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Beyond a bottle of liquid: pesticide dependence in transitional rural China

Zhanping Hu* and Sanzidur Rahman

School of Geography, Earth and Environmental Sciences, University of Plymouth, Plymouth, UK

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Abstract

Pesticide dependence is a major threat to food safety and local environment. Although numerous studies have explored different causes of pesticide dependence, few have examined how pesticides are locked into agricultural modernization and rural transformation. Based on a case study of a Chinese village, this paper demonstrates how agricultural modernization trajectory and rural changes have perpetuated the use of pesticides as necessities in agriculture as well as for farmers' livelihoods. Modern technologies, such as hybrid rice, conservation tillage, changes in crop structure, and reduction of intercropping all contribute highly towards pesticide dependence. The Household Responsibility System in China has provided the institutional foundation for increased pesticide use. Rural transformations driven by livelihoods diversification have created conducive social spaces for pesticide application. To step out of pesticide dependence, promotion of genetic diversity in agriculture, a reassessment of locational suitability of conservation tillage, institutional strengthening and the promotion of Integrated Pest Management methods are suggested.

Key words: pesticide dependence, development process, agricultural modernization, rural transformation, China

Introduction

Pesticides, in a series of important agricultural technologies, have been considered as a "necessary evil" for a long time (Wu and Sardo 2010). On the one hand, pesticides have contributed in solving famines and food shortages of the world by substantially enhancing grain yields. However, on the other hand, pesticides have caused more problems, including water pollution, soil erosion, ecological imbalance, and potential health risks (Pimentel and Lehman 1993). Although in the last few decades, alternatives such as Integrated Pest Management (IPM) and botanical pesticides have been developed and extended successfully (Pimentel and Cilveti 2007), the chemical control of agricultural pests still dominates at present (Ekström and Ekbom 2011; Rahman, 2013). Geographically, developing countries are applying most of the chemical pesticides in agricultural production, for example China, India, Bangladesh, Mexico, Costa Rica, and Colombia among others (FAOSTAT 2009).

China ranks first in the world in terms of pesticide use, increasing from 0.64 million tons in 2000 to 1.67 million tons in 2008[1], although the national grain output and per unit yields of various crops from 1990 to 2008 have fluctuated significantly, if not stagnated (Collection of Chinese Agricultural Statistics of Thirty Years 2009). According to a survey conducted by the Ministry of Agriculture in 2005, 47.5% of the total agricultural production (16.5 million tons) exceeded the limit of pesticide residues in output (Liu 2006), thereby indicating the extent of food contaminated with pesticides. A more explicit warning comes from the *2009 Greenpeace Chinese Pesticides Detection Report* which reports that more than 50 types of pesticide residues are found in 45 vegetables and fruit samples, and claims that "people are consuming a cocktail of pesticides unwittingly which is comprised of manifold pesticides and the hazard of this ‘pesticide cocktail’ can be more significant in determining the total influence than that accounted for by individual pesticides” (2009:1). Behind these unsettling statistics and worrying implications is the pesticide dependence of contemporary Chinese agriculture.

Given this backdrop, the main objective of this paper is to examine the nature of pesticide dependence through exploring the trajectory of agricultural development and the interaction between agricultural production and socio-economic transformation in rural China. The importance arises because China is one of the largest economies in the world experiencing rapid transformation and has the need to produce food in sufficient amounts to safeguard its population from depending on uncertain and volatile world markets for food, particularly grains. Furthermore, serious land degradation due to high levels of agrochemical use has greatly threatened land productivity worldwide and the food security of China according to several authors (Pimentel 2006, Bai *et al*. 2008, Bai and Dent 2009). Concerned about food security and environmental pressures, the Chinese government has promoted “modern agriculture” as the major development strategy from 2007, emphasizing investment in modern agro-technologies as well as the development of ecologically sustainable agriculture. Under this new political economy of transforming traditional mode of agricultural development, pesticides have become an important parameter, the use of which however greatly dampens the sustainability of agro-ecosystems. Therefore, with a shrinking population base engaged in agriculture and the need to grow more food to satisfy a growing urban population, it is important to examine the nature of pesticide dependence of the existing Chinese agricultural system to ensure future growth in agriculture. The findings of this research may also shed light on other countries, such as South Asia, Southeast Asia and some

African countries which have similar agricultural development path and are undergoing similar agrarian transition driven by urbanization and industrialization (Bryceson 1996, Rigg 2001).

