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Integrated Pest Management in Chinese Agriculture:

A review of challenges and opportunities

LWS 548 Major Project Proposal

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Abstract

This review addresses the adverse environmental and human health impacts associated with the use of chemical pesticides in agriculture. It assesses the significance of integrated pest management (IPM) as a viable solution for reducing chemical pesticide reliance and transitioning towards sustainable agricultural practices. However, the adoption of IPM globally faces numerous challenges. The review systematically examines the barriers to IPM adoption across different regions worldwide and delves into effective strategies to increase its implementation. Additionally, it focuses on China as a case study, evaluating three specific methods employed to address IPM adoption challenges and assessing their effectiveness. Based on the findings, the review concludes by offering a set of practical recommendations and strategies tailored to the Chinese context. These recommendations can serve as valuable insights for promoting IPM adoption, not only in China but also in other regions globally. By addressing the barriers and providing targeted solutions, the review aims to facilitate the widespread adoption of IPM and contribute to the development of sustainable agriculture practices worldwide.

Introduction

Agriculture plays a crucial role in the global economy, serving as a fundamental sector that provides essential resources, notably food and income, to communities worldwide (Kumar et al., 2022). According to the latest estimates from the United Nations, the global population is projected to reach approximately 8.5 billion by 2030, 9.7 billion by 2050, and 10.4 billion by 2100 (United Nations, 2022). These projections highlight the increasing necessity for expanding food production to meet the escalating demands of a growing population and ensure their sustainable well-being.

The ever-increasing demand for food necessitates a continuous need to enhance agricultural production. However, the adverse effects of climate change on agriculture, including shifts in temperature, precipitation, and extreme weather events, are expected to have detrimental consequences including diminished soil productivity, water availability, and crop yields (Aydinalp & Cresser, 2008). Additionally, the impact of climate change on pest and pathogen dynamics poses significant challenges to agriculture. Changes in temperature and precipitation patterns can facilitate the emergence of new pests and diseases, or alter the distribution of existing ones, ultimately leading to crop losses and yield reductions (Schneider et al., 2022). Furthermore, the process of globalization has facilitated the transportation and introduction of crops across regions, which often lack natural enemies and genetic resistance, making them more susceptible to pests and diseases. As a result, there is a growing need for innovative technologies in agriculture to create more intensive and robust pest management systems to achieve sustainable development goals (FAO, 2021).

While some consequences of climate change are extremely difficult to address through human interventions, problems due to pests and pathogens can be mitigated through various management techniques. To meet the growing demands of an increasing population, the widespread use of pesticides in agriculture has been the conventional approach adopted to enhance crop production. A pesticide also called plant protection product (PPP) is any substance utilized to prevent, eliminate, or manage pests, which can include insects, fungi, rodents, weeds, or undesirable plant species that cause harm either before or after harvest to prevent deterioration during storage or transport, includes compounds such as defoliants, fungicides, herbicides, insecticides, molluscicides, and others (Perez-Lucas et al., 2019). These pesticides can be categorized based on their origin as either chemical pesticides or biopesticides. Chemical pesticides can be further classified into organochlorine, organophosphate, carbamate, and pyrethroid compounds. On the other hand, biopesticides are a group of pesticides derived from natural sources such as animals, plants, and microorganisms (Abubakar et al., 2020). However, the use of pesticides presents acute risks to the environment and human health.

Impacts of Agricultural Pesticides

The use of pesticides has detrimental effects on the environment, and human health, particularly concerning the land and water system. Therefore, understanding the behaviour of different pesticide groups within the land and water system is essential for mitigating their negative effects.

Various factors such as the physicochemical properties of pesticides, soil permeability, texture, organic matter content, and pesticide application methods and dosages play an important role in determining the behaviour of pesticides in water and soil systems (Perez-Lucas et al., 2019). Pesticides applied in agricultural lands are susceptible to runoff from surface water sources exposed to rainfall or irrigation water and have the potential to enter groundwater sources through leaching from the soil (Figure 1). These pesticides share common characteristics, including high solubility and low adsorption to soil particles (Perez-Lucas et al., 2019). Pesticides that enter surface water can upset the balance of the ecosystem by directly affecting aquatic organisms, including fish, amphibians, and invertebrates (Rani et al., 2021). Pesticides that leach from the soil can contaminate groundwater, posing a risk to communities that rely on groundwater as their primary source of drinking water. Conversely, pesticides that exhibit high adsorption capabilities tend to attach themselves to soil particles, leading to their gradual accumulation in the soil. As a consequence, this accumulation can lead to long-term contamination of agricultural soils, potentially affecting soil fertility, beneficial soil microorganisms, and other non-target species residing in the soil, and disrupting the overall balance of the soil environment (Perez-Lucas et al., 2019).

