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Implementing Agri-policies on Pesticide Reduction through Subsidies and Plant Clinics in China

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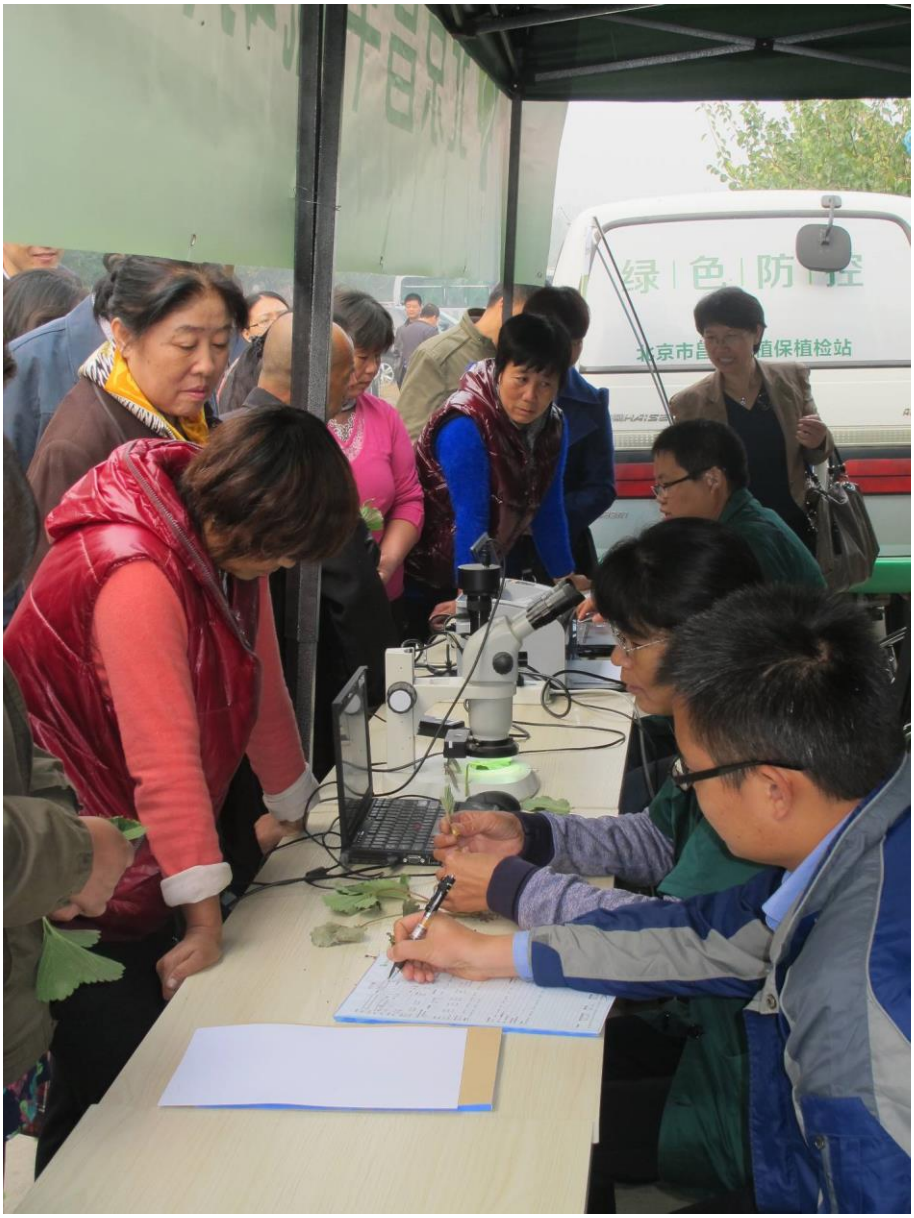
Acronyms and Abbreviations

BPPS	Beijing Plant Protection Station
BPRMS	Beijing Pesticide Reduction Management System
CNY	Chinese Yuan
IPM	Integrated pest management
MoA	Ministry of Agriculture of the People's Republic of China
POMS	Plantwise Online Management System
pp	Percentage points
PPS	Plant Protection Station
QR Code	Quick Response Code
USD	United States Dollar



Abstract

This study assesses whether the implementation of agricultural policy through plant clinic-linked subsidy programmes can lead to a reduction in pesticide use. A governmental “Green Pest Control” subsidy programme has been coordinated by the Beijing Plant Protection Station since 2009. In 2017, the subsidy programme was combined with the Plantwise plant clinic network to increase outreach to smallholder farmers. A new online system, the “Beijing Pesticide Reduction Management System” was established as an extension of the “Plantwise Online Management System”. It manages prescription data, subsidies, plant clinics, agri-input shops and suppliers, and monitors processes and outputs.

We analysed 72,474 prescription forms issued by plant doctors to over 6000 farmers in the Beijing area between 2015 and 2018 to assess changes in pesticide recommendations, and in 2018 also changes in sales. Of the 30 million CNY (4.4 million USD) spent on subsidies in 2018, 66% were spent on macrobial natural enemies, 14% on plant protection tools, 11% on biopesticides, 6% on pollinators and 3% on least toxic/residual chemical pesticides, representing 20%, 3%, 34%, 6% and 37% of prescriptions and sales, respectively. Prescriptions for non-chemical plant protection products increased by 20%, and prescriptions for pesticides decreased by 4%. The crop area treated with non-chemical or least toxic/residual pesticides was 45% greater in 2018 than in 2015. The number of yearly prescriptions tripled from between 10,000 and 13,000 to 37,000+; each clinic issuing 20% more prescriptions. The combination of pesticide reduction policies, subsidies and effective agricultural extension services such as plant clinics appears to be a sound example of successful agri-policy implementation.

1 Context

1.1 The problem

Pesticides are commonly used in agriculture to reduce plant pests in order to prevent yield losses. For years, crop pest management has been becoming more difficult, and pesticide use has increased due to: (a) intensifying agricultural production; (b) expanding high-value crop production and thus increasing cash availability for farmers; (c) pest resistance to pesticides; and (d) crop stress and pest outbreaks due to climate change. Roughly 311,000 tons of active pesticide substances were used annually in China between 2012 and 2014 (MoA, 2015); a 9.2% increase on the period 2009–2011. The overuse of pesticide leads to higher production cost and may adversely impact both food safety and the environment.

Beijing is a typical example of urban and suburban agriculture. The agricultural area is 3,245,000 mu[1] (216,300 ha) including 1,100,000 mu (73,300 ha) of grain crops, 550,000 mu (36,700 ha) of vegetables, and 1,070,000 mu (71,300 ha) of fruits. In order to ensure a steady supply of fresh agricultural produce and to maintain self-sufficiency level, the local government of Beijing plans to increase the vegetable growing area to 700,000 mu (46,700 ha) and to reduce grain growing to 800,000 mu (53,300 ha) (BJDRC, 2018). The "Vegetable Basket" industry for Beijing city customers, especially greenhouse vegetables, became a major force in agricultural development. Greenhouse vegetables are grown all year round, which results in a higher frequency and severity of pests. Farmers often try to resolve these pest outbreaks through use of chemical pesticides. Given that some farmers may lack awareness and expertise on rational pesticide use, an overuse and misuse of pesticides may happen. For example, pesticides used to manage pests in vegetables account for over 60% of all pesticides used in the Beijing area (Zhao *et al*., 2018). Therefore, in order to reduce pesticide use, it is essential to change crop protection techniques in the greenhouse vegetable industry, and to replace chemical pesticides with natural enemies or biopesticides. However, by the end of 2010, there were approximately 591,000 farmers in Beijing and more than 85% of them were commercial smallholder farmers who operate one to three greenhouses or tiny plots. This farmer group is large and pesticide reduction is difficult to implement and even more difficult to monitor, so it is a challenge to assure food safety.