Pesticide dependence of modern agriculture: a literature review

The pesticide issue has been studied widely in different disciplines, demonstrating that it is not merely a technological problem but that many complex elements influence their use (Galt 2008). With regard to pesticide dependence, scholars use the term—“pesticide treadmill”, which refers to the tendency that pests become resistant to particular pesticides so that farmers have to apply new and more toxic pesticides, to which pests also eventually gain resistance (Nicholls and Altieri 1997, Stone 2004). The pesticide treadmill also has been expanded to encompass the whole modern agricultural regime. For example, Clunies-Ross and Hildyard (1992) criticize industrial agriculture as a “chemical treadmill” as an explanation of the dramatic increase in the use of the whole range of agrochemicals. They argue that the application of pesticides and fertilizers can improve yields impressively at the very start, and then yields stagnate and prices fall, and farmers who don’t use these chemicals go bankrupt due to a squeeze in profits. In their words, “those who adopted the new approach, however, stepped onto the chemical treadmill” (p. 61).

Technological trajectories of agricultural pest control have been explored to explain why farmers continue to apply pesticides when IPM is available (Cowan and Gunby 1996, Woff and Recke 2000, Wilson and Tisdell 2001). These studies focused on the technological properties of IPM and chemical pesticides, revealing that increasing returns from adopting pesticides, high R&D costs for agrochemical control development, markets locked into pesticides, high switching costs from chemical pesticides to IPM, as well as the knowledge-intensive characteristics and uncertain effects of IPM, make farmers unable to overcome the technological inertia and remain locked into the pesticide application path (Cowan and Gunby 1996).

Pesticides are a technological medium between farmers and the agro-ecosystem, and some scholars have noted the process of deskilling farmers caused by pesticides (Vandeman 1995, Stone 2004, 2007, 2011). According to Stone (2007, 2011), two agricultural technologies, hybrid seeds and pesticide sprays, are the prime technologies implicated in agricultural deskilling. In other words, pesticides deskill farmers and, in turn, the process of agricultural deskilling reinforces dependence on pesticides.

Several scholars have sought structural explanations for pesticide dependence from broad political economic contexts (Thrupp 1990, Thrupp *et al*. 1995, Galt 2008). For instance, some attribute pesticide dependence to the export strategy in Latin America and/or other areas (Murray 1991, 1995, Thrupp 1990, Thrupp *et al*. 1995, Nicholls and Altieri 1997).

Whilst previous studies have significantly extended pesticide studies into broader intellectual spheres, and also provided great inspirations for this research, most of these tend to explain pesticide dependence within the production domain often narrowing down the pesticide issue into the technological sphere (e.g. Nicholls and Altieri 1997, Woff and Recke 2000, Wilson and Tisdell 2001) and, rarely viewing pesticides as an agent that actively interacts with underlying socio-economic changes. Simply put, pesticide dependence is considered as a technological issue determined by external factors, such as markets and development policies, rather than as a part of the ongoing developmental process of agriculture and rural society. Those who have noted the structural elements of pesticide dependence have often overemphasized the influence of political economic or political ecological factors at the macro level, such as export strategies and global pesticide regulation regime (e.g. Murray 1991, 1995, Thrupp *et al*.1995, Galt 2008) and thus failed to capture the dynamic interactions between pesticides and embedded socio-economic transitions at the micro level. Therefore, to fill these gaps, through the perspective of technology-society interaction, we put pesticides back into their socio-economic settings, and examine pesticide dependence through linking it with the development process of agricultural modernization and transitions of rural society, particularly in the context of transitional China. In doing so, we demonstrate that not only have pesticides served as a kind of "growth hormone" which has significantly facilitated the development of agricultural systems and the transformation of Chinese rural society, but also in turn, pesticides have instantly been locked and embedded into the web of current agricultural production and farmers' livelihoods on the path of agricultural development and societal changes. Through an examination of historically-situated trajectory of pesticides in a village of Sichuan Province in southwest China, this paper therefore contributes to the understanding of pesticide dependence as a developmental process which is embedded in agricultural modernization and rural transformation.

Methodology

Study site

The research took place in Hu Village, Qingshen County, Sichuan Province. The County is situated in the southwestern edge of the Western Sichuan Plain and Chengdu Plain, at longitude 103° 41-103° 59 east, latitude 29° 42-29° 55 north. The region experiences a northern hemisphere humid subtropical climate with a nearly year-round growing season, long, hot and humid summers and short, mild and cloudy winters, with a frost-free period of up to 313 days, annual mean temperature of 17.1°C, and sunshine of up to 1181.7 hours p.a., all of which factors are suitable for a variety of plants and animals. The natural landscape and climatic characteristics of Hu Village represent the general agricultural geography of not only the great majority of Sichuan, but also some other parts of south China.

