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The determinants of unmanned aerial vehicle (UAV) adoption and status quo of UAV-based pattern management in Chinese agriculture: insights from expert interviews

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Abstract

In China, unmanned aerial vehicles (UAVs) are increasingly used for broadcast application of agricultural inputs such as pesticides, fertilizers, and seeds. UAVs have the potential for site-specific precision agriculture, facilitating precise management of fertilization, plant protection, and irrigation to reduce environmental footprint of farming. There has been research on the use of UAVs in agriculture, but less is known about UAV-based precision agriculture, particularly pattern management. To close these research gaps, this paper conducted structured in-depth interviews with 18 experts from various fields related to UAVs in Chinese agriculture to study the status quo, drivers, and barriers of adopting UAVs, focusing on UAV-based precision agriculture, particularly pattern management. The results show that the adoption of UAVs in China is influenced by farmers' production characteristics, farmers' perceptions about UAVs, and social factors. UAV-based precision agriculture is at the initial stage in China, and the promotion of this approach still needs to overcome technical barriers such as improving the accuracy of crop measurements, developing real-time UAV positioning systems, and enhancing the response time of variable-rate spraying systems, as well as socio-economic barriers like farmers' limited UAV-related knowledge, small farm sizes, and lack of technical assistance.

Keywords
unmanned aerial vehicles, adoption, determinants, pattern management, China

UAVs mounted with tanks and sensors can be used in a range of agricultural practices (Michels et al. 2021, Rejeb et al. 2022, Tsouros et al. 2019a) such as pesticide spraying (Faiçal et al. 2014), fertilizer spraying (Abd. Kharim et al. 2019), seeding (Huang et al. 2020), and crop measurements (Maimaitijiang et al. 2020). China has been using UAVs in agriculture since 2010 (Zheng et al. 2019). Over a decade of development in China, agricultural UAVs have become cheaper, smarter, and better than before with respect to the overall performance (Chung 2019). UAVs, which can only be used in pesticide spraying at the beginning, can now be applied in seeding, fertilizer spraying, and crop monitoring, etc. (Sylvester 2018, Zhang et al. 2012). Up to now, China's agricultural UAV industry leads the world in terms of the number of UAVs, flight control technology, and cumulative annual operating area. (Ministry of Agriculture and Rural Affairs of People's Republic of China 2019). In 2020, 70,344 UAVs were being used in China for plant protection purposes and they were treating 14.48 million hectares of cropland (China Agricultural Machinery Industry Association 2021) (Figure 1).

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Next to supporting research and development, there are different aspects that explain the rise of agricultural UAVs in China. In 2017, China launched nationwide agricultural UAV purchase subsidies

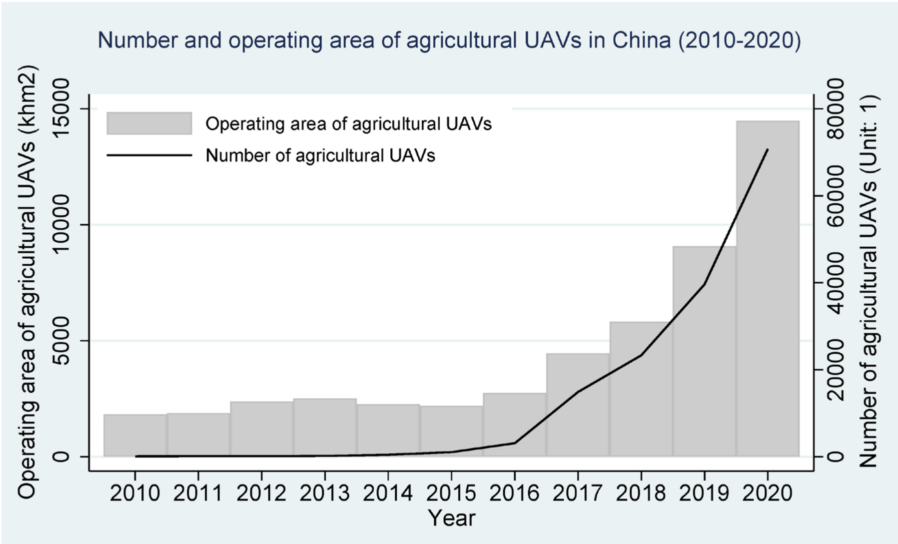

Figure 1: Number and operating area of agricultural UAVs in China (2010-2020); data source: China Agricultural Machinery Industry Association (2021).

in six provinces to promote the use of UAVs in agricultural production. Agricultural cooperatives and plant protection organizations are eligible to apply for these subsidies, which can be granted up to 30% of the purchase price of UAVs, with a maximum subsidy of $4,370 per UAV (Ministry of Agriculture and Rural Affairs of People's Republic of China 2017). UAV purchase subsidies have had a great impact on the use of UAVs, and their numbers have increased significantly since 2017 (Figure 1). The most popular forms Chinese farmers use UAVs are either by purchasing their own or by hiring UAV services (e.g., pesticide spraying, fertilizer application, seeding, and crop measurements) from agricultural cooperatives or private UAV pilots (Chung 2019). Large-scale corporate farmers prefer to purchase their own UAVs, while small and medium-sized farmers favor UAV services due to the affordability of service prices compared to the cost of purchasing UAVs (Chen et al. 2020, Chung 2019).