1.2 Agri-policy

China has moved towards an integrated pest management (IPM) approach highlighting pest prevention, proper pest monitoring and decision making, and rational direct pest control. The IPM-compatible pest control techniques are called "Green Pest Control" techniques in Chinese, and include cultural control, non-chemical control, plant protection tools such as insect traps (technological control), as well as the rational use of least toxic and least residual pesticides. There is also a governmental area-wide pest management approach ("Professional Unified Pest Control" in Chinese) where government institutions or their subcontractors provide professional pest management services area-wide for a larger group of farmers. Since 2006, China has been promoting "Green Pest Control" and area-wide pest management approaches on major crops.

In 2006, China issued its "Green Pest Control Policy" (Fan, 2006; MoA, 2011) aimed at reducing pesticide risks to humans, animals and the environment. In 2015, the Chinese government published the "Pesticide and Fertilizer Zero Growth Action Plan 2015–2020", in which concrete targets were set, such as: (a) a minimum of 40% of the agricultural area with major crops under government-organized area-wide pest management; and (b) keeping total pesticide use below the average level of 2012–2014 (MoA, 2015). The policy also demanded local financial support, such as subsidies for non-chemical and least toxic plant protection measures (Figure 1).

[1] A unit of area in China, 1 mu = 0.067 ha (1 ha = 15 mu).

Figure 1: Subsidized predatory mites used for the biological control of pest mites

1.3 Agri-policy implementation via a "Green Pest Control" subsidy programme

As in many Chinese provinces, the provincial government of Beijing municipality and its Beijing Plant Protection Station (BPPS) have launched a series of actions to facilitate pesticide reductions as per China's agri-policy. These include: (a) the promotion of "Green Pest Control" technologies; (b) the establishment of farmer demonstration plots; (c) publishing recommended lists of non-chemical and least toxic/residual plant protection products; (d) the establishment of a three-level plant health advisory system (central and district plant health hospitals, local Plantwise plant clinics); and most importantly (e) the implementation of a subsidy programme for non-chemical and least toxic/least residual plant protection products.

This programme started in 2009, and is called the **"Green Pest Control" subsidy programme** (BPPS, 2015). In 2018, 30 million CNY (4.4 million USD) of subsidies were made available by the Beijing local government via the BPPS for "Green Pest Control" products for farmers in the Beijing area. Subsidized "Green Pest Control" products should have little or no effect on the consumers and the environment (see 2018 list in Annexe). Products are subsidized at different rates prioritizing natural enemies (macrobial biocontrol agents), followed by pollinating insects, biopesticides and plant protection tools, and finally by least toxic/residual synthetic pesticides (Table 1).

Table 1: Governmental subsidy rates for IPM-compatible plant protection products (in China called "Green Pest Control" products),* financed by the government in 2018

	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.

1.4 Agricultural extension including plant clinics

Plantwise is a global programme enhancing plant health systems, in particular agricultural advisory services for famers (Romney *et al*., 2013). Plantwise started in Beijing in 2012, with the aim to improve the quality and outreach of the existing agricultural extension systems (Qiao *et al*., 2018; Zhao *et al*., 2018). Targeting the scattered smallholder farmers who might lack plant protection knowledge and skills, **plant clinics** were established to provide face-to-face crop health problem diagnosis and pest management advice (Romney *et al*., 2013). Plantwise uses plant clinics as a demand-driven service run by frontline extension workers or other intermediaries interacting with farmers, with the aim to reach more growers than traditional services. Plant clinic sessions are held regularly at places convenient to both farmers and local extension workers. Once trained, the plant doctors provide free and on-the-spot diagnosis and pest management advice for growers who bring crop samples suffering from a plant health problem to the clinics (Romney *et al*., 2013). The diagnosis and advice are provided to the grower in the form of a prescription, as known from the human health system. The prescription helps the grower to better manage his/her crop and to potentially buy the right agri-inputs in a shop. Prescription forms contain information about the plant clinic location as well as the advising plant doctor, the advised farmer, symptoms and diagnosis of the plant health problem, and advice details. This information is captured on electronic prescription forms, available to the farmer, plant doctor, supervisor and quality assurance staff.

Working together with CABI, BPPS set up six pilot plant clinics in three districts in 2012 (Zhao *et al*., 2018). Due to successes, the plant clinic numbers continuously increased (Qiao *et al*., 2018). By 2018, 83 plant clinics had been established of which 68 are still running regularly in 11 districts of Beijing municipality (Figure 2). Plant clinic services cover catchment areas of 164 towns and 855 villages in the Beijing area. In addition to the local village-level plant clinics, the Beijing government's Plant Protection Station (BPPS) launched a three-level plant health advisory system by establishing one central plant hospital and two district-level government plant hospitals. These provide systematic support to local plant clinics particularly in pest diagnosis, and help to overcome human resource limitations at the local level with regard to data validation and quality monitoring.

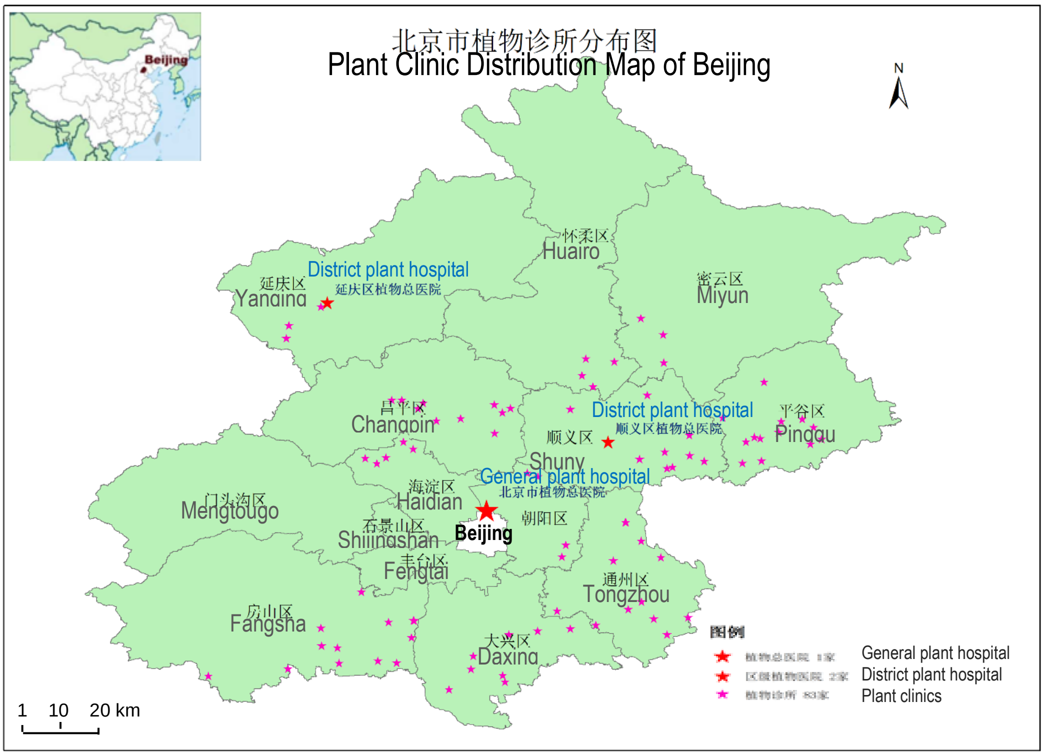


Figure 2: Plant clinics in agricultural suburban districts of Beijing municipality in 2018

1.5 A new model for better "Green Pest Control" subsidy implementation

Between 2009 and 2017, the common subsidy implementation approach was that government-purchased, subsidized and promoted plant protection products were distributed for free to farmers, which to some extent promoted the "Green Pest Control Policy". However, this distribution model did not widely benefit the scattered smallholder farmers. Instead, big farmers, large cooperatives or demonstration plots in the policy-targeted areas received most of the subsidized products, sometimes even repeatedly from different governmental levels and institutions. This caused some problems such as overuse and waste of subsidies, limited subsidy coverage, or decreasing farmer interest.

