Geoforum 141 (2023) 103751

Contents lists available at ScienceDirect

Geoforum

journal homepage: www.elsevier.com/locate/geoforum

Farmers' practices and the political ecology of agrochemicals in rural China

Sarah Rogers [a,*], Zoe Ju-Han Wang [b,e], Jun He [c,d]

[a] Asia Institute, University of Melbourne, Australia
[b] Centre for Tropical Environmental and Sustainability Science, James Cook University, Australia
[c] National Centre for Borderland Ethnic Studies in Southwest China, Yunnan University, China
[d] School of Ethnology and Sociology, Yunnan University, China
[e] College of Science and Engineering, James Cook University, Cairns, Australia

ARTICLE INFO

Keywords:
Fertiliser
Pesticide
Agrarian change
Rural development
Organic agriculture

ABSTRACT

Chinese agriculture is in the midst of profound change, driven in part by the state's goals to scale up and modernise the sector and to promote more sustainable practices by reducing chemical fertiliser and pesticide use. Much of the existing literature on agrochemical use reduces these complex and highly politicised processes to a set of variables and models in which farmers are defined by characteristics such as age, education, and land size. This results in a poor understanding of why farmers do what they do. By examining case studies in Hubei and Yunnan, in this article we aim to better understand Chinese farmers' agrochemical practices, and to begin to situate these in a broader political ecology of agrochemicals in China. Drawing on research conducted in 2017–2019, we examine the socio-ecological relations of production and exchange in these two places and how farmers make decisions about, and access, fertilisers and pesticides. We find no single trajectory, but a complexity of practice shaped by local conditions and policies. External drivers are constraining chemical pesticide use and promoting commercial organic fertiliser products, but actual on-farm practices complicate some of these goals. To drive forward our understanding of agrochemicals in China, we argue that a political–ecological approach is needed that is attuned to farmers' decision-making about their particular crops, the local political economy that shapes access to resources such as alternative pest management tools and sets particular agendas, and the networks of agrochemical production and sales that bring different products to farms.

1. Introduction

China now dominates the global production and export of agrochemicals, and at the same time, is the world's largest consumer of chemical fertilisers and pesticides (Wu et al., 2018). Over-application is common: Chinese farmers apply almost three times the global average of fertiliser per hectare and 2.5–5 times the amount of pesticide used in developed countries (Yang and Fang, 2015; Hu and Rahman, 2016; Li et al., 2018). Following sustained concern about impacts on soil health, water quality, and food safety, China's central government recently introduced a target of zero growth in the use of chemical fertilisers and pesticides by 2020 (Ju et al., 2016). In addition, a range of agricultural standards now exist including organic, green, hazard-free and geographic labelling, each of which have different requirements for the use of chemical inputs (Scott et al., 2014; Ding et al., 2019). These and other initiatives are aimed at reducing dependence on synthetic inputs and increasing Chinese farmers' use of integrated pest management and organic fertilisers.

There is growing scholarly interest in the question of fertiliser and pesticide use on Chinese farms (and in pesticide use globally, see for instance Galt, 2014; Schreinemachers et al., 2017; Shattuck, 2021a). Our assessment is that the existing literature on Chinese farmers' use of agrochemicals is dominated by large surveys and models examining the effects of training, the take-up of organic fertilisers and integrated pest management, the use of protective equipment for pesticides, and whether farm size affects fertiliser use (Ding et al., 2019; Fan et al., 2015; Ju et al., 2016; Zhang et al., 2017; Chen et al., 2018; Pan and Zhang, 2018; Wu et al., 2018; Zhou et al., 2018; Ma and Abdulai, 2018; Yang and Fang, 2015). These studies reach contradictory conclusions about the extent to which gender, age, education, farm size, membership of a cooperative or years of farming experience shape fertiliser and pesticide use, and therefore what policy interventions to reduce synthetic inputs should look like.

Such confusion points to the difficulty of generalising input use and

* Corresponding author.
E-mail address: rogerssm@unimelb.edu.au (S. Rogers).

https://doi.org/10.1016/j.geoforum.2023.103751
Received 2 November 2022; Received in revised form 1 March 2023; Accepted 10 April 2023
Available online 19 April 2023

practices given how diversified Chinese agriculture has become, both in terms of crop specialisation and types of farms (see Zhang, 2015). A 2008–9 survey of households in Yunnan showed significant variation in fertiliser use across different crops and at different times of year, with winter crops such as beans, barley and wheat generally not fertilised. Overall, the authors found that a shift from grains to cash crops would likely increase demand for synthetic and organic fertiliser (Li et al., 2012). Based on a cluster analysis of 421 Yunnan households, Zinda and Kapoor (2019) also found that, even in the same area, different farm strategies shape the kind and amount of synthetic and organic inputs used by households, with intensive commercial strategies not necessarily reflecting higher use of synthetic inputs.

We discuss this literature further below. While it provides a valuable foundation for examining the way Chinese farmers deal with agrochemicals, further examination of the on-farm practices through which farmers understand and use fertilisers and pesticides is clearly warranted. Mixed methods or qualitative research is particularly lacking: research that actually goes to people's farms, talks to them directly, observes their practices, and seeks to understand the local political-economic context in depth. In this article we aim to better understand Chinese farmers' agrochemical practices, and to begin to situate these in a broader political ecology of agrochemicals in China. Our purpose is to generate a more nuanced understanding of everyday practices of agrochemical use in China and how they are intimately related to broader political ecological processes.

To do this we begin with a review of the critical literature on agrochemicals beyond China and bring this into conversation with existing studies of fertiliser and pesticide use on Chinese farms. We then further outline our framework, drawing attention to rapid agrarian change in the Chinese countryside today. Next, we introduce our methods and then outline the two case studies. Our discussion brings together key findings from both cases that will help move us towards a political ecology of agrochemicals in China.

2. Understanding agrochemicals

There is a growing body of work on the politics and geographies of global agrochemical flows that offers important insights for thinking through agrochemical use on Chinese farms. This literature is almost exclusively about pesticides, and often focuses on glyphosate, but is nonetheless relevant for fertilisers. Those focused on the global agrochemical complex highlight the need to engage in critical commodity studies of individual chemicals (Werner, 2022), taking into account shifting firm networks, state policies, and new South-South relations of pesticide production and trade (Werner et al., 2022). Shattuck (2021b: 248) in particular highlights the changing political economy of the pesticide complex: "an approach to sustainable agriculture that has a prayer of turning this tide must grapple with the proliferation of agrichemicals, their embeddedness within systems of value production, and the multi-polar nature of agrichemicals production and governance". Others look to implications for sovereignty and how chemical flows reshape the relations between the body politic and biological bodies (Widger, 2021). What all of these studies point to is the deeply political-economic nature of agrochemicals that extends so far beyond the farm.

Also relevant here is Julie Guthman's (2019) work on the novel ecologies produced by the widespread use of chemical fumigants in California's strawberry industry. Guthman details the political economic threads of soil fumigants and the ecological problem of pathogen resistance to show how chemical-intensive agriculture "gives rise to entire assemblages that are so entrenched that when toxicity becomes an issue or conditions of production are compromised, there is little room for maneuver" (Guthman, 2019: 203). Given recent changes in agrochemical use within China that are beginning to shift a deeply entrenched reliance on chemical inputs we return to this notion in our discussion.

But it is Ryan Galt's work that most closely informs our own. In his book *Food Systems in an Unequal World: Pesticides, Vegetables, and Agrarian Capitalism in Costa Rica,* Galt considers the multi-scalar nature of the pesticide problem: "there is little attention to the multiple socio-ecological factors of these often diverse horticultural production systems, in which farmers grow a number of different vegetables, protect their crops with dozens of pesticides, contract with different produce buyers or selling to intermediaries who sell to spot markets, and are embedded in larger political economic and ecological relationships" (Galt, 2014: 18). Political ecologists, geographers, and agrarian studies scholars are used to thinking across these scales and often trace processes, commodities or actors from the farm to other locations (and/or back again). Pesticides (and we would argue fertilisers) are clearly an "intriguing political ecological puzzle" (Galt, 2014: 30), bringing together integration into markets, agrifood governance, unequal power relationships in commodity chains, crop characteristics, and climatic and biophysical processes. But while there is a substantial literature on agrochemical inputs and use on Chinese farms,[1] as we now turn to, existing studies do not fully reflect the nuances of this puzzle nor trace processes across different scales in a meaningful way.