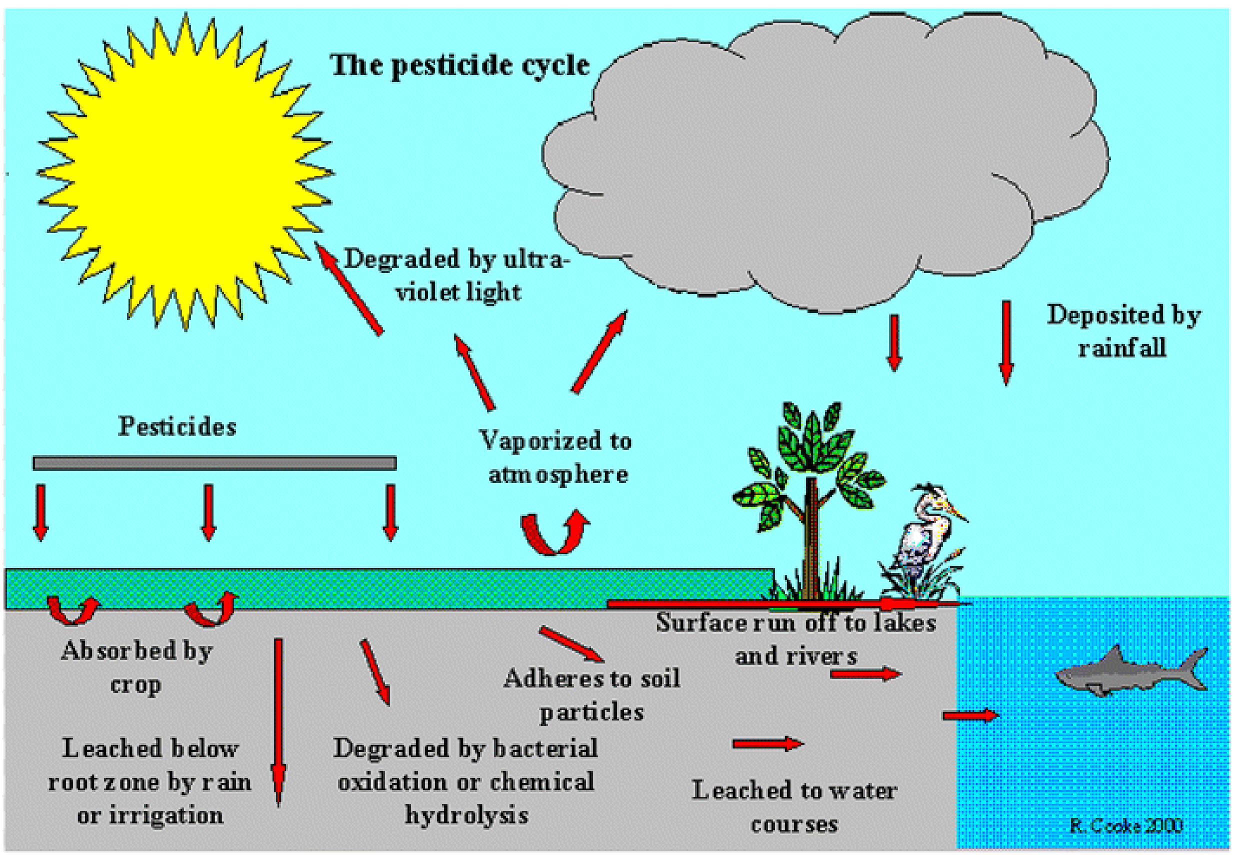

Figure 1 An overview of the pesticide cycle in the environment (Shakeel et al., 2017).

In addition to environmental impacts, pesticides also pose acute and chronic health risks to both agricultural workers and consumers (Yeboah, 2014). Workers in pesticide manufacturing factories and agricultural fields are particularly susceptible to direct and indirect pesticide exposure. This exposure can occur through skin contact or handling pesticide residue present in food items, leading to various health issues including cancer, respiratory disorders, neurological dysfunction, and more (Rani et al., 2021). Some pesticides, particularly those that are persistent can accumulate in the tissues of living organisms. As organisms consume contaminated food, the pesticide residues can become more concentrated as they move, or bioaccumulate, in the food chain. This can pose risks to predators at the top of the food chain, including humans.

Excessive reliance on pesticides in agriculture not only poses risks to the environment and human health but also contributes to the development of pesticide resistance among pest populations. When pesticides are applied extensively, the pests that have genetic traits enabling them to survive the chemical treatments are more likely to survive and reproduce. As a result, these resistant pests pass on their resistant genes to subsequent generations, leading to the emergence of "super pests" that are highly resilient to pesticides (Greentumble, 2022). The consequences of pesticide resistance have negative implications for agricultural systems. The escalation of pesticide resistance exacerbates the problem by reducing the effectiveness of pesticide applications, leading to increased damage and crop losses, and creating greater challenges for pest control in agricultural systems.

Integrated Pest Management (IPM) in Agriculture Pest Management

To mitigate the impacts of pesticides in agriculture, integrated pest management (IPM) was developed over sixty years ago as an alternative approach to chemical pest management (Deguine et al., 2021). According to the Food and Agriculture Organization of the United Nations (FAO), IPM involves the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations, keep pesticides and other interventions to economically acceptable levels, and reduce or minimize risks to human health and the environment (FAO, 2020). IPM emphasizes the growth of a healthy crop with the least possible disruption to agroecosystems and encourages natural pest control mechanisms (FAO, 2020).

Implementing IPM on the ground involves an integrated approach that combines strategies to minimize the use of chemical pesticides while effectively controlling pests. The implementation of IPM varies depending on the specific crop, region, and other challenges. The six key steps and practices for implementing IPM in the agriculture production system include :

1) Implementing appropriate measures to actively prevent the emergence of pests, such as crop rotation, intercropping, and planting resistant varieties.
2) Understanding pest dynamics and developing control strategies by identifying pests, their natural enemies, and the damage they cause.
3) Setting thresholds for action, which are predetermined levels of pest populations where it is necessary to take intervention to prevent economic losses. Decisions are based on the potential damage caused by the pest, the cost of control methods, the value of production, the impact on beneficial organisms, and the overall impact on the environment.
4) Continuous monitoring of pest populations, beneficial organisms, pest damage levels, and environmental conditions.
5) When action thresholds are surpassed, implementation of control strategies, such as integrated control strategies, such as biological, chemical, and cultural methods, to manage pest populations and reduce them to acceptable levels.
6) Review of the management strategy to determine if it is appropriate for a particular pest to be present in the area.

IPM can be implemented on a wide range of farm scales, from small individual farms to large commercial farming operations (Grasswitz, 2019). The modes of IPM engagement can also be varied, depending on locally available support systems. Farmers at different scales may seek technical guidance and training from a variety of sources, including local agricultural consultants, research institutions, and government-supported programs and institutions (Farrar et al., 2018). Agricultural consultants and experts play a key role in supporting farmers by helping with pest monitoring, pest identification, and the development of IPM strategies based on the unique needs of each group or farm. This contextualized approach ensures that IPM methods are relevant and practical for the specific agricultural environment. By working with consultants and experts, farmers gain specialized knowledge and practical tools that enable them to make informed pest management decisions.

Barriers to Integrated Pest Management (IPM) Adoption

As a holistic approach to pest control, IPM offers numerous benefits for farmers, the environment, and consumers seeking non-toxic produce. Despite its conception in the mid-20th century, there remain challenges hindering the widespread adoption of IPM techniques and technologies beyond research and pilot-level projects, to industry-wide practices on a global scale.

Deguine et al. (2021) conducted a comprehensive analysis of the challenges impeding the widespread adoption and dissemination of IPM practices (Figure 2). They identified several key factors contributing to the low adoption rates. Firstly, there is a notable deficiency in farmers' ecological knowledge and a limited understanding of the IPM process. This knowledge gap hinders the effective implementation of IPM strategies. Secondly, end-users often perceive IPM as a difficult approach to implement, leading them to favour more risk-averse methods such as the preventive use of chemical pesticides. The convenience and user-friendly nature of such approaches further contribute to their preference. Additionally, there is a lack of consumer willingness to pay a premium price for pesticide-free produce, which reduces the economic incentives for farmers to adopt IPM practices. Moreover, the availability of non-chemical alternatives or well-developed IPM options remains limited, further hindering adoption. Policy complications, including a lack of regulatory frameworks and support mechanisms, pose additional challenges. Lastly, cultural barriers and a lack of coordination in research efforts undermine the effective dissemination and implementation of IPM practices (Deguine et al., 2021).