Many studies have focused on commercial crop communities or regions (Murray 1991, Grossman 1992, Galt 2008, 2009) exploring how pesticide use can be specifically dominated by markets forces and regulations, but have often overlooked some other factors, e.g., development of agricultural system and socio-economic changes. Hu Village is not dependent on any specific commercial crops, although cash crops are quite pervasive in this area. The village's agricultural production is very typical of southwest China where rice, rapeseed, corn, and sweet potatoes are widespread traditional and general crops. Geographically, Hu Village is located 9 kms away from the Township and 10 kms from the County. It is a relatively large administrative village with an area of 4.5 sq kms. The village has 882 households distributed in 8 groups, with population of 2,938 (1,532 males and 1,406 females). The village has a labour force of 1,405 (723 males and 682 females). Of these, a total of 976 persons, mainly the elderly and women, work in agriculture, and 718 persons work out in cities elsewhere.

Data collection methods

This research draws upon the multiple-methods approach. Since the main concern of this research was to explain pesticide dependence from historically-situated socio-economic contexts, qualitative interviews and participant observation were applied as the main methods, and were conducted from October 2009 to February 2010. These were supplemented with a questionnaire survey conducted from March to September 2012. Specifically, the following strategy was used. First, 50 farmers were interviewed in-depth. The respondents were selected from 8 clusters of the village to cover the different age ranges age (5 persons </ =30 years; 12 persons 31-40 years of age; 15 persons 41-50 years of age; and 18 persons >/=51 years of age =18), gender (28 males, 22 females) and livelihood system (23 farmers working solely on agriculture, 27 farmers holding off-farm jobs).

The interviews were semi-structured and included content on farmers' basic demographic information, land use patterns, farming technology adoption, pesticide application practices (purchase, modulation, spray, stock), and farmers' attitudes towards the environmental and health effects of pesticides. The interviews then progressed deeper into "why" questions, such as the reasons for applying extra pesticides, not continue to mow weeds, and not raising buffaloes anymore and so forth. Second, key informants were interviewed for specific information. Five ex-village cadres were visited to understand the historical development of Hu Village's agriculture. One of them was the village chief from 1953 to 1983 and was interviewed three times for information on agricultural production in the collectivization era. Another one was the party secretary from 1962 to 1993, who was visited four times. The remaining three were village cadres from the 1990s until present and were interviewed two times each for information on rural transformation and agricultural production over that time. Apart from the cadres, seven older farmers with rich farming experiences and who were members of the research team in the collectivization era were interviewed for information on the relationships between pesticides and other agricultural technologies, such as conservation tillage. Third, the first author also conducted interviews with other actors, such as pesticide sellers, franchisers, and officials of the government agricultural bureau, to gain information about their perceptions of pesticides dependence. Fourth, the author observed farmers' actions related to pesticide application. On one hand, the author often stayed with them in the field when they were spraying or doing other farming activities. On the other hand, the author went to the bazaar and found some pesticide sellers, stayed with them and observed farmers' purchasing behaviours and the interaction between them and the sellers.

The questionnaire survey covering 225 households with 854 individuals was conducted to collect information on basic household demographic information, land use pattern, agro-technology use, and livelihood diversification for the year 2011. To achieve representativeness, the survey adopted a cluster sampling strategy. As the village has been officially divided into 8 clusters based on different socio-economic characteristics, 30 households were randomly selected in each cluster, with 240 samples for the whole village being the target. Eventually, 225 questionnaires were completed with valid information. Finally, existing data about Hu Village, such as its historical records and annual village statistical reports, were utilized in this research to examine the agricultural history of the community.

Social-historical trajectory of agricultural production of Hu Village

Since the establishment of People's Republic in 1949, China's agriculture has experienced significant transformation, which can be roughly divided into two stages: the collectivization era and the Household Responsibility System (HRS) era. In the collectivization era from the

1950s to late 1970s, farmland was collectivized and agricultural production was highly controlled by the state. Traditional techniques were used in agriculture, and the productivity of the land was relatively low. At the end of the 1970s, China initiated the HRS reform through which the collectively-owned land was equally distributed to individual households. This land tenure reform, with a series of modern technological extensions, greatly enhanced agricultural productivity (Lin 1992, Huang and Rozelle 1996, Lohmar *et al*. 2009). Since the 1980s, China began rapid urbanization and industrialization processes, which created many opportunities for farmers to seek off-farm activities, either in their local area or through migration to urban areas. This diversification of farmers' livelihoods became the most fundamental characteristic of agrarian transformation in China (Yang 2009), as found in other developing countries (Bernstein 1992, Ellis 2000).