On fertiliser use in China, there are studies that measure use rates of synthetic and organic fertilisers (Zhang et al., 2017) as well as soil testing techniques (Yang and Fang, 2015), and those that identify the characteristics of organic fertiliser adopters (Chen et al., 2018). Wang et al. (2019) document how supposedly "organic" farmers participating in an NGO project often mix organic and inorganic fertilisers, blurring the definition of organic farming. Others focus on the relationship between farm size and fertiliser use, with some arguing that small-scale farming is less able to take on modern management practices and technological innovations (Wu et al., 2018), and others finding that there is no clear relationship between farm size and fertiliser intensity (Li et al., 2012; Xu, 2019). One study in Henan looks in detail at the factors driving over-fertilisation (Zhang et al., 2020), finding that over-application of fertilisers is not linked to environmental awareness, but to a complex mix of factors such as labour, time constraints, risk-aversion, land attachment, and farm size. In general, there is little discussion of biophysical processes, commodity chains, information flows, certification processes, or the chemical inputs used for specific crops and how exactly these are used. Yang and Fang (2015) identify fertiliser dealers as a key source of knowledge for farmers, but this not explored in any detail. Importantly, their mixed methods study recognises that fertiliser application is largely driven by habitual practices and individual judgements about crop, weather, and soil conditions.

On pesticides, there is little distinction between pesticide type, though overall, by volume, Chinese farmers use 26 per cent fungicides, 37 per cent herbicides, and 36 per cent insecticides, and non-biological pesticides account for nearly 92 per cent of total use (Zhang et al., 2018). Nor is there much of a focus on different kinds of crops, though one study does list the different chemicals used on rice, canola, corn, and citrus (Hu and Rahman, 2016). Others find evidence of continued use of highly-toxic banned pesticides (Wang et al., 2018). A number of studies are concerned with the factors that explain pesticide use, such as farm size, farming experience, or membership of a cooperative (Jin et al., 2017; Ma and Abdulai, 2018; Wang et al., 2018). One econometric study of several rice-growing provinces finds that larger-scale farmers are more likely to use larger doses of pesticides at higher frequency than small-scale farmers, but are also more likely to adopt alternative pest control measures (Qin and Lü, 2020).

There is more evidence of actual on-farm practices for pesticides than for fertilisers, with Zhou et al. (2018) finding that the majority of

[1] We found little analysis of fertiliser or pesticide practices on the small vegetable plots where families grow food for their own consumption. One paper suggests that agrochemical use is either limited or non-existent on these plots, reflecting food safety concerns (Si et al 2019), but this deserves more attention (and is a limitation of our own study).

farmers apply pesticides based on their own experience, Jin et al. (2017) finding that farmers in Shandong use pesticides on average 11 times during the growing season, and in Shaanxi, Wang et al. (2018) finding continued use of Class II restricted pesticides, including in certified pollution-free apple-growing areas. Hu and Rahman (2016) note that many farmers report not being able to read the instructions on pesticide containers and that to guarantee effectiveness, most apply more than the amount recommended by suppliers. However, there is little discussion of where farmers buy pesticides, whether they have changed the products used over time, or the extent to which they are integrating non-chemical controls into their practices. While there is very little research on storage and disposal practices in China, one study in Shandong found that 89.9 per cent of farmers surveyed stored pesticides in their homes rather than storerooms, and that 47 per cent discarded empty containers near their fields (Jin et al., 2017). In general, the majority of literature describes Chinese farmers as lacking sufficient knowledge or capacity to appropriately manage agrochemicals.

What is noticeable for studies of both pesticide and fertiliser use is that farmer behaviour and farm characteristics are rarely discussed with reference to particular local contexts (including climate, soil, production arrangements, supply chains, local government investment and development projects), or to the networks through which agrochemical products circulate. We argue that this is at least in part a reflection of the quantitative methods commonly used, which when not paired with qualitative methods such as interviews and farm walks, provide only a limited snapshot of actual agrochemical practices and how they are linked to broader processes.

The spread of food standards in China also has implications for agrochemical use, but there are few existing studies. Ding et al., (2019) find that agribusiness-led food standards play little role in improving apple growers' knowledge of pest and disease management. One key study by Chan and Flynn (2018) outlines the agrochemical inputs allowed and residue testing required under different local and international standards for bamboo shoot growers. The development of these standards is increasingly shaping local farmers' growing practices, but so far for a minority of farmers linked to agricultural cooperatives. The proliferation of standards is intimately linked to intergovernmental politics and the local state's attempts to secure investment and resources. Chan and Flynn's (2018) study is notable in that it situates farmer practices in the context of local political machinations, a point which we return to in our discussion.

These disparate studies suggest that agrochemical use in China is a complex picture of cropping systems, farm size, organic and non-organic production, sales channels, changing standards, labour, knowledge, habit and experience. Combined with insights from studies beyond China we can see that these farm- and local-level dynamics of production and exchange will also likely interact with climate, supply chains, and local and national politics. This is why a political ecological approach can be helpful in achieving our aim.

3. Socio-ecological relations of production and exchange in China

Understanding the puzzle of agrochemical practices on Chinese farms requires us to draw together on-farm practice with commodity chains, expanding forms of capitalist agriculture, local political dynamics, certification processes, environmental governance, and biophysical crop characteristics. We aim to make a first step in this direction. To return to Galt, our analysis adapts his work on the political ecology of pesticide residue violations (Galt, 2010). This framework considers how entities and processes operating at a number of scales shape pesticide use on farms and is underpinned by a focus on the social and ecological arrangements of petty commodity production and the social relations of exchange. Social-ecological relations of production here include the organisation of farming and relationships to the means of production, and the specific pests and diseases and the broader biophysical environment in the area of production, while social relations of exchange encompass specific exchange relationships and oversight of production (Galt, 2010: 338). We use this framework to contextualise both pesticide and fertiliser use in our two case studies.

A focus on the social-ecological relations of production and exchange in China necessarily entails an engagement with how these relations are rapidly changing as new agricultural operators (large family farms, cooperatives, and agribusinesses) increasingly move into the countryside and shift the nature of land tenure, labour, cropping, sales, and marketing (Zhang, 2015; Yan and Chen, 2015; Gong and Zhang, 2017; Hu et al., 2017; Schneider, 2017b; Zhan, 2019; Rogers et al., 2021). These shifts are a response to central government directives: a series of policies and regulations over the past decade has gradually loosened controls on exchange of land use rights to the point of encouraging a quasi-land market (Zhan, 2019) and encouraged the use of scale-based subsidies to support larger-scale producers (Gong and Zhang, 2017). Some scholars argue that these changes amount to a form of agrarian capitalism with Chinese characteristics that is displacing a previously smallholder-dominant economy and leading to large-scale land appropriation (Sargeson, 2013; Gong and Zhang, 2017). While social relations of production and exchange in rural China are certainly in flux, as we discuss below, this manifests in specific ways in Hubei and Yunnan.

There is little dialogue between the literature on agrochemical use and that on agrarian change in China. Two important exceptions are Schneider (2017a) and Zinda and Kapoor (2019), both of which draw on the notion of a metabolic rift - "a rupture in nutrient cycling between town and country and a rupture in the metabolic relation between humans and nature under capitalism" (Schneider and McMichael, 2010: 462). Schneider (2017b) examines how China's industrial meat regime separates people from land, and pigs from feed, with the result that rural spaces become dumps for the waste of agro-industrialisation. While not directly examining on-farm fertiliser practices, Zinda and Kapoor (2019) highlight the uneven ways in which metabolic rifts manifest given different household trajectories. Through their livelihood analysis, the authors find that capitalisation does not necessarily lead to higher use of synthetic inputs. This study reminds us that local agrochemical practices will reflect the diverse ways in which the state, capital, and socio-natures come together in rural China.