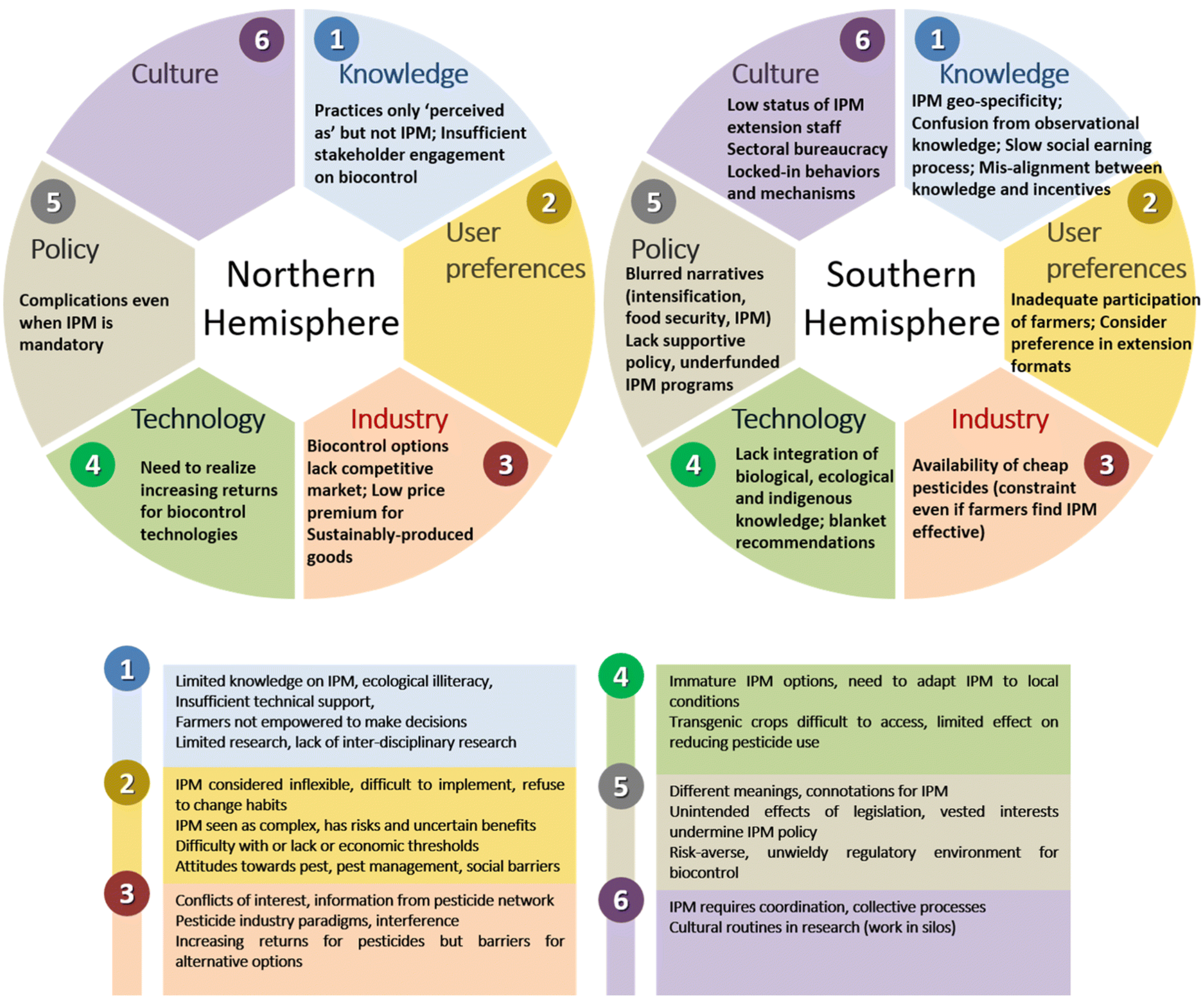

Figure 2 Barriers to adoption of Integrated Pest Management in the Northern and Southern Hemisphere. (Deguine et al., 2021)

Case Study of Integrated Pest Management: China

China was selected as a case study as it is the world's largest agricultural producer, with a large population, vast area, and diverse climatic zones, which are favourable conditions for growing a wide range of crops (Ross, 2023). Therefore, Chinese agriculture provides a unique opportunity to study how IPM techniques can be skillfully adapted and proven to be effective in different environments and cropping systems and different regions, as well as in the global food supply.

Chemical pesticides play a critical role in China's efforts to ensure stable and high agricultural yields, enabling the country to feed 20% of the world's population on only 7% of the world's arable land (Wang et al., 2022). To achieve these goals, Chinese farmers rely heavily on chemical pesticides to maintain high crop yields and long-term agricultural productivity. Over the past few decades, Chinese farmers have increasingly resorted to arbitrary practices, such as higher pesticide doses, more frequent applications, and shorter application intervals (Yu et al., 2021). These practices aimed to maximize crop protection and increase yields, but they also led to a significant increase in chemical pesticide use. Chemical pesticides used in China include fungicides, herbicides, and insecticides, with herbicides accounting for more than 60% of total pesticide use (Figure 3). Since 1991, the total annual consumption of pesticides in China has increased steadily and peaked in 2014 with over 1.5 million tons (Figure 3). After 2014, China experienced negative growth in chemical pesticide consumption, reflecting the country's efforts to address environmental and health concerns associated with excessive pesticide use. Despite the decline in recent years, China remains a major contributor to global pesticide use (Wang et al., 2022).