For the convenience of operation and economic viability, most Chinese farmers adopt UAVs for broadcast spraying (e.g., pesticides, fertilizers, and seeds) instead of site-specific precise spraying (Chung 2019, Hu et al. 2022, Lan et al. 2019). In addition to broadcast spraying, UAVs can also be applied in precision agriculture for crop measurements and precise field management (Radoglou-Grammatikis et al. 2020, Sylvester 2018, Tsouros et al. 2019a). Shifting UAVs from broadcast spraying to precision spraying comes with a great potential because precision spraying rather than broadcasting can greatly improve yield and sustainability of farming (Radoglou-Grammatikis et al. 2020, Roma et al. 2023). One example is UAV-based pattern management, which is an innovative and holistic approach proposed by Spohrer (2019) for sustainable and site-specific precision agriculture concerning fertilization, plant protection, and irrigation. This approach is regarded as holistic because it combines three important aspects of agricultural management into a comprehensive system, optimizing many production processes concurrently for better overall efficiency and sustainability. Pattern management includes three pillars: structured land management, UAV-based image acquisition, and data management (Figure 2). Structured land management divides fields into different spatiotemporal patterns. UAVs attached with sensors (e.g., infrared and hyperspectral) fly over fields to capture images and spatiotemporal datasets of these patterns. Images and field spatiotemporal datasets are processed by modified algorithms (Zhang 2012) and stored in the database. These algorithms are modified to accommodate the variability in crop types, growth stages, and soil conditions, with the aim of achieving higher accuracy in plant health and water stress detection. Fertilizer, pesticide, and water variable-rate prescription maps are derived from processed data to instruct fertilization, plant protection, and irrigation (Tsouros et al. 2019b). Data management is responsible for data storage, data retrieval, data processing, data mapping, and UAV flight control, etc. The processed spatiotemporal datasets will be shown as application maps on terminal devices (e.g., tablets, smartphones, and laptops) in a straightforward way, and farmers can manage and monitor different patterns on the field through user-friendly interfaces.

