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FOOD SOVEREIGNTY AND SYSTEMS CHANGE



# Pesticides and food sovereignty: (dis)connections and challenges for agrarian movements

Soledad Castro-Vargas [a], Carol Hernández Rodríguez [b], Grettel Navas [c], Enrique Castañón Ballivián [d], Yunan Xu [e] and Daniela Ayelén Marini [f]

[a]Department of Geography, University of Zurich, Zürich, Switzerland; [b]University Program of Bioethics, National Autonomous University of Mexico, Mexico City, México; [c]Department of Political Studies, Facultad de Gobierno, Universidad de Chile, Santiago, Chile; [d]Institute of the Americas, University College London, London, UK; [e]Centre of Development Studies in the Department of Politics and International Studies (POLIS), University of Cambridge, Cambridge, UK; [f]School of Interdisciplinary Studies, Brooks College of Interdisciplinary Studies, Grand Valley State University, Allendale, MI, USA

**ABSTRACT**

Agriculture has become increasingly dependent on pesticide use, with significant growth over the past three decades. While food sovereignty and agroecology have strengthened during the same period, the pesticide complex has expanded and deepened its reach. Drawing on research in China, Mexico, Costa Rica, Argentina, and Bolivia, we analyze the structural drivers behind pesticide adoption, the challenges faced by farmers, the tensions between pesticide use and socioecological health impacts in rural communities, and the strategies mobilized by anti-pesticide movements. This paper intends to open a political research agenda for rethinking food sovereignty in the context of chemically dependent agriculture.

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Pesticide complex; agriculture; social movements; China; Latin America

## 1. Introduction

Pesticides are central to industrial agriculture, and their global use has steadily increased alongside the intensification of agriculture. These substances are intended to kill or control unwanted organisms and are classified depending on their target organisms, such as herbicides, insecticides, fungicides, and nematicides (FAO and WHO 2014; Sparling 2016). Between 2008 and 2018, global pesticide use by volume increased by 20%, especially in low-income (153%) and lower-middle-income (85.5%) countries. Growth is primarily driven by intensified usage rather than the expansion of agricultural land (Schreinemachers and Tipraqsa 2012; Shattuck et al. 2023b). Actual use might be higher due to limited reporting data on domestic pesticide formulations in many countries (Shattuck et al. 2023b). A key factor behind this intensification is the boom in generic, off-patent pesticides, which currently dominate the international pesticide market, broadening access to low-cost pesticides across the globe (Shattuck 2021).

**CONTACT** Soledad Castro-Vargas soledad.castro@geo.uzh.ch
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This trend reflects a broader reconfiguration of the 'pesticide complex,' encompassing all aspects of the stages of the pesticide life cycles, from production and commercialization to application and environmental fate (Galt 2008). Among all pesticide classes, herbicides are the most widely used – especially in the global South – where they have transformed agricultural dynamics by serving as chemical substitutes for manual labor (Haggblade et al. 2017).

The increasing reliance on pesticides is unfolding within a global food system at a critical juncture, which the High Level Panel of Experts on Food Security and Nutrition (HLPE) describes as a 'crossroads' demanding urgent transformation (HLPE 2019; 2020). This fundamental shift must also address complex, interrelated challenges such as intensified pressures on land, water, and biodiversity driven by climate change. While the FAO has acknowledged both the shortcomings of industrial agriculture and the potential of agroecology to feed and nourish the global population (FAO 2014), agroecological and food sovereignty initiatives have developed in parallel to technology and digitization-driven consolidation of industrial agriculture and the growing dominance of the pesticide industry. This dynamic presents a significant paradox for agrarian movements: How can food sovereignty be realized and agroecology gain wider ground while confronting the pervasive and entrenched global pesticide complex?