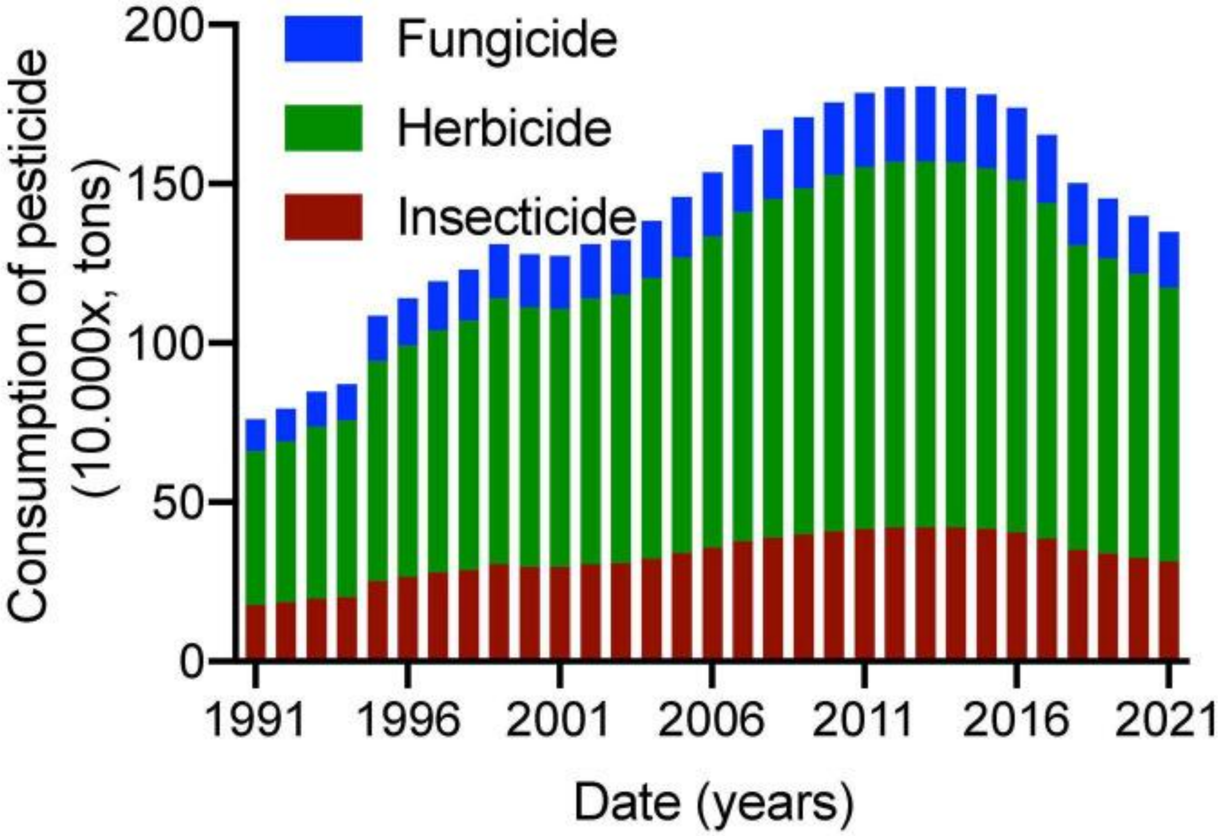

Figure 3 Chemical pesticide consumption in China from 1991 to 2021. Pesticides include fungicides, herbicides, and insecticides (Wang et al., 2022).

Unfortunately, the rapid growth in the production and consumption of chemical pesticides in China has led to negative impacts. Pesticide residues have become a serious problem in China, contaminating a wide range of crops, including vegetables, fruits, and herbs. The presence of pesticide residues not only compromises the safety and quality of food, but also poses risks to the environment, including air, water, and soil pollution, and poisoning or death of wildlife, plants, and beneficial insects (Wang et al., 2022). As stated earlier, pesticide residues can leach into nearby soils and waterways, leading to contamination of drinking water sources and degradation of soil quality. Alarmingly, reports indicate that more than 150 million acres (~ 70 million hectares) of farmland in China are contaminated (Peshin et al., 2009). These findings underscore the urgent need for sustainable pest management practices and alternatives to the overuse of chemical pesticides. As a result, efforts to balance the benefits of chemical pesticides with environmental and health considerations remain a top priority for China's agricultural sector.

China's status as the largest global agricultural producer, combined with its diverse agroecosystems and large population, makes it a valuable case study for understanding the practical implementation and effectiveness of IPM. The main objective of this paper was to provide a comprehensive assessment of the application of IPM in agriculture. China was selected as an example to evaluate the factors affecting the implementation of IPM as an alternative to the use of conventional pesticides. In addition, considering the prevailing social, economic, and environmental challenges, this review concludes with a series of IPM application strategies and practical recommendations that are suitable for the Chinese context. Lessons learned from studying IPM in China can inform and inspire similar places worldwide, as countries strive to achieve sustainable and resilient agricultural systems.

Objectives

This study's goal is to contribute to the ongoing evaluation of IPM adoption and its impacts with an example from China. By gaining deeper insights into the barriers to IPM adoption, this can provide valuable information to guide strategic efforts aimed at transitioning to greater IPM adoption by agricultural producers. The intended audience for this report includes the government of China and the agriculture sector. The specific objectives of this study are as follows:

1. Conduct a comprehensive evaluation of IPM adoption in China, including an assessment of the existing barriers.
2. Assess the effectiveness of three specific methods used in China to increase IPM adoption.
3. Review methods employed to encourage the adoption of IPM practices in other places.
4. Provide recommendations for reducing barriers to IPM adoption in the Chinese context.

This study offers valuable insights into IPM adoption, with the ultimate goal of facilitating informed decision-making and driving sustainable agricultural practices.

Methods

This study employed a systematic literature review approach, which involved summarizing, analyzing, and generalizing the existing relevant literature from academic journals, industry publications, and government agencies to identify gaps that need to be explored, or to develop new theories (Xiao & Watson, 2019). The primary focus of the literature review was to assess existing barriers to IPM adoption in Chinese agriculture fa. The review also explored general strategies that have been proposed to encourage the adoption of IPM practices. Additionally, the study assessed the effectiveness of specific methods that have been implemented in China, as a case study region with a significant agriculture sector. By synthesizing the findings from the literature review, practical recommendations are formulated to increase the adoption of IPM in China. The systematic approach ensures comprehensive coverage of relevant literature, enhancing the reliability and validity of the study's findings.