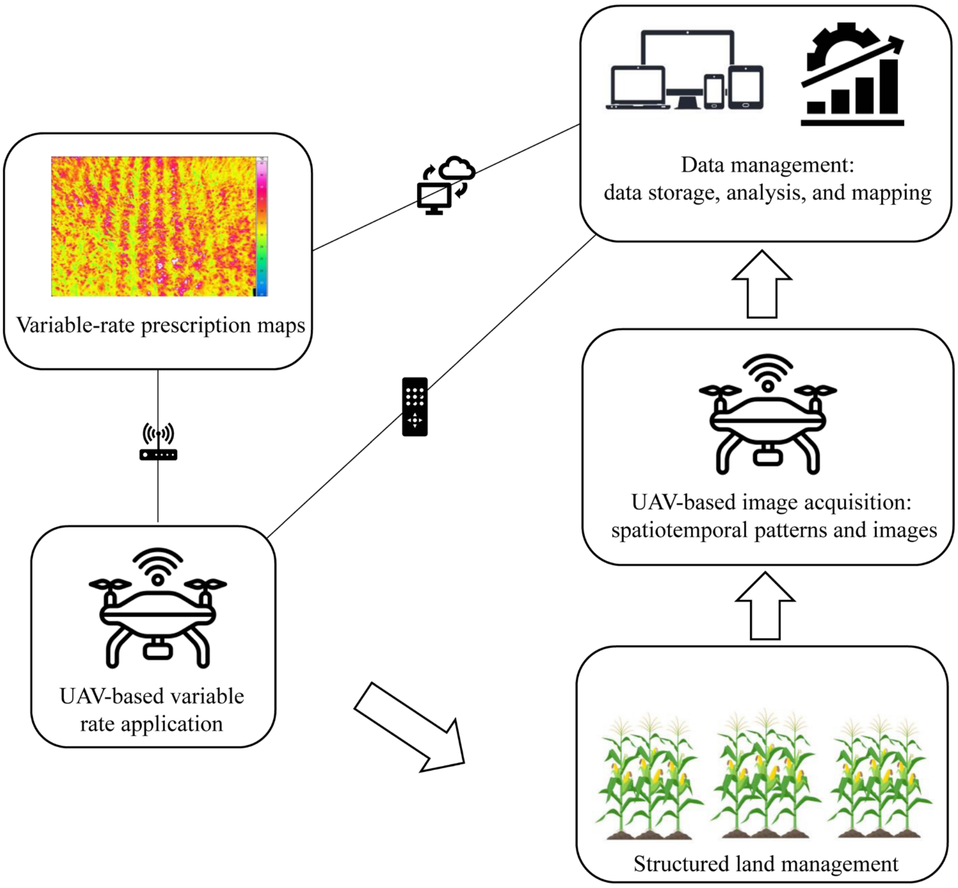

Figure 2: UAV-based pattern management based on the three pillars-structured land management, UAV-based image acquisition, and data management-variable rate application maps are created and UAV based VRA is executed.

The determinants of UAV adoption can be divided into drivers and barriers. Drivers are factors that promote the adoption of UAVs in agriculture. In contrast, barriers are factors that slow down or complicate UAV adoption in agriculture. Drivers and barriers can be economic, technical, social factors that affect farmers' decision-making. Several studies have explored the determinants of adopting UAVs in Chinese agriculture, finding that perceived usefulness, perceived ease-of-use, UAV-related knowledge level, farm size, agricultural income share, cooperative membership, within-family and village leadership, credit availability, government subsidies, extension services, and training have positive effects on UAV adoption (Chen et al. 2020, Han et al. 2022, Wachenheim et al. 2021, Zheng et al. 2019). However, these studies only analyzed the determinants of UAV adoption from the farmers' perspective and did not explore the social environment essential for the successful promotion of this technology. For this, it would be important to interview other stakeholders such as agricultural UAV manufacturers, UAV service providers (e.g., UAV service agricultural cooperatives and private UAV pilots), agricultural extension staff from government, and UAV researchers. Moreover, although there has been some research on UAVs in Chinese agriculture, the extent to which UAVs are used for precision agriculture (e.g., pattern management) and barriers for adopting UAVs for precision agriculture still remain unclear. To close these research gaps, this study conducted a series of structured in-depth expert interviews with 18 experts from various fields of expertise related to UAVs in Chinese agriculture to get a holistic view on drivers, barriers, and institutions that are needed for UAV adoption, particularly in precision farming for field pattern management.

The main findings of this study are as follows: Firstly, the adoption of UAVs in China is influenced by farmers' production characteristics, farmers' perceptions about UAVs, and social factors. Secondly, the adoption of UAVs for broadcast spraying is more common than site specific spraying due to cost and convenience. Thirdly, UAV based pattern management for precision crop measurements and precise field management to improve yield and sustainability is not commonly used in practical farming in China today. Research is ongoing to overcome technical barriers such as improving the accuracy of crop measurements, developing real-time UAV positioning systems, and enhancing the response time of variable-rate spraying systems, as well as socio-economic barriers like farmers' limited UAV-related knowledge, small farm sizes, and lack of technical assistance.

Materials and methods

To better understand the status quo of UAV use, determinants of UAV adoption, and development of UAV-based pattern management in China, this qualitative study conducted a series of structured in-depth expert interviews with 7 main stakeholders of UAVs in Chinese agriculture from various backgrounds. Purposeful sampling (Palinkas et al. 2015) was used to select several different types of respondents that are related to agricultural UAVs in China and are able to answer research questions with their practical experience. The sample consisted of 18 experts from China (Table 1): university professor (n=1), agricultural UAV manufacturers (n=3), farmers adopting UAVs (n=4), farmers not adopting UAVs (n=3), professional UAV pilots (n=3), agricultural extension staff from government (n=1), and managers of UAV service agricultural cooperatives (n=3).