As members of the Collective of Agrarian Scholar Activists from the South (CASAS), we aim to support grassroots organizations in their struggle to build Food Sovereignty (FS) (Aguiar et al. 2023).[1] We intend to contribute to the global food sovereignty movement, namely the 'Nyéléni Process', supporting a systemic transformation towards more just, inclusive, and sustainable food systems. Scholar-activism is a social justice-oriented and community-driven approach to knowledge production, rooted in social and political activism. It seeks to challenge inequalities and other forms of oppression, while advancing alternative frameworks to understand and transform reality (Bashiri 2023). Agrarian scholar-activism, in turn, embraces the intellectual and political work necessary to articulate the structural difficulties that the agrarian working class faces in engaging in contentious politics to change their conditions (Borras and Franco 2023; Borras and Franco 2025). Closely related, it is key to question what counts as knowledge, whose knowledge is considered valid and valuable, and how social movements can effectively participate in and shape knowledge politics (Causadias et al. 2024; Mora 2017). Using a lens of critical agrarian studies and political ecology, this paper interrogates the (dis)-connections between pesticides and a food sovereignty agenda of systemic transformation, focusing on the power dynamics and social justice dimensions of the pesticide complex (Borras 2023b; Shattuck et al. 2023a). As a counter-hegemonic perspective, critical agrarian studies examines the social, political, and economic forces shaping rural life and agriculture, addressing power relations, social justice, and alternative possibilities. This approach allows us to explore the pesticide question without falling into teleological modernization narratives and to examine food sovereignty beyond celebratory accounts.

The article is informed by insights from our longstanding ethnographic research and agrarian scholar-activism, including mixed methods, based on published work and ongoing research from China, Mexico, Costa Rica, Bolivia, and Argentina. We have

[1] https://casasouth.org/sample-page/

observed the ambivalence farmers experience as pesticides both support the reproduction of livelihoods and simultaneously constrain them in environments marked by toxic exposure, health risks, and ecological degradation. Ethnographic work, we contend, is particularly helpful here as it allows us to (i) capture concrete dynamics and contradictions experienced by farmers in the field and (ii) establish connections between agrarian localities and global forces (e.g. the generics revolution in the global pesticide market) as a way to construct globalizations from below, or 'grounded globalizations' as Michael Burawoy et al. (2000) puts it.

We analyse global features of pesticide use dynamics within contemporary food systems while situating our reflections on China and Latin America. China and Latin America are key nodes of the pesticide complex: China is the global leading producer and exporter of pesticides, especially active ingredients (AIs) (Xu and Chen 2024; Zhao and Rogers 2024), while Latin America has led global pesticide use for the past four decades (Murray 1994, Schreinemachers and Tipraqsa 2012, Berndt et al. 2025). As we will analyse in Section 2, the rise of China as the global leader of pesticide production is key to understanding the recent configuration of the pesticide complex and its South-South dynamics. China's 'going-out' strategy and the Belt and Road Initiative (BRI) have brought emergent geopolitical relationships, as analyzed by Xu et al. (forthcoming) in this special forum.

The new geometries of the pesticide complex raise questions about the possible transition of contemporary food systems within a multipolar world: whether they will further entrench industrialized, high-tech agriculture, or shift toward agroecology-inspired transformations from below (McMichael 2020). At this moment of flux or potential transition in global food systems, we focus on the in-between areas that might emerge as farmers try multiple combinations of vital strategies for sustaining life in agrarian worlds within agrarian capitalism. A closer engagement with these varied vital strategies, which often rely on the use of pesticides, offers fertile ground for sharpening the critical focus of food sovereignty.

The paper is divided into five sections. In Section Two, we analyze how pesticides are imbricated in the food sovereignty debates in the context of the reconfiguration of the global pesticide complex. In Section Three, we explore key drivers behind pesticide adoption and consider these in relation to the challenges farmers face and the complex constraints of agrarian political economies. Section Four explores a fundamental duality faced by agrarian and environmental justice movements: recognizing both the crop-protecting and labor-saving role of pesticides and, simultaneously, experiencing their ecological and human health impacts. The fifth section analyzes the actions and lessons learned from movements facing the burden of pesticide contamination worldwide. Finally, drawing on the previous sections, we close with a reflection on the six pillars of FS and how they intersect with pesticide use challenges, to consider what could be fruitful in advancing political agendas to challenge the deeply rooted and globally widespread pesticide industry.

## 2. Food sovereignty and the pesticide complex

As a political project, Food Sovereignty (FS) has been embraced by multiple agrarian social movements around the globe. By agrarian movements, we understand collective mobilizations centered on struggles for access to and control over land and natural

resources, as well as for fair agricultural policies (Borras 2023a). Agrarian movements primarily involve peasants, small- and middle-scale farmers, landless rural laborers, and other collectives of the rural working class. Although rooted in land-based livelihoods, agrarian movements are far from being 'agrarian-centric'; they are critical actors against broader anti-capitalist struggles, while also constructing systemic alternatives for social justice and broader emancipatory projects.