Results & Significance

Current Status of IPM Implementation in China

Recognizing the adverse effects of chemical pesticides on the environment and human health, the government of China has implemented various policies to reduce their use and address issues related to food safety, water pollution, and soil contamination. To reduce and control the usage of chemical pesticides, and provide ecological and environmental safety, thereby promoting the sustainable development of agriculture, the government of China is committed to promoting the Chinese practice of Green Control Techniques (GCTs) (Chen et al., 2022). GCTs is the Chinese concept of IPM and emphasizes the use of resource-efficient and environmentally friendly practices, including ecological regulation, biological and physical control methods, and judicious application of chemical pesticides (Zhang et al., 2023). Furthermore, it helps reduce crop losses, increase yields and improve the net income and welfare of farmers. By the end of 2019, the GCT coverage range of major crops in China was only 37% (Ministry of Justice of the People's Republic of China, 2020), and the application level was not high. Therefore, the effective implementation of GCT in China has become a key issue that needs to be solved urgently to ensure the quality of agricultural products and promote the sustainable development of agriculture. To further accelerate the adoption of GCT, the government of China has launched initiatives such as the Action Plan to Achieve Zero Growth in Pesticide Use by 2020, and the goal of achieving more than 50% GCT coverage of major crops by 2022 (Shuqin and Fang, 2018).

IPM adoption in China is commonly associated with farmers' traits such as gender, education level, resource availability, and cognitive attributes. Additionally, external factors, such as government policies and technical training also play a significant role in GCT/IPM adoption (Zhang et al., 2023; Gao et al., 2019). These factors collectively shape farmers' decisions to embrace sustainable and environmental-friendly technologies in agriculture. Understanding these influencing factors can help policymakers and stakeholders develop targeted strategies and interventions to increase the widespread adoption of GCT/IPM in China.

Methods used to increase IPM adoption in China.

Farmer cooperative

The adoption of IPM offers numerous benefits, including the assurance of safe agricultural practices, product quality, and environmental protection. However, there are inherent risks associated with adopting IPM practices. As highlighted by Yu et al. (2021), these risks include uncertainty regarding the premium selling price derived from IPM products and the potential for improper use of the technology. Risk-averse farmers tend to be more cautious in their management decisions, and the uncertainty introduced by IPM technologies can create reluctance to adopt these practices, despite the various advantages they offer. It is crucial to address these concerns and provide farmers with the necessary information, support, and incentives to mitigate risks and encourage the widespread adoption of IPM in agriculture.

In China, due to its large population and dispersed land owned by individual farmers, the agricultural sector is suited for small-scale farming but with large-scale production methods (Huang, 2014). The emergence of farmers' cooperatives is considered an important institutional innovation in agricultural programs that have been effective in organizing dispersed farmers, enabling small-scale farmers to access larger markets, promoting large-scale and standardized agricultural operations, and ensuring quality and safety through regulation. Cooperatives also enhance farmers' bargaining power in the market, reduce logistics costs and increase incomes (Huang, 2014). As a result, the cooperative model is widely used in various agricultural sectors, including crop farming, livestock raising, forestry, and more.

Further, farmer cooperatives play a key role in mitigating risk aversion among smallholder farmers (Ma & Abdulai, 2019). Cooperatives can share the expenses related to technology adoption by centralizing resources and dividing the costs of technology among all cooperative members. As a result, the financial burden on individual farmers is significantly reduced. This cost-sharing arrangement increases the ability and opportunity for each farmer within the cooperative to adopt new technologies. Cooperatives also play a key role in providing technical guidance among farmers to ensure the proper use of agricultural technologies. In addition, cooperatives promote cooperation and exchange among members, creating an environment where farmers can share knowledge, learn from each other's experiences, and reduce the risk of improper technology use. Furthermore, cooperatives provide farmers with access to important resources and services, including production materials, procurement services, and credit guarantee services. These services help address production and credit constraints, increase mobility, and provide a platform for farmers to establish collective sales contracts with dealers or agribusinesses (Yu et al., 2021; Ma and Abdulai, 2019).

In Wang et al.'s study in 2018, on apple growers from the Loess Plateau in China, they found a significant relationship between farmers' membership in a farmer cooperative and their adoption of non-chemical pest management methods. Such linkages can be attributed to the role of cooperatives as facilitators, linking small agricultural producers to larger markets (including contractors and dealers) by facilitating sales contracts between farmers and these market participants. The study showed that when farmers had a sales contract, they were 7.2% more likely to choose non-chemical pest management methods. This increase can be attributed to several factors. A key factor was that the signed sales contracts enhanced farmers' concern for apple quality. Contracts serve as a mechanism to ensure that farmers' apples meet specific quality requirements and motivate them to adopt IPM during planting. In addition, sales contracts help create a longer, more trustworthy relationship between the farmer and the apple distributor. This relationship reduces farmers' risk aversion and provides farmers with the assurance that their apples will sell well. As a result, incentivizing them to adopt IPM practices as part of their overall approach to producing high-quality fruit (Wang et al., 2018).

Subsidy programme

While IPM offers long-term benefits, such as reduced pesticide use, improved sustainability, and higher crop productivity, the initial cost of IPM adoption can create economic challenges for farmers during the start-up phase. This includes modifications to farming practices and infrastructure, as well as the higher initial investment required for alternative IPM products. Since 2009, the province of Beijing Municipality has implemented the "Green Pest Control" subsidy program, which provides financial support to farmers in different regions of the country (Wei et al., 2019). For instance, in 2018, the Beijing local government allocated a total of 30 million CNY (approximately 5.5 million CAD) in subsidies specifically for IPM products to assist farmers in the Beijing area (Figure 4).

	Natural enemies (macrobial biocontrol agents)	Pollinating insects	Biopesticides (microbial biocontrol agents, botanicals, soaps, oils, minerals)	Plant protection tools (technological methods such as traps)	Least toxic/residual synthetic pesticides (including antibiotics)
Subsidy of total product price	90%	50%	50%	50%	30%
Upper limits/mu area**	300 CNY (44 USD)	200 CNY (30 USD)	Together 150 CNY (22 USD)		100 CNY (15 USD)

* Information provided by BPPS.

** 1 mu = 0.0667 ha.

Figure 4 Governmental subsidy rates for IPM-compatible plant protection products in 2018.

However, this distribution model of the IPM subsidies has failed to effectively reach and benefit scattered smallholder farmers (Wei et al., 2019). Instead, the majority of the subsidized products were received by big farmer operations or large cooperatives in the area. In some instances, these beneficiaries even received subsidies multiple times from various levels of government and institutions. This skewed distribution created several issues, including the overuse and wastage of subsidies, limited coverage of subsidies for small farmers, and a decline in farmers' interest in the program (Wei et al., 2019).