Alongside these socio-economic transitions, Chinese agricultural policy also experienced dramatic changes. Before the twenty-first century, Chinese agricultural policy was mainly oriented towards favouring industrial accumulation through price scissors[2] between industrial and agricultural products and the unbalanced financial system[3] (Huang and Ma 1998, Anderson *et al*. 2004). The agricultural sector as a whole was significantly downplayed by the central government during that time. However, at the beginning of the twenty-first century, the central government came to realize that the Chinese economy had evolved to the stage whereby industry should repay the agricultural sector rather than continue to extract from it, which signified an epoch-making moment for Chinese agricultural policy. Since 2004, the central government has embarked on an array of policies of cancelling agricultural taxes and fees from farmers and in turn subsidizing them through various programmes. A systematic subsidy framework has been developed in Chinese agricultural policy, comprising of subsidies on grains, high quality seeds, equipment and inputs, and the magnitude of the financial support involved has kept rising. In 2013, around 30 billion dollars were paid to farmers in the four subsidy systems, as compared to less than 3 billion dollars in 2004. In addition, the agricultural market has also substantially developed in China, and has become the fundamental force guiding agricultural production activities, with an integrated market having emerged at the national level (de Brauw et al. 2000, Huang and Rozelle 2006). Additionally, accession to the WTO in 2001 further liberalized Chinese agricultural markets and integrated them into international markets (Huang *et al.* 2007, Carter *et al.* 2012). At present, with given levels of subsidies, Chinese farmers are free to produce either for consumption or for the markets, and to purchase inputs autonomously from increasingly improved input markets. Comparatively at the global level, in the European Union, since the 1950s the Common Agricultural Policy (CAP) has been subsidizing agricultural production through price guarantees, direct payments and other instruments (Grant 1997). In the beginning of twenty-first century, the CAP initiated a new subsidy system, Single Farm Payment, for direct subsidy payments to landowners. The payments have been increasingly oriented towards environmental management and animal welfare (Schmid *et al.* 2007). Similarly, since the 1930s the USA agricultural policy has also long been oriented towards supporting and subsidizing agriculture through various approaches (Orden *et al.* 1999). The newly emerged Chinese agricultural support system has resonance with the above two established systems. To overcome the unstable agricultural markets and safeguard national food security, especially in such as populous country like China, supportive agricultural policies are likely to continue to be the major pillar of Chinese agricultural policy in the foreseeable future.

It is noteworthy that genetically modified (GM) crops, which are often designed to control plant diseases and insects by genetic engineering techniques, have been largely banned or strictly constrained in China so far, with only two GM crops (*Bt* cotton and disease-resistant papaya) allowed to be promoted commercially (Li *et al.* 2014). However, Chinese government has been making great efforts in recent years to develop a variety of GM crops to address the pressing food security issue (Zhang *et al*. 2013, Li *et al*. 2014), and this may bring significant change in pesticide application in Chinese agriculture in the future.

Alongside the macro socio-economic transitions at national level, Hu Village's agriculture and livelihoods have been remarkably transformed. As Table 1 shows, Hu Village's agriculture has been modernized gradually. In addition, since the 1980s, Hu Village farmers have increasingly moved out of agriculture and gone to work in urban areas. According to the village statistics, one third of the population, mainly the better educated and physically more capable, are now working away from the village throughout the year. Agricultural modernization and farmers' livelihood diversification both have significant implications for pesticide use on the land as evidenced in the next section.

Agricultural production and pesticide application in Hu Village

The main cropping patterns of Hu Village are of: rice, corn, and sweet potato in the first cultivation season; rapeseed, wheat, and pea in the second cultivation season; and citrus as the main cash crop. Apart from citrus, more than half of the agricultural outputs are consumed by farmers, with the rest being sold to markets. As for pesticide application, more than two tons of pesticides are sprayed on its 142 ha arable land every year (Hu Village Report 2009). Table 2 shows that farmers tend to spray pesticides more intensively than are recommended. More tellingly, as shown in Table 3, 80% of the farmers tend to increase the dosage of pesticide application, and only 16% follow the instructions. As Chinese agriculture is extremely small scale, there is no comparative data to interpret the relationship between pesticide usage and farm size. Related studies have presented rather dissonant conclusions on the correlation between farm size and pesticide use intensity in global contexts (e.g. Dasgupta *et al*. 2001, Ghimire and Woodward 2013). In this research, according to interviews with experienced farmers and agricultural experts, there is a consensus among them that the current land fragmentation does increase pesticide dosage. Large farm size is more efficient to manage, and the currently scattered land plots greatly increase management costs and compel farmers to spray heavily to save labour. The education levels of the farmers are low, with 76% receiving less than 5 years of education (Table 3). In the fieldwork, many farmers, especially the old ones, reported that they could not read the pesticide instruction on the bottle. Table 3 also shows that 82% of the farmers received information regarding pesticide application from pesticide suppliers, rather than government extension services which have been very weak in transitional China (Hu *et al.* 2009), as found in other developing countries (Ngowi *et al*. 2007). The domination of application information from suppliers can be a potential factor of pesticide overuse as they tend to tell farmers to use more to guarantee effectiveness and, thus maintain their reputation (Jin *et al*. 2014). Furthermore, there was only one pesticide shop in Hu Village in the 1980s, but now there are five shops selling pesticides. Therefore, it is safe to argue that pesticide dependence does exist in Hu Village agriculture. Lastly, as illustrated by

Figure 1, the most common equipment is a hand held sprayer and farmers prepare and spray pesticides carelessly without any proper protection.