Food Sovereignty has figured prominently in the international campaign of *La Via Campesina* since 1996. The 2007 Nyéléni Declaration offers a nature-human-centered, rights-based definition of food sovereignty that integrates the right to food, the right to a healthy environment and the right to dignified livelihoods (Wittman 2023). It defines it as 'the right of peoples to healthy and culturally appropriate food, produced through ecologically sound and sustainable methods, and their right to define their own food and agricultural systems' (Nyéléni 2007). For its advocates, food sovereignty has the potential to articulate an effective Polanyian countermovement against corporate industrial agriculture (McMichael 2014; Patel 2007). Critics, on the other hand, question it as a highly problematic project given its adherence to small-scale farming and failure to properly account for the effects of capitalist relations, particularly in terms of class formation and the dull compulsion of market discipline (Bernstein 2014; Li 2015). In this paper, we contribute to this broader debate by exploring the intricate relationship between food sovereignty and pesticide use.

As intrinsic to corporate industrial agriculture, pesticides are often positioned at odds with food sovereignty. Their deleterious social and environmental impacts seem incompatible with socially just and environmentally sustainable agriculture. Farmers are thus expected to reject pesticides. In this regard, we identify two main contradictions between pesticides and the FS campaign. The first one relates to what has been termed the 'localisation dimension' (Robbins 2018) of food sovereignty. As elaborated below, pesticides' production, distribution, and usage epitomize the transformation of agriculture into a globally interconnected system. The pesticide complex is global in nature and, as such, appears to be the antipode of the FS vision of locally based farming systems. We thus agree with Robbins (2018) that it is necessary to go beyond small-scale agriculture and local markets to build FS. Second, and relatedly, the FS campaign advocates for healthy environments and explicitly promotes agroecology as the 'basis for peasant agriculture and food sovereignty' (Campesina 2017). Under this definition, FS promotes an agroecology revolution that is not only technological, but also epistemological and social (Altieri and Toledo 2011). However, transitioning towards agroecology raises important challenges for smallholders who have gone through a widespread process of chemicalization of their agricultural systems (Castellanos-Navarrete and Jansen 2018; Soper 2020). Pesticide use is not only common among peasants and smallholders, but it is on the rise in various regions of the world. This uncomfortable fact, we argue, demands urgent and fresh reflection from those committed to making food sovereignty a transformative political project. To organize our discussion, we address the six pillars of food sovereignty, namely (i) food for people, (ii) localizing food systems, (iii) making decisions locally, (iv) valuing food providers, (v) building knowledge and skills, and (vi) working in harmony with nature. Exploring the relationship between food sovereignty and pesticides via these pillars is a useful heuristic move to discuss the complexities and contradictions involved.

In this section, we limit ourselves to presenting some general thoughts/questions pointing towards the possible (dis)connections between pesticide use and the different pillars of food sovereignty. To move the debate forward, we bring a committed and critical perspective to rethinking food sovereignty, considering how the dilemmas and challenges faced by farmers and movements within capitalist agriculture invite us to reconsider food sovereignty strategies. The *food for people* pillar highlights the importance of people accessing sufficient, nutritious, and culturally appropriate food. Arguably, pesticide use has played an important role in ensuring sufficient food production to sustain a growing and increasingly urbanized global population. By serving as a substitute for human labor, pesticides have had a very tangible effect in this regard. Yet food produced this way usually goes against the environmental, nutritional, and culturally sensitive demands of the FS framework. By *localizing food systems,* the FS project seeks to confront the global food regime built on the so-called free market agenda of the WTO. It calls for the dismantling of corporate-controlled global production networks and the reorganization of agriculture, prioritizing local livelihoods. In particular contexts, pesticides can potentially play a limited role in building national sovereignty while enhancing domestic production versus imports and free trade agreements. Potato production in Costa Rica illustrates this well, as the country kept protective tariffs in the Central American-Dominican Republic-United States Free Trade Agreement (CAFTA-DR) and the Canada-Costa Rica Free Trade Agreement to support domestic production. Conversely, supporting potato production under the present local agriculture conditions has also meant protecting a crop that can only be maintained through high doses and frequent pesticide application, representing significant profit to the domestic generics industry (Galt 2014). In this sense, pesticides have the potential to contribute to a vision of sovereignty that prioritizes domestic over non-domestic production.