To address the equitable distribution of IPM subsidies for smallholder farmers, the Beijing Municipality Government has taken steps in 2017 to integrate a network of plant clinics with the subsidy program (Wei et al., 2019). This integrated approach ensures that smallholder farmers receive personalized support to enable them to access IPM-related information and subsidized products. According to Wei et al. (2019), the practical steps of this approach were as follows:

1) Smallholder farmers who may lack plant protection knowledge and skills can seek help from plant clinics,
2) At the plant clinics, farmers can submit samples of crops with health problems, and the plant doctor provides a diagnosis and IPM advice based on the sample observations and communication with the farmer,
3) After diagnosis, the plant clinic issues a prescription order for non-chemical or minimally toxic/residual plant protection products,
4) The farmer can then take the prescription form to a registered plant protection product store and purchase the recommended IPM products at a subsidized price.

Wei et al. (2019)'s study of smallholder farmers in Beijing showed that combining a subsidy program with plant clinics can be effective in increasing farmers' motivation to adopt IPM. Specifically, the implementation of plant clinic prescriptions linked to IPM-compatible subsidized plant protection products in 2017 resulted in a notable 15% decrease in the use of the most common low-toxicity synthetic pesticides (Figure 5). Conversely, there was a significant 10%

increase in the use of the most common IPM-compliant biocontrol and biopesticide products (Figure 5). These trends indicate that the combination of the subsidy program and the plant clinics had a positive impact on reducing pesticide usage in the study area and encouraging farmers to adopt more sustainable IPM-compatible pest control methods.

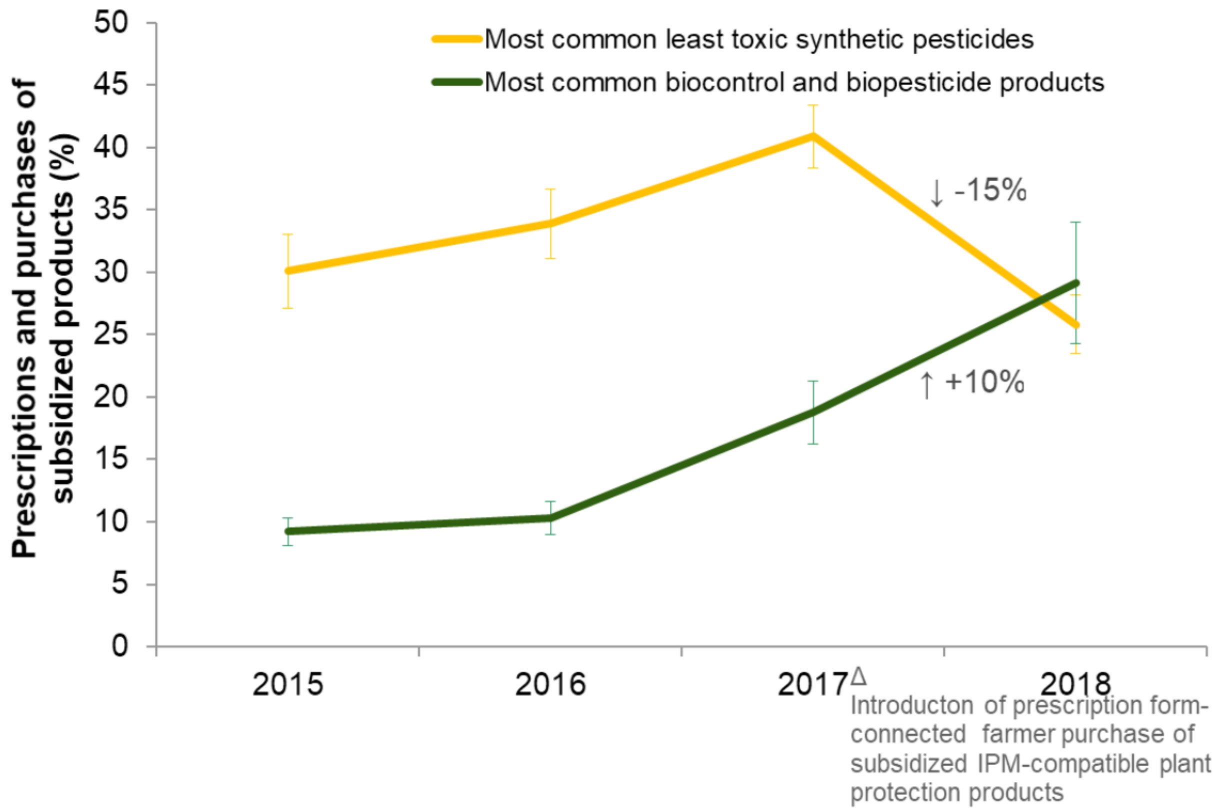

Figure 5 Yearly changes in prescriptions and purchases of IPM-compatible plant protection products in Beijing (Wei et al., 2019).

Integrating the "Green Pest Control" subsidy program with plant clinics is an innovative approach to increase the adoption of IPM in China. This approach can significantly reduce the overall reliance on conventional pesticides and foster greater utilization of biological products for pest management. Such a successful combination could serve as a model for other provinces in China and even inspire similar initiatives in other countries, contributing to more sustainable and eco-friendly agricultural practices globally.

Certification of agricultural products

Creating a favourable market environment is an important incentive for farmers to adopt IPM methods. The government can play an important role in ensuring that agricultural products grown using IPM methods receive a premium price in the market, which encourages farmers and helps them recover their initial investment costs.

In China, the government implemented a certification policy for agricultural production, including organic, green, and qualified agricultural products, in the 1990s (Tong et al., 2022). These certifications classify agricultural products according to the restrictions on chemical pesticides they use. Certified organic agricultural products prohibit the use of chemical pesticides and promote non-chemical pest control methods. Green-certified agricultural products allow the use of low-toxicity chemical pesticides while encouraging non-chemical pest control methods. Qualified agricultural products allow the use of low- and medium-toxicity chemical pesticides while restricting the use of highly toxic pesticides (Tong et al., 2022). This hierarchical structure means that agricultural products subject to stricter restrictions on the use of chemical pesticides can receive higher market prices.

A study conducted by Wang et al. (2018) on small-scale apple growers in the Loess Plateau of China demonstrated the effectiveness of certification in promoting the adoption of IPM. Certification of fruit cultivation zones encouraged the use of IPM practices, leading to a higher probability of adoption of these practices by farmers in certified areas. The study showed that farmers who knew their apple orchards were in certified green or organic apple growing areas adopted 61.9% more non-chemical pest management practices compared to farmers in noncertified green apple areas. This phenomenon can be attributed to farmers' realization that certified orchards tend to receive higher market prices for their yields, which strengthens their incentives to engage in this practice.