Pesticides dependence of agriculture in Hu Village

Lock-in along agricultural modernization

Previous studies have indicated the interdependent relationship between chemical pesticides and hybrid varieties (Altieri 1995), conservation tillage (Wen and Pimentel 1992, Koch and Stockfisch 2006, Gianessi 2013), and reduction of intercropping (Richards 1985, Altieri 1999).The findings from Hu Village show that pesticides have been locked into the developmental trajectories of these various agricultural technologies.

Hybrid varieties

Hybrid rice is the first modern agricultural technology that showed dependence on pesticides in Hu Village. The 100% adoption rate of hybrid rice is more conducive to breeding of pests and their spreading between adjacent plots, which means a greater demand for pesticides. Hybrid rice normally requires spraying at least four times in its growth cycle according to Hu Village farmers. The first two applications are during the seedling period before May, the third application is after transplanting during late May or early June, and the fourth application is before the rice tassels in July. In contrast with the popularity of hybrid rice, traditional rice varieties have vanished, even though they are more adaptive to local environment and are pest resistant. Thus, the loss of genetic diversity due to the hegemony of hybrid rice has created room for the monopoly and spread of pests and diseases. One respondent said,

> *Comparing with traditional varieties, hybrid rice can produce more output, but is more vulnerable to diseases. Hybrid rice needs much more pesticides. Moreover,*

> *because of pesticide resistance of pests, we apply more and more pesticides year on year while the productivity is largely the same.*

Furthermore, almost all other crops of contemporary Hu Village agriculture are hybrid varieties, such as rape, corn, soybean and so forth. The dependence of hybrid varieties on pesticides was clearly expressed by an official of Qingshen County Agricultural Bureau,

> *According to our investigation, hybrid varieties need more pesticides, and are more vulnerable. Now, all farmers purchase hybrid varieties rather than cultivate traditional ones. There is no traditional variety cultivation in this region anymore. We will face increasingly serious pesticide dependence in the future.*

Conservation tillage

Conservation tillage has become the dominant tillage method in Hu Village since the 1990s. According to a text from the Chinese Ministry of Agriculture (2008), conservation tillage has four basic technological constituents: (1) straw covering; (2) no tillage and fertilizer application; (3) preventive treatment of pests, diseases and weeds; and (4) deeply ploughing the surface soil. In the first step, straw covers the land, which can provide favourable environments for pests throughout the cold winter. Hu Village farmers haven't ploughed their land for many years, which has inevitably created fertile ground for all kinds of pests. In the second step, more and more chemical fertilizers are sprayed on their conservation tillage land, which makes the plants grow stronger and also entice more pests. The third step is explicitly directed to pesticides. The fourth step is omitted by most of the farmers in Hu Village, whereby conservation tillage needs at least one additional spray of herbicides than normal tillage, and the farmers know that such tillage will facilitate pests, but are not sure exactly how much more pesticides to use. As Table 4 shows, 71.9% Hu Village households applied no tillage in 2011, and herbicide application of these households was clear higher than that of the other households. According to the interviews, many households have not ploughed their land for more than 5 years.

Due to long-term no tillage and increased use of pesticides and chemical fertilizers, the pH of the soil has fallen to around 4.5 according to an official from the Agricultural Bureau, and this has caused a very serious disease called *rape plasmodiophora brassicae* in recent years. Even worse is that there are no specific pesticides for this disease, which compels farmers to apply a range of various chemicals on their rapeseed. After adopting conservation tillage for more than a decade, farmers in Hu Village have now realized its pesticide-dependence effect. Most farmers interviewed have the following reasoning for herbicides, weeds, farming cattle and conservation tillage:

> *Because there is no need to plough, therefore, we do not raise cattle any more. Before conservation tillage, every household had cattle, and we mowed every day even before sun rose. Before, we were very poor, and we did not have so much grain, so we fed cattle with weeds. Now even though we raise cattle, we will never mow weeds for them but feed them with commercial fodder. No one mows weeds for cattle or pigs now.*

At the time of this research there were only 56 buffaloes in Hu Village, most of which were for commercial use and only two or three for ploughing land. Commercial fodder, as the substitute for weeds and grains, has separated farmers from their land, and the era of all farmers waving sickles to mow weeds for their cattle will not return due to the efficiency-oriented market economy. Pesticides, as an integral part of conservation tillage, are locked firmly through the interplay between technologies and farmers' livelihoods. Yet, conservation tillage is so popular because, from the farmers' viewpoints, it saves both labour and capital investment. To hire a buffalo and a man costs 150 dollars per ha while to hire a tractor to plough needs 120-150 dollars per ha. The profit squeeze of agriculture leads farmers to embrace conservation tillage.