4. Methods

We examine socio-ecological relations of production and exchange through a mixed methods study. We draw some basic information about farming and agrochemicals from a farm survey[2] that was conducted for a larger project: this included 142 coffee farms in Yunnan and 266 orange farms in Hubei, providing an overall picture of agrarian change in the two locations. Our case studies are primarily developed from qualitative data collected for the same project. Fieldwork in Hubei was conducted by the first author in 2019 and in Yunnan by the second and third author in 2017 and 2019.

During fieldwork a series of semi-structured interviews were conducted with smallholders, family farm owners, local agents and salespeople, agribusiness managers and agronomists, cooperative leaders, and local officials in both places (approximately 25 in total). These interviews were selected by convenience. Though we did attempt to cover a range of farm types in our selection of participants (small farms, family farms, cooperatives, agribusinesses), not all of these were present at the study sites and there needed to be someone present at the farm. All of these interviews took place at people's farms so that we could see their

[2] The survey was implemented via a face-to-face questionnaire by trained university postgraduate students in the two provinces. At each location we systematically sampled the population by distributing the questionnaire to every second house or facility, meaning we captured both smallholders and larger-scale operators.

crops and some of their inputs. Fertiliser salespeople were selected because their shop was open on the main street. For both of these groups only members of the research team were present, no local officials accompanied us for our interviews. Local officials were selected for interview based on our contacts in the local area. In the Hubei case this was a joint discussion with township officials from many different offices, and a separate discussion with county officials, again from different bureaus.

Many topics were covered in these interviews as part of a broader study of agrarian change in these places, but farmers were specifically asked about their day-to-day fertiliser and pesticide use, local officials were asked about drivers of change in farming practice, and salespeople were asked about the products on sale in the local area. Interview notes and transcripts were then coded thematically using themes such as brand/product, fertiliser/herbicide/insecticide/fungicide use, organic/alternative pest management, production conditions, sales channels/standards, certification etc. The authors worked separately on the case study they were most familiar with.

We recognise that our data is based on recollection only, but farmers typically have a very good recollection of cost, products used and application procedures. As far as we know we were not dealing with any banned chemicals in these sites, so there is little reason for people to mislead us about their agrochemical use. We asked straightforward questions about people's common practices through the year, how they made decisions about which product to use, how much money they spent, and what changes had taken place in recent years. During fieldwork we directly observed the products used, the tools used for application, and the places nearby where these products were sold. In Yunnan we also observed when and how farmers discussed agrochemical use with each other. In what follows we endeavour to situate farmer practices firmly in their local political ecology, which in these two cases includes a range of state interventions aimed at agricultural scaling up and environmental protection.

5. Orange farmers in Hubei

5.1. Social-ecological relations of production and exchange

Our survey in Hubei covered 266 orange-growing households in three villages in the same township in Zigui County. Interviews were conducted with smallholders in each village, one large family farm, a fertiliser salesman, a village leader (village head or Party Secretary) in each village, and township and county officials. The township lies on a tributary that runs into the Yangtze River, upstream of the Three Gorges Dam. It has 55,000 *mu* of navel orange orchards, producing 100,000 tonnes per year. While in other villages in the township tea, walnuts and vegetables are also grown, in the three villages we sampled oranges are the only product. Orange production has a long history in the area, but it was not until the 1990s and 2000s that development was fast-tracked as part of Three Gorges Dam-related investment in the county. The three villages all lost several thousand *mu* of farmland as tributaries were gradually flooded, with residents relocated higher up the mountainside. A specialised orange industry has driven a rapid rise in rural incomes: household gross incomes in our sample rose from 33,400 RMB in 2013 to 75,896 RMB in 2018 (compared to 35,059 RMB in 2018 in Yunnan).

Several varieties of oranges are grown in the township, meaning fruit is harvested in most seasons. The main varieties are Lunwan (伦晚), Jiuyuehong (九月红) and Niuhe'er (纽荷尔 - Newhall navel). Farmers mostly referred to two varieties of Newhall: Changhong (长虹) and Yuanhong (圆虹). Given strong specialisation and external investment, and in line with the agrarian change literature, we might expect to find the gradual decline of smallholding as cooperatives, agribusiness and large family farms move in and consolidate landholdings. In fact, our data shows a thriving and fairly autonomous smallholder economy. In the survey of this area, when asked who makes decisions about what you grow and who you sell to, almost all households (95.1 % and 99.6 % respectively) responded that they – not government, agribusiness or cooperatives – make these decisions. Almost all respondents (95.9 %) defined themselves as smallholders, not professional or family farms, or agribusinesses. When asked about their future plans, 84.2 % responded that they intended to continue to farm on the same amount of land. This is despite the limited availability of land in the area, particularly following the Three Gorges Dam inundation: average contracted land is 0.3 *mu* (0.02 ha) of flat land and 5.3 *mu* (0.35 ha) of sloping land. There is limited evidence of more capitalist operators fundamentally changing relations of production in Zigui's orange farms. And while state interventions have changed the nature of landholdings in this area and prompted out-migration through resettlement, there is little evidence of state oversight of production. The state and university technicians may shape what varieties of orange saplings are available for farmers to grow and set certain requirements on agrochemical use relating to water pollution control (discussed below), but there are no quotas for production, no state buyers, and no day-to-day controls on farmwork.

In terms of labour, this smallholder dominant economy shows a strong reliance on hired seasonal labourers – 97.7 % of respondents reported needing additional labour in the previous year. Of these, the vast majority hired and paid for other farmers in the village (57.7 %) or labourers from other villages (42.3 %) to do this work, rather than labour being arranged through cooperatives, agribusiness or local government. We do not have data on what this labour is used for, though from interviews it is clear that both pesticide and fertiliser application require additional labour several times per year. On credit, 44.7 % of respondents had borrowed money in the past year, with the largest source of credit being relatives and friends, followed by the formal banking system. We did not ask what this money was used for. One final point about production is that most respondents (95.7 %) reported having access to irrigation infrastructure and 55.9 % collected rainwater, but very few other farm technologies were used (such as weather monitoring, orchard netting, processing equipment, and cold storage).

For exchange, in Hubei the primary sales channel for almost all households (97.6 %) is intermediaries, based on verbal, not written agreements. These middlemen (typically men, 中间商) or local agents (代理) drive to the orchards, look at size, colour, and flavour, pay a deposit to the farmer, and then send a van to collect the produce following harvest. There do not appear to be any fixed standards or pesticide residue testing by these intermediaries. A farmer we interviewed who was also a local agent explained that there are no inspections, the fruit is just cleaned, sorted, and packaged. And while one might expect the county's leading agribusiness to be driving standards and testing, the farmers we interviewed were not selling to the agribusiness as their price was too low, buying lower quality fruit for processing. Similarly, in the village with an active cooperative, one resident explained that the cooperative has no sales channel and provides very little benefit to farmers, only some free sticky, pheromone traps. Intermediaries are therefore critical to exchange relations in these villages. The township government was attempting to displace these intermediaries through a new company that would purchase, sort and classify oranges through "high tech" facilities and use the Alibaba platform for sales. Currently though, most people still sell to intermediaries: as a woman in her 40 s explained, she knows all the local agents and trusts them, selling her different varieties to different agents. One final point to note about intermediaries is that they are a critical source of crop information for smallholders: 84.2 % of respondents reported getting information about crop selection and prices from intermediaries (very few people reported getting this from village officials, cooperatives, agribusiness, online sources, or extension workers).