Based on these findings, it is recommended that the government plan to expand certified green farming areas, certified organic farming areas, and certified pollution-free fruit growing areas. This expansion will provide more opportunities for farmers to participate in IPM adoption, as certification requirements encourage the use of sustainable pest management practices.

Methods to encourage IPM adoption in other places

The global adoption of IPM in agriculture encounters various behavioural obstacles, including lack of education, resistance to change among end users, and limited availability of technology options (Deguine et al., 2021). However, overcoming these obstacles to IPM adoption involves employing methods that can be both costly and time-consuming. Some of these methods include mass media dissemination, extension visits, and farmer field schools (Alwang et al., 2019).

An effective and timely approach to address behavioural factors that impede the adoption of IPM is to send text messages and animated video subscriptions of IPM-related information directly to farmers by agricultural advisory firms (Alwang et al., 2019). By adopting this approach, farmers can be helped to overcome the constraints that prevent them from adopting IPM due to limited knowledge and technical support. Text messages can be used as a convenient means of communicating the benefits and importance of IPM to farmers by providing concise, actionable information that makes it easier for farmers to understand and adopt IPM practices on their farms. In addition, animated videos provide a visually appealing way to present complex concepts in a simplified manner. Through visual storytelling, farmers can better understand IPM techniques and witness their potential impact on pest management and crop yield.

Delivering IPM-related information through text messages and animated video subscriptions offers an attractive alternative to traditional training approaches. This method provides incentives for farmers to overcome behaviour constraints and build knowledge. The accessibility and personalized nature of text messages stimulate interest and prompt action, bridging knowledge gaps and encouraging the adoption of sustainable pest management practices among farmers.

In a study conducted in Ecuador, Larochelle et al. (2017) investigated the effects of utilizing text messaging to promote the adoption of integrated pest management (IPM). The results of the study showed that receiving text messages had a favorable impact on farmers' knowledge and was associated with a higher likelihood of adopting IPM practices. In specific, the study showed that when farmers subscribed to text messages, their understanding of the various IPM practices improved by about 20% (Figure 6). In addition, farmers who subscribed to the text messages were 10% more likely to adopt IPM practices compared to farmers who did not subscribe to the text messages (Figures 7).

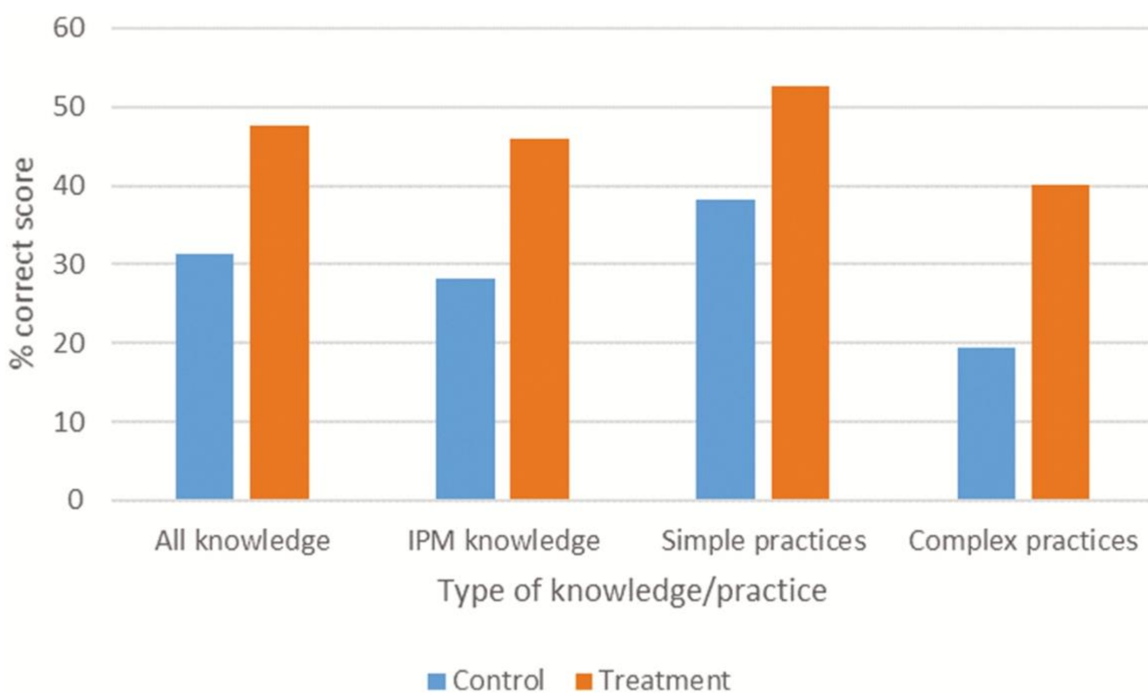

Figure 6. Increase in different forms of IPM knowledge by exposure to treatment. (Larochelle et al., 2017).