In order to better reach smallholder farmers for such agri-policy implementation, the **Plantwise plant clinic network was combined with the "Green Pest Control" subsidy programme** from the end of 2017 onwards. Based on plant doctor prescriptions to farmers, and subsequent sales of non-chemical or least toxic/residual plant protection products from registered agri-input shops, subsidies are paid to the agri-input suppliers delivering to the agri-input shops. Different plant protection product groups were differently subsidized, with higher rates for natural enemies (macrobial biocontrol agents), followed by pollinators, biopesticides and plant protection tools, and finally least toxic/residual chemical pesticides (see 2018 rates in Table 1). It was hoped that the plant clinic involvement would lead to a better reach of smallholder farmers, and would facilitate a change in their agricultural practices leading to a reduction of problematic pesticides.

In practice, the "Green Pest Control" subsidy implementation process (Figure 3) is as follows. Farmers take crop samples with health problems to the plant clinics, where plant doctors make a diagnosis and provide pest management recommendations to the farmers according to sample observation and through communication with the farmer. An electronic prescription form is issued to capture this information (sometimes also a paper printout). Then the farmer can decide to go to a registered agri-input shop to buy the recommended products as per the prescription sheet. If the recommended product is in the "Recommended List of Green Pest Control products" published by BPPS (see Annexe), then the farmer could purchase the products at a subsidized price (see Table 1). If farmers want to purchase natural enemy products, prescriptions need to be submitted in advance, in order to give suppliers time for agent multiplication and preparation. Once the plant protection products had been sold by the agri-input dealers at a subsidized price and as per prescription forms, then agri-input suppliers claim the subsidy back from BPPS on a monthly basis of sales records and plant clinic prescription data.

Thus, there are five key actors in the new subsidy management model: farmers, plant doctors, agri-input shop dealers, agri-input suppliers and governmental PPS (Figure 3).

By the end of 2018, 48,185 farmers and their farms and households had been registered in the Beijing Pesticide Reduction Management System (BPRMS) (see below) by local authorities as potential beneficiaries of the subsidies (Figure 4). At the time of writing, a total of 400 individuals in the Beijing area had been trained as plant doctors with Plant Doctor Certificates authorized by BPPS and CABI. Many of these were trained as part of a local initiative to improve knowledge and skills for agri-extension service providers and not all are associated with officially recognized clinics. Of these trained plant doctors, 294 became registered as part of the BPRMS in 2018 (45% females) of which 15% are government extension officers, 35% are technicians/managers from farmer cooperatives and growing companies, and 50% are sales/owners from agri-shops. Of these, 137 from 68 clinics were making prescriptions, though it is expected that others may start to issue prescriptions through the BPRMS in 2019. At the same time 102 professional, medium- and large-size agri-input shops have been carefully selected in 11 districts by district-level plant protection stations (PPS) in communication with BPPS; as well as seven professional large agri-input suppliers related to these shops. The strict selection process included screening of certifications, registrations, and public reputation (i.e. among farmers). The BPPS and 11 district-level PPS are the main actors who manage the local government subsidies.

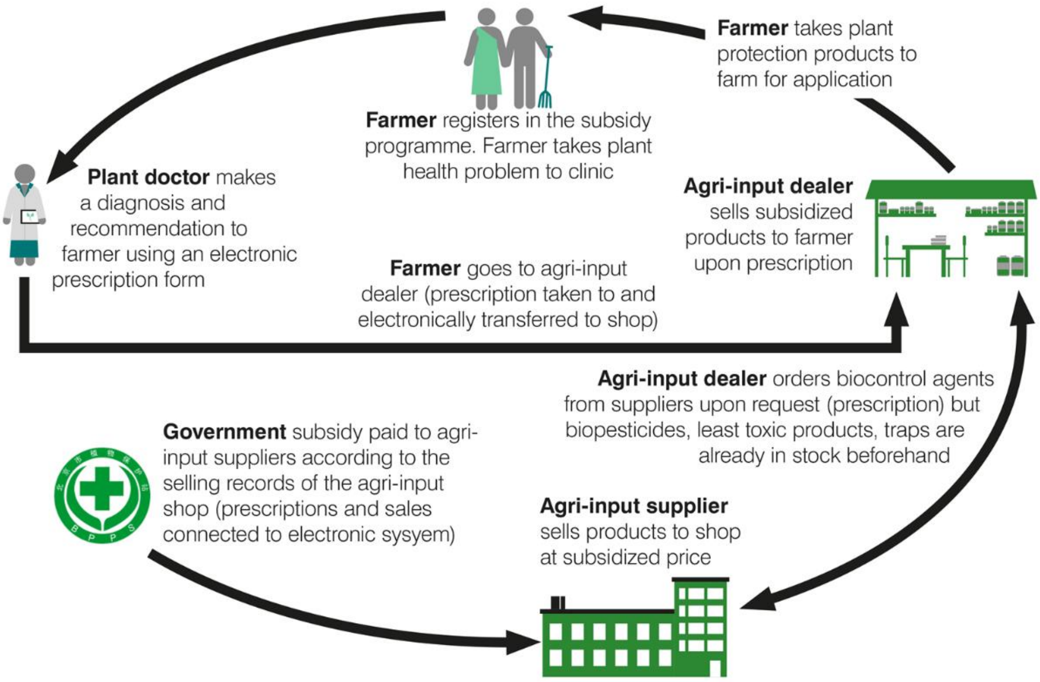


Figure 3: Beijing Pesticide Reduction Management System (BPRMS) implementing governmental subsidies for IPM-compatible plant protection products, according to China's "Green Pest Control" agri-policy

1.6 The Beijing Pesticide Reduction Management System

A novel online plant clinic and subsidy data management platform, called the "Beijing Pesticide Reduction Management System" (BPRMS, www.nyjl.bpps.org.cn), was developed by BPPS and put into use in October 2017. The BPRMS is an online system that enables the automatic management of plant protection related tasks: (a) managing agricultural extension such as the prescription forms by plant doctors to farmers; (b) implementing an automatic and dynamic management of agri-policy-driven subsidy flows; and (c) monitoring of processes and outputs (Figures 3 and 5, Box 1). Therefore, the BPRMS expands on functions of the "Plantwise Online Management System" (POMS) used in other Plantwise countries (Romney *et al*., 2013).