To the extent that the 'generics revolution' (Berndt et al. 2025) altered corporate monopolies and made pesticides more affordable, we should consider its implications for small farmers' access to chemical inputs. Doing so could be part of a broader discussion on the *making decisions locally* pillar. Pesticide adoption cannot be merely presented as a farmer's legitimate and rational decision, given the structural factors that constrain people's agency. But neither can it be simply disregarded as a practice of those not committed to food sovereignty. More open discussion on the dilemmas that pesticide use entails for small farmers on the ground, alongside the structural conditions and pressures that can motivate pesticide usage, can inform efforts to broaden the political appeal of the FS project. Relatedly, discussions on *valuing food providers* could benefit from a wider framing that includes smallholders who actively (and even eagerly) participate in agribusiness structures and not just those who reject them. Valuing and recognizing people's efforts to sustain their livelihoods should, in this regard, include their struggles to access pesticides and other inputs. Earnest attention to these efforts can also elucidate the ways that pesticides may simultaneously underwrite *and* undermine smallholder livelihoods and local food production.

Pesticide adoption may have contradictory effects with regard to *building knowledge and skills*. On the one hand, it contributes to 'agricultural deskilling' by eroding systems of traditional knowledge, such as know-how, practices, and innovations that have been developed and adapted to local cultures and environments by communities over more than 10,000 years through domestication and their close relationship with nature

(SCBD 2007). On the other hand, using pesticides can require another set of skills and specialized knowledge. Recognizing this knowledge can be a critical entry for food sovereignty advocates to more fully acknowledge the personal investments that many pesticide users have in particular practices and compounds, and the invisible expertise that often underwrites industry profits by suturing idealized agrochemical practices with the actual conditions and contexts of application. The last FS pillar, *working in harmony with nature*, does seem to be incompatible with pesticide use. As part of modern capitalist agriculture, pesticides are designed to standardize or 'tame' natural processes to improve yields and reduce costs. Their intrinsic toxicity and organic link with fossil fuel-dependent farming make them ecologically unsustainable.

Before further discussing some of the points raised above, we outline the nature and changing dynamics of the global pesticide complex (Berndt et al. 2025; Mansfield et al. 2023; Shattuck 2021). The pesticide industry has undergone significant transformations over the past two decades. The expiration of patents previously held by multinational research and development (R&D) companies led to the emergence of the generics industry and shifted the core of pesticide production to China and India. This facilitated the availability of cheap generic pesticides, particularly in developing countries (Shattuck 2021). While this development may appear beneficial for farmers – prompting, for instance, protests in countries such as Bolivia and Costa Rica demanding state support for greater access to generic pesticides – the outcomes are not so straightforward (Castañón Ballivián 2024; Castro-Vargas and Werner 2022). Although it was initially presumed that R&D-based multinationals were transitioning toward specialized markets and technological strategies, such as integrated agricultural services and digitalization, these companies continue to rely on off-patent pesticides. They not only maintain production in their own plants but also outsource to smaller, generic firms. This trend has been accompanied by corporate mergers and acquisitions that increasingly blur the boundaries between generics and R&D companies (Berndt et al. 2025). Thus, rather than dismantling monopolistic structures and corporate control, which is concentrated mainly in four major legacy R&D firms (Syngenta Group, Bayer, BASF, and Corteva), the rise of generics appears to be part of an industry reconfiguration into 'new hierarchies' and elusive business models (Berndt et al. 2025, 14).

The generics boom, moreover, has not been accompanied by corresponding measures to reduce associated human health and environmental risks. This gap is particularly significant given the uneven regulatory frameworks governing pesticide use across the globe, which result in a differentiated distribution of pesticide exposure and toxicity (Bertomeu-Sánchez 2019). In this regard, pesticide registration is a very sensitive issue. FAO's framing of pesticide registration strategies reveals how health and environmental risk evaluations are primarily geared toward developed countries, transitioning toward simpler models that rely on risk evaluations developed elsewhere, with a gradient depending on the availability of resources (FAO 2025). Returning to the issue of corporate control, pesticide registration reveals how R&D companies continue to exert influence even over off-patent products in circulation. By withholding complete data packages, as part of a broader competitive strategy, these firms contribute to the continued use of old active ingredients in the global South without updated risk assessments based on current scientific standards (Castro-Vargas and Werner 2022; Jansen 2017).

## 3. Structural drivers and farmers' challenges around pesticide use

This section examines the structural drivers and agrarian political economies that constrain farmers' decisions and entrench pesticide use, highlighting the complex subjectivities shaped by ecological, labor, and market pressures. The growing reliance on pesticides and the expansion of their adoption have placed farmers within what Wright (1990) terms the 'modern agriculture dilemma' – a condition in which agricultural systems, optimized for short-term productivity, ultimately erode the ecological and social foundations