Table 1 Characteristics of 18 agricultural experts

ID	Category	Expert information
1	University professor	A pioneer of agricultural UAV research in China and more than 15 years of research experience in agricultural UAVs; Expertise: UAVs for pesticide application and precision variable-rate pesticide spraying technology.
2-4	Agricultural UAV manufacturers	Agricultural UAV industry leaders in China; Expertise: Research and development of agricultural UAVs.
5-8	Farmers adopting UAVs	Farmer (ID 5): male, 35 years old, 5.3 ha land, college degree, and 2 years of farming experience in rice and black soybean production; Farmer (ID 6): male, 50 years old, 40 ha land, high school degree, and 6 years of farming experience in rice production; Farmer (ID 7): male, around 30 years old, 6.7 ha land, college degree, and 5 years of farming experience in citrus production; Farmer (ID 8): male, 27 years old, 13.3 ha land, college degree, and 6 years of experience in Areca catechu plantation.
9-11	Farmers not adopting UAVs	Farmer (ID 9): male, 38 years old, 66.7 ha land, high school degree, and 12 years of farming experience in potato production; Farmer (ID 10): female, around 60 years old, 0.1 ha land, middle school degree, and 40 years of farming experience in maize, soybean, and vegetable production; Farmer (ID 11): male, 40 years old, 2.7 ha land, master degree, and 3 years of farming experience in loquat plantation.
12-14	Professional UAV pilots	Pilot (ID 12): male, around 30 years old, middle school degree, and 7 years of work experience as an UAV pilot; Pilot (ID 13): male, around 30 years old, college degree, and 2 years of work experience as an UAV pilot; Pilot (ID 14): male, around 30 years old, middle school degree, and 6 months of work experience as an UAV pilot; Expertise: proficient UAV operation skills and working as an individual for farmers in UAV pesticide spraying.
15	Agricultural extension staff from government	12 years of work experience in agricultural extension; Expertise: UAV extension services and training.
16-18	Managers of UAV service agricultural cooperatives	Cooperative (ID 16): 5 years of experience in UAV services, 3 UAVs, and 10 employees; Cooperative (ID 17): 6 years of experience in UAV services, 5 UAVs, and 5 employees; Cooperative (ID 18): 3 years of experience in UAV services, 5 UAVs, and 3 employees; Expertise: teamwork, providing UAV services to farmers, including pesticide spraying, fertilizer spraying, and seeding, etc.

The experts were interviewed through phone calls in November and December of 2022. Interview questions were sent to them before the interview. To maintain consistency, the first author conducted all interviews. Expert interviews focused on the following topics (Table 2): status quo, opportunities and challenges of UAVs more generally, and specifically about UAV-based pattern management in Chinese agriculture. During the interviews, experts were asked to answer the related questions in each topic (Table 2). Averagely, each phone call was around 25 to 30 minutes. The contents of expert interviews were documented word by word. Then, transcripts were analyzed by qualitative inductive content analysis (Mayring 2021) in three steps. Firstly, the transcripts were thoroughly examined sentence by sentence and the key concepts of transcripts were labeled. Secondly, according to similarities, labels were grouped together into themes, and subsequently into higher-level categories. Thirdly, categories with close meanings were merged into core categories. Although the sample size of 18 experts may appear small, they represent 7 main UAV stakeholders in Chinese agriculture, and the findings of this research show a high correlation with other relevant studies. Therefore, the number of interviews in this study can be considered sufficient to derive reasonable results.

Table 2 Interview topics and questions

Topics	Keywords for questions
Topic 1 Overview of UAV usage in Chinese agriculture	Supply, services, operation, work efficiency, maintenance, and training
Topic 2 The determinants of UAV adoption in Chinese agriculture	Advantages, disadvantages, drivers, and barriers of UAV adoption
Topic 3 UAV-based pattern management in Chinese agriculture	Status quo of UAV-based pattern management in China, socio-economic and technical prerequisites to apply UAV-based pattern management

Results

Overview of UAV usage in Chinese agriculture

Supply of UAVs

UAVs are typically supplied through self-purchase, rental, or UAV services. Large-scale farmers prefer self-purchase over other options due to the large size of their farms, which requires UAVs to replace manual labor, providing flexibility and cost efficiency, especially during busy farming seasons. Conversely, small-scale farmers opt for hiring UAV services because they use UAVs infrequently and avoid to purchase or learn to operate UAVs themselves. The university professor (ID1) mentioned that UAV services and rental provide farmers convenient access to the latest UAV technology at low costs compared to purchasing UAVs outright. Additionally, frequent replacement due to shorter UAV lifespans maximizes benefits from technical progress for farmers. WANG et al. (2022) also highlighted that UAV services can reduce production costs, increase production efficiency, lower the price threshold for UAV use, and accelerate UAV adoption in Chinese agriculture.

