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The agrochemical complex of China: historical, global and intersectoral connections

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ABSTRACT

China is the world's largest producer, exporter, and a key consumer of agrochemicals, with Chinese corporations dominating the global market. This paper, based on a literature review of both English and Chinese sources, provides a historical analysis of China's agrochemical industry. It highlights the insufficiencies and reductionism in existing studies, arguing that the sector is deeply intertwined with (i) China's agrarian transformation, (ii) global interactions, and (iii) intersectoral connections. The paper calls for a more comprehensive framework to understand these dynamics historically, interactively and connectively. It aims to contribute to a deeper understanding of the global agrochemical complex.

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KEYWORDS
Agrochemical complex; China; China-global interaction; intersectoral; historical

1. Introduction

Currently, agrochemicals are increasingly utilised in agriculture and have significant impacts on the global food system, ecological environment and human and animal health (Fan et al. 2021; Fenner et al. 2013; Horton et al. 2014; Maggi, Tang, and Tubiello 2023; Tang et al. 2021).[1] Thus, understanding the agrochemical complex can contribute to finding pathways to the world's sustainable transition underlying a series of food, financial and environmental crises. However, our current social science research on agrochemicals fails to keep pace with the complicated transformation of the agrochemical sector, as highlighted by the Pesticide Research Network (Mansfield et al. 2024).

In an attempt to gain a better understanding of the global agrochemical complex, this paper explores China's agrochemical dynamics, given its crucial role in this complex. China is currently the world's largest producer, exporter, and key consumer of pesticides, especially generic ones. Meanwhile, Chinese corporations, particularly large-scale state-owned companies (e.g. *SinoChem* and *ChemChina*), have taken the lead in the global agrochemical market via a series of mergers and acquisitions (Shattuck et al. 2023; Werner, Berndt, and Mansfield 2022).

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[1]Agrochemicals are typically defined as the chemicals used in agriculture, including pesticides and chemical fertilisers. This paper mainly focuses on pesticides, which include herbicides, insecticides, fungicides and nematicides, as the features of chemical fertilisers are different from those of pesticides. In this paper, we use the term agrochemical interchangeably with pesticides. In addition, in a few places, we use the more general term, pesticides, to describe herbicides.

With a systematic literature review of articles both in English and Chinese languages, this work offers an overview of the current research on China's role within the global agrochemical complex. This paper finds that while scientific studies are mushrooming, they are insufficient to capture the contour and trajectory of China's agrochemical complex. While most current scientific studies focus mainly on domestic pesticide practices in China, there is a lack of historical analysis of the transformation process. However, the development of the sector in China is neither ahistorical nor self-sustained. It is embedded in a broader historical process and is constantly shaped by global dynamics and other relevant sectors (e.g. the food sector). This implies that we will need to go beyond a reductionist lens to better understand the agrochemical complex of China.

As an initial effort to address this gap, this paper offers a historical overview of the Chinese agrochemical sector. It attempts to include not only the dynamics of the agrochemical sector in China but also the intersectoral and geographic interconnections. The analysis is largely based on the secondary data obtained from international and national databases, policy reports and news reports and primary data collected from fieldwork in China.

This study identifies the four stages of the agrochemical sector development in China, namely, (1) the initial/infancy stage (low usage, low export), (2) the rising stage (increasing usage, low export), (3) the expansion stage (increasing usage, increasing export) and (4) the restructuring stage (decreasing usage and fluctuating export). It argues that the increasingly important role of China in the global agrochemical industry is closely associated with the rise, expansion and restructuring of the agrochemical sector within China. The latter is shaping and is shaped by (i) the agrarian transformation in China historically, (ii) China-global interactions, and (iii) interconnections between the agrochemical sector and the food and infrastructure sectors. This implies that the agrochemical complex is embedded in a broader system. To be specific, the rise, expansion and restructuring of the agrochemical sector are closely associated with the historical transformation of land-labor relations, sales network, food patterns and the role of the state. Moreover, the development of the agrochemical sector in China cannot be separated from the global dynamics (particularly the global market change) and vice versa. In addition, the dynamics of the agrochemical sector cannot be fully captured without exploring the interconnections between related sectors (particularly the agri-food and infrastructure sectors).

Instead of focusing solely on China's historical development process, this paper intends to highlight the current research gap in the agrochemical complex and put forward a more comprehensive framework to understand the dynamics historically, interactively, and connectively. By doing so, it hopes to contribute to a better understanding of the global agrochemical complex.

The remainder of this paper is structured as follows. The next session (Section 2) focuses on the overview of the literature on the agrochemical sector in China based on a systematic literature review. To partly fill the gap, section 3 traces the historical trajectory of the development of the pesticide industry in China. Then, section 4 involves the discussions and future research direction.

2. Overview of recent studies

In this study, we conducted a systematic literature review of the published journal articles on the agrochemical complex in China in both English and Chinese from the year 1990 to February 2023. We reviewed the papers in the Web of Science and CNKI (中国知网) and we have excluded those studies purely covering technical aspects and engineering. The review protocol, including search keywords and inclusion and exclusion criteria, is attached in the appendix. After two rounds of selection, 184 studies, including 90 English and 94 Chinese journal articles, are included. As shown in Figure 1, the booming of research on the Chinese agrochemical complex started in 2018. This is largely aligned with the timeline of the restructuring stage, when Chinese corporations started to take the lead in the global pesticide sector through mergers and acquisitions (hereafter M&As) and the sector received more domestic attention during the green transformation (see section 3.4).

As shown in Figure 2, most of the selected papers (127 out of 184 studies) focus on factors that affect the use of agrochemicals in China.[2] The factors studied included management innovation (e.g. certificate, crop insurance, cooperatives), farm size (the relationship between farm size and the usage of pesticides), technological innovation (e.g. BT cotton, biological control practices), farmers' perspectives/behaviours, information access, state policy and combined factors. These studies tend to attribute the use of pesticides in China to one or multiple factors. They imply that the paths to more environmentally friendly farming practices are constructed based on one or multiple certain institutional, technological or managemental fixes. For example, the twenty papers that studied the relationship between farm size and usage of pesticides highlighted the importance of farm size supported by statistical analysis. These papers conclude that rural land consolidation and farm size expansion would contribute to the reduction of pesticide use and green transition in China.[3] But these studies are over-simplified and ignore the complicated power relations around the agrochemical complex and, thus, miss the nature and root. Do large-scale villager-dominated farms practice in the same way as corporate-dominated ones in terms of agrochemical use? What will be the outcome of land consolidation, especially for those who will lose control of their land? As a result, it might end up that each 'repair' of these factors will lead to a new problem requiring new repair, as suggested by Romero (2016) and Guthman (2019). This reminds us to go beyond such simplification and avoid traps of endless repair.

Meanwhile, 23 studies focused on the domestic status of pesticide dynamics in China at either the macro or micro level. At the macro level, studies include temporal and spatial trends of domestic pesticide usage and related policy shifts. These studies traced the history, expressed alarm at the overuse and pointed out the geographic unevenness of agrochemical usage. Although these studies show a broad picture of the domestic agrochemical trajectory in China, they largely remain descriptive and without analysis of the impacts of global dynamics. At the micro level, there is a study analysing the institutional and socio-economic foundations of farmers'

[2]There are also many studies focused on the impacts of pesticides in the first round of selection. The majority of these studies are purely technical (about experimental outcomes), and thus are excluded.

[3]Eighteen of these papers promoted large-scale farming as they found a reserved relationship between farm sizes and usage of pesticides, and 2 others promoted medium-scale farming as they found a U-shaped relationship.