Cropping pattern changes and decline of intercropping

Two changes in the cropping patterns in Hu Village have facilitated pesticide application. The first is the cash crop-citrus, which is the most heavily sprayed crop. One farmer said, "The citrus uses the highest amount of pesticides. The price of citrus is much higher than the grain, so we spray heavily on the fruit. Normally, we spray at least six times on the citrus tree every growth period, and most of the pesticides are highly toxic". Income is the primary impetus for farmers to spray heavily on the citrus trees, and the commercialization has affected farmers' technological decision-making.

In contrast with the boom of citrus, Hu Village farmers have given up cultivating wheat since around 2005, because the procedures in harvesting wheat are too complicated and require too much labour, which is in short supply in Hu Village. Now, in the second cultivation season, farmers only plant rapeseed whose harvest is relatively easy, and which women and the elderly can manage.

As Table 5 shows, intercropping was prevalent in Hu Village during the collectivization era and the beginning of the HRS reform because, at that time, the village had enough labour, land was scarce, and farmers struggled to survive, factors which formed the social foundation for intercropping. These intercropping patterns could maximize efficiency of land use. After the reform, along with increasing migration and absence of labour, intercropping reduced dramatically. Now in Hu Village, only a few farmers are intercropping. It can be seen here that the rural structural changes, farmers' demands, and the adoption of modern agricultural technologies have influenced the decrease in intercropping profoundly. The decline of intercropping has a dependent relationship with pesticides application, which has been perceived by farmers,

> *Yes, intercropping is associated with pesticides. Before, we intercropped a lot, and there were not so many diseases and pests. Now, we do not have enough labour, and most farmers dropped intercropping. The diseases and pests are thriving in the monocrop field. That is quite evident.*

Institutional foundation for pesticide dependence

Some have studied the influence of Chinese land reform on farmers' technological and environmental behaviour (Luo and Wen 1996, Wang 1999). Wang (1999) argues that individually-organized farming due to land subdivision in the rural reform is the institutional cause of farmers' misusing pesticides as well as using other practices that adversely influence the environment. This research finds that the increase of spraying dosage and the dependence on pesticides can also, to some degree, be ascribed to the transformation of the land tenure institution as discussed below.

In the collectivization era, agricultural production was highly unified and organized by the production team, and multiple strategies of pest management were applied, combining modern pesticides with traditional techniques. When crops were attacked by pests or diseases, the production team often organized farmers to light oil lamps around the field, which utilized the photokinesis of manta to attract and burn them and also to reduce pest eggs. Or sometimes, they even mobilized farmers to go to the fields and pick the pests by hand. In the 1960s, an agricultural research team, constituted of several experienced farmers, was established for improving land productivity. All the pesticides then were sprayed by the research team, and the members were regularly trained by local agricultural bureaus. At that time, traditional rice varieties were cultivated and only needed two sprays during the whole growth period, and the research team tried to maximize the effect with the minimal volume of pesticides. The unified management from this research team also maximized the effect of pesticides, which improved efficiency and avoided waste. Furthermore, farmers seldom got fake pesticides in that controlled political environment.

The HRS system transformed the collectivized agricultural system based on a planned economy into a market-oriented and individualized smallholder agriculture in China, and this fundamental institutional shift has also consequently contributed to the pesticide dependence phenomenon, and is realized via four mechanisms. First, the HRS empowered individual households to organize farming activities and livelihoods independently. This made pesticide spraying much more uncoordinated because farming activities, crop growth, and land conditions became so spatially heterogeneous and temporally dynamic. However, effective pesticide application entails pertinent timings and coordinated actions. As one cadre vividly explained,

> *Sometimes, this farmer sprays one week earlier; that farmer sprays one week later, and their land is adjacent. Therefore, the pests in the sprayed land will migrate to*

the land that is not sprayed. So if they do not spray at the same time, the effect of spraying is never very good, which also increases the dosage and frequency of spraying. HRS increases spraying.