UAV training, operation, maintenance, and work efficiency

Experts summarized several important aspects related to UAV training, operation, maintenance, and work efficiency (Table 3). For UAV training, UAV operators must attend and pass training courses lasting from 2 to 7 days to get pilot licenses. The training includes UAV operation and maintenance, preparation of pesticides, UAV mapping, and UAV security issues. All farmers in this survey prefer to learn UAV technology from local professional extension staff or demonstration sites. They believe it would be easier if local professional extension staff illustrate UAV usage in the field or if demonstration sites provide some practical UAV training courses. Similarly, HAN et al. (2022) emphasized that extension services and promotion programs have positive effects on farmers' intention to adopt UAVs. During operation, licensed UAV pilots are responsible for the deployment of UAVs. 10 to 30 minutes are needed for preparation work such as field observation, marking obstacles, flight planning, and UAV testing. One person is responsible for UAV operation, and the other person is in charge of battery replacement, pesticide or fertilizer loading, and field observation. Pilots need 2 to 5 minutes to refill UAV tanks and to replace new batteries. Maintenance tasks, including UAV battery charging and UAV repairs, are usually performed by professional technicians. UAV battery capacity affects charging duration, while charging habits impact battery lifespan. Depending on the model, charging an UAV battery needs 8 to 30 minutes, and the battery lifespan is about 500 to 1500 cycles. Wings and nozzles are the most easily damaged parts of UAVs because wings often hit on obstacles, and nozzles are often clogged by pesticides. Regarding UAV work efficiency, it varies based on UAV types and field conditions. Depending on battery capacity, load, and field conditions, a single UAV flight last from 8 to 25 minutes, covering field crops ranging from 0.5 to 3.3 ha and fruit trees from 0.1 to 0.4 ha. The daily flight range of an UAV can reach 10 to 13.3 ha in fields and 3.3 to 6.7 ha in orchards.

Table 3 UAV training, operation, maintenance, and work efficiency

Questions	Answers
UAV training course duration	2-7 days
UAV training contents	UAV operation and maintenance, preparation of pesticides, UAV mapping, and UAV security issues
UAV training tuition fees	300-900 $
Preparation time before flight	10-30 minutes
Single flight time	8-25 minutes; depending on battery capacity and load
Single flight range	0.5-3.3 ha for field crops; 0.1-0.4 ha for fruit trees; depending on battery capacity, load, and field conditions, etc.
Time to refill tanks and to replace new batteries	2-5 minutes
Daily flight range of an UAV	10-13.3 ha for field crops; 3.3-6.7 ha for fruit trees
Battery charging time	8-30 minutes
Battery lifespan	500-1500 cycles; depending on battery capacity and charging habits
Which parts of UAVs are easily to damage?	Wings and nozzles

The price of UAV services

UAV operation fees depend on the types of crops, severity of pests and diseases, topography, and field conditions. In general, UAV operation fees are lower for large and easily navigable fields and higher for crops with severe pests and diseases. For field crops, UAV operation fees range from 22 $ /ha to 56 $ /ha. For fruit trees, UAV operation fees (78 $/ha to 178 $/ha) can be higher due to the challenging terrain of some hilly orchards and increased pesticide use required for large canopies. Likewise, CHUNG (2019) found that UAV operation fees depend on types of crops and topographies, and LI et al. (2022b) reported that, compared to plain regions, UAV operation efficiency drops significantly by 30% to 50% in hilly regions.

The determinants of UAV adoption in Chinese agriculture

Advantages of UAV adoption

The experts were asked to point out advantages of UAVs in agricultural production (Table 4). Labor efficiency and time efficiency are the most distinctive merits of UAVs. In the context of labor shortages in rural areas, UAVs play an important role in replacing manual labor in agricultural production. In pesticide applications, an UAV can work 4 to 10 hectares in one hour, which is equivalent to the workload of 30 to 100 workers using manual spraying (Yang et al. 2018). The saved labor costs significantly reduce production costs and increase profitability. Resource efficiency is an advantage of UAVs. Compared to ground-based pesticide application methods, UAVs can conduct timely and effective pest and disease control with considerably fewer labor, water, and pesticide. A citrus farmer (ID 7) holding 6.7 ha land in this research reported that UAV broadcast pesticide spraying increased the effect of pest and disease control by 20% and saved cost by 266 USD/ha compared to ground-based pesticide spraying. UAVs release workers from applying pesticide directly, separating operators from pesticides to avoid pesticide poisoning. Overcoming terrain obstacles is another benefit of UAVs. UAVs are capable of accessing challenging terrains to perform agricultural tasks that are difficult or impossible for people to reach, offering notable benefits regarding accessibility and efficiency.

Table 4 Advantages and disadvantages of adopting UAVs

Advantages	Disadvantages
Time efficiency	Pesticide drift
Labor efficiency	High prices
Resource efficiency	Unstable performances
Overcoming terrain obstacles	Weather dependent
Precision in pest and disease control	Inefficient in scattered field plots and treating severe pests & diseases

Disadvantages of UAV adoption

Regarding the disadvantages of adopting UAVs in agricultural production (Table 4), all experts acknowledged that UAVs may cause pesticide drift, leading to the damage of crops nearby and resulting in environmental pollution (Biglia et al. 2022, Wang et al. 2020). High prices discourage many farmers from using UAVs. Unstable performances are disadvantages of UAVs, including safety incidents, unstable flight control systems, repeated and omitted spraying of pesticides. Another drawback of UAVs is their reliance on favorable weather conditions for operation. UAVs cannot work in high temperatures or windy conditions; high temperatures can damage batteries, and windy weather exacerbates pesticide drift. However, traditional ground-based pesticide application methods are constrained by these weather conditions as well. UAVs are inefficient in scattered field plots because of the increased complexity of operation. For severe pest and disease outbreaks in specific field areas, UAVs may be less effective than ground-based spraying methods. UAV spraying requires 5 to 30 times higher pesticide concentration than ground-based spraying, but the high concentration and low volume of pesticides may lead to undesirable treatment effects due to the low water content. Likewise, Li et al. (2022a) found that UAV spraying is more effective at controlling mild or moderate cotton Aphis than the severe one.