5.2. Farmer practices and networks

This is the context in which fertiliser and pesticide use takes place in Zigui: a highly specialised, smallholder-dominant industry, with a large network of intermediaries who purchase oranges, and little evidence of

any inspections or standards. Agrochemical use is almost universal: 99.6 % of our survey respondents were using synthetic fertilisers and 98.9 % organic, while 98.9 % were using pesticides. The most common pesticides in survey responses were Kemante (克螨特 – an insecticide), Dusipi (毒死蜱 – an organophosphate insecticide), and Safu (飒复 – a fungicide). Average annual expenditure was 5822 RMB on synthetic fertilisers, 5211 RMB on organic fertilisers, and 3187 RMB on pesticides. We do not have a clear picture of the cost of individual products: there are many different formulations in use in Zigui.

The use of organic fertilisers is notably high. In 2017 Zigui was designated as a model county for replacing chemical with organic fertilisers (Zigui Government, 2018), and while this project was implemented through cooperatives and model farms, there seems to be widespread uptake, but also continued use of synthetic products, and similar expenditure on both. As outlined below, these are commercial products, not farm-based composts or animal manures. A county official explained the link with intensive pig farming: that some places had oranges but no pigs, while others had pigs but no oranges, so they were looking to integrate these and use the manure from 600,000 local pigs. There are also demonstration projects for using green manure crops in orchards, and alternative insect control methods.

In one village a woman in her 50–60 s, with 2 *mu* of land managed by herself and her husband outlined her agrochemical use. The couple use both an organic and synthetic variety of fertiliser, bought in the nearby township centre, and started using organic fertilisers 10 years ago (this predates the interventions discussed above, suggesting there were earlier iterations). The organic variety used locally has 45 % organic content, presumably animal manure, and is produced by a company called Yishizhuang Agricultural Science and Technology Co Ltd (湖北宜施壮农业科技有限公司) based in Yichang, Hubei (see Fig. 1). The synthetic variety she was using was a compound fertiliser made by Hubei Lekaihuai Fertiliser Co Ltd(湖北乐开怀肥业有限公司); she had previously used a brand called Zhenzhu but this resulted in poor fruit quality. She has been using the same brands (of fertiliser and pesticide) now for eight years and also uses urea (尿素) when the trees are small to stimulate growth.[3] In April-May during spring growth, she and her husband mix the organic and compound fertilisers *together* and apply them to each orange tree. Organic fertiliser is then used separately in June-July (summer). Every year they use about 2.5–4 kg of organic fertiliser and hire additional labour: five people are needed to apply fertiliser to their 200 trees. Given their gross income is 40,000 RMB, their fertiliser expenditure is very high at 10,000 RMB per year (this does not include labour costs). She described choosing the brand based on many years of experience, with no need to look in detail at the trees (such as leaf colour), and with no instructions from the government. On the different kinds of fertiliser she explained that organic makes the oranges sweeter, while compound makes the fruit larger.

The couple manage weeding themselves and do not use herbicide. But they do use an insecticide, sprayed in May and September and needing six workers for application. Their total expenditure on pesticides is 1400 RMB per year (excluding labour costs) and insecticide application is based on tree size, with application to each leaf. She uses a backpack sprayer (see Fig. 2), wears a mask when spraying, and washes on return to the house. Empty containers are put in the village rubbish bin provided by the township government, while all pesticides and fertilisers are stored in a storeroom inside the house. As discussed above, the local government is promoting alternative pest management practices, with insect-attracting lamps and sticky traps visible in all three villages (see Fig. 3). The woman explained that she received sticky traps last year, but that distribution was based on connections to the village committee, so she got fewer than other people. She has no lamps and claimed that only cooperative members and people in demonstration areas have these. She also noted that older traps are no longer working (they need to be replaced yearly), so some people have started using insecticides again. They also use a fungicide to deal with a disease spread to the area through the contaminated tools of locals who work seasonally in orange orchards in Jiangxi Province. This was effective as she noticed the problem before harvest and had burnt all the affected small fruit.

Practices were similar in the other villages. In the second village a woman in her 60 s also bought inputs in town and in general, used what the salesperson told her to use, though she did state that you cannot necessarily trust what is on the market, so you have to use your own experience. She also mixes organic and synthetic fertilisers, stores them in her house and disposes of containers in the rubbish. Her fertiliser application was slightly different: she observes the tree size and leaf colour and if yellowing is evident applies more fertiliser, but is careful not to apply too much as this can damage the tree roots (i.e. quantities are not fixed year-to-year). Her fertiliser use is also aimed at improving the soil quality which she described as thin and unable to store moisture. She uses a general pesticide to deal with red spider mite and when applying, wears a mask and uses a government-subsidised motorised sprayer. Pesticides are applied four to five times per year and each time about 2000 L of water are used for dilution. In terms of alternatives, the village committee had given her 120 sticky traps for the first time in 2019, but no lamps.

In the third village a man in his 40 s with 300 trees on 3 *mu* mixed synthetic and organic fertilisers together for application in spring, and in summer applied a compound fertiliser. He said that high phosphorous content affects the quality of the fruit and also mentioned using a trace metal supplement every-two years to improve iron content of the soil (120 RMB/0.5 kg which is enough for 20–30 trees). He claimed that if they did not use this their trees would get flowers but no fruit. He also discussed the disease brought from Jiangxi, which was not in this area before 2000: he uses a fungicide in May to treat this disease and burns any affected leaves, He was not using herbicides but had been using Kemante for the past 20 years to treat red spider mite, spraying in March, May, July and September. His annual expenditure is 3000 RMB on pesticides and 6000 RMB on fertilisers: he always buys the same brand but shops around in town for the best price. He also explained that they use household water (not more expensive pumped irrigation water) for pesticide dilution. During the interview his wife and hired labourers returned from spraying in their orchards: they were using masks, his wife had covered her skin, and they were washing before eating lunch.

In town a fertiliser and pesticide salesman provided some further insight into local practices and recent changes in agrochemical use. He does not buy direct from suppliers but through an intermediary. Farmers come down to the shop to choose the varieties they want and he then delivers them to farms. He explained that compound fertilisers are targeted for different growing periods: high potassium compound fertilisers promote taste and skin quality, high nitrogen is for sapling growth and high phosphorous is for root growth. At present the government was promoting high nitrogen and potassium fertilisers due to the effect of phosphorous on water quality. All his fertilisers were Chinese made (he mentioned Guizhou's phosphorous industry); he was not selling any imported fertilisers, though he was selling a fungicide made by Dupont. On pesticides (see Fig. 4) he said that phosphorous-based pesticides had been banned also because of potential water pollution and that there was government training for salespeople like him about such bans. While he sells glyphosate, many farmers are now leaving weeds to encourage natural predators. He also noted that the insect lamps are not fully effective, so people are still using insecticides. Finally, he confirmed that the disease mentioned by the farmers was citrus canker (溃杨冰) and that farmers should be doing what they can to prevent its spread (i.e. using fungicides).

In discussions with township officials, they claimed that it was

[3] Other fertilisers used in Zigui included an ammonia fertiliser made by Huaqiang Chemical Group Co ltd (华强化工集团股份有限公司) based in Dangyang City, Hubei and trace elements made by Hunan Tiancibao Agricultural Technology Co ltd (湖南天赐宝农业科技有限公司).

Fig. 1. Examples of organic (left) and compound (right) fertilisers in Zigui (First author 2019).

Fig. 2. Backpack pesticide sprayer (First author 2019).

difficult to get households to move from synthetic to organic fertilisers and that two-thirds still used the former (our survey results suggest in fact most are still using synthetic). In demonstration sites the township government was experimenting with a yeast-based fertiliser and also with a combined fertiliser-water drip irrigation system made in Shanghai, but these technologies were not evident on the small farms we visited. One of these demonstration sites was a large family farm run by a man who had completed a course to be certified as a "professional farmer". He said that professional farmers should lead the way in demonstrating advanced farming practices like the combined water/fertiliser system. In Zigui there seems to be a continuum of access to

Fig. 3. Alternative pest management techniques in orange orchards: sticky traps (left) and insect-attracting lamps (right) (First author 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

alternative technologies, with smallholders receiving sticky traps from the village committee, those attached to cooperatives or demonstration areas perhaps also getting insect lamps, and larger-scale farmers trialing more expensive technologies. And yet despite these many government activities, most smallholders continue to use both pesticides and synthetic fertilisers purchased through established, convenient, local channels, and based on a combination of prior experience, tree observation, and advice from local salespeople.