Second, farmers' educational levels are uneven and differentiated, and not every farmer can spray properly as shown in Table 3. For the farmers who cannot read, it is impossible to follow pesticide instructions on the bottle without being told by others. One strategy for them is to enhance the dosage, to safeguard the effectiveness, which inevitably increases the quantity of pesticide application. Third, the land distribution and tenure system of HRS have created an extremely fragmented land pattern, which has significantly enhanced the managerial cost for small farmers. In Hu Village, land is highly fragmented, with every household having around 7-8 small plots, and some having more than 10 plots. Land fragmentation can potentially increase the dosage of pesticide application. As an experienced farmer explained,

I have 11 small land plots. If I had one larger land, I can spray at one time. However, when I spray the 11 separate, sometimes very remote, plots, I have to spray at different times which take me a week or longer. This process lets me miss the best time to spray on some plots. Then, I spray again. Or, I adopt another strategy, spraying heavily to safeguard the effectiveness and reduce my labour intensity. Both the two ways increase the dosage of pesticide application compared with that on one large plot of land.

Fourth, the HRS reform has engendered a lack of government intervention on public services within agricultural system (Wang 1999, Jin *et al*. 2014). Technological support from governments for farmers in rural China has been weak as the government retreated from agriculture since the reform. Consequently, farmers have no reliable information source to consult about pesticide application, which can be an important reason for pesticide overuse. Out of the 50 interviewees, 46 (92%) said that without technological guidance, they would in practice apply more dosage of pesticides than the recommended dosage. As a respondent said,

> *Now, there are no research teams in village to guide us how to apply pesticides. We are free to apply any dosage on our land. To guarantee the effectiveness, we all apply much more pesticides than the recommended amount from suppliers, or the instruction on the bottle. We do not want to do it again. We want to kill the pests or weeds once and for all.*

Overall, the institutional transformation from collective cultivation to the individual responsibility system provided a suitable environment for dependence on pesticides. Yet, to be clear, we do not argue that agricultural collectivization is a better choice than the market-oriented HRS system. Rather, we argue that, comparatively, HRS has indeed induced farmers to misuse and overuse pesticides, and thus laid the institutional foundation for pesticide dependence within Chinese smallholder agriculture.

Socio-economic foundations for pesticide dependence

The institutional reform of HRS together with farmers' livelihoods diversification have driven rural social structures to change significantly in China, which has created more social space for pesticide application.

Livelihood diversification and pesticides

Due to the state-led urbanization and industrialization of China, farmers' livelihoods have been dramatically diversified, including through rural-urban migration, local non-farm employment and so forth (de Brauw *et al.* 2002). As Table 6 shows, the livelihoods of the 854 family members in the 225 sample households are greatly diversified. Apart from dedicated farmers, the most common non-farm activity is rural-urban migration, 31.8% of total. Another important observation is that females are much more likely to undertake agricultural production and much less likely to diversify their livelihoods.

The demographic changes in agriculture have caused adjustments in technology use. Table 7 shows that one third of the sample households are female-dominated farming households. It is found that female farmers tend to spend significantly more on pesticides than other households (p=0.007). Moreover, female farming households are also more likely to use no tillage adoption and less likely to intercrop.

The main reason for these practices is the labour shortage in agriculture caused by livelihoods diversification. One female respondent said,

> *My husband is working outside, and I am the only labour to take care of farming and other housework. Without his help, I try to practice simple agriculture, use no tillage, and less intercrop. But, this also means I need to apply more pesticides and herbicides to guarantee production. I often try to kill all the pests without extra dosage of pesticides because I do not have enough time and labour to do it on time. I need to take care of my whole family. You know, my husband is away.*

Pesticides, especially herbicides, cater to this agricultural demography, just as they initially were invented to liberate rural labour from hoeing up weeds (Gianessi 2013). As a result, more and more farmers can escape from laborious agricultural farming, going to work outside agriculture to earn income, whilst the people left behind can easily manage the farming activities.

Alongside livelihood diversification, farmers' income structure has changed significantly and non-farm income has been the predominant income source for the farmers. According to the survey, the income from non-farm employment occupies a dominant proportion of household income, at more than 70%. Under such an income structure, agricultural production becomes a marginal business. Farmers cannot concentrate on their land to the point that it is carefully and seriously treated and, furthermore, simple and convenient pesticides together with other modern technologies can save them more time thus giving more opportunities to gain other income sources.

To sum up, pesticide dependence is gradually constructed through the trajectory of agricultural system development and rural transformation, and it is actually an ongoing process in which modern agricultural technologies, agricultural institutions, cropping patterns, rural socio-economic changes jointly lock agriculture and farmers onto pesticide dependence. Under these circumstances, the whole modern agricultural technological system and the socio-economic transformations have been oriented to entrench pesticides. The modern agricultural technologies in Hu Village, such as hybrid rice and conservation tillage, along with the structural transitions of the rural community, interact and interweave to lock agriculture and farmers into pesticide dependence. If farmers want to step out of this path, the price will be to give up efficiency and productivity criteria, which is, however, a very hard decision for farmers who are still confronting so many uncertainties posed by the limits of subsistence farming and unequal development of the modern society.