In detail, farmers carry their quick response (QR) code-based registration card (called Crop Health Security Cards in Chinese, Figure 4) to visit a plant clinic, get a personalized prescription on the considered plant health problem, and buy subsidized products in the agri-input shops (Figure 3). By scanning the QR code on the card, plant doctors can access the basic information about a farmer and the farm including the farmer's name, address and contact details, crops, as well as farm area. Plant doctors can electronically record prescriptions, including pest symptoms, pest diagnosis and pest management recommendations, which are uploaded to the online BPRMS system. Upon scanning the farmer's QR code at the agri-input shop, the agri-input shop dealers can access the prescription forms online, as well as the recommended plant protection product(s). A farmer can then buy a product at a subsidized price. For every product sold in the shops, the system will recognize its category (Table 1), price, subsidy and supplier. Every month, the system will calculate prescription summaries, sales records and detailed subsidy statements. PPS will then pay the subsidies to the agri-inputs supplier. The whole process can be tracked and monitored on the system (Figure 5).

Figure 4: QR code-based registration card of farmers and their farms (farm households), called the farmer's "Crop Health Security Card" in Chinese, used in the BPRMS

There are nine functional modules on the web page of the online BPRMS (see Box 1), including basic information, recommended plant protection product lists, prescriptions, plant protection product sales, subsidy calculations, statistics and analysis, user feedback, announcements and news, and system management. The five key actors of the BPRMS (see Figure 3) have different levels of access rights to the nine modules.

Box 1: Functional modules in the online Beijing Pesticide Reduction Management System (BPRMS)

- **Basic plant health system information**: Personal and contact information of farmers, plant doctors, agri-input shops, agri-input suppliers.
- **Recommended plant protection product lists**: Annually updated recommended list of subsidized “Green Pest Control” products as well as an agri-input supplier interface providing product information first reviewed by district-level PPS and later by the BPPS before making it public (see Annexe).
- **Prescriptions**: Issue, search and management of prescription forms.
- **Plant protection product sales**: Sales of subsidized products according to the prescriptions, including procurements, storage, sales, disposal and recycling of pesticide packages.
- **Subsidy calculation**: Subsidy rates, automatic calculation of subsidies per product sold, and management of key stages including financial statements and monthly summaries.
- **Statistics and analysis**: Figures or tables of descriptive statistics on subsidy funds, products sold and farmers reached per location and across time (Figure 5).
- **User feedback**: Recording and managing complaints, field visits and farmers’ feedback.
- **Announcements and news**.
- **IT-systems management**.

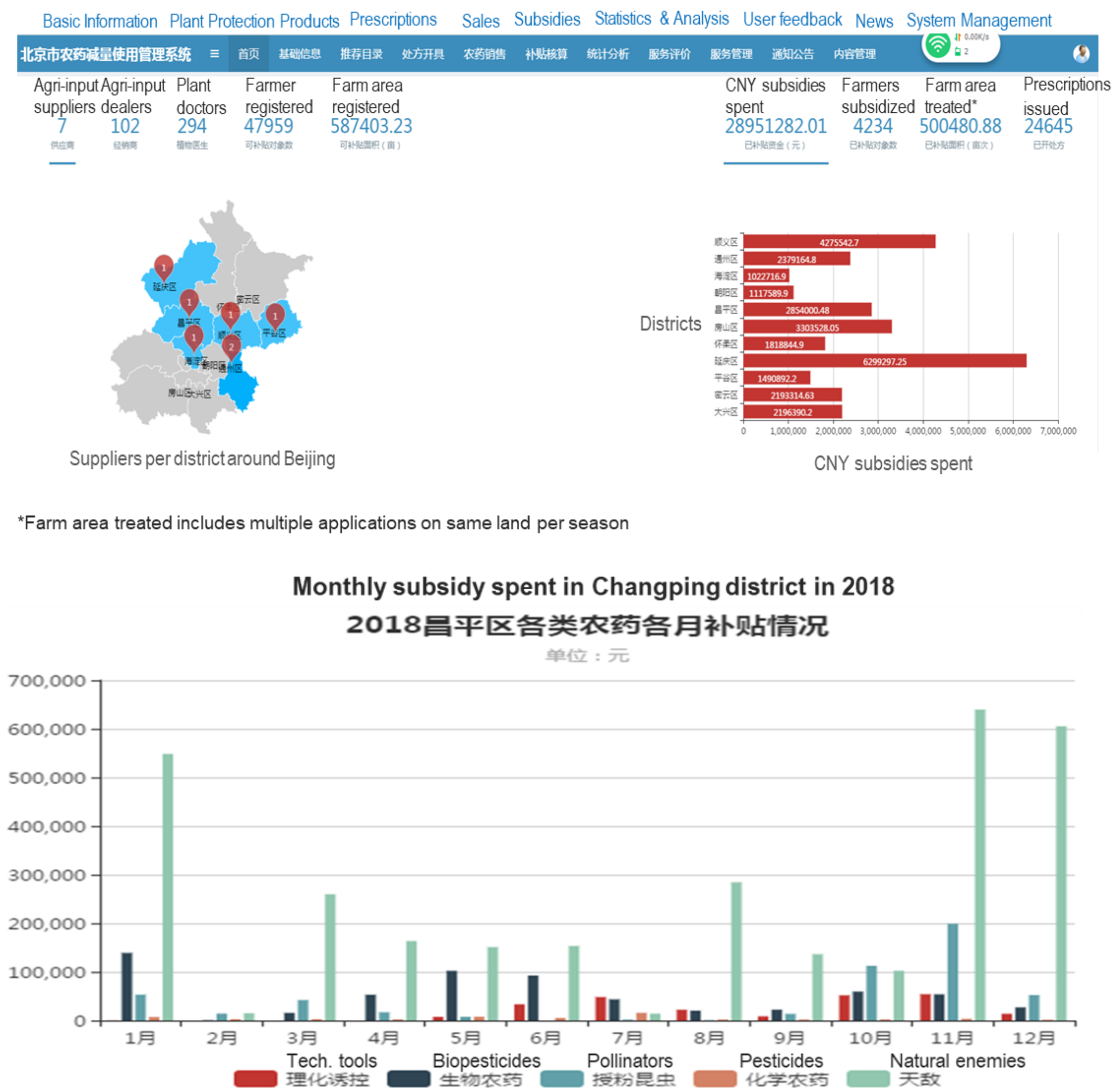


Figure 5: Online screenshots showing information from the Beijing Pesticide Reduction Management System (BPRMS)

2 Study Methods

A study was initiated to document the developments described above, to estimate the impacts on pesticide reduction and to draw lessons learnt for further improvements. Methods used included analyses of pest management recommendations in the prescription forms from plant clinics as well as stakeholder interviews. The **specific objectives** were to:

- document how the plant clinic system can facilitate a subsidy programme and policy implementation;
- analyse whether farmer reach is improved through a novel plant-clinic-connected subsidy system;
- analyse whether more non-chemical plant protection products are prescribed and sold due to subsidies; and
- analyse whether pesticide use decreased due to the subsidy programme.

2.1 Study area

In China, Plantwise is running in Beijing, Guangxi and Sichuan provinces. This study concentrates on the province of Beijing municipality because the "Green Pest Control Policy" has been implemented there since 2006 along with a related subsidy programme initiated in 2009. The subsidy programme was connected to the plant clinic network and managed via a novel electronic data management system (studied here) from the end of 2017. By 2018, 83 plant clinics (largely public, some private, some mixed) had been established of which 68 still run regularly in 11 agriculture-driven suburban districts of Beijing municipality (Figure 2, Table 2). They serve 164 townships and 855 villages. Therefore, the study followed an unaligned, clustered sample design with the clinic districts as clusters.