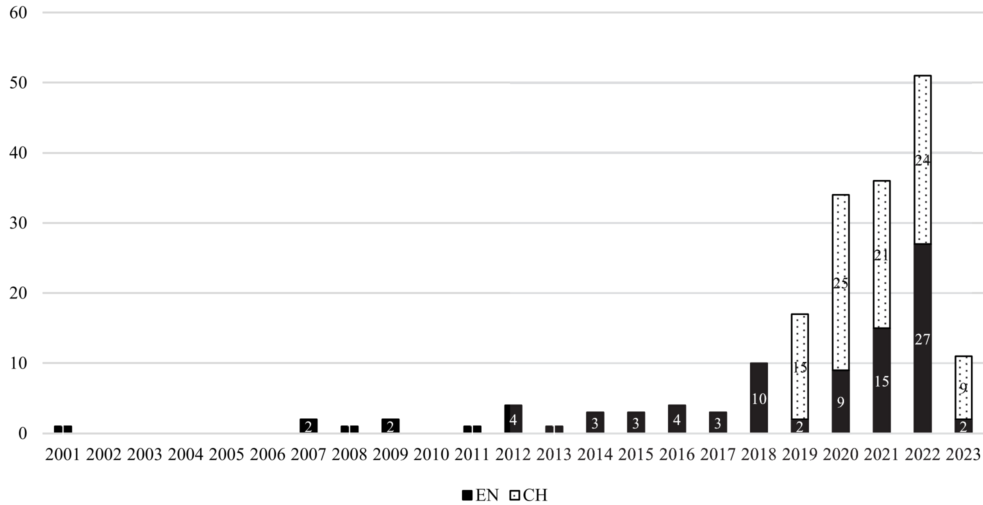

Figure 1. The publication year of the selected studies.

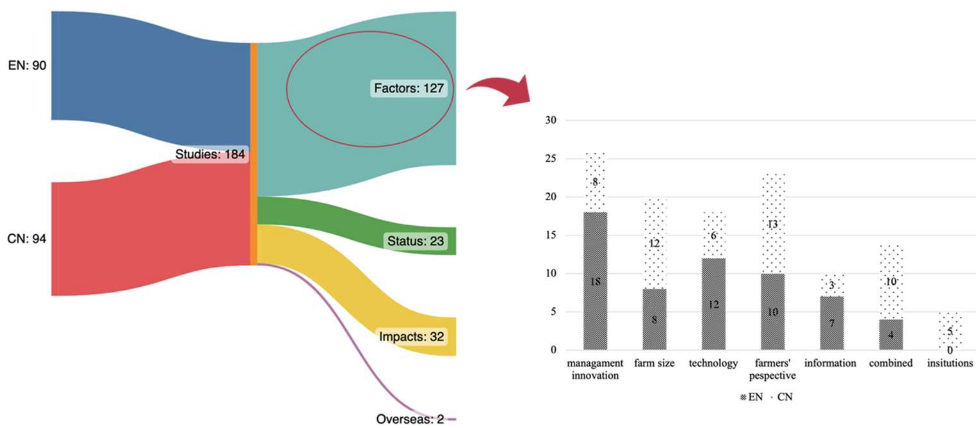

Figure 2. the distinct focuses of recent literature related to China's agrochemical complex.

dependence on pesticides based on an ethnographic study at the village level in China (Hu and Rahman 2016) that demonstrated that farmers in the studied villages have locked in to agricultural modernisation. They argue that dependence on herbicide is closely associated with agrarian transformation, including rural land reform and the labour shortage caused by the diversification of farmers' livelihoods. This empirical study offers a valuable lens to understand the domestic agrochemical complex from the local level. However, this is insufficient to fully capture the complexities at the national level, and it also lacks a global view given the fact that this is both shaping and shaped by the agrochemical complex internal to China.

Furthermore, 32 studies focus on the negative environmental and health impacts of pesticides. These are important studies that offer evidence for the urgency of a sustainable transition of farming practice. But again, such a transition cannot be achieved without a complete understanding of the pace and direction of the development of the agrochemical sector in China, the power dynamics involved in the complex, and its interaction with global dynamics.

Two papers do mention the role of China in the global agrochemical complex (Shattuck 2021; Werner, Berndt, and Mansfield 2022), but these are at the global scale, thus without a comprehensive analysis of the associated dynamics internal to China.

Thus studies on China's agrochemical complex are increasing, yet do not cover the dynamics of the development of China's agrochemical sector. A fuller understanding of this complex is essentially not ahistorical. Moreover, these studies that exist are over-focused on China and the sector *per se* while ignoring the complexity caused China-global interactions or the dynamics and interconnections between the agrochemical sector and other related sectors (e.g. the food sector and infrastructure sector). This reminds us that we will need to go beyond the current prevalent reductionist and agronomic lens and adopt a more nuanced framework (i.e. an interconnected-historical-interaction one) to better understand the Chinese agrochemical complex. As an initial step here, we offer an overview of the historical trajectory of pesticide development in China.

3. The trajectory of pesticide development in China

Domestically, the Chinese agrochemical sector has been expanding rapidly and massively since the 1990s. As shown in Figure 3(a), the intensity of chemical pesticide usage in China has increased by over 70%, from 1.17 kg/ha in 1990 to 2.01 kg/ha in 2020. Its use of pesticides has increased by 67% from 154 thousand tonnes in 1990 to 259 thousand tonnes in 2020, while usage figures remained unchanged in the EU and USA, according to the FAO database.[4] Such an increase in pesticide usage during the past three decades is even more evident based on the data from the National Statistics Bureau of China (NSB-CN), as shown in Figure 3(b).

Along with the boom in domestic pesticide use, China's role is increasingly vital in the global market. In 1990, when the EU and USA exported over 60% of the world's chemical pesticides, China only accounted for 5%. In the past three decades, China has surpassed the EU and USA and become the biggest exporter of chemical pesticides worldwide. This process echoed the rapid rise of the newest Chinese super-corporation. Before 2015, none of the Chinese corporations held more than a 10% share of the domestic market (Mitchell 2017) and, as shown in Table 1, the global market was dominated by the six key corporations: Syngenta (Switzerland), Bayer (Germany), Monsanto (USA), Dupont (USA), Dow (USA), BASF (Germany) in 2009. However, in 2020, three Chinese companies were listed in the top 10 global agrochemical companies. Of the three, the newly formed Syngenta Group, based on the merger of ChemChina and Sinochem, became the world's largest agrochemical conglomerate and accounted for 24.6% of global agrochemical sales (ETC Group 2022).

As shown in Figure 3, there are four key stages within the trajectory of pesticide development in China, namely, (i) the initial/infancy stage (low usage, low export), (ii) the rising stage (increasing usage, low export), (iii) the expansion stage (increasing usage, increasing

[4]But the quality of FAO's pesticide data has declined since 2007, as pesticide usage in low and lower-middle income countries is underestimated (Shattuck et al. 2023).