Drivers of UAV adoption

Experts pointed out some drivers of UAV adoption in China (Table 5). Rural labor shortages make UAVs an attractive alternative to perform agricultural tasks. UAV purchase subsidies can facilitate UAV adoption because subsidies lower prices and make UAVs more affordable for the majority. Likewise, Li et al. (2022b) also found that UAV purchase subsidies can boost UAV adoption, and subsidies based on cumulative areas of UAV operation can also promote UAV adoption, especially among small and medium-sized farmers. The increasing need for efficient and precise agricultural practices drives market demand, prompting UAV pilots to provide relevant services to farmers. The convincing benefits of using UAVs, such as time savings due to faster inputs applying and costs savings through precision applying, have a positive effect on farmers' adoption of this technology. This finding is consistent with Han et al. (2022), Skevas and Kalaitzandonakes (2020), and Li et al. (2020) who found that perceived usefulness can affect farmers' UAV adoption. Specialized farming, where 50% or more of its income derives from a single crop, is a driver of UAV adoption. Specialized farming allows UAVs to work easy and efficient due to the uniformity of crops across the field, enabling for optimized scheduling and application. The expansion of farm size needs automation measures to replace manual labor and improve productivity, and UAVs are effective tools to achieve this. This finding is in line with Michels et al. (2020), who expected that UAVs can considerably assist farmers in reducing time costs, labor costs, and management complexity as the farm size is increasing.

Table 5 Drivers and barriers of adopting UAVs

Drivers	Barriers
Rural labor shortages	Knowledge gap
UAV purchase subsidies	Small farm size
Market demand	UAV operation skills required
Farmers' positive perceptions	Lack of standardized UAV operating protocols
Specialized farming	Unfavorable field conditions
Expansion of farm size	UAV pilot shortages

Barriers of UAV adoption

Meanwhile, there are several barriers of UAV adoption (Table 5). Many farmers have insufficient awareness and understanding of UAV technology and its potential benefits in agricultural production. Small farm sizes can reduce the perceived usefulness of UAVs because farmers can manage all field work by manual labor. Many farmers are discouraged from using UAVs due to perceived difficulty in learning UAV operation. This finding is consistent with Han et al. (2022) and Zheng et al. (2019) who reported that perceived ease of use has positive effects on UAV adoption. The lack of standardized UAV operating protocols can be barriers for UAV adoption because incorrect UAV operations may cause inconsistent performance and safety concerns. Unfavorable field conditions (e.g., scattered field plots and high voltage lines) complicate the adoption of UAVs and slow down their promotion. Pilot shortages are barriers of UAV adoption because many farmers lack UAVs and relevant operational skills, necessitating the hiring of pilots. Chung (2019) also mentioned that the low supply of agricultural UAV pilots does not match with the fast speed of UAV adoption in China, highlighting the need for more UAV training institutes to educate additional pilots. Insufficient UAV technical assistance, after-sales service, and training are also barriers of UAV adoption. Han et al. (2022) also emphasized that external environment such as UAV technical assistance and after-sales service are important in UAV adoption.

UAV-based pattern management in Chinese agriculture

Status quo of UAV-based pattern management

UAV-based pattern management is still at the experimental phase, and it will take some time to achieve commercial use in China's precision farming. The university professor (ID1) mentioned: "UAV-based pattern management is an innovative approach and has great potential in the future, but this concept needs time to elaborate. In China, UAV-based pattern management is only partially used in some large-scale farms for specialized farming, where 50% or more of its income derives from a single crop".

Benefits of UAV-based pattern management

The university professor (ID1) mentioned: "UAV-based pattern management provides environmental benefits such as optimizing resource use and enhancing sustainability through the precision application of agricultural inputs (e.g., water, fertilizers, and pesticides) and field management". According to three agricultural UAV manufacturers (ID2-4), another benefit of UAV-based pattern management is efficient data-driven decision-making, which supports real-time field and crop data measurements and analysis. An UAV pilot (ID 12) mentioned that UAV-based pattern management also offers economic benefits by reducing labor costs and increasing productivity.