The study focused on farmers in these 11 districts of the Beijing municipality that have been served by the main actors involved in the BPRMS system including the 294 plant doctors; 102 carefully selected professional, medium- and large-size agri-input shops; seven professional large agri-inputs suppliers related to those shops; and 11 district-level PPS. Farmers' problem crops were mainly greenhouse and outdoor vegetables and berries, fruit trees and ornamental plants, reflecting the major crops grown in the Beijing municipality.

2.2 Data analysis of prescription forms

Plant doctor prescription forms giving plant health problem diagnosis and its management to a farmer as described above were analysed (find an example of a form in Zhang *et al*., 2017). Only 2015–2018 data were used assuring comparable plant clinic quality levels. From those, 72,474 of 74,739 forms were analysed (see Table 2). Prescription forms from 2015 to 2017 were recorded and processed by the Plantwise offline data management tools (i.e. Excel spreadsheets for data recording, harmonization and validation). Most prescription forms from 2018 were recorded and managed in the BPRMS (only 5% were still processed by the offline data management tools). All data were validated by PPS staff and external experts. Descriptive summary statistics were applied to understand the outreach of the advisory service and the subsidy programme.

To analyse the proportions of prescriptions for certain non-chemical and least toxic chemical plant protection measures, 1000 prescriptions were randomly chosen per year from plant clinic datasets between 2015 and 2017 and the recommended products categorized manually based on the descriptive recommendation parts of the forms. All 2018 data were used as these data are readily categorized and plant protection products individually extractable in the BPRMS system. We chose 18 of the most commonly used subsidized products in five categories from the recommended list of "Green Pest Control" products (See Annexe): (1) natural enemies: predatory mites, predatory bugs and ladybird beetles; (2) pollinating insects:

bees and bumblebees; (3) biopesticides: spinetoram, *Pythium oligandrum*; (4) plant protection tools: non-baited sticky sheet traps, exclusion nets, baited traps; and (5) least-acute-toxic/least residual synthetic pesticides: fungicides (azoxystrobin, difenoconazole, procymidone, mancozeb) and insecticides (acetamiprid, chlorantraniliprole, emamectin benzoate and avermectin). The frequency of such prescriptions was calculated over years to estimate the effects of subsidy programmes on promoting IPM-compatible plant protection products due to China's agri-policy. For the full list of subsidized products in 2018, see Annexe.

2.3 Farmer and agri-input dealer key informant interviews

To better interpret the prescription form data analysis, small-scale qualitative stakeholder interviews were organized for farmers and agri-input shop dealers at Changping district of Beijing, where strawberry is the main crop. In May 2018, ten strawberry farmers (six females and four males) and five agri-inputs shop dealers (two females and three males) were interviewed individually. Of these, seven farmers were BPRMS-registered farmers and had received subsidized products, while three farmers had not. Similarly, three agri-input shop dealers and their shops were registered in the BPRMS, and the other two shops were not. Interviews with farmers focused on the purchase and application of the subsidized non-chemical and least toxic plant protection products during the 2016–2017 and 2017–2018 strawberry growing seasons to capture changes possibly caused by introducing the BPRMS system. Interviews with agri-inputs shop dealers focused on 2-year sales performances to try to understand the impacts of the BPRMS and subsidies, and thus the agri-policy.

3 Findings

3.1 Farmers reached

The combination of the "Green Pest Control" subsidy programme, plant clinics and training of additional intermediaries as plant doctors improved the outreach and efficiency of the extension services in implementing agricultural policies and related subsidies. Between 2015 and 2018, the number of plant clinics grew by 63% from 25 to 68 serving an increasing number of farmers (Table 2). Since connecting the subsidy programme with plant clinic services via the BPRMS, 22 more clinics were established (+ 32% from 2017 to 2018).

Between 2015 and 2017 around 12,000–13,000 prescriptions annually were issued to the advice-seeking farmers. In 2018, the BPRMS became fully functional, which allowed a tripling of advice to farmers, with 37,000+ prescriptions written. The numbers of farmers served remained relatively stable – with individual farmers in 2018 receiving 6 to 7prescriptions/year on average (compared with 2 prescriptions/year from 2015 to 2017) suggesting an increase in the regularity of visits. In a complementary study most growers visited a plant doctor about once a month (i.e. 13 ± 12 times/year; Wan *et al*., 2019).

The total area treated is estimated by adding the area covered by each prescription, with multiple treatments on the same area of land being added separately. In 2018 the total area treated with non-chemical or least toxic/residual pesticides was roughly 45% greater than the area covered in 2015 (about 64,000 ha in 2018 vs 35,000 ha in 2015) when the scheme was not linked to clinics. By the end of 2018, there were 48,185 farming households and their farms registered in the system, but only about 15% of them profited from the provided services due to late registration and deficient public awareness/promotion. This indicates a large potential for upscaling if the reach can be improved beyond the 15% of registered farmers currently using the system.

Table 2: Plant clinic and “Green Pest Control” subsidy outreach in Beijing municipality

Outreach of plant clinics	2015	2016	2017	2018
Number of districts with plant clinics	9	9	9	11
Number of active plant clinics*	25	28	46	68
Number of active plant doctors	34	42	56	137
Number of prescriptions issued to farmers	11,495	12,788	12,972**	37,484
Average prescriptions issued/clinic	460	457	282**	551
Number of different farmers reached (31% females)	5,779	5,486	5,102**	5,805
Average number of different farmers reached/clinic	231	196	110**	85
Outreach of “Green Pest Control” subsidy programme⁺	**2015**	**2016**	**2017**	**2018**
Treated area (mu)⁺⁺	527,200	No data	No data	966,200⁺⁺⁺
Treated area (ha)⁺⁺	35,150	No data	No data	64,400⁺⁺⁺

Subsidy connection to plant clinics and the online prescription forms as part of the “Beijing Pesticide Reduction Management System” (BPRMS) started in October 2017. The manual or electronic offline Plantwise prescription forms were used from 2015 to 2017 and to a small extent (5%) in 2018. Of 400 plant doctors, 294 were registered in the BPRMS (45% females) by 2018.

* Active plant clinics refer to clinics that issue over ten prescriptions per year.

** Figures include 2,265 prescriptions for 1,584 different farmers recorded in BPRMS which started pilot operations between October and December 2017. These records were not included in data analysis, because many of the prescriptions were not filled in standard format and were therefore hard to harmonize and validate.

⁺ Rough estimates only based on local annual reports (source: BPPS, 2015, 2016, 2017).

⁺⁺ Multiple applications are added separately, therefore treated area can exceed farm area).

⁺⁺⁺ Data only available for vegetable and strawberry production but not for other crops.

3.2 Distribution of plant protection subsidy funds

Overall, the 30 million CNY (4.4 million USD) subsidies from the Beijing local government for "Green Pest Control" products for farmers in the Beijing area were entirely spent on non-chemical and least toxic plant protection products in 2018 (Figure 6). Due to the high subsidy rate for natural enemies, most subsidy costs were spent on them (66%), followed by plant protection tools such as traps (14%), and biopesticides (11%). Subsidies for pollinators and least toxic/residual chemical pesticides accounted for 6% and 3% of the total, respectively. Given that 5800 farmers received subsidies, around 760 USD has been invested per farming household in 2018.