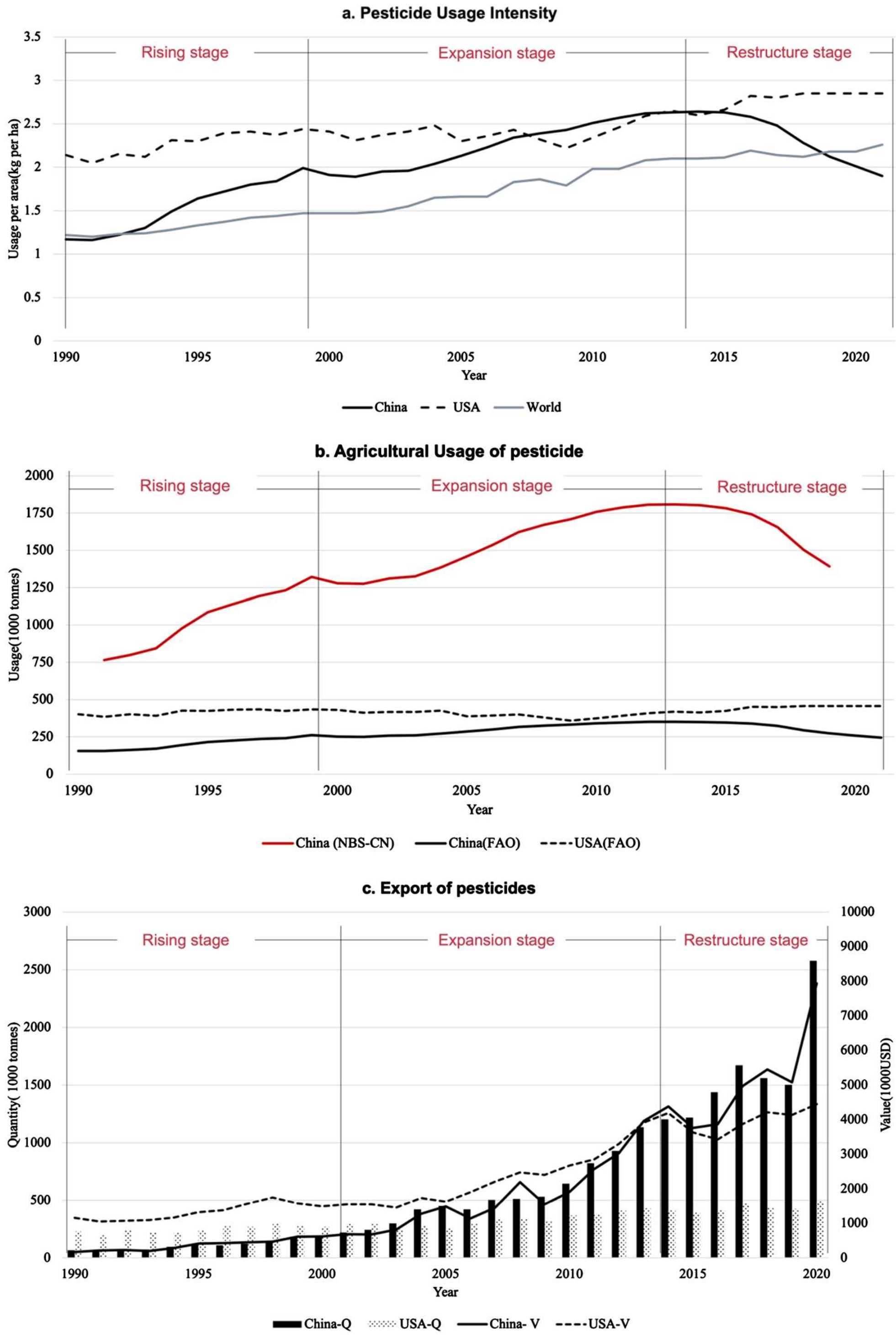

Figure 3. Pesticide use intensity, agriculture use and export in China and the USA. Source: FAOSTAT accessed in October 2022; National Statistics Bureau of China (NSB-CN).

Table 1. The change in the global top 10 agrochemical companies in 1996 and 2020.

2009				2020			
		Agrochem Sales	% Global			Agrochem Sales	% Global
No	Company	$US millions	Market Share	No	Company	$US millions	Market Share
1	Syngenta (Switzerland)	8491	19.00%	1	ChemChina + SinoChem (China) *pro forma* (Syngenta Group)	15336	24.60%
2	Bayer (Germany)	7544	17.00%	2	Bayer (Germany)	9976	16.00%
3	BASF (Germany)	5007	11.00%	3	BASF (Germany)	7030	11.30%
4	Monsanto (USA)	4427	10.00%	4	Corteva (USA)	6461	10.40%
5	Dow AgroSciences (USA)	3902	9.00%	5	UPL(India)	4900	7.90%
6	Du Pont (USA)	2403	5.00%	6	FMC(USA)	4642	7.40%
7	Sumitomo Chemical (Japan)	2374	5.00%	7	Sumitomo Chemicals(Japan)	4010	6.40%
8	Nufarm (Australia)	2082	5.00%	8	Nufarm (Australia)	3491	5.60%
9	Makhteshim-Agan Industries (Isael)	2042	5.00%	9	Jiangsu Yangnong Chemical Co., (China)	1413	2.30%
10	Arysta Life Science (Japan)	1196	3.00%	10	Shandong Weifang Rainbow Chemicals Co..(China)	1048	1.70%

Source: ETC reports (ETC Group 2011; 2022)

export) and (iv) the restructuring stage (decreasing usage and fluctuating export). These four stages show distinct features in terms of pesticide use and export and are shaped by the dynamics both domestically and globally.

3.1. The initial/infant stage (before the late-1980s)

Globally, the commercialisation of pesticides started during the 1930s to 1950s. The emergence and expansion of chemical pesticides, which allowed low labour expenditure and standardisation of farming, shifted farming practices and social relations around food production and paved the way for industrialised agriculture such as large-scale growing and monoculture. In other words, without pesticides, the capitalist relation would be unable to penetrate the countryside worldwide as extensively as it has today.

At this stage, the USA and European countries dominated the industry. They were the major inventors, producers and exporters of pesticides worldwide (Galt 2008; Weir and Schapiro 1981). Meanwhile, pesticide use became prevalent in many developing countries, including Mexico, the Philippines, India, and Brazil, through *Green Revolution*, a USA-initiated technology transfer from the 1950s to the late 1980s (Patel 2013; Pingali 2012).[5] In the early 1980s, the global pesticide complex was conceptualised as the 'circle of poison' by Weir and Schapiro (1981). This concept described the phenomenon that pesticides banned in developed countries were being exported to developing countries with no or limited environmental regulation, and those exported poisons partly returned to developed countries through crop imports. But this had shifted due to the

[5]The dominant narrative of the Green Revolution was to ease the food shortage. The massive cheapened grain produced by industrialised farming during this time contributed to the supply of cheap labour for industrialisation, as happened in India (Sau 1988). However, the Green Revolution had uneven impacts, deepened social differentiation, and faltered in the mid-1990s, as shown in the case of India (Harriss-White and Janakarajan 1997).

changes in global pesticide production, circulation and regulations in the 2000s (Galt 2008).

In the global pesticide complex at this stage, the role of China was rarely mentioned, since the whole sector in China was in its infancy before the 1990s, especially before the Opening Reform (*Gaige Kaifang*) of China. According to FAOSTAT, the intensity of chemical pesticide usage in China in 1990was below the world average and around half that of the USA. At this point, China was only responsible for 5% of the global import quantity, 2% of the global export value, and 5% of the global export quantity. During this period, unlike Mexico, the Philippines, India, and Brazil, the research, production and circulation of pesticides largely relied on domestic resources, were directed by the Chinese state and had unique socialist features, vividly described as an 'intersection of red and green revolutions'(Schmalzer 2016).

During the collective period (the 1950s to the late 1970s/early 1980s), rural land was collectively owned and farming practices were collectively organised in China.[6] At that time, limited types of pesticides like DDT, DDVP and Isotox were used in farming.[7] Meanwhile, these pesticides, like other industrial goods, were produced and circulated through a centrally planned system (Young and Deng 1998). These pesticides were only produced by a few state-owned corporations and sold to villagers by the China National Agriculture Means of Production Group (a state-owned corporation) via the *Agricultural Technology Extension System (nongye tuiguang tixi*) at the county and village levels at a specific price the state sets. The set price was relatively low and state subsidised (Chen 2018). Thus, in this period pesticides were not a real commodity in China. However, the *Agricultural Technology Extension System* conditioned a localised sales network in rural China after the commodification of pesticides (see more elaboration in section 3.3).

In the late 1970s/early 1980s, the Household Responsibility System (HRS) reform started. During the HRS reform, although property rights to the rural land remained owned by the collectives, the user rights were distributed to rural households based on the principle of fairness (Unger 2002; Ye 2015). After the reform, rural households actually controlled the land and became units of production. In other words, villagers were able to decide what to produce, how to produce and how much to sell/consume, although their decisions were far from completely free, given their vulnerable positions in the market (Xu 2019). This redistributive land reform created a unique land-labour relationship, enabling the penetration of capitalist relationships in rural areas without large-scale displacement (Huang, Yuan, and Peng 2012; Zhang and Donaldson 2008).[8] Although the HRS reform did not immediately change the use of pesticides when rural labour was still abundant and the manufacturing capability of pesticides was low, it did motivate rural households to find ways to improve the productivity of land, thus paving the way for the rise of pesticides in China (Hu and Rahman 2016).

[6]According to a few critical scholars, such collectivization *de facto* paved the way for industrialisation in China by creating a market for the machines produced in urban industrial sectors and extracting agricultural surplus via price scissors underlying the planning economy regime (Knight 1995; Wen 2021).

[7]DDT and Isotox were banned in China in the 1980s.

[8]When the rise of capitalism was observed to be followed by dispossession and expulsion in many other regions (Oya 2013; Levien 2012).

3.2. The rising stage (1990s)

During the 1990s, the pesticide sector started to rise in China. China's agricultural usage rapidly increased by 62% to reach 251 million tonnes in 2000, while its pesticide imports and exports were still at a low level (see Figures 3 and 4).[9] This implies a significant rise in pesticide supply alongside the surging demand domestically during that period. According to Yang (2018), the production of pesticides doubled from 176.7 thousand tonnes in 1988 to 395 thousand tonnes in 1997.