6. Coffee farmers in Yunnan

6.1. Socio-ecological relations of production and exchange

Interviews in Yunnan were conducted with smallholders, hired labourers, middlemen, owners of large farms and family farms, managers of both domestic and international agribusinesses, cooperative leaders, and village leaders in three villages across Puer, Baoshan and Dehong prefectures. We selected three villages as study sites due to the different level of agribusiness involvement in coffee farming. Coffee farming has existed in Puer and Baoshan for more than 40 years, while in Dehong coffee farming only started in the 2010s.

Like Hubei, the vast majority (93 %) of coffee farmers across these three sites identify themselves as smallholders, 17 % are cooperative

Fig. 4. Pesticides on sale in the township centre (First author 2019).

members, and 82 % intended to continue to farm on the same amount of land in the next five years. Otherwise, the production models differ substantially: overall, 53 % of farmers were selling coffee to an agribusiness compared to 1 % in Hubei. While smallholders dominate production in both Puer and Baoshan, farmers in Puer are closely linked to multinational firms such as Nestle and Starbucks. In Dehong a domestic agribusiness – Hogood – monopolises production, operating under a model of 'firm + production base + farmers'. In this model the agribusiness provides finance, technology and inputs, and purchases the product from the household (Neilson and Wang, 2019). The "base" here refers to the land area used for production, which can be an area leased by the agribusiness or managed by smallholders. These different production models and farmers' relationships with agribusiness influence the way individual farmers use agrochemical inputs.

Labour availability and cost are critical to understand socio-ecological relations in these coffee- growing regions. Across all three sites, 61 % of respondents required additional labour. This number is higher in those areas where coffee farming is the majority income source and has a longer history. In Puer, for instance, 86 % of respondents needed required additional labour. On average, 37.5 % of expenditure is spent on hired labour, which is higher than any other items including machinery and agrochemical inputs. Hired labour is highly in demand during harvest season, usually spanning from November until February, but some family farms who own bigger plots may also hire labour for fertiliser application, herbicide application and manual weeding. The majority of respondents (69.7 %) had recently borrowed money, mostly (74.7 %) from the formal banking system, but it is unclear whether this was reinvested in farming or for other uses.

The cost of labour varies depending on the location of the farms. In areas closer to the Myanmar border such as Dehong, labour costs are relatively cheap (60–70 RMB/day) due to the availability of Burmese migrant workers, while in Puer labour costs approximately 100 RMB/day or even higher. The source of hired labour is usually external to the village. In Puer, hired labour usually comes from other counties or even from other prefectures. These migrant workers, mostly ethnic minorities, seek work as a group, and are provided with boarding during the harvest season. The majority of these migrant workers are female. Back home, they either have no or little land to farm (some have leased out their land); or they also work on other crops during a different time of the year (such as tea). While labour is in high demand during harvest season, Yunnan's coffee farmers enjoy-two advantages: proximity to Myanmar and harvest season being in winter, which is a relatively quiet season for other farming activities, meaning there is a surplus of workers at this time.

Another key aspect of socio-ecological relations is how farming knowledge (crop information, price, inputs and technology) is disseminated and exchanged. In Yunnan, formal channels like cooperatives do not function well in term of information exchange and dissemination, while extension services are also limited – farmers often have low trust in these services. This is reflected in our survey: most of the respondents obtained information from informal channels, mostly agribusinesses and their technicians (38 %), following by middlemen (26.8 %). Some also obtained information from TV or social media (12 %), but fewer selected government or extension services (1.4 %) or cooperatives (11.3 %). Our understanding is that farmer-to-farmer information exchange is often based on farmers' own experiences and observations, including from demonstration projects. Day-to-day experience appears to be the key mechanism shaping farmer behaviour.

6.2. *Farmer practices and networks*

Given coffee plantations in Yunnan are so far immune to the most harmful pest - coffee berry borer - our discussion focuses on fertiliser and herbicide use. Similar to Hubei, the majority of coffee farmers in Yunnan employ both synthetic and organic fertilisers. Almost all (99.3 %) coffee farmers use synthetic fertilisers and a very high percentage of farmers have adopted organic fertiliser (93 %). However, there are various sources of organic fertiliser, and the driver or rationale for adopting these varies from place to place. The majority of farmers are applying a herbicide (60.6 %): we discuss herbicide use in more detail below.

Many small farmers produce their own organic fertiliser, which is called household manure (农家肥) locally. The majority of coffee farmers still raise either chickens or pigs, so it is common for them to mix animal faeces with the skin of coffee cherries and ferment the mix. For most coffee farmers, rather than environmental concerns, their rationale is to reduce the cost of synthetic fertiliser inputs. Use of household manure is prevalent in all three surveyed villages. Second, agribusinesses like Hogood which own production bases may provide organic fertiliser to the farmers in the form of a loan - these are also made from fermenting manure and cherry skins. Hogood only provides organic

fertiliser to farmers in certain areas where they expect to have better quality coffee production, so it is not a universal or concerted effort to promote organic fertiliser use. Finally, some farmers in Puer (but not the other locations) use commercial organic fertilisers, either purchased by themselves or subsidised by government. Local government in Puer has since 2013 being promoting Puer's green credentials, including subsidising organic fertiliser and intercropping seedlings for coffee farms. In the village we surveyed these resources were provided through the agricultural cooperative, so were not available to all farmers. To explore farmer practices in more detail, we consider the case of the Puer coffee village. In this administrative village there are 650–700 households with approximately 10,000 *mu* of coffee plantations. While Puer is famous for tea, coffee production has become the major income source in this village, with an average gross income of about 40,000 RMB in 2018.

Coffee farming started here in 1987 when Beigui - a state-owned farm - signed a 35-year contract to rent 2000 *mu* of land and recruited 200 households from other areas to work on these plantations. Since then, local farmers started to transition their crops to coffee due to the increasing profit. The major sales channel here is to agribusiness due to proximity to Puer City where many international and domestic coffee companies (including Nestle which is the largest buyer of local coffee) own procurement centres or processing factories. Beigui, now transformed into a private business, is another major buyer. While agribusiness is consistently the dominant sales channel, often there is no formal contract between the farmers and the agribusiness: only 11.8 % of respondents had either written or oral contracts.

The village Party leader, Mr H, is chairman of the agricultural cooperative and also owns a coffee trading company and processing factory. In 2014–2016, he managed to secure a three-year supply of organic fertilisers from Puer's government for the cooperative. Mr. H. received a subsidy of 600 RMB/*mu* which he used to purchase organic fertiliser from other provinces and distribute to his fellow villagers. He eventually came to operate a fertiliser trading company. According to Mr. H, the production area of "organic" coffee in the village is approximately 1,000 *mu* (of which 200 *mu* belongs to him) and production is said to meet European Union-certified organic standards. Mr. H claims the production model is well managed, with only organic fertiliser applied to the entire area of 1000 *mu*. Farmers have been instructed not to apply herbicide, but only to weed manually.

Most local farmers sell their organic cherries (see Fig. 5) to Mr. H, whose company purchases, processes, brands, and resells both organic and non-organic product. In the 2017–2018 season, farmers' organic cherries sold for 3.6 RMB/kg and non-organic for 2.2–2.3 RMB/kg. After processing, Mr. H sold the organic coffee to domestic and international coffee buyers for more than 40 RMB/kg (compared to 15–16 RMB/kg for non-organic).