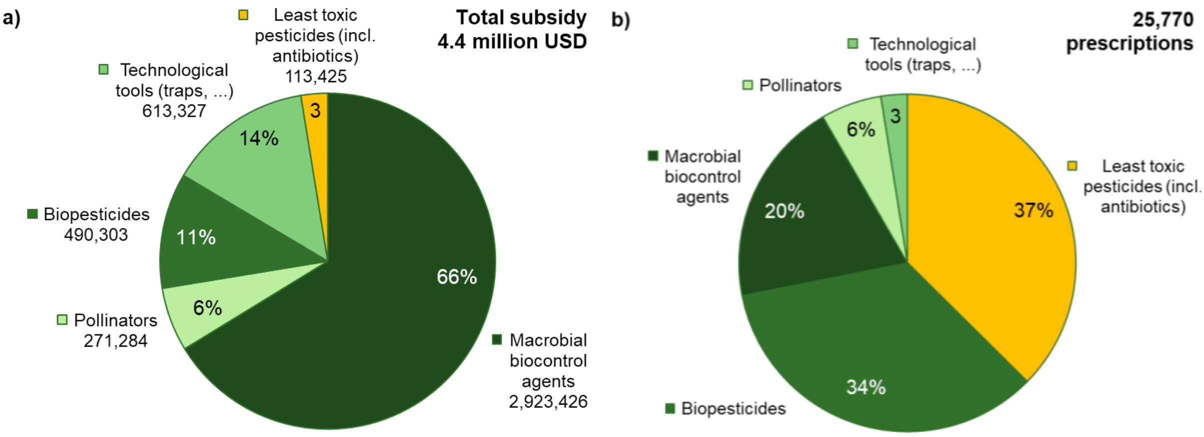


Figure 6: Subsidies in USD (a) and number of prescriptions (b) for IPM-compatible plant protection products for farmers, called in Chinese "Green Pest Control" products, in Beijing during the subsidy term running from late 2017 to mid-September 2018

Note that macrobial natural enemies are subsidized by 90% of product price, biopesticides, plant protection tools and pollinators by 50%, and least toxic/least residual synthetic chemical pesticides by 30%.

Agri-input dealer interviews revealed that sales shares of specific groups of plant protection products differed between the shops inside and outside the subsidy system of BPRMS. For instance, sales shares for natural enemies and pollinators were much higher among the 'inside' agri-input shops, while chemical pesticides shares were higher among the 'outside' shops. This difference was 65% vs 3% for natural enemies, 17% vs 2% for pollinators and 5% vs 68% for chemical pesticides for inside vs outside shops. In addition, by participating in the "Green Pest Control" subsidy programme and cooperating with the plant clinic scheme, agri-input shops saw a significant increase in their sales. Interviewees claimed a 5–20% increase in sales performance compared with last year, and stated that most of this profit growth came from sales of natural enemies and biopesticides. High levels of sales and profits indicate that it may be effective to use subsidies to encourage farmers to use non-chemical or least toxic/residual pesticides. All those interviewed from 'outside' system shops expressed their interest to join the programme.

"I have an agri-input shop and would like to join the Plantwise programme, thus connect my shop to a plant clinic and the subsidy programme, because I think this is a good idea and my profit will increase."

Ms Wu Yaling, an agri-input shop owner in Changping district of Beijing

3.3 Impact: pesticides reduced and IPM-compatible pest control achieved

Prescription form analysis indicates that an increasing proportion of prescriptions recommended subsidized products (Figure 7) from the recommended list of non-chemical or least toxic/residual plant protection products (see Annexe). The percentage of prescriptions issued for the five most common **non-chemical products increased by 20 percentage points (pp)** from 2015 to 2018 (9% in 2015 vs 29% in 2018) including 10pp of this growth being achieved between 2017 and 2018 (common natural enemies by 12%; common biopesticides by 7%) (Figure 8). Regarding the eight most commonly used least toxic **chemical pesticides** (four insecticides, four fungicides), prescriptions to farmers increased by 11pp between 2015 and 2017, but **dropped by 15pp between 2017 and 2018** after the implementation of the BPRMS (30% in 2015 vs 41% in 2017 vs 26% in 2018). When considering all products, one-third of prescriptions were made for least toxic/residual pesticides (37%) and biopesticides (34%) in 2018, one-fifth for macrobial biocontrol agents (20%) followed by pollinators (6%) and plant protection tools (3%) (Figure 6).

As prescriptions were connected to sales of subsidized products in 2018, this also reflects the actual purchases of products and not only the prescriptions. More toxic/longer residual pesticides were not allowed to be prescribed in 2018. As for the 2015–2017 data, farmer surveys conducted in 2016 revealed that more than 90% of the plant protection recommendations on the plant clinic prescriptions were accepted and implemented by the farmers (Wan *et al*., 2019). Therefore, we assume that changes in the advice given by plant doctors, following the pesticide policy of China and subsidies by the local government, indeed led to a reduction in pesticide use.

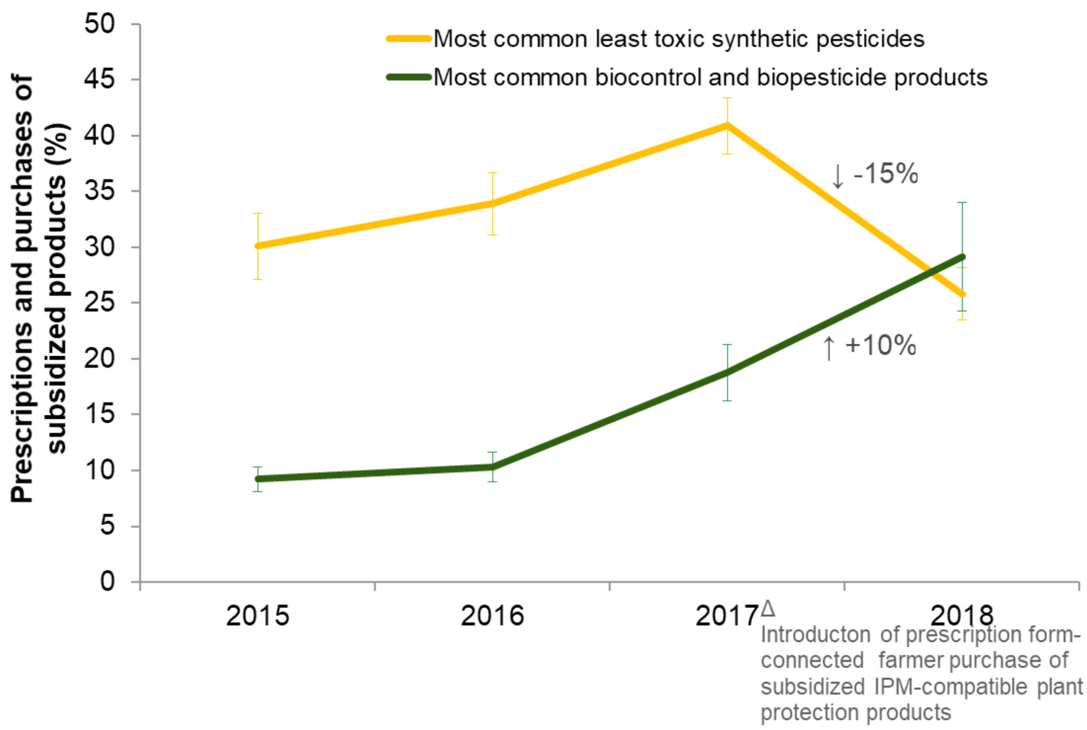


Figure 7: Yearly changes in prescriptions and purchases of non-chemical and least toxic/least residual pesticides in Beijing municipality (i.e. IPM-compatible plant protection products).

