farm and farmer characteristics) and external characteristics (i.e., observability, trialability and support), as well as those of the technologies themselves. Many of the internal and external factors, consistently shown within the literature (summarised in Table 3) to influence PA adoption globally, influenced adoption in this context. Although, several dimensions of these factors were specific to the Chinese agricultural context (see also Clark et al. (2018)).

Farm size, land fragmentation and farming discontinuous plots was considered a fundamental obstruction to the modernisation of farming practice, including adoption of PA technologies. The socio-political landscape, specifically the land reforms in China, as well as policy tensions surrounding land use (i.e., conflicts between environmental, food management policies and agricultural modernisation) had impacted farmer's ability to increase farm size. The Chinese government may need to consider the trade-offs made by farmers because of policies in different

545 domains (i.e., agricultural and environmental). Coherence across policies and improvements to the
546 land transfer market to reduce fragmentation and uncertainties associated with tenancies, would allow
547 for more long-term farm management planning and reduce the risks associated with making financial
548 investment on farm. This would have multiple benefits, broadly helping to achieve agricultural
549 modernisation goals, improve the suitability of existing PA technologies to small-scale farming as
550 well as obtaining environmental co-benefits (Qian et al., 2016).

551 The suitability of technology for small scale farming is a fundamental barrier to adoption identified in
552 other developing agricultural economies, e.g. India (Mondal & Basu, 2009), and indicates the need for
553 low-cost PA technologies better suited to small-scale farms that will benefit both farmers and the
554 environment (Cheema & Khan, 2019). Galindo et al. (2012) argue that site-specific agriculture is
555 usually associated with high levels of technology, although demonstrate that providing new
556 approaches follow the "observe-interpret- evaluate-implement" principles then more low-tech
557 approaches are suitable and beneficial to smallholder farmers. This supports the arguments for
558 improved understanding of the challenges faced by family farmers to support the design of and
559 increase the relevance of PA applications. Future research should look to: 1) create technologies
560 suited to small-scale, fragmented farmland; 2) look to adapt the provision of existing technologies to
561 suit the identified challenges, and 3) have greater involvement from end-users alongside experts
562 throughout the development process (Galindo et al., 2012).

563 Despite recognised and proven potential, and notable attempts made by the Chinese government over
564 the last two decades to promote PA technology (e.g. via the establishment of demonstration centres in
565 both regions surveyed), awareness, engagement, trial and adoption opportunities to engage with
566 research and demonstration activities were perceived to be limited. The exception to this was the use
567 of UAV for spot agri-chemical application. Here the economic benefits were quantifiable, and
568 awareness and adoption had been facilitated through peer observation and more informal knowledge
569 networks. UAVs have more typically been utilised for data (image) gathering exercised in more
570 developed agricultural economies. This difference is also more widely facilitated through the
571 regulatory environment, which allows for the use of UAVs for agrichemical application in China.
572 Widespread adoption here reiterates the importance of information, observation and trial and
573 knowledge exchange opportunities for increasing awareness and facilitating adoption (external
574 factors). Research findings suggest that farmers who engage with and adopt PA technologies are more
575 likely to consider adopting additional technologies (Winstead et al., 2010). Therefore, there is a need
576 for more targeted informational and educational opportunities alongside more frequent demonstration
577 and field-days that specifically address the challenges faced by family farmers and stimulate initial
578 trial (Heiniger et al., 2002). Future research should look to quantify the effect of different forms of
579 knowledge provision and exchange on PA technology adoption, to identify those most suited to
580 encouraging and importantly sustaining update, ensuring that heterogeneity in farm and farmer

characteristics are acknowledged. The following paragraphs provide some suggestions for avenues to explore.

Findings identified two categories of farmers: 1) those who are pioneers and enthusiastically engage with and invest in PA technologies, although these were less typical of the sample, and; 2) those who were interested, although needed reassurances from observing others adopt, but who were not able to invest in technology directly and were interested in service provision options. This suggested that market segmentation to differentiate adoption profiles would be useful to identify those most likely to lead adoption within communities and enable improved product positioning and targeting of local extension agents in disseminating information (Li et al., 2020). Care needs to be taken to ensure a more objective measure of this, given that participants often reported higher levels of perceived technology readiness than their behaviours characterised.

In the absence of formal and regular educational opportunities, farmer awareness was typically gained via informal mechanisms associated with peer networks, such as mobile phone platforms (WeChat), and observation of the benefits obtained by other farmers illustrated by the widespread adoption of UAV's as well as motivated by concerns about "being left behind". This highlighted the importance of peer-to-peer support mechanisms and illustrated the value of supporting farmers to engage with these networks (Heiniger et al., 2002; Kernecker et al., 2020). Widespread adoption of mobile phone technology has been shown to reduce information asymmetry amongst farmers in developing agricultural economies (Aker, 2010; Ma et al., 2018). In the Chinese context, widespread adoption and reported reliance on internet and smartphone technology as a primary information sharing mechanism, has consequences for how technologies are disseminated though family farm communities. Providing there is the appropriate network coverage infrastructure in rural communities, smartphone and internet-based technology represents an opportunity to improve communication between researchers, agricultural policy makers, local extension agents and farmers (Aker, 2010; Ma et al., 2018). Even so, differences in digital competencies amongst end-users must be recognised to avoid divisions within rural communities (Galindo et al., 2012).