On the demand side, the emerging outflow of labour from rural to urban areas in China led to a significant increase in pesticide usage. An increasing number of villagers, particularly those young and strong, chose to migrate to urban areas for off-farm endeavours during the 1990s. Their migration, either as an active livelihood choice (Ploeg and Ye 2016) or a forced transition (Bernstein 2015), was normally temporary and circular because of the restriction of the Hukou system in China (Chan and Zhang 1999). As a result, the old, the weak and children were normally left behind (Ye et al. 2013). Thus, while serving as cheap labour for industrialisation in urban areas, there was an increasing labour gap in rural China. In response, more pesticides were used by villagers to reduce the need for manual labour for weed and pest control, following the same trend as happened elsewhere worldwide at a different time (Clapp 2023). As shown in Figure 3, the intensity of pesticide usage in China surpassed the world average in 1993 and increased by 63% to 1.91 kg/ha by 2000.

On the supply side, with the Reform & Opening (*Gaige Kaifang*), the pesticide market gradually became formalised and liberalised in China, as reflected by a series of policy changes (see Table 2). According to the *Circular of the State Council on Refining Sales Channels of Fertilisers, Pesticides and Agricultural Film* [No 87] issued in December 1989, the monopoly of the China National Agriculture Means of Production Group and the *Agricultural Technology Extension System* at county and township levels was dismantled. Crop protection stations at the local level were also allowed to sell pesticides. Furthermore, after introducing the *Circular of the State Council on Refining Management of Fertilisers, Pesticides and Agricultural Film* [No 60] in 1992, production corporations were also allowed to directly sell extra pesticides at the market price after they completed and delivered the quota. Another key step was the launch of the *Regulations on Administrative Protection of Agricultural Chemical Products* in 1993, which aimed at protecting patents of agrochemical products. In 1997, the *Regulations of the Control of Agricultural Chemicals,* the first national regulation on pesticides, were issued. It regulated the pesticide registration, production, trade, and use. Specifically, it introduced the production permit system for producers of pesticides and the operating permit system for pesticide traders. This formally confirmed the opening of the pesticide market in China to whomever has a permit. These policies largely motivated the pesticide producers to increase their production quantity.

Aligned with the policy change, many domestic private companies started to engage in the pesticide sector with the economic reform in China in the late 1980s and 1990s. The involvement of private companies significantly expanded the pesticide production capacity in China.

[9]China's pesticide trade accounted for 5.4% of global imports (by quantity), 5.7% of global exports (by value) and 9.8% of global exports (by quantity) in 2000.

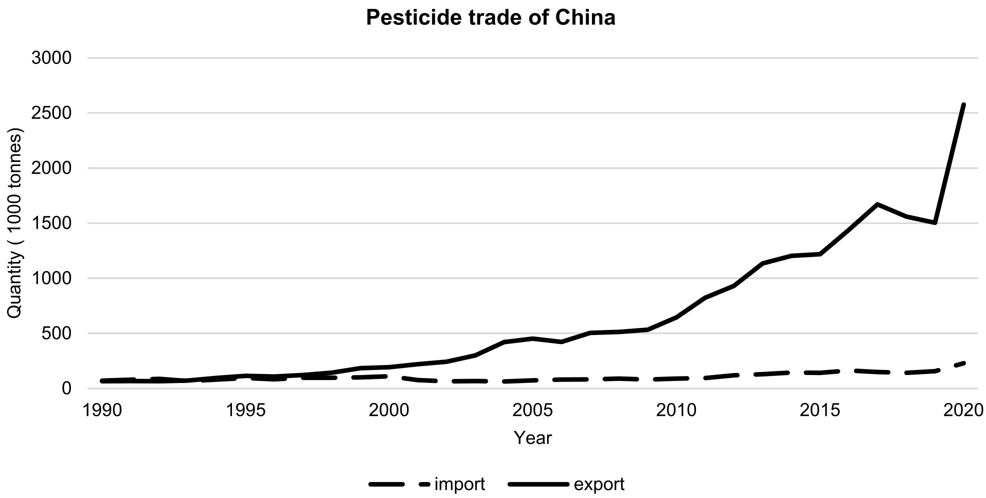

Figure 4. Pesticide trade by China. Source: FAOSTAT accessed in October 2022.

Table 2. Key policies/ regulations related to the development of the pesticide sector in China.

Year	Item	Note
1989	Circular of the State Council on Refining Sales Channels of Fertilisers, Pesticides and Agricultural Film [No 87]《国务院关于完善化肥、农 药、农膜专营办法的通知》	Extending the sales channels of pesticides to local crop protection stations
1992	Circular of the State Council on Refining Management of Fertilisers, Pesticides and Agricultural Film [No 60]《国务院关于加强化肥、农药、农膜经营 管理的通知》	Allowing production companies to sell extra pesticides at the market price
1993	Regulations on Administrative Protection of Agricultural Chemical Products 《农业化学物质产品行政保护条例》	The first step to formalise the pesticide market in China, protect the patents of pesticides
1997	Regulations of the control of agricultural chemicals 《农药管理条例》	The first national regulation on pesticides
2015	Actions to achieve zero growth in the use of chemical fertiliser and pesticides by 2020 《化肥农药使用量零增长行动》	Aimed at reducing the agricultural usage of chemical inputs
2017	New regulations of the control of agricultural chemicals 新《农药管理条例》	Stricter regulations on pesticide registration, production, use and trade

Meanwhile, the Chinese government increased research and development (R&D) expenditure after launching two National Innovation Centres for Chemical Pesticides in the mid-1990s. The R&D in the pesticide sector was mainly dominated by the public actors in China, including colleges/universities and research institutes, and aimed at developing new pesticides. But at this stage, most of the R&A in China was focused on cheap ways to manufacture agrochemicals and developing new formulas based on off-patent active ingredients (AIs) rather than new AIs (ETC Group 2022; Haggblade et al. 2017). Thus, off-patent and generic pesticide production dominated the Chinese market.

In the same period, there was a concentration trend in the global market. According to ETC Group (1997), in 1996 over 80% of the global total agrochemical sales came from the top 10 agrochemical corporations in Europe and the USA. The corporations' power largely stemmed from intellectual property ownership gained through heavy investment in the

R&D of new AIs and HT-GM seeds in the mid-1990s. Moreover, many of these big corporations expanded their control over the whole value chain from mining (e.g. Monsanto's ownership of phosphate mines) and producing key intermediates to trading.

Within this trend, these big corporations were observed to build plants worldwide to ensure cheap production and easy market access. During the 1990s, many agrochemical giants, including Syngenta, DuPont and Bayer, started to build manufacturing plants in China. DuPont Agricultural Chemicals Limited, Shanghai was established in 1990s as a company specialising in the production of AIs and formulas of herbicides. Similarly, Syngenta Nantong Crop Protection Company Limited, a pesticide manufacturing plant established in 1999, is one of Syngenta's three global production bases. These big international corporations' investments in China were led by low wage costs, lax environmental regulations and a huge market in China. And it, in turn, conditioned the further expansion of the pesticide sector in China.

3.3. The expansion stage (early 2000s to early 2010s)

During the early 2000s to early 2010s, the agrochemical sector in China entered a stage of rapid expansion. On the one hand, China's production and domestic use of pesticides further increased. According to the National Statistics Bureau of China, China's production of AIs increased by over 40% from 12.8 million tonnes in 2000 to 18.1 million tonnes in 2013. The pesticide production quantity in China increased over eightfold from 0.4 million tonnes in 1998 to 3.5 million tonnes in 2012 (Yang 2018). As to pesticide use, the usage in China surpassed that in the EU (27) in 2009 and increased by 40% from 2000 to 351 thousand tonnes by 2013, according to FAOSTAT. In the same vein, in 1998, pesticide usage intensity in China surpassed that of the USA and by 2013 had increased by around 38% from 1.91 kg/ha in 2000 to 2.63 kg/ha. China became a key supplier of pesticides, particularly cheap AIs, in the global market. As shown in Figure 3, China surpassed the USA in export quantity in 2003 and value by 2013. By 2013, the 2000 quantity and value of exports had increased sixfold. Such expansion was an outcome of the interactions of both internal and external dynamics.