Conclusion

This paper attempts to provide a detailed examination of the path dependence of pesticides as an integral part of modern agricultural technologies, farmers' livelihoods as well as rural transformation. The results revealed that pesticides have not been perpetuated at one stroke, but as a historically ongoing social-technical process of agricultural modernization and rural transformation in China. Broadly, the agricultural trajectory of Hu Village is just an epitome of the progress of modern agriculture in China. From the end of the 1970s, China's agriculture and rural society have dramatically experienced modernization, commoditization, marketization and rural-urban migration, all of which have transformed the whole rural landscape. Pesticide dependence is just embedded in this process.

Stepping out of pesticide dependence and the transformation of conventional agriculture are of great importance to China to guarantee food quantity and quality. Efforts in several directions may be effective for contemporary Chinese agriculture. Priority should be attached to breaking down the interdependence between modern agricultural technologies. This would require in-depth analysis of the interdependent functions amongst modern agricultural technologies and developing alternative technologies which are less dependent on agrochemicals. One effective method to reduce pests and diseases is to improve genetic heterogeneity of the current agro-ecosystem (Altieri 2004), which will alter the tendency of monoculture practice driven by agricultural modernization. Genetic diversification does not reduce yield as evidenced by a research on rice varieties in Yunan Province, China (Zhu *et al*. 2000). Therefore, precise planning of cropping designs along with pest and disease regulation is vital to promote genetic diversification (Altieri 2004).

Conservation tillage should be promoted more discreetly and differentially in China as noted by Zuo (2003) and Meng (2009) as well as elsewhere (Wen and Pimentel 1992, Koch and Stockfisch 2006). For example, in the north of China where the weather is relatively dry, this new tillage method may be more effective and beneficial, but for the south and southwest of China where the climate is more humid, conservation tillage needs to be reassessed against the sustainability of the agro-ecosystem (Wu and Sardo 2010). This system is ideal for modern and large scale farms as in the US and Canada but not for small-scale farms in China because of the inadequacy of appropriate machineries required for conservation tillage. Thus the government should promote conservation tillage in a more flexible way instead of merely encouraging farmers to naively apply the no tillage method everywhere.

As this study has revealed, without scientific guidance from authorities, farmers tend to apply extra pesticides on their land. Therefore, extension services from governments or other organizations regarding information and training on pesticides application are top priorities for contemporary Chinese agriculture. Moreover, since a substantial proportion of households, especially migrant households, face labour shortages in agriculture, and mutual help has been greatly diminished, some initiatives can be proposed to promote mutual help among the left-behind farmers, either from government interventions or by other organizations, such as non-governmental organizations (NGOs).

Farmers have realized the hazards of pesticides and some are even aware of its effect on the soils, but are unsure whether the links are scientifically validated or not. For example, a farmer said, “We just know pesticides are harmful to body and soil, but we are not sure whether they exist or not. We need evidence from scientists”. These concerns can be utilized as an ideological prerequisite for the promotion of environment-friendly pest management systems, e.g., IPM. Promotional programmes of IPM and relevant knowledge training should be supported by governments as well as other rural agents, e.g., NGOs. For example, the Pesticide Eco-Alternatives Centre (PEAC) in Yunnan, China organizes various training on pesticide risks for farmers and promotes a community-based alternative pest management system, which collects and explores traditional knowledge and technologies to control and prevent pests and diseases locally. In addition, action networks for reducing agrochemicals involving government agencies, experts, NGOs, farmers, and consumers should be encouraged. The challenges to realize all of these policy options are formidable. However, breaking pesticides dependence and transforming conventional agriculture in China is vital to ensure a sustained food supply, which is a goal worth pursuing.

Note

1. Pesticide in the Chinese context is an umbrella name of insecticides, herbicides, fungicides and various other substances used to control plant pests and disease.

2. Price scissors in this context signifies the increasingly diverging prices gaps between the industrial and agricultural sectors, which is often characterised by disproportionately high industrial prices and low agricultural prices. This process often favours the industrial sector through controlling the price of agricultural product by the state, in order to facilitate industrial accumulation, which is an important strategy for socialist countries (including China) in order to achieve industrialization at the initial developmental stage (Knight 1995, Lin and Yu 2009).

3. Unbalanced financial system refers to the strategy followed to achieve rapid industrialization by the Chinese government before the twentieth century when it deliberately prioritised channelling huge amounts of finance to industrial sectors at the expense of agricultural or rural sectors, which has caused severe long-term underinvestment of Chinese agriculture and rural regions (Anderson *et al.* 2004).

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