Informal mechanisms for education and support should be coupled with more formal educational opportunities, with the level of engagement with PA also influenced by education level and greater efforts to engage demonstrated by those with more formal agricultural education. Research indicates that encouraging skilled agricultural graduates back to rural communities can support the dissemination of PA technologies within rural communities. Therefore, there is an important role for relevant stakeholders to acknowledge the value of both formal and informal education mechanisms to improve dialogue with end-users and in so doing improve current innovation trajectories (Clark et al., 2018; Heiniger et al., 2002; Qian et al., 2016) .

Despite a low awareness and knowledge of PA technologies, farmers were principally motivated by the potential economic benefits that the adoption of PA technologies could bring, including improved profits and livelihoods from farming. This is unlike developed countries, such as the US, where evidence suggests farmers consider a broader range of benefits in addition to financial incentives, including, environmental benefits and increased convenience to the farmer when deciding to adopt (Thompson et al., 2019). However, whilst recognising the protential economic benefits farmers were inherently risk adverse and cautious about investing in technologies where the benefits were difficult to quantify, return on investment is uncertain and adoption requires end-users to make fundamental, and expensive changes to their farming practice (see also Hasler et al. (2017)). This aversion to risk was compounded by the short-term approach to farm management planning by farmers, influenced by tenancy rather than land ownership, the informality of land contracts between and the low profitability of farming as well as demographic characteristics including age and succession status (Adesina & Baidu-Forson, 1995). All of these have been shown to influence confidence and security in making on farm investment (Dean & Damm-Luhr, 2010; Gao et al., 2017).

It is important to provide farmers with cost/benefit analysis data particularly in the decision-making stage to mitigate farmer concerns and reduce the perceived barriers related to economic risks. Future research is required to evidence the economic benefits PA adoption including economic studies that demonstrate that PA technologies can increase farm profitability (e.g. through resource efficacies) (Daberkow & McBride, 2003; Schimmelpfennig & Ebel, 2016). A further policy recommendation would be to consider reforms to the land transfer policies, providing market-based mechanisms for land purchase and ownership, which is recognised to incentivise farmer investment in land improvements and technologies that may have multiple farm efficacies (Wainaina et al., 2016).

Finally, limited and poor access to information regarding financial support mechanisms, such as subsidies and low interest credit, further contributed to the perceived risk of adoption. Improved information and access across a spectrum of financial support mechanisms including credit, rental and affordable full-service provision and contractor options would reduce the economic barriers to adoption (Wossen et al., 2015). Agri-tech service providers have a vital role to play in reducing the influence of cost as a barrier to adoption by alleviating the need for long-term capital investments and the need for knowledge and skills acquisition by farmers by acting as professional consultants. In lieu of such services, and as a means of improving farm profitability, farmers were shown to have established informal service provision networks. This finding illustrated the arguments presented by regarding the importance of social capital as a determinant of technology adoption in low resource economies and the importance of community networks to facilitate uptake in the absence of formal financial support and credit access. It also further demonstrates a demand and role for formal PA service provision. It also raises concerns around the unregulated adoption of PA technologies, for example, the unregulated use of UAV's could carry risks to operators and bystanders. Farmers were

open to, and recognised, a role for a top-down approach form the Chinese government to support adoption. Farmers acknowledged that for many producers, unless regulated, the adoption of modern farm management mechanisms including precision technologies will be very slow to occur.

Recommendation and Limitations

Research, policy and education supporting the adoption of PA technologies in developing agricultural economies should explicitly include farmers and end-users as key stakeholders in the process. This must be from initial idea conception through the research and development process to product commercialisation, as is advocated by institutions such as UK Research and Innovation the European Commission. This requires the role of farmers and end-users, as the target market for PA technologies, to be reframed and for them to be included as co-developers of technology. This approach is consistent with the principles of 'Responsible Research and Innovation' (RRI) advocated by the European Commission and within the domain of PA (Clark et al., 2018).

Adoption success is influenced by a broad range of stakeholders in addition to farmers and end-users, including but not limited to, local policy makers, rural community members, agronomists and service providers. Future research should incorporate the views of these stakeholders in addition to farmers and end-users. The findings presented here relate specifically to the experiences of family farmers in the North China plain, but highlighted several themes likely to be similar across China, e.g. impact of agricultural policies, financial and information constraints. Future research should consider the perspectives of farmers in other regions of China, who may be exposed to different contextual factors.

Economic cost-benefit analysis and information regarding specific technologies is necessary to help mitigate the principle barrier to adoption (cost), including evidencing the long-term economic advantages to adoption, and improved translations and communication to support farmer decision making and improve uptake. Resources should be allocated for knowledge building, including demonstration, extension and information provision tailored to smallholder farmers, and is required to acknowledge the importance of utilising formal and informal educational channels, alongside technological development. Finally, differences in perceived readiness to adopt were identified, future research could quantitatively explore differences in farmer adoption characteristics to understand communication preferences and support more targeted interactions with local farming communities.

Conclusions

Incentivising adoption to meet the 'ubiquitous' adoption ambitions of the Chinese government, requires consideration of the unique factors influencing adoption in the Chinese context. Whilst land reforms have provided the facilitating conditions for more widespread adoption, they have also created additional challenges (i.e., land fragmentation) that have acted as a barrier to uptake. Increasing rates of adoption requires clear understanding of these challenges and the unmet needs of

685 farmers to reduce adoption barriers. A clear role for PA and untapped market opportunities for the
686 researchers, developers and agronomic service providers of PA technologies in China was
687 highlighted. Limited awareness of suitable and affordable technologies was identified as an important
688 barrier to adoption, highlighting the need for small scale, low cost PA applications, improved
689 information provision, financial support mechanisms, including more accessible subsidies, and service
690 provision, as well as, reliable implementation and aftercare support.

691

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