On the demand side, the soaring demand for pesticides in China during this period was related to (i) the drop in prices influenced by the global market, (ii) the increasing shortage of labour in rural areas, (iii) the trend toward land consolidation, (iv) diet transformation, and (v) promotion by the local sales network. Firstly, pesticide prices dramatically decreased in the early 2000s. This is closely associated with international corporations' successive patent expirations and innovation slowdowns. For example, Monsanto's patent on glyphosate expired in 2000. This enabled cheaper production of glyphosate-based herbicides by generic producers in China (Werner, Berndt, and Mansfield 2022). Similarly, a series of patents for neonicotinoid insecticides expired in 2005 (Shattuck 2021). Related to this, these big corporations' control of the market was weakened when developing and commercialising a new patented AI became more expensive and required longer due to stricter environmental laws in developed countries during this period (Shattuck 2021). These contributed to decreased pesticide prices in the early 2000s (Huang, Wang, and Xiao 2017). The lower pesticide prices motivated villagers in China to adopt them.

Secondly, rising pesticide use was related to increased rural-urban migration. On the one hand, the prevalence of rural-urban migration led to changes in labour conditions, namely labour shortage in rural areas. During the 2000s, the rural labour shortage worsened with rapid urbanisation and industrialisation in China. According to economists, China reached the Lewis turning point in the mid-/late-2000s, when wages in agricultural and unskilled industries increased due to the depletion of rural cheap surplus labour (Zhang, Shao, and Dong 2018; Zhang, Yang, and Wang 2011). Such an internal migration contributes to the industrialisation of urban areas, while also shaping farming practices in rural areas. This is also observed in the industrialisation process of other regions (e.g. India, see Nielsen and Oskarsson 2016). The shortage of labour for manual pest and weed control increased the villagers' demand for chemical substances, namely pesticides. The wage income gained via off-farm work in urban areas in turn supported the villagers' purchase and use of chemical inputs (both fertilisers and pesticides) for farming at home. As an elderly villager in Guangxi province explained, 'Buying fertilisers and pesticides [for farming] mainly relies on my son's off-farm urban wage' (Fieldnotes, 13 March 2016). Thus, the prevalence of off-farm work in urban areas *de facto* locked the villagers into chemical-dependent farming practices (Hu and Rahman 2016) and thus contributed to a transformation from labour-intensive production towards chemical-intensive production, including the 'herbicide revolution' in China (Haggblade et al. 2017; Huang, Wang, and Xiao 2017).

Thirdly, the trend of land consolidation also had a role in pushing the expansion of the pesticide sector in rural China. After the HRS reform, the rural land rental market gradually emerged in the 1990s (Zhang, Qingguo, and Xu 2004). In 2008, rural land consolidation was formally put forward by the state and became a national strategy in the National Centre Document No. 16 [2008].[10] The land consolidation was aimed at constructing large farms, as stated in the same document: '[p]laces with mature conditions can develop big specialised households, family farms, farmers' professional cooperatives, etc.'. After this, a series of policies were released by the state to confirm rural land contract rights and promote land transfers. However, unlike regions where agricultural land can be converted into industrial uses (e.g. industrial parks or Special Economic Zones) and thus directly supports industrialisation (Levien 2012; Nielsen and Oskarsson 2016), the land use change of transferred agricultural land is forbidden by the land law in China. With the land consolidation, large farms operated by big households (*da hu*), collectives and specialised companies mushroomed. These large farms are usually used to cultivate commercial crops in a monocultural, standardised and industrialised way. Thus, these farms are essentially pesticide dependent. In many cases, temporary workers or specialised teams were employed by farm owners to spray herbicides (Fieldnote, March 2016).

Fourthly, the changing food consumption pattern in China caused by the rise of the middle class in urban areas and underlying rapid urban development led to changes in farming practices aimed towards more chemical inputs. To be specific, the diet transition in China towards more consumption of higher-value agro-products combined with population growth means significantly increased domestic demand for vegetables, fruit and animal feed. Because such surging demands on these high value-added agro-products

[10]Decision of the Central Committee of the Communist Party of China on Several Big Issues on Promoting the Reform and Development of Rural Areas.

could not be satisfied by the traditional farming methods in a short time, these dynamics essentially pushed the transition of farming towards more capital-intensive modes, identified as a 'hidden agricultural revolution' in (Huang 2016; Huang, Yuan, and Peng 2012). In addition, compared with grain crops, vegetables, fruits and cotton are high pesticide-consumption crops (Qiu and Hu 2020). Thus, land use changes from the cultivation of grain crops towards the production of vegetables, fruits and cotton *de facto* led to more agricultural use of pesticides.

Fifthly, the localised sales network of pesticides popularised the use of pesticides in rural China. In rural China, the sales network of pesticides was transformed from the previous *Agricultural Technology Extension System* at the county and township levels in the collective times as mentioned above. Thus, it is deeply rooted at the local level. The retailers at the county/township level were usually villagers *per se*, and they employed salesmen/women at the village level, usually villager elites, to sell pesticides. For example, a retailer in one county in Shandong employed over 20 villagers, mainly villager cadres, who are respected and have abundant social capital in the villages, to sell pesticides to their fellow villagers (Fieldnotes, 19 April 2017). In this way, a rooted sales network enabled deep penetration by pesticides to villagers in China. Furthermore, these localised retailers also offer free training to villagers to spread the knowledge about cultivating commercial crops that are not traditionally produced locally but popular in the market (e.g. fruits) and thus promote the usage of chemical inputs in farming.[11] According to fieldwork, a retailer in Guangxi always invited technicians from agrochemical and fertiliser companies to offer low-cost training for villagers in the county. In 2016, he coordinated over 500 group trainings (Fieldnote, 25 March 2017). Such rural-rooted knowledge transfer channels are largely dependent on the development of infrastructure in rural areas, including both physical (e.g. roads) and digital. They do accelerate the dismantling of traditional farming methods and contribute to the construction of a new path of farming dependent on pesticides, similar to what has happened in India (Stone and Flachs 2018). In short, the sales network in China has a critical role in shifting farming practices and boosting the demand for pesticides in rural China.

On the supply side, with further marketisation, mushrooming private companies in China engaged in the pesticide industry. By the end of 2010, over 1800 companies and 192 thousand formal employees were conducting pesticide production (MIIT 2012). Half of these companies were small scale,[12] and over 500 were specialised in the production of AIs. These companies contributed to a sharp increase in pesticide production.

In addition to domestic demand, a large share of the pesticides produced were exported. Further, after China's entry into the WTO in 2001, China's pesticide exports increased. swiftly This was related to China's low cost of production, lax environmental regulations and favourable tax policy during this period. Firstly, the costs of pesticide manufacturing were low in China, which benefited from the relatively cheap labour (K. H. Zhang 2006). The cheap labourers used were largely peasant workers (*nong ming gong*) sourced from rural areas. These peasant workers were very cheap because they were registered as rural residents under the Hukou system and thus excluded from a

[11]Because such training fits the demand of many villagers seeking to change their production from grain to high-value crops in response to China's changing food consumption pattern.
[12]With less than 5 million yuan in annual sales.

series of benefits (e.g. social insurance) in their working contract (Chan 2010). Also, while environmental regulations were already strict in many developed countries, environmental regulation in China was relatively lax before the promotion of ecological civilisation by the state in the 2010s (He et al. 2013). This pushed pesticide production, particularly AIs production (which has more significant environmental impacts and higher health risks for workers) to China. Thirdly, there were favourable export tax rebate programme on key pesticide products. In China, the export tax refund rate for formulations is 5%, while that for certain key AIs was only 9%, increasing to 13% in 2014. This encouraged the exports of AIs rather than formulations. It also matched big international companies' demands for cheap outsourcing of raw materials (AIs) underlying the asset-light strategy caused by the intensified competition (Werner, Berndt, and Mansfield 2022). As a result, China became the largest supplier of cheap AIs in the global pesticide market.

In short, the agrochemical sector in China was expanding rapidly, with a sharp increase in both domestic use and exports. The development of the pesticide sector in China at this stage was summarised as 'more AIs exports while fewer formulations exports … more manufacturers but fewer self-brand developers' by Wang Wencai, the director of Shandong Weifang Rainbow Chemical Co., Ltd, a big private pesticide company in China. (Wang 2018).

3.4. The restructuring stage (after the mid-2010s)

The expansion of the pesticide sector in China came to a halt in the mid-2010s. As shown in Figures 3 and 4, domestic pesticide use in China decreased by 30% to 244.8 thousand tonnes in 2021. The production of pesticide AIs decreased by around 30% to 21.48 million tonnes in 2020 (Figure 5). Exports started fluctuating. Export quantity increased to 1.67 million tonnes in 2017 but dropped to 1.5 million tonnes in 2019. In addition, there was an increase in AI production and pesticide export after 2020. This is related to the sharp increase in global food prices caused by the COVID-19 pandemic and the Ukraine war (Clapp 2023). These dynamics imply a structural shift occurred in the pesticide sector. Such change is related to the national policy shift toward green development in China. And the policy shift in China partly contributed to the global market restructuring.