However, interviews with villagers revealed a very different story of "organic" production. Organic practices did not apply to the entire area of 1000 *mu*. While on average, each household owned approximately 20–40 *mu* of coffee plantation, organic fertiliser was applied to only a fraction of that. For example, Mr. Z who lived immediately adjacent to Mr H's residence only applied organic fertiliser to six out of his 20 *mu*. This was mainly due to the extensive labour and associated cost: compared to non-organic coffee plantations where fertilisers are applied twice per year, organic fertiliser needs to be applied four times a year. In addition, organic coffee plantations require manual weeding four times per year, and the harvesting process has to be much more careful. On average, weeding adds additional labour costs of 300–500 RMB per *mu* per year.

Landholding is highly fragmented in Yunnan. Across our survey sites, 83.7 % of respondents own more than one piece of land. In Puer, farmers typically own several pieces of land: some are located closer to the village and on flatter land with relatively easy access while others are further into the forest where access is more difficult. Farmers usually grow organic coffee on land closer to the village; they are reluctant to adopt organic practices for the plantations that are located further into the forest. During harvest season, farmers harvest organic cherries by themselves but depend on migrant labor for harvesting the non-organic plantation. Farmers such as Mr Z are happy to continue farming organically on part of their land due to higher premiums, even after free organic fertilisers are discontinued (he planned to switch to his own household manure), but there is little appetite to expand organic practices. This is despite Puer government advocacy as part of a Green Economy Pilot Demonstration zone.

Fig. 5. Harvesting organic cherries in Yunnan (Second author 2017).

While international buyers and certification programs (e.g. UTZ and 4C) are prevalent in Puer, the push to transition to organic fertiliser comes primarily from local government. As long-time purchasers, international companies like Nestle nonetheless play a role in shaping agrochemical practices. In 2018 Yara started to collaborate with Nestle to promote its synthetic fertiliser Yara Mila (雅苒苗乐) in Yunnan. The two companies arranged many training workshops in Puer to promote the brand. Nestle also influences local farmers' pesticide use. For several decades, Nestle ran an agronomy service providing training to coffee farmers across Puer, including 4C certification training and other agronomy techniques. In our surveyed village, farmers with 4C certificates noted specific environmental requirements that they had to comply or improve, including restricted fertiliser use (e.g. only using fertiliser approved by Nestle and applying fertiliser in approved ways); restricted insecticide use (e.g. no use, low use or Nestle-approved insecticides) and restricted herbicide use or the prohibition of glyphosate. While glyphosate is widely used in coffee production in Yunnan, Puer farmers stated that they had had coffee rejected by Nestle's quality control team due to glyphosate residue. Herbicide use became a hot topic among farmers and many believed they could not use glyphosate to meet Nestle's standards. No such discussion was observed in the other two locations where there had been no certification process.

A local Wechat group called Puer Coffee Growers discussed glyphosate use. This chat group was set up by a Nestle agronomist to be a

platform for coffee growers in the region to exchange information. 156 Wechat account holders joined the chat group. In the early days the group was mainly used by the agronomist to disseminate information on global coffee prices. Gradually, the information sources have become more varied. While the agronomist still uses the platform to distribute information, other group members were also active in providing and exchanging knowledge of agrochemical inputs. One farmer re-posted an online article about the negative environmental and health impacts of glyphosate. On many occasions farmers would also upload photos of their plantation and ask others to identify the issue such as weak growth or low fruit yield. The internet is clearly an important source for local farmers to obtain and exchange their information on agrochemical use.

7. Towards a political ecology of agrochemicals in China

Our two cases of Yunnan coffee and Hubei oranges highlight how varied agrochemical use is amidst different relations of production and exchange. Much like Zinda and Kapoor (2019) we find no single trajectory in agrochemical use. While animals (pigs) have long been separated from farming in the Three Gorges region, farmers in Yunnan continue to have access to animal manure and make use of this on their coffee plantations. While production is still dominated by smallholders in both locations, the greater role of agribusiness in the Yunnan case shapes particular agrochemical practices, including the spatially uneven uptake of "organic" farming. The crops themselves also have different needs and different vulnerabilities to pests and disease. The relations of exchange are quite different in these places: companies like Nestle in Yunnan have certain requirements, and production standards can sometimes be enforced through household relations with agricultural cooperatives (as in Chan and Flynn's, 2018 case of bamboo shoots). In Hubei, intermediaries have no evident requirements for their orange purchases and cooperatives play little role in production or exchange (Wilmsen et al., 2023). Our two cases also highlight how agglomeration into generic categories of 'fertiliser' and 'pesticide' can hide the varied materials that are being used and the varied practices associated with these. This is most obvious for the mixing of organic and chemical fertilisers on farm, but also for water quality concerns associated with phosphorous-based fertilisers, Nestle's glyphosate prohibitions, and specific fungicides that point to disease spread in Zigui.

Despite these distinct economies there are nonetheless common threads here. In both cases there are external drivers that are encouraging more organic fertiliser use and constraining chemical pesticide use: in Hubei this is a local government initiative linked to high phosphorous loads and water quality, while in Yunnan it is a local government pilot paired with the influence of certification standards (the specific role of agricultural extension workers here needs further examination). In both cases, actual on-farm practices are revealing and trouble some of these goals. In Zigui, organic fertilisers are mixed with synthetic products and chemical pesticides continue to be used when government-provided alternative pest management fails. In Puer, farmers use organic inputs on accessible land and sell part of their product as "organic", but the additional labour and cost required prevent more widespread changes in agrochemical use.

What we find is a far more complex picture than presented in much of the existing literature. Academic studies variously claim that fertiliser is over-applied because Chinese farmers lack adequate knowledge (Pan and Zhang, 2018), have limited knowledge of rational fertilisation (Hua et al., 2017) and are poorly educated with low awareness of environmental sustainability and food safety (Zhou et al., 2018). Our study shows that Zigui's orange farmers make regular judgements about tree growth and health, as well as the cost and effectiveness of certain products. Oranges are heavy feeders (citrus in general demands a lot of fertiliser to produce a good crop), so many different products are used and these are targeted at tree growth stage and for particular characteristics such as colour and sweetness. Biosecurity concerns require the use of fungicides. Coffee farmers use available inputs to make their own composted manure, thereby reducing their fertiliser expenditure, and increasingly share information about agrochemicals with other farmers on social media. All of this suggests a level of local knowledge and capacity that challenges common tropes about smallholders. This is by no means unique to China: as Galt notes, "technocratic regimes of protection discursively shift the cause of the pesticide problem to the deficiencies of local cultures and individuals, labeled 'underdeveloped' and 'ignorant'" (Galt, 2013, 337). But it warrants re-emphasising yet again: smallholders in China have a complexity of practice that deserves our attention and in-depth understanding. This foundational premise of political ecology so rarely gets aired in the literature on Chinese farmers' agrochemical use.

Making sense of what is happening on farms is of course only one scale at which a political ecology of agrochemicals needs to operate. Our two cases orient us to processes well beyond the farm and village - networks that tie these places to much broader dynamics. These networks are first and foremost the agrochemical salespeople, agribusiness extension workers, and local leaders who, through their own intermediaries, are linked to China's massive agrochemical production complex and who facilitate the flow of particular products and information about these products into these locations. We have only just touched the surface of this complex (commercial organic fertilisers, Guizhou's phosphorous industry, common insecticides etc): far more detailed work needs to be done to trace the flows of capital, chemicals, and power that define China's agrochemical industry.

There are also networks of government policy that set agendas for pollution control, food standards, and agricultural sustainability and in doing so, prohibit, discourage, or promote particular commercial products. As shown in Chan and Flynn's (2018) study, these networks can directly facilitate flows of particular agrochemical products. Agrochemical agendas are closely tied to China's broader push to scale-up agriculture and prioritise larger-scale farms, which in subtle and not so subtle ways is further marginalising smallholders. In our study, not every-one has access to alternative pest control technologies and not every-one can afford the purchase and labour costs of organic fertilisers. To really understand changing agrochemical practices we must link to these larger "chains of explanation" (Blaikie and Brookfield, 1987: 27).