Percent changes in percent points

In detail, the prescriptions of macrobial biocontrol agents increased by 12pp from 2015 to 2018 including 10pp from 2017 to 2018 (Figure 8). This means, that after connecting subsidies to plant clinic services via the BPRMS, the high subsidy rate of 90% for supporting natural enemies pushed up the percentage of prescriptions for environmentally friendly and safe plant protection products. Predatory mites were most commonly recommended, followed by ladybird beetles and predatory bugs.

Prescriptions of biopesticides increased by 7pp from 2015 to 2018 including 1pp from 2017 to 2018. Spinetoram (bacterial insecticide) and *Pythium oligandrum* (oomycete fungicide) were the two most popular products. Spinetoram increased by 8pp between 2015 and 2018, but *P. oligandrum* dropped in 2018.

The most common pollinating insects and plant protection tools, such as traps, accounted for around 6% and 3% of prescriptions, respectively, between 2015 and 2018. However, since the Plantwise offline data management tools and the BPRMS have different recording requirements for these two categories and subsidy rates changed over time, no temporal analysis is possible.

Interviews with strawberry farmers in Changping district revealed that farmers value the "Green Pest Control" subsidies, especially for natural enemies and pollinators. For example, due to pest control successes, about 70% of the interviewees said that they would purchase predatory mites by themselves in the next growing season even if government subsidies were reduced. Some farmers expressed their hope that the upper subsidy limits for natural enemies would, although being quite high already, be further elevated. Some subsidy rates even appeared too high, thus products became too cheap leading to overuse (although safe). For example, a farmer reported that she used almost ten times the standard rate of predatory mites in her greenhouse, and she was happy with the results. In addition, there were a few farmers that did not apply all of the subsidized products purchased, due to other overlapping or inconsistent subsidy programmes provided by different governmental levels and bodies (such as the Professional Unified Control Programme, or the Agricultural Insurance Projects). Some district programmes have higher than 50% subsidy rates for biopesticides (e.g. 80% in Changping district in 2018), and subsequently more farmers choose to purchase biopesticides there. This indicates a direct link between the level of subsidy rates, product prices and the prescription and use of such products.

"Predatory mites are good; I would like to buy predatory mites for my greenhouses next year even if the subsidy rate for it might decrease in next year."

Mr He Rongan, a strawberry farmer in Changping district of Beijing

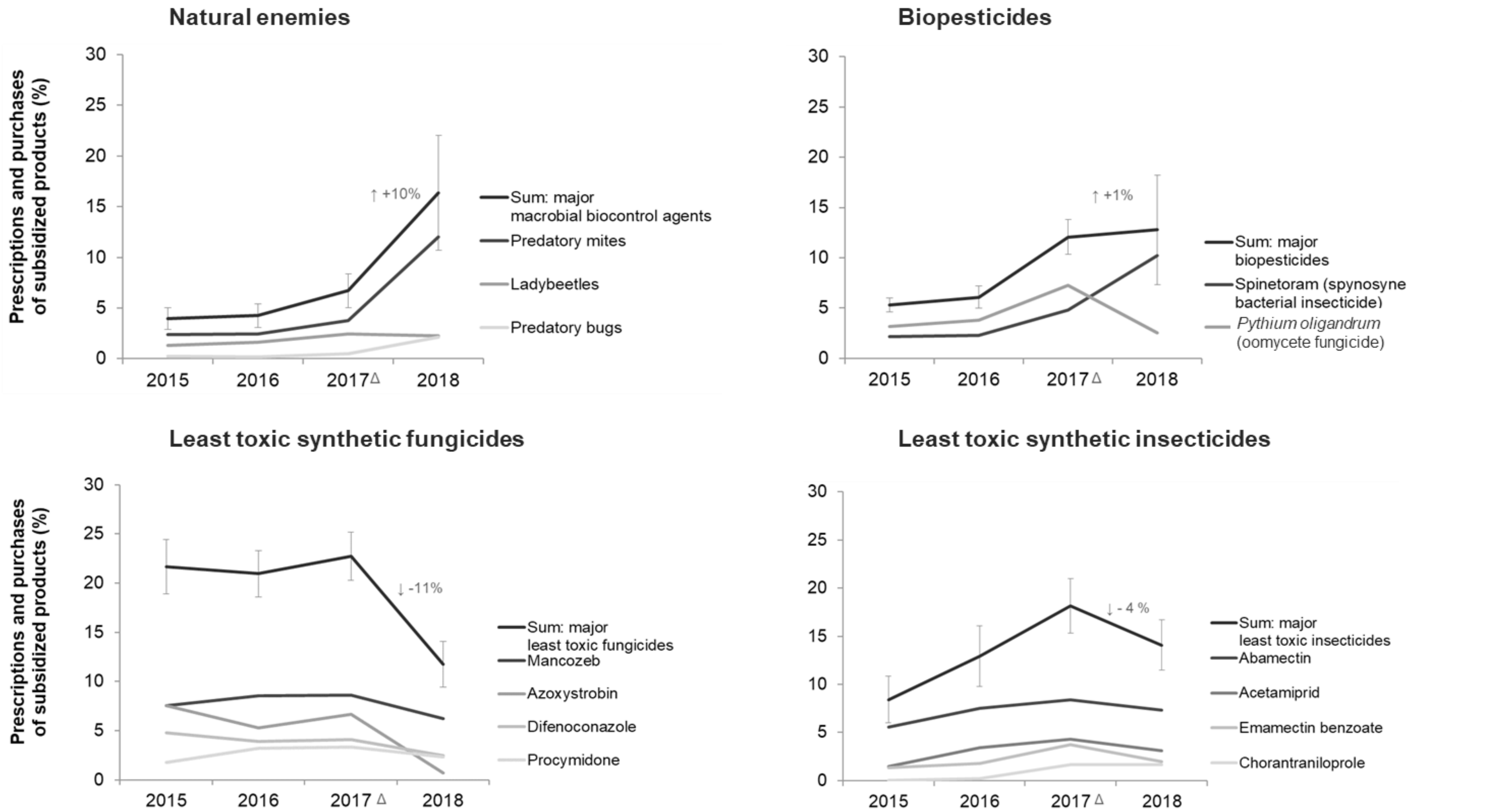


Figure: Yearly changes in prescriptions of the most common biocontrol and biopesticides and least toxic/least residual pesticides in Beijing municipality (i.e. IPM-compatible plant protection products)

Percent changes in percent points; Δ = Introduction of prescription form-connected farmer purchases of subsidized IPM compatible plant protection products .

3.4 Improvements to data management

The novel electronic and online BPRMS is a well-designed and large extension of the POMS (Romney *et al*., 2013) used in other Plantwise countries.

The BPRMS successfully connects, handles and monitors the "Green Pest Control" subsidy programme and its distribution processes and outcomes in accordance with China's "Green Pest Control Policy", as well as the agricultural advisory services provided through Plantwise plant clinics. This includes managing the registration of farmers, agri-input dealers and supplies; issuing prescriptions on pest diagnosis and management recommendations at the plant clinics to farmers and managing those data; tracking sales of recommended and subsidized products at agri-input shops; and reimbursing the agri-input suppliers according to the prescription and sales records. Compared with the POMS of prescription data including farmer and plant doctor information, the BPRMS additionally includes the name, price, amount and usage details of plant protection products prescribed to the farmers, as well as information about the stocks and sales of the agri-input shops and suppliers. The system also records the use of subsidy funds. Further improvements on service feedback functions were being made in 2018, including quality control of prescriptions and collecting feedback from farmers. The current system could be further improved by: (a) diversifying the recommendation sections on the online prescription forms (e.g. adding preventive measures and pest monitoring, adding possibilities to recommend non-subsidized products); and (b) adding better diagnosis and advice quality validation tools to reduce validation workload.