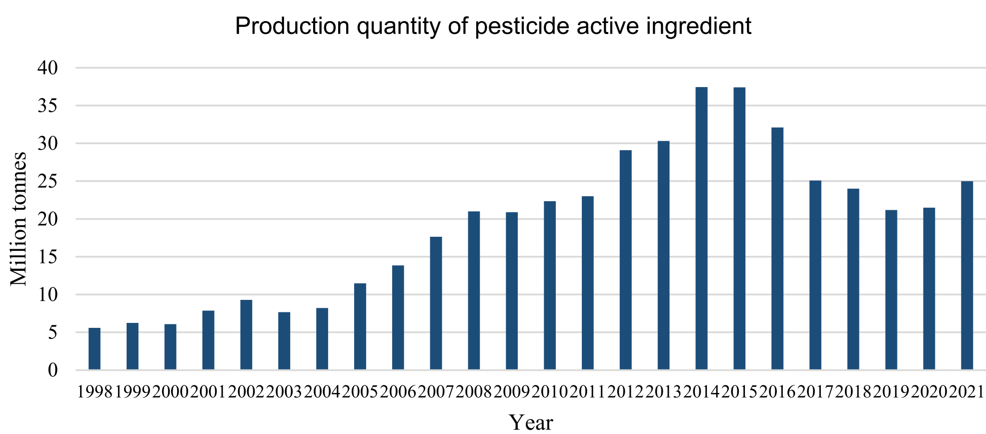

Figure 5. Production quantity of pesticide active ingredient in China. Source: National Statistics Bureau of China (NSB-CN).

Although lagged behind some developed countries, Chinese society has started to focus on environmental sustainability, including promoting green agriculture after the emergency of multiple food safety crises in the 2000s. In China, ecological civilisation (*shengtai wenming*) was first proposed in the 17th National Congress of the Communist Party of China (NCCPC) in 2007 and became a national strategy after the 18th NCCPC in November 2012.[13] The idea that 'lucid waters and lush mountains are invaluable assets' has been highlighted by Chairman Xi Jinping many times. Aligned with the trend of green transformation, in 2015, '[a]ctions to achieve zero-growth in the use of chemical fertilisers and pesticides by 2020' (hereafter *The Actions*) were launched by the Ministry of Agriculture. The actions aimed to curb increasing pesticide use in China through a series of technical channels. These included promoting biological and physical pest control methods, encouraging the construction of a pest monitor and a warning system and improving the efficiency of pesticide use. The last point is intended to be realised by replacing high-toxicity and high-residue pesticides with low-toxicity and low-residue ones, popularising relevant knowledge on pesticide use, and promoting new machinery and specialised and standardised service teams for pesticide use. This implies that this transformation is technically based and requires the pesticide industry to transition higher R&D capacities. This will further shape the agrarian transformation in China and beyond, albeit, at this stage, in an uncertain way. Matched with *The Actions*, a stricter version of the *Regulations of the Control of Agricultural Chemicals* was introduced in 2017. In this version, companies need to meet stricter requirements in order to get permission to register, produce and trade pesticides. Moreover, under the *Regulations*, those who violate these regulations will get several punishments. This policy shift, called the 'environmental storm', is closely related to the drop in agricultural use and production of pesticides internal to China.

Aligned with these policies, precision/smart agriculture has recently been promoted by the state to precisely control the use of chemical inputs and thus contribute to more sustainable farming practices.[14] Precision/smart agriculture requires procurers to use sensors, drones, and satellite data to control the use of agrochemicals, thus is entirely dependent on the development of digital infrastructure in rural areas. This dependency highlights a strong linkage between the infrastructure and agrochemical sectors.

This state-directed green transformation is also partly related to the Chinese companies' attempt to upgrade from a cheap AI supplier to a high-value formulation developer and producer in the value chain of the agrochemical industry. Because compared with formulation, the production of AIs has more significant negative environmental impacts. To realise such an industry upgrade, the state promotes the consolidation of pesticide companies (mainly via M&As) to reduce the number of production companies and the construction of chemical industry parks and to integrate the upstream and downstream businesses in the pesticide sector. According to the *14th Five-Year Plan for the*

[13]Ecological civilisation is a loaded concept, involving complicated power dynamics(Goron 2018). In this paper, we intend to highlight the relevant state policies that affect the agrochemical sector underlying the state's promotion of ecological civilisation.

[14]See *the14th Five-Year Plan for Promoting Agricultural Modernisation in Rural China*, introduced by State Council of the People's Republic of China in 2021.

Agrochemical Industry in China issued in 2020, the number of pesticide production companies has decreased from 2000 in 2015 to 1705 in 2020. Among them, 11 companies have become the world's top 20 agrochemical companies.

This means that Chinese companies started to take the lead in the global agrochemical industry during this period. The process includes a series of M&As. The most known case is the M&As dominated by ChemChina, a small Chinese state-owned company. In 2011, ChemChina acquired 60% share of ADAMA (based in Israel), one of the largest global generic agrochemical producers. Then in 2016, ChemChina bought the remaining shares and fully acquired ADAMA. In 2017, ChemChina acquired the Swiss-based Syngenta, the global top-tier agrochemical giant, for US$43 billion, which is China's biggest foreign takeover in history. Following this, Syngenta pursued further acquisitions, including Nidera Seeds (focused on the South American seed market and previously owned by COFCO) in 2017, Floranova (UK-based) in 2018, the Cropio Group (an Eastern Europe-focused agricultural tech company) in 2019, and Valagro (an Italian biologicals company) in 2020. Later in 2021, ChemChina further merged with Sinochem's agricultural input branches and newly formed the world's largest agrochemical manufacturer, namely, the Syngenta Group. The Syngenta group continued expanding by acquiring several Brazilian agricultural corporations (including Agro Jangada Ltda, Feltrin Sementes Ltda, Kubix AgroIndustrial Ltda and Agrocerrado Produtos Agricolas E Assistencia Tecnica Ltda) in 2022 and 2023 and Macspred Australia in 2023 (a company specialising in weed management across forestry, infrastructure, and utility sectors).[15] As a result, the Syngenta Group has become the world's leading agricultural input company, ranking as the top agrochemical company (with a 24% global market share) and the third-largest seed company (with a 7% global market share) in 2020 (ETC Group 2022). This means that the Syngenta group, a Chinese state-owned company, is emerging as a dominant force in shaping the global industrial agriculture system.

Such M&As are not solely caused by the demand of Chinese actors but are also pushed by a global market shift. At this stage, those international agrochemical corporations face great challenges due to intensified competition with generic firms from the south (including China and India) and high R&D barriers (Shattuck 2021). To be specific, those corporations are not in an advantageous position when producing cheap off-patent products, given the relatively high costs in developed countries. Moreover, their advantage in innovation is affected by stricter food and environmental regulations worldwide. According to Phillips McDougall, during 2010-2014, the cost to develop a new pesticide was as high as 286 million USD and the average time required to have a new pesticide commercialised was 11.3 years.[16] This means a long R&D circle, high R&D cost, high R&D risk and thus low R&D investment return. It also means the control power of the original agrochemical giants is weakened, and the global market is seeking a reorganisation. As a result, there is a rush of M&A at the global level, including the merger deals between Dow and DuPont in 2017, and between Bayer and Monsanto in 2018.

[15]Source: https://www.syngenta.com/en/company/media/syngenta-news/year/2023/syngenta-acquisition-macspred-australia-boost-focus-global#:~:text=Basel%2C%20Switzerland%2C%20May%2002%2C,rail%2C%20utilities%20and%20infrastructure%20sectors. Accessed on 7 Oct 2024.

[16]The commercialization of a new pesticide requires a series of biological and chemical tests to ensure its low impacts on human health and environment.

Table 3. Top 10 destinations of China's export in 2020.

No	Country	Quantity (1000 tonnes)	Percent of total export
1	Brazil	300.09	12.53%
2	Australia	218.48	9.12%
3	USA	175.12	7.31%
4	Indonesia	114.42	4.78%
5	Argentina	95.75	4%
6	Thailand	78.41	3.27%
7	India	61.36	2.56%
8	Russia	46.18	1.93%
9	Vietnam	43.25	1.81%
10	Pakistan	42.77	1.79%

Source: Cao (2021).