Conflicts of interest in UAV-based pattern management

The university professor (ID1) mentioned: "There is a conflict between the efficiency gains of applying UAV-based pattern management in large field uniform applications and the environmental benefits of keeping higher biodiversity". UAV-based pattern management achieves higher efficiency in large field uniform applications, while farming diversity brings difficulties in UAV operations and field management. To address this conflict, it is important to find an appropriate farm size to implement UAV-based pattern management, balancing economies of scale and farming biodiversity simultaneously.

Socio-economic prerequisites of adopting UAV-based pattern management

According to answers from experts in this survey, there are three main socio-economic prerequisites to apply the UAV-based pattern management. Firstly, farmers' good UAV-related knowledge and the convincing benefits of using UAVs. The application of UAV-based pattern management requires good knowledge about UAV operations, UAV image processing, and data management, etc. Farmers' UAV-related knowledge affects the quality of UAV-based pattern management. The convincing benefits of UAV-based pattern management, such as time savings due to faster inputs applying and costs savings through precision applying, can encourage farmers to adopt this approach. Most farmers do not adopt UAV-based pattern management because of the huge investment required, which involves the costs of purchasing UAVs, data processing software, UAV training, and maintenance. In addition, the returns from adoption are unforeseen due to the varied field conditions, crop types, and farmers' proficiency with using UAVs (Sylvester 2018). Farmers are concerned that the economic benefits of adoption may not offset the investment. However, up to now, limited studies have analyzed the economic returns of using UAVs in precision agriculture (Andujar et al. 2019, Späti et al. 2021), and more empirical analysis should be conducted in the future to estimate the economic benefits of using UAVs (Kerry et al. 2021). Secondly, a relatively large arable land size (≥ 2 ha) and high-value crops producing on the farm. Large arable land and high-value crops prompt farmers to invest in UAVs for profitability. Thirdly, social facilitating conditions like UAV subsidies, after-sales service, training, and mature UAV markets are essential for implementing UAV-based pattern management.

Technical prerequisites of adopting UAV-based pattern management

Based on answers from three agricultural UAV manufacturers (ID2-4), there are also three main technical prerequisites to apply UAV-based pattern management. Firstly, accurate crop measurements. UAVs should be attached with sensors that accurately measure the reflection of light from crops. Then, pests, diseases, and nutrient status of crops can be derived from the data collected by UAV sensors. Fertilizer and pesticide variable-rate prescription maps are made based on the measurement data. The accuracy of measurement, such as positional accuracy, spectral accuracy, and the reliability of the models used, can affect the following field operations such as spraying and irrigation. Due to the limitations of current technology, UAV-based crop measurements still need to improve its accuracy in some cases (Maimaitijiang et al. 2020, Xie et al. 2021). Secondly, precise real-time UAV positioning systems. UAVs need real-time positioning systems to guide during site-specific precise spraying (Yang et al. 2018). However, real-time positioning systems, even the real-time kinematic positioning (RTK) global navigation satellite system (GNSS), can encounter challenges in signal interference and connectivity problems, which can affect the accuracy during UAV flights. Thirdly, fast response time of variable-rate spraying systems. To achieve variable-rate spraying, UAVs require fast response times from variable-rate spraying systems to synchronize with their speed, which remains challenging.

Discussion and conclusions

This paper conducted structured in-depth expert interviews with 18 experts in China from various field of expertise related to UAVs and agriculture to study the status quo of UAV use, determinants of UAV adoption, and development of UAV-based pattern management in China. Most Chinese farmers adopt UAVs for pesticide spraying; other UAV applications such as seeding, fertilizer spraying, and crop monitoring are not widespread, but are gradually increasing. The determinants of UAV adoption come from these major aspects: farmers' production characteristics (e.g., arable land size and specialized farming), farmers' perceptions about UAVs (e.g., perceived ease of use and perceived usefulness), and social factors (e.g., UAV purchase subsidies, training, and technical support). In this study, the determinants of UAV adoption and their effects on UAV adoption are consistent with Han et al. (2022), Li et al. (2022b), Li et al. (2020), Michels et al. (2020), Skevas and Kalaitzandonakes (2020), Wachenheim et al. (2021), Zheng et al. (2019), and Zuo et al. (2021).

UAV-based pattern management is at the initial stage in China, and the promotion of this approach still needs to overcome technical barriers (e.g., accurate crop measurements, precise real-time UAV positioning systems, and fast response time of variable-rate spraying systems) and socio-economic barriers (e.g., farmers' limited UAV-related knowledge, small farm sizes, and lack of technical assistance). At this stage, UAV-based pattern management can be promoted first in large-scale farms for specialized farming because of its high expected returns. Given economic viability, agricultural cooperatives offering UAV services can provide UAV-based pattern management services for small and medium -sized farms.