4 The Way Forward

Based on the results of this study, several suggestions are made for further discussion. First, reasons why each plant clinic is only serving a certain number of different individual farmers, and why increases in farmer reach could only be achieved through more clinics need to be understood. Second, the prescription sheets in the novel system could be adapted to allow prescribing non-subsidized products to strengthen the tracing of pesticide use in general. Given that more and more farmers are using plant clinics, more comprehensive recording of prescriptions would provide a more detailed and reliable reference for the pesticide usage statistics in the Beijing area. Third, excessive subsidy rates might drive down product prices so much that it may lead to overuse of these products. Even though the toxicity levels of the recommended and subsidized IPM-compatible products are low, excessive usage still can cause environmental pollution and may be a waste of resources. Therefore, regulations, standards and subsidy prices should be adapted based on the yearly lessons learnt from analysis of the BPRMS data. Fourth, some of the plant doctors involved in the BPRMS are also engaged in agri-input shops and thus have a direct financial interest, which may raise some conflicts of interest (Wan *et al*., 2019). A plant doctor supervision mechanism could be developed within the BPRMS framework to avoid potential risk, as well as to improve transparency on decisions. Finally, it would be interesting going forward to assess whether farmers would continue to use the recommended plant protection products if there was less or no subsidy, in other words whether the agri-policy-driven subsidy programme has led to a behavioural change in farmers towards acceptance and use of non-chemical pest management.

5 Conclusions

The novel electronic and online "Beijing Pesticide Reduction Management System" (BPRMS) successfully combines the management of the "Green Pest Control" product subsidy programme according to China's agri-policy, the advisory services of the Plantwise plant clinics to farmers, and the traceability and monitoring of plant protection product prescriptions, sales, and subsidies spent. It helps to promote non-chemical and least toxic/least residual pesticides leading to less overall pesticide reliance and a more frequent use of biological products. BPPS felt that the combination of the "Green Pest Control" subsidy programme with plant clinics and plant doctor networks greatly improved the outreach and efficiency of implementing agri-policy-driven subsidies compared with earlier distribution systems. The electronic, online BPRMS became a well-designed extension of the POMS used in other Plantwise countries. The now fully functional but constantly improving BPRMS will certainly facilitate and monitor the implementation of pesticide reduction in the Beijing municipality, and ultimately lead to safer food. It may serve as an example for other provinces in China, and beyond.

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Annexe

This is a list of beneficial organisms, active substances, active substance combinations or plant protection tools of IPM-compatible products (“Green Pest Control” products in Chinese) promoted in Beijing municipality in agreement with the “Green Pest Control Policy” of China (status as of 2018).

Macrobial biocontrol agents (called natural enemies in Chinese)
3 Parasitoids (*Encarsia formosa*, *Trichogramma chilonis*, *Trichogramma dendrolimi*)
2 Predatory bugs (*Nesidiocoris tenuis*, *Orius sauteri*)
1 Predatory coccinelid (*Harmonia axyridis*)
6 Predatory mites (*Amblyseius tsugawai*, *Neoseiulus barkeri*, *N. californicus*, *N. cucumeris*, *Phytoseiulus persimilis*, *Stratiolaelaps scimitus*)

Pollinators
2 Pollinators (honeybee, bumblebees)

Biopesticides
2 Fungal fungicides (*Paecilomyces lilacinus*, *Trichoderma harzianum*)
1 Fungal viricide (polysaccharide from *Lentinula*)
2 Bacterial fungicides (*Bacillus subtilis*, *Pseudomonas fluorescens*)
2 Bacterial insecticides (*Bacillus thuringiensis*, *Empedobacter brevis*)
3 Viral insecticides (*Plutella xylostella* PxGV, *Spodoptera litura* SpltNPV, *Spodoptera exigua* SeMNPV)
1 Water mould oomyceticide (*Pythium oligandrum*)
1 Botanical fungicide (physcion)
2 Botanical herbicides (cineole, D-limonene)
4 Botanical insecticides (azadirachtin, matrine, osthole, veratrine)
3 Botanical insecticide/acaricides (ivermectin, pyrethrins, *Pyrethrum cinerariifolium*+matrine)
2 Natural source fungicides (chitosan, oligosaccharins+plant activator protein)
1 Oil-based insecticide/acaricide (mineral oil)

Plant protection tools such as traps
5 Sticky trap types (blue sticky traps non-degradable, blue sticky traps degradable, yellow sticky traps degradable, baited yellow sticky traps, yellow sticky traps non-degradable)
9 Sex pheromones (*Agrotis ypsilon*, *Ostrinia furnacalis*, *Dichocrocis punctiferalis*, *Helicoverpa armigera*, *H. assulta*, *Plutella xylostella*, *Athetis lepigon*, *Spodoptera exigua*, *S. litura*)
3 Attractants (biological food attractants, thrips phagostimulant, whitefly phagostimulant)
1 Vector exclusion tool (fly nets for greenhouse windows)
1 Light trap (solar lamp)

Least toxic/residual pesticides
7 Antibiotics (kasugamycin, kasugamycin+zhongshengmycin, ningnanmycin, polyoxin b, pyrimidine nucleoside antibiotics, tetramycin, zhongshengmycin)
43 Fungicides (iprodione, azoxystrobin, boscalid+procymidone, chlorothalonil, cyazofamid+chlorothalonil, cymoxanil+mancozeb, dazomet, difenoconazole, difenoconazole+azoxystrobin, difenoconazole+kresoxim-methyl, difenoconazole+prochloraz-manganese chloride complex, dimethomorph, dimethomorph+ametoctradin, imethomorph+cymoxanil, dimethomorph+mancozeb, dimethomorph+pyraclostrobin, dimethomorph+zhongshengmycin, famoxadone+cymoxanil, flusilazole, flutriafol, fosetyl-Al, hexaconazole, hymexazol, iprodione+chlorothalonil, iprodione+procymidone, kasugamycin+copper oxychloride, kresoxim-methyl, mancozeb+fosetyl-aluminium, mandipropamid, metalaxyl+hymexazol, metalaxyl-M+mancozeb, moroxydine hydrochloride+cupric acetate, oxadixyl+mancozeb, oxathiapiprolin, procymidone, propamocarb hydrochloride, propineb, pyrimethanil+iprodione, sulfur+thiophanate, sulfur, thiophanate-methyl, thiophanate-methyl+hymexazol, triflumizole)
2 Fungicide/bactericides (copper hydroxide, oxine-copper)
1 Fungicide/oomycide (mancozeb)
19 Insecticides (acetamiprid, acetamiprid+pyridaben, avermectin, avermectin+fosthiazate, chlorantraniliprole, cyromazine, diflubenzuron, dinotefuran+pyridaben, emamectin benzoate, emamectin benzoate+chlorbenzuron, emamectin benzoate+indoxacarb, flonicamid,

ivermectin+chlorfenapyr, lufenuron, methoxyfenozide, spinetoram, sulfoxaflor, tebufenozide, tetra-chlorantraniliprole)

2 Insecticide/acaricides (abamectin, abamectin+azadirachtin)

1 Molluscicide (metaldehyde)

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