In addition to the market restructuring, the development of the pesticide industry in China is and will be shaped by the infrastructural dynamics, including Belt& Road Initiative (BRI) and seed dynamics (GMO and non-GMO).

At the first glance, the BRI launched in 2013 is focused on the investment and development of the infrastructure sector along with partner countries and thus has little direct connection with the pesticide sector. But the physical connectivity does enable and facilitate the movement of commodities, including agrochemical and agro-food products (Clapp 2014). Moreover, the countries along the Belt and Road mutually recognise pesticide registration information. Thus, BRI actually is and will further facilitate China's pesticide export (McMichael 2020). As shown in Table 3, BRI partner countries, for example, Indonesia, Argentina, Thailand, Russia, Vietnam and Pakistan, are key destinations for China's pesticide export. These pesticide exports are bound to facilitate the transition of farming practices in those import countries towards a more agrochemical-dependent direction. However, the actual impacts will require further empirical studies in the future.

In addition, the agrochemical sector can also facilitate the development BRI. As mentioned above, Syngenta Group acquired Macspred Australia in 2023. The company's expertise in weed management for the infrastructure sector (e.g. roads and rails) is expected to contribute to the BRI by facilitating infrastructure construction and maintenance.

Regarding the seed complex, GMO crops (e.g. GM soybean, GMO maize, and GMO rapeseed) are prevalent now due to the world's surging demand for cheap food, feed, and biofuel in response to the contemporary convergence of food-fuel-environmental cries. However, unlike the trajectory of other countries, where herbicide selling is packaged with certain herbicide resistant-GMO seeds, the rise of pesticide use in China has little relationship with GMO seeds (Haggblade et al. 2017), because China was cautious about adopting large-scale commercial GMO seeds. According to the Agricultural Department of China, China is taking the route of 'firstly nonfood, then indirect food(feed), and finally food' to commercialise GMO seeds (L. Zhang 2014). Aligned with this route, before 2020, the only commercialised seed in China was Bt-cotton. In 2021, the *Action Plans for Seed Industry Revitalisation* was launched and promoted GMO seed development in China. After this, several GMO feed crops, including herbicide-resistant GMO maize and soybean, got commercialisation permissions. This means that herbicide-resistant GMO seeds are expected to popularise and be widely used in 2024. This will largely promote the use of certain brands of herbicides, which will shape the development of the whole industry not only in China but also globally.

Although China's direct production of GMO crops is limited, China is indirectly involved in the complex via glyphosate export and GMO soybean import. On the one hand, the production of herbicide-resistant-GMO crops is essentially associated with the massive use of glyphosate-based herbicides (e.g. Roundup) and China is the key producer and exporter of generic glyphosate (Werner, Berndt, and Mansfield 2022). This illustrates the crucial role of China in the global GMO production. On the other hand, the imports of GMO crops (mainly GMO soybean) were liberalised only in the late 1990s in response to the surging demand for food and animal feed (Fares 2022; Oliveira and Schneider 2016; Wesz, Escher, and Fares 2023; Yan, Chen, and Bun 2016). After the opening up of the market, soy imports increased over a factor of 50: from 2 million tons in 1990 to 103 million tons in 2020, according to the FAO database. In 1990, China imported 7.7% of the world's soybeans, while the European Union (EU) imported 51%. In 2003, China overtook the EU and became the largest soybean importer, and in 2020, China's share of global soybean imports increased to 61% while the EU's share shrank to 10%. The majority of these imported soybeans for feed and oil are genetically modified[17] and the imports of these herbicide-resistant-GMO soybeans implies the massive use of packaged herbicides in the production sites. Thus, both the export of glyphosate from China and the import of GMO crops to China contribute to the prosperity of GMO crop production, which is agrochemical dependent. Additionally, the Chinese state-owned Syngenta group, as the world's 3rd largest seed company, sells GMO seeds, especially for corn and soybean crops, worldwide. In 2023, the sales of corn and soybean seeds (including GMO and other varieties) by the Syngenta group reached 2.18 billion dollars (Syngenta group 2023). This implies that a large quantity of certain pesticides is also sold worldwide in packaged ways with these GMO seeds by Syngenta. In this sense, the GMO dynamics complicate the China-global agrochemical interconnection.

In addition to GMO seeds, non-GMO commercialised seeds are also observed to be involved in the agrochemical complex. For example, using a hybrid corn seed variety produced by Cargill allows producers to seed and fertiliser at the same time, thus being labour-saving. But it requires using specific fertiliser manufactured exclusively by a Cargill subsidiary that does not damage seedlings (Chen 2018). In the same vein, specific pesticides might also be packaged with non-GMO seeds on the ground. However, more empirical cases, detailed seed-agrochemical dynamics and the role of China in it are yet to be explored.

4. Discussion

Combining this initial analysis of the dynamics of the agrochemical sector in China with the systematic review of the literature above, we argue that our current understanding cannot fully capture the contour and trajectory of the development of China's agrochemical sector. As already shown in Section 3, the agrochemical complex in China has its

[17]Most imported soybeans (94.8% in 2020) are from Brazil, the United States or Argentina, where GMO soybeans are prevalent. According to a news report, only 1.3% of the imported soybeans in China are not genetically modified. (source: https://oilcn.com/article/2023/02/02_86934.html). As imported GM soybeans are much cheaper than domestically produced soybeans, the domestic production of soybeans has shrunk, and small producers are being pushed out. To protect the domestic market, the state prohibited the direct use of soybeans for food. However, the crushing of soybeans for oil and feed is allowed. (Fares 2022).

political-economic roots but is not self-sustaining. Instead, the agrochemical complex in China is embedded in a broader system, including the (i) process of agrarian transformation, (ii) China-global interaction and (iii) intersectoral interconnection.

4.1. Historical: agrochemical complex embedded in the agrarian transformation

The agrochemical complex is essentially part of the history of agrarian transformation. It both reflects and is shaped by the agrarian transformation, particularly the transition toward commodified agriculture. It is a historical process. The current stage does not emerge in a vacuum but is transformed based on the institutions and conditions of past stages. On the one hand, the increased pesticide use in China is closely associated with diet transformations and the related shift towards more commercialised farming practices. The latter is linked to changes in land relations (e.g. the HRS reform and land consolidation) and labour conditions (e.g. rural labour shortage caused by rural-urban migration). On the other hand, the low labour cost resulting from massive rural-urban migration contributes to the massive cheap production of pesticides, thus conditioning the rise of China's agrochemical industry in the global market. These dynamics are not unique, but echo the story of endless capital accumulation in other regions (e.g. India) where land and labour in rural areas are cheapened via distinct channels to facilitate industrialisation in urban areas (Levien 2012; Nielsen and Oskarsson 2016)

Meanwhile, along with the agrarian transformation, today's sales system of pesticides in China has transferred from the *Agricultural Technology Extension System* of collective times. This sales network is deeply embedded at the local level, thus facilitating a swift knowledge transfer related to pesticide use based on social relations in the course of the transformation. Thus, it *de facto* facilitated the popularised transition towards a more chemical inputs-dependent way of farming. How these specific institutional settings in the communist regime affect the penetration of pesticide use in rural China will be further explored in future research.

During this process, the role of the state in the development of the agrochemical sector, especially in the early stage, is in China more evident than in many other regions. While R&D and the promotion of pesticides in many regions were primarily under direct corporate control,[18] the rise of the agrochemical sector in China was directly initiated by the state. As mentioned in 3.1, before the Open and Reform, the state controlled the production and circulation of pesticides. Later, the pesticide market was gradually liberalised, and more corporate power was involved. However, the role of the state remains crucial in accelerating the development of the agrochemical sector. The related state action included the increased public expenses in the R&D of pesticides, the encouragement of land consolidation, the introduction of a formalised pesticide market and the promotion of related corporations, particularly those state-owned ones, 'going out' (i.e. investing overseas). Later, the shift of state policies towards green transformation did promote the upgrade of Chinese corporations in the global agrochemical industry away from the more polluted AI production.

So, advancing the understanding of the agrochemical sector requires further research to link the agrochemical complex with agrarian transformation as a historical process. In

[18]It is not free of state intervention.

other words, it needs to explore who owns what (the social relations around farming); who does what (farming practices); who gets what (the distribution of social, economic and environmental goods and deteriorations); what they do with the created surplus wealth (how the social and economic reproduction are sustained); and how these change with time.