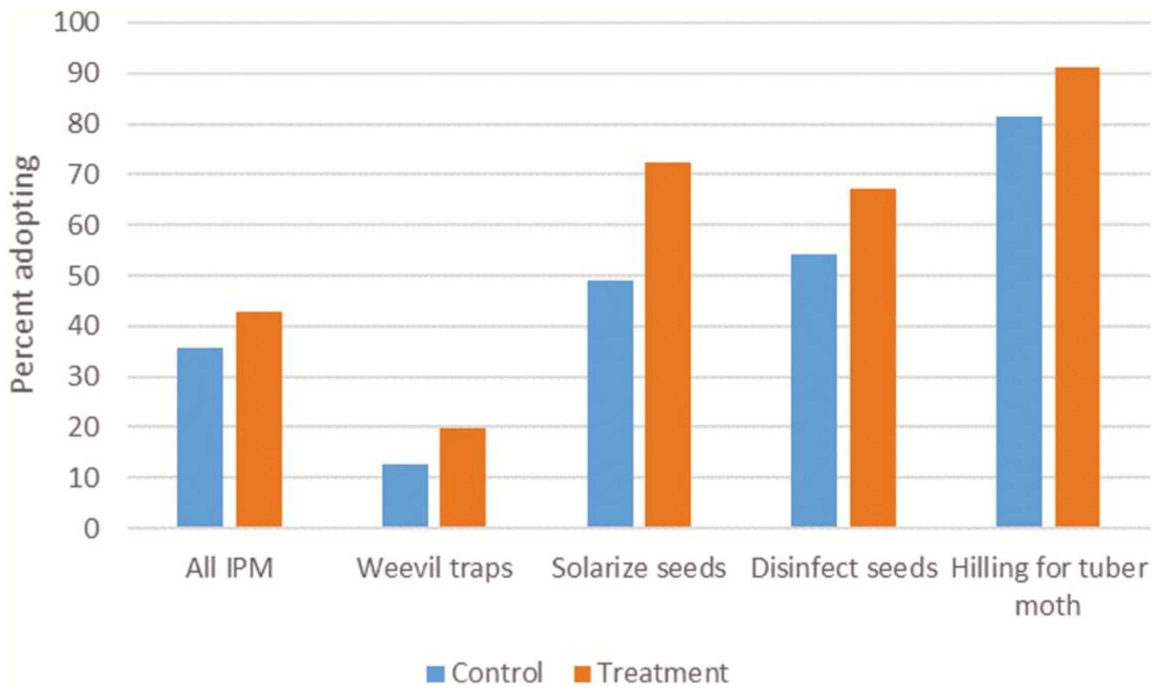

Figure 7. Increase in adoption of IPM practices (% of participants adopting each practice) by receiving text message subscription treatment (Larochelle et al., 2017).

While these new technological methods hold great potential, they may require educational programs to be effective. This is largely due to uncertainty about farmers' familiarity with digital tools and the accessibility of technology. It is therefore imperative that education programs are tailored to address these potential gaps. For example, guiding the use of mobile devices or the viewing of video content is an important component of such programs.

Recommendations to increase IPM adoption.

The adoption of integrated pest management (IPM) practices in Chinese agriculture has encountered several challenges, including limited education, farmers' risk aversion, and economic barriers. This comprehensive review focuses on three specific approaches used to address barriers to IPM adoption among small-scale apple growers in the province of Beijing municipality and the Loess Plateau of China: agricultural cooperatives, government subsidies, and certification of IPM agricultural products. Analysis of the data confirms the effectiveness of these methods in addressing barriers to IPM adoption by Chinese farmers.

To further incentivize farmers to adopt IPM methods, it is recommended that the government actively promote the establishment and participation of agricultural cooperatives. These cooperatives can facilitate cost-sharing among farmers and provide mutual support in learning and implementing new technologies. The government should also provide financial and material subsidies to incentivize farmers to embrace IPM technologies. In addition, expanding the certification field and strengthening the certification process for agricultural production can contribute to creating a favourable market environment and increasing the prices of IPM-grown agricultural products. Distributors and stakeholders should consider offering a premium for high-quality agricultural products that exceed contracted quality requirements, thereby improving farmers' income and financial position. Currently, these three strategies are limited to small-scale apple farming in northern China. It is recommended that the application of these methods be extended to similar crops and different geographic regions, thereby expanding the application of IPM. In addition, these techniques provide a valuable blueprint for scaling up IPM adoption on a global scale.

An additional economical and easily accessible approach suggested in the review involves the utilization of text message subscriptions to convey IPM-related insights directly to farmers. To effectively implement this strategy on a widespread level, it is recommended that the government establish educational programs. These programs should be designed to offer guidance on mobile device utilization, tailored to the technological accessibility of farmers. By implementing these recommendations, the text message and animated video approach can effectively overcome behavioural constraints, capture farmers' interest, and motivate them to adopt IPM practices, contributing to sustainable agricultural practices in China.

This study offers valuable insights for policymakers by providing a deeper understanding of the factors hindering farmers' adoption of IPM practices. With this knowledge, policymakers can develop targeted and effective policies to address the barriers hindering the widespread adoption of IPM among farmers. These tailored policies have the potential to foster greater adoption of IPM strategies and contribute to the advancement of environmentally friendly agricultural practices. IPM technology has no international boundaries, and other governments can likewise implement corresponding measures to address issues in IPM adoption. By embracing these sustainable practices, countries can collectively contribute to a more environmentally conscious and climate-friendly future, working together to address global challenges and foster a more sustainable world.

In summary, this review provides valuable insights into effective strategies for promoting IPM adoption in agriculture. By addressing educational, economic, and behavioural barriers, implementing agriculture cooperatives, providing subsidies, and creating an enabling market environment, Chinese farmers can be encouraged to embrace sustainable IPM practices. In addition, the use of text messages and animated videos provides an economical means of delivering IPM-related information and promoting IPM adoption. These findings and strategies are applicable not only in China, but as recommended, also to other parts of the world, and contribute to the widespread adoption of IPM practices in agriculture.

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Appendix

INTEGRATED PEST MANAGEMENT (IPM) IN CHINESE AGRICULTURE

AGRICULTURAL PESTICIDES

Environmental impacts
- Pollute soil and water system

Human health impacts
- Acute or chronic health risks

IPM IN AGRICULTURE

- **IPM**: A practical and environmentally sensitive approach to pest management that relies on a combination of practices.
- **Advantage**: Reduce environmental/ health risks, ensure long-term agricultural viability
- **Barriers**: Lack of knowledge, resistance to change, economic constraint

IPM ADOPTION IN CHINA

- World's **largest** agricultural producer
- **Overreliance** on chemical pesticides (Figure 1) - pesticide residue problems
- Committed to spreading IPM in China, incorporating policies, research, and practices - 37% coverage by 2019

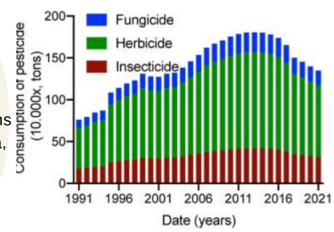

Figure 1. Chemical pesticide consumption in China from 1991 to 2021. Pesticides include fungicides, herbicides, and insecticides (Wang et al., 2022).

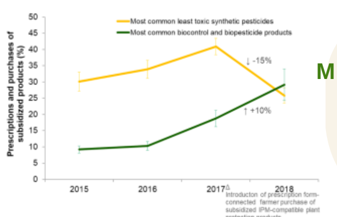

Figure 2. Yearly changes in prescriptions and purchases of IPM-compatible plant protection products in Beijing (Wei et al., 2019).

METHODS TO INCREASE IPM

- Farmer cooperative
- Subsidy programme (Figure 2)
- Certification of agriculture product
- Text message subscriptions

RECOMMENDATIONS

(To the government of China and the agriculture sector)

- Promote the establishment and participation of **agricultural cooperatives**
- Provide financial and material **subsidies** to incentivize farmers to adopt integrated pest management technologies
- Expand the field of **certification** and strengthen the certification program for agricultural production
- Develop **educational programs** on how to use mobile devices

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