To take this one step further, China now dominates the global production and export of fertilisers and pesticides, including off-patent glyphosate production. Emerging studies on the global pesticide complex have only just begun to come to terms with this shifting ground and its implications: as Shattuck (2021b: 247) argues, "the entrance of China to the global pesticide market has profoundly shifted the center of gravity for both pesticide production and governance". Off-patent products are produced by lower-cost Chinese manufacturing facilities, making them available at low cost to farmers. Upgrading within China has seen productive capacity concentrated into large conglomerates, with an increased focus on exporting formulations (rather than raw chemicals), and the build-up of brands (Werner et al., 2022). ChemChina's takeover of Syngenta was "the largest merger in Chinese history" (Werner et al., 2022: 26). There is little discussion of global flows of Chinese-produced fertiliser, nor of the internal geographies of China's synthetic and organic fertiliser industries. If we are to move towards a political ecology of Chinese agrochemicals, the on-farm practices outlined in this paper and the local networks that shape these need to be linked to the nexus of state, capital, and socio-natures at a much larger scale.

Returning to the literature we introduced early on, our findings raise some further unanswered questions. The first relates to Guthman's (2019) warning about entrenched chemical-intensive agricultural assemblages. Toxicity and pollution are clearly front of mind at many layers of government in China. Our study provides further evidence that there are major changes taking place in agrochemical use in China and a gradual reduction in chemical inputs overall. Should we conclude that these systems are reaching the limits of repair or are resistant to change? On the surface it does not seem that way: in these two cases a whole

industry of actors is being mobilised to provide less polluting alternatives to Chinese farmers. Go a little deeper into farmer practices and long-standing problems of soil and water pollution though, and we are less optimistic about the better environmental and human health outcomes. Guthman's work also draws our attention to how pesticides (and in this case fertilisers too) are a *knowledge* problem: "those in the business of repair are therefore trying to fix something that is changing because of what they thought they had fixed" (Guthman, 2019: 202). The dynamics of this are playing out in China right now: policies that produced a metabolic rift and intensified use of chemical inputs are being replaced by policies attempting to repair some of this rift but primarily with industrial-scale organic fertiliser production.

Questions also remain about how to move forward empirically. Certain assumptions behind research design in much of the existing literature on Chinese farmers' agrochemical use (chiefly that large farms are better) have resulted in a poor understanding of why farmers do what they do. The problem is not quantitative approaches as such, but the need to at least use qualitative methods (or insights from qualitative studies) to produce better quantitative studies. To understand agrochemical use on Chinese farms we still need large-scale data on information sources, products used (synthetic and organic), purchase, additional labour requirements and cost, timing and influence of certification/standards among other things. But these need to be attentive to local socio-ecological relations of production and exchange and begin from the starting point that farmers intimately know their crops and conditions.

Further, multi-sited and multi-scalar analysis is clearly central to critical work on pesticides (Galt, 2014; Guthman, 2019; Werner et al., 2022), but a little more clarity is needed here. As Sayres (2005: 280) notes: "One's choice of scale may strongly determine what, if anything, one 'sees'". Our study has focused very much on the farm and local-level engagements with networks at broader scales. Our starting point was always farmers and their complex relationships with crops, inputs, large-scale farms, and local politics. To better understand the puzzle of agrochemical use in China and to begin to unpack China's agrochemical complex, not everything has to be multi-scalar. Rather, we need further research that delves into processes at different scales, but is attentive to their interactions across scales. These different pieces of the puzzle might include intermediaries and agrochemical salespeople, key sites for the mining and production of agrochemicals, firm dynamics and ownership relations, and export commodity chains.

8. Conclusion

If China is to shift to more sustainable agrochemical practices, there needs to be both a better appreciation of the complexity of practice on Chinese farms and of the ways that these practices are shaped by political-economic processes far removed from the control of individual farmers. There is a lot at stake here. Some scholars conclude categorically that larger-scale farms have better performance in terms of fertiliser use than smallholder farms and that land transfer should therefore be accelerated (Ju et al., 2016). As we have seen in the case of Yunnan and Hubei, the state, capital, and socio-natures come together in such precise ways that sweeping conclusions like this are deeply problematic. Further, as Xu (2019: 3) argues, "the problem is not in farm size per se, it is in the capitalist system in which both small and large farms keep consuming more and more fertilizer". Critical scholars should be attentive to these systemic drivers and how they are changing - for instance, concerted efforts to shift towards commercial organic fertilisers. Critical scholars should also be attentive to the ways in which tropes of hygiene, quality, and "good farming" (Chan and Enticott, 2019) can be used to marginalise Chinese smallholders and naturalise land transfer to larger-scale operators.

To drive forward our understanding of agrochemicals in China, a political–ecological approach is needed that is attuned to farmers' decision-making, the materiality of local crops, pests, and diseases, the local political economy that shapes access to resources such as alternative pest management tools and sets particular agendas, and networks of agrochemical production and sales. The latter requires a much deeper understanding of China's agrochemical complex, as China consolidates its position as the central player in global agrochemical flows. How capital, materials, energy, and waste come together in China's agrochemical facilities and how the industry is responding to the government's push towards "organic" inputs is an industrial political ecology (Huber, 2017) that requires urgent attention.

CRediT authorship contribution statement

Sarah Rogers: Methodology, Conceptualization, Investigation, Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing, Project administration, Supervision. **Zoe Ju-Han Wang:** Methodology, Investigation, Formal analysis, Writing – original draft, Writing – original draft, Writing – review & editing. **Jun He:** Methodology, Investigation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This research was funded by the Australian Research Council (DP180100519) and we would like to acknowledge the other investigators on this project – Dr Brooke Wilmsen, Professor Duan Yuefang, Professor Li Jie, Professor Lin Wanlong, and A/Prof Han Xiao. The Hubei case would not have been possible without Brooke, Han Xiao and Duan Yuefang's organisation and assistance. We thank Dr Sonia Graham for generous comments on the draft manuscript and two reviewers who gently pushed us to think more expansively about the article's implications. We are grateful to all participants in Hubei and Yunnan for generously sharing their time and thoughts with us.

References

Blaikie, P., Brookfield, H., 1987. Land Degradation and Society. Methuen, London and New York.
Chan, K.-W.-R., Enticott, G., 2019. The *Suzhi* farmer: constructing and contesting farming subjectivities in post-Socialist China. J. Rural. Stud. 67, 69–78.
Chan, K.-W.-R., Flynn, A., 2018. Food production standards and the Chinese local state: exploring new patterns of environmental governance in the bamboo shoot industry in Lin'an. China Q. 235, 849–875.
Chen, X.K., Zeng, D., Xu, Y., Fan, X.J., 2018. Perceptions, risk attitude and organic fertilizer investment: evidence from rice and banana farmers in Guangxi, China. Sustainability 10 (3715), 1–14.
Ding, J.P., Moustier, P., Ma, X.D., Huo, X.X., Jia, X.P., 2019. Doing but not knowing: how apple farmers comply with standards. Agric. Hum. Values 36, 61–75.
Fan, L.X., Niu, H.P., Yang, X.M., Qin, W., Bento, C.P.M., Ritsema, C.J., Geissen, V., 2015. Factors affecting farmers' behaviour in pesticide use: insights from a field study in northern China. Sci. Total Environ. 537, 360–368.
Galt, R.E., 2010. Scaling up political ecology: the case of illegal pesticides on fresh vegetables imported into the United States, 1996–2006. Ann. Assoc. Am. Geogr. 100 (2), 327–355.
Galt, R.E., 2013. From homo economicus to complex subjectivities: reconceptualizing farmers as pesticide users. Antipode 45 (2), 336–356.
Galt, R.E., 2014. Food Systems in an Unequal World: Pesticides, Vegetables and Agrarian Capitalism in Costa Rica. University of Arizona Press, Tucson.
Gong, W.G., Zhang, Q.F., 2017. Betting on the big: state-brokered land transfers, large-scale agricultural producers, and rural policy implementation. China J. 77 (1), 1–26.
Guthman, J., 2019. Wilted: Pathogens, Chemicals, and the Fragile Future of the Strawberry Industry. University of California Press, Oakland.