To effectively promote the shifting of UAVs from broadcast spraying to precision spraying in Chinese agriculture, joint efforts are needed from all stakeholders (Figure 3). Government is the head of all stakeholders and is expected to formulate laws and regulations to instruct the development of agricultural UAV industry in China. For example, investing in UAV research and development, formulating UAV operating protocols, certifying UAV technologies and processes, providing UAV extension programs and UAV related subsidies (e.g., UAV purchase subsidies, subsidies based on cumulative areas of UAV operation, and UAV training subsidies), and establishing UAV demonstration sites. Formulating UAV operating protocols is very important to guarantee safety, efficiency, and consistency. These protocols should include flight safety rules, correct calibration of UAVs, and accurate dosage of pesticides, etc. Through setting clear standards, farmers and UAV pilots can optimize UAV efficiency and reduce risks. The certification of UAV technologies and processes, such as quality guarantee and reduced spray drift, will promote safety and reliability. UAV manufacturers are supposed to develop UAVs with reliable and precise UAV technologies but affordable prices. UAVs should have user-friendly interfaces that are easy to learn and to operate. UAV training and after-sales service or support are also expected from UAV manufacturers. Professional UAV pilots should be proficient in UAV operating protocols. Agricultural cooperatives offering UAV services are expected to provide cheap, efficient, and high-quality services for farmers, including crop spraying and crop measurements, etc. Farmers should attend UAV extension programs, receive UAV training, and understand how UAVs can improve their productivity. Farmers are also supposed to assess the needs of their farms and determine how UAVs can be adopted economically.

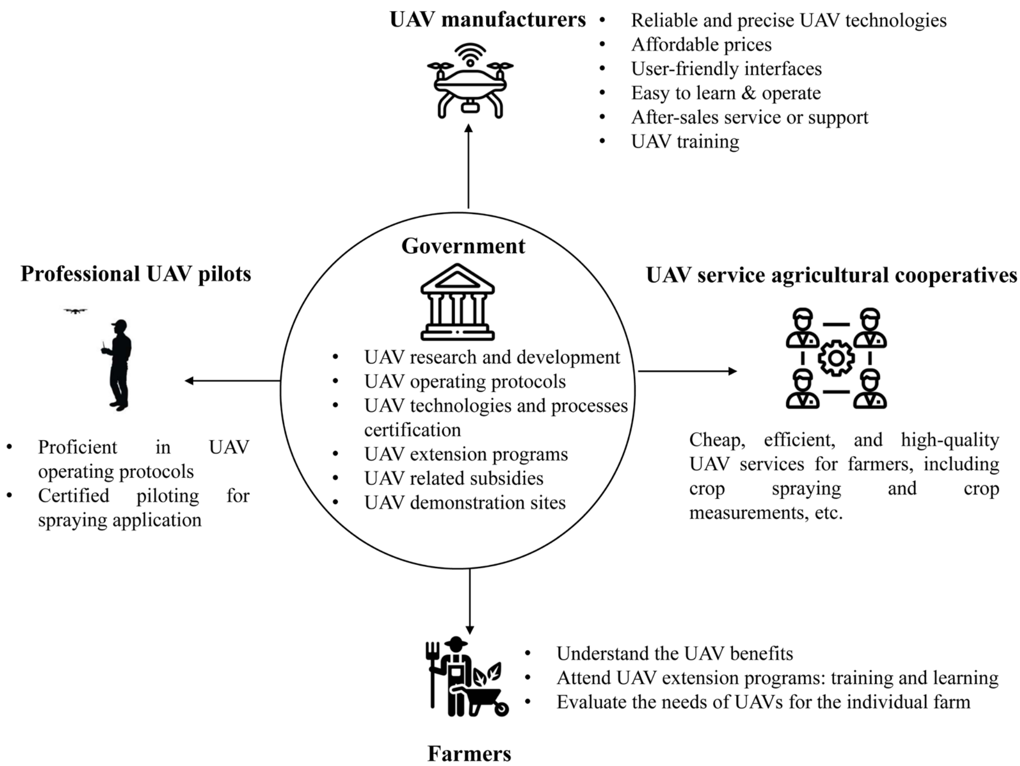

Figure 3: UAV promotion model in China.

However, this qualitative study is based on interviews with a small group of experts and is inevitably somewhat subjective. Nevertheless, this study sets the foundation for the future research of UAV adoption in Chinese agriculture and provides an overview of UAV-based pattern management in China, and it opens the flow for further investigation and research fields, e.g., a more comprehensive questionnaire based quantitative survey with a large number of participants.

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Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

The data used in study are available from Professor Dr. Xiongkui He on reasonable request.