4.2. Interactive: agrochemical complex embedded in China-global interaction

The development of the agrochemical sector in China is never independent of the global dynamics and vice versa. The rise in pesticide use in China, particularly the herbicide revolution, was related to the expiration of patents of key pesticides and the associated price drop in the global market. Meanwhile, increased R&D costs caused by ever-increasingly strict environmental laws globally combined with the cheap production costs in developing countries (particularly China) led to the shift of pesticide production from the North to the South. This further led to the expansion of the pesticide industry in China. Moreover, the outward dynamics of Chinese actors (including international M&As conducted by corporate actors) are not independent but are constantly conditioned, shaping and shaped by the internal transformation inside China (including the policy change in China as mentioned above).

The rise and expansion of the pesticide industry in China in turn shifts the global dynamics. As the largest pesticide exporter, China's export not only offers cheap raw materials for big corporations in developed countries, but also shapes the pesticide market and then lead to the shift of farming practices in other (e.g. African) developing countries (Sarkar et al. 2021; Tamru et al. 2017).

This implies that everyday farming practices and domestic pesticide industry development in China are inseparable from the international agrochemical complex. In the same vein, the development of the pesticide industry and farming transition in other countries cannot be fully captured without understanding the agrochemical complex in China. Therefore, the agrochemical complex, whether at local, national or international level, is bound to the China-global interaction both the internal and external level and any interaction of the two.

4.3. Intersectoral: agrochemical complex embedded in intersectoral interconnections

The agrochemical sector is not a self-standing sector. It is co-constitutive with other sectors, including the food sector and infrastructural sector. The intersectoral interconnections further complicate the dynamics of the agrochemical sector, including the China-global interactions.

4.3.1. Infrastructure-agrochemical interconnection

Infrastructure, including physical (e.g. roads, highways, railroads, ports, airports, etc.) and digital infrastructure, are closely associated with the agrochemical complex. Domestically, infrastructure development in rural areas enable the mobility of commodities and information infrastructure facilitates producers', especially smallholders', access to agrochemicals and the technology needed to use these agrochemicals at the local level, as briefly mentioned in section 3.3. Meanwhile, digital infrastructure also plays a critical role in controlling agrochemical usage in the smart agriculture promoted by the state (see section 3.4). Internationally, the BRI initiated by China conditioned the trade of agrochemicals from China to other Belt & Road countries. This coincides with the increase in Chinese companies' share in the global agrochemical market due to waves of M&As (primarily dominated by state-owned companies). These dynamics have led and continue to lead to substantial increases in pesticide exports from China. These massive pesticide exports are expected to significantly affect the farming practices in importing regions, and thereby contributing to agarin transitions there.

4.3.2. Food-agrochemical interconnection

The agrochemical complex, as a key input used in industrialised farming, is directly and indirectly intertwined with the transition of the agro-food sector and vice versa. Firstly, the diet transition in China towards more value-added agro-products contributed to more pesticide usage, thus further promoting the development of the pesticide industry in China.

Secondly, the agrochemical complex in China is being shaped significantly by the global agriculture market. On the one hand, productivity and the cost of food production are closely associated with how much agrochemicals are accessed and used in farming (Popp, Pető, and Nagy 2013). Thus, the agrochemical complex in China affects not only domestic food production and consumption but also the international food market via export. In addition, the massive exports of agrochemicals from China, especially cheap generic ones, tend to affect the farming practices and production costs in importing countries, further affecting the global food markets. On the other hand, the changes in food prices in China are affected by the global market, and in turn tend to shape the decision-making of producers around pesticide usage (i.e. how much pesticide and which types of pesticides are used) on the ground.

Thirdly, China plays a significant role in global GMO dynamics as the leading producer and exporter of generic glyphosate, the active ingredient in herbicides used for herbicide-resistant GMO crops. In line with this, China is also the world's largest buyer of GMO soybeans due to the increasing domestic demand for cheap feed in the trend of meatification. Such imports essentially maintain the GMO production system and promote the use of packaged herbicides at Chinese GMO soy production sites. Additionally, the Chinese state-owned Syngenta group is also the world's leading seeds company and sells GMO and non-GMO seeds worldwide, several packaged with certain agrochemicals.

These discussions remain initial attempts and are far from providing a full understanding of the interconnections among the sectors. But they do imply that a fuller understanding of the agrochemical complex requires a lens that includes intersectoral interconnections. To think one step further, if we take these intersectoral interactions into account, China's impacts on the global food regime might be more profound than commonly understood. Historically, the invention of chemical fertilisers and pesticides enabled the transfer of the main sites of production in agro-food systems largely from the settler economies anchored by the United Kingdom to the USA. This partly defined the transition of the First Food Regime to the Second Food Regime (McMichael 2013).

In this way, given China's key role in the global agrochemical-food-feed-infrastructure interactions, does it imply the emergence of a new food regime transition dominated by China, as indicated by McMichael (2020)?

To conclude, the agrochemical complex of China is far more complex than our current understanding. It is shaping and is shaped by the changes in social relations around farming and farming practices, China-global dynamics and intersectoral interactions. Given these, China tends to play an increasingly crucial role in shaping the current global agrochemical complex. This suggests the role of China must be taken into consideration in order to eliminate agriculture's dependence on chemical inputs and achieve a sustainable transition.

Beyond this, it also suggests that our current predominant approach to studying the agrochemical industry remains primarily reductionist and agronomic. This might hinder a fuller understanding of the agrochemical complex and suggest misleading solutions for reducing pesticide use in agriculture and minimising the corresponding environmental and health impacts. So, it implies that we need to go beyond the current simplistic framework and instead develop a more comprehensive framework to *historically, interactively and connectively* understand the agrochemical complex. With this framework, this paper intends to stimulate further discussions of the agrochemical complex. It calls for further research on tracing the political-economic roots and power relations that shape the development of the agrochemical sector in China and beyond – both examining interconnected food-infrastructure-agrochemical dynamics and the role of China in such interconnections, and exploring how such global interconnected dynamics are shaped by the dynamics internal to China, and vice versa. Key questions include why and how agrochemicals have penetrated rural society in China in such a swift (but quiet) way and the extent and manner in which China shapes the global food-infrastructure-agrochemical complex.

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Appendix

Protocol of systematic literature review

A1. Purpose

(i) To explore and map the agrochemical dynamic in and directed by China;
(ii) To ask new research questions about the role of China within the current agrochemical complex

A2. Research question

What are the trends and dynamics of agrochemical transformation in and directed by China? And how are these shaping and shaped by the global agrarian transformation?

A3. Key words

Set	Category	Synonyms
Set1	Agrochemical industry	Agri-chemic*, pesticide*, chemical input*, agrochemical, synthetic chemical 农药
Set 2	Agriculture	Agriculture 农业
Set 2	China	Inside China, in China 中国

Terms within each individual set are connected via OR whereas each set is connected with the other sets through AND. All sets search in the title, abstract and keywords of papers. The general search query was:
('agri-chemic*' OR 'chemical input*' OR 'agrochemical' OR 'synthetic chemical *' OR 'pesticide*') AND (' in China' OR 'inside China')
('农药') AND ('农业') AND ('中国')

A4. Sources/digital libraries

Web of Science (core) & CNKI (中国知网)

A5. Inclusion criteria

Articles that satisfy the following criteria are included:

(a) Language: English & Chinese
(b) Type of publication: published journal articles
(c) Time frame: from 1990 – Feb 2023
(d) Studies that contain information about agrochemical transformation in China

A6. Exclusion criteria

(a) Papers that do not include empirical information.
(b) Duplicated items
(c) Papers that focus on the engineering and chemistry aspects of pesticides (e.g. monitoring the residue of pesticides in soil/ food/water, different functions of different pesticides, formulation of pesticides, pesticide resistance, and the efficiency of spraying techniques)

A7. Study selection

We conducted a two-stage selection process, as shown in the flow chart. At the 1st stage of the search, we used the English keywords identified in section A3 to search the Web of Science (core collection) and got 474 search outcomes. We screened the titles and abstracts of all the 474 studies and included 90 studies after two rounds of screening. Similarly, we used the Chinese keywords identified in section A3 to search the CNKI (中国知网) and got 247 search outcomes. After two rounds of screenings, 94 studies were included.