Hu, Z.P., Rahman, S., 2016. Beyond a bottle of liquid: pesticide dependence in transitional rural China. Local Environ. 21 (8), 919–938.
Hu, Z.P., Zhang, Q.F., Donaldson, J.A., 2017. Farmers' cooperatives in China: a typology of fraud and failure. China J. 78 (1), 1–24.
Hua, C.L., Woodward, R.T., You, L.Z., 2017. An ex-post evaluation of agricultural extension programs for reducing fertilizer input in Shaanxi, China. Sustainability 9 (556), 1–26.
Huber, M.T., 2017. Hidden abodes: Industrializing political ecology. Ann. Assoc. Am. Geogr. 107 (1), 151–166.
Jin, J.J., Wang, W.Y., He, R., Gong, H.Z., 2017. Pesticide use and risk perceptions among small-scale farmers in Anqiu County, China. Int. J. Environ. Res. Public Health 14 (29), 1–10.
Ju, X.T., Gu, B.J., Wu, Y.Y., Galloway, J.M., 2016. Reducing China's fertilizer use by increasing farm size. Glob. Environ. Chang. 41, 26–32.
Li, Y.J., Kahrl, F., Pan, J.J., et al., 2012. Fertilizer use patterns in Yunnan Province, China: implications for agricultural and environmental policy. Agr. Syst. 110, 78–89.
Li, Q., Yang, W.J., Li, K., 2018. Role of social learning in the diffusion of environmentally-friendly agricultural technology in China. Sustainability 10 (5), 1527.
Ma, W.L., Abdulai, A., 2018. IPM Adoption, Cooperative Membership and Farm Economic Performance: Insight from Apple Farmers in China. China Agricultural Economic Review (in press).
Neilson, J., Wang, Z.-J.-H., 2019. China and the changing economic geography of coffee value chains. Singap. J. Trop. Geogr. 40 (3), 429–451.
Pan, D., Zhang, N., 2018. The role of agricultural training on fertilizer use knowledge: a randomized controlled experiment. Ecol. Econ. 148, 77–91.
Qin, S.L., Lü, X.Y., 2020. Do large-scale farmers use more pesticides? Empirical evidence from rice farmers in five Chinese provinces. J. Integr. Agric. 19 (2), 590–599.
Rogers, S., Wilmsen, B., Han, X., Wang, Z.-J.-H., Duan, Y.F., He, J., Li, J., Wong, C., 2021. Scaling up agriculture? The dynamics of land transfer in inland China. World Dev. 146, 105563.
Sargeson, S., 2013. Violence as development: land expropriation and China's urbanization. J. Peasant Stud. 40 (6), 1063–1085.
Sayre, N.F., 2005. Ecological and geographical scale: parallels and potential for integration. Prog. Hum. Geogr. 29 (3), 276–290.
Schneider, M., 2017a. Wasting the rural: Meat, manure, and the politics of agro-industrialization in contemporary China. Geoforum 78, 89–97.
Schneider, M., 2017b. Dragon head enterprises and the state of agribusiness in China. J. Agrar. Chang. 17 (1), 3–21.
Schneider, M., McMichael, P., 2010. Deepening, and repairing, the metabolic rift. J. Peasant Stud. 37 (3), 461–484.
Schreinemachers, P., Chen, H.P., Nguyen, T.T.L., et al., 2017. Too much to handle? Pesticide dependence of smallholder vegetable farmers in Southeast Asia. Sci. Total Environ. 593–594, 470–477.
Scott, S., Si, Z.Z., Schumilas, T., Chen, A.J., 2014. Contradictions in state- and civil society-driven developments in China's ecological agriculture sector. Food Policy 45, 158–166.
Shattuck, A., 2021a. Risky subjects: embodiment and partial knowledges in the safe use of pesticide. Geoforum 123, 153–161.
Shattuck, A., 2021b. Generic, growing, green?: the changing political economy of the global pesticide complex. J. Peasant Stud. 48 (2), 231–253.
Si, Z., Li, Y., Fang, P., Zhou, L., 2019. "One family, two systems": food safety crisis as a catalyst for agrarian changes in rural China. J. Rural. Stud. 69, 87–96.
Wang, J.-H.-Z., Fisher, R., Connell, J., 2019. Participatory natural resource management in rural China: making and unmaking environmental narratives. Asia Pac. Viewp. 60, 205–219.
Wang, Y.Q., Wang, Y., Zhu, Y.C., 2018. What could encourage farmers to choose non-chemical pest management? Evidence from apple growers on the Loess Plateau of China. Crop Protect. 114, 53–59.
Werner, M., 2022. Geographies of production III: global production in/through nature. Prog. Hum. Geogr. 46 (1), 234–244.
Werner, M., Berndt, C., Mansfield, B., 2022. The glyphosate assemblage: herbicides, uneven development, and chemical geographies of ubiquity. Ann. Am. Assoc. Geogr. 112 (1), 19–35.
Widger, T., 2021. Glyphosate regulation and sovereignty politics around the world. Anthropol. Today 37 (4), 1–2.
Wilmsen, B., Rogers, S., Duan, Y.F., Wang, Z.J.-H., 2023. Farmer cooperatives and the limits of agricultural reform in rural Hubei. China J 89, 1–23.
Wu, Y.Y., Xi, C.C., Tang, X., et al., 2018. Policy distortions, farm size, and the overuse of agricultural chemicals in China. PNAS 115 (27), 7010–7015.
Xu, Z., 2019. Farm size, capitalism, and overuse of agricultural chemical in China. Capital. Nat. Social. 31 (3), 59–74.
Yan, H.R., Chen, Y.Y., 2015. Agrarian capitalization without capitalism? Capitalist dynamics from above and below in China. J. Agrar. Chang. 15 (3), 366–391.
Yang, X.Y., Fang, S.B., 2015. Practices, perceptions, and implications of fertilizer use in East-Central China. Ambio 44, 647–652.
Zhan, S.H., 2019. The Land Question in China: Agrarian Capitalism, Industrious Revolution, and East Asian Development. Routledge, London and New York.
Zhang, Q.F., 2015. Class differentiation in rural China: dynamics of accumulation, commodification and state intervention. J. Agrar. Chang. 15 (3), 338–365.
Zhang, L.G., Li, X.R., Yu, J.L., Yao, X.L., 2018. Toward cleaner production: What drives farmers to adopt eco-friendly agricultural production? J. Clean. Prod. 184, 550–558.
Zhang, Y.N., Long, H.L., Wang, M., et al., 2020. The hidden mechanism of chemical fertiliser overuse in rural China. Habitat Int. 102, 102210.
Zhang, J., Manske, G., Zhou, P.Q., et al., 2017. Factors influencing farmers' decisions on nitrogen fertilizer application in the Liangzihu Lake basin, Central China. Environ. Dev. Sustain. 19 (791), 805.
Zhou, J.H., Liu, Q., Liang, Q., 2018. Cooperative membership, social capital, and chemical input use: Evidence from China. Land Use Policy 70, 394–401.
Zigui Government, 2018. 有机肥替代化肥助推秭归柑橘提档升级 (Organic fertiliser replacing chemical fertiliser to push forward the upgrading of Zigui citrus) Zigui: Zigui County Propaganda Department http://www.zigui.gov.cn/2018/0320/698017.shtml (Accessed 26/11/2019).
Zinda, J.A., Kapoor, S., 2019. Metabolic fractures: how household livelihood practices differentiate agricultural input use in southwest China. J. Rural. Stud. 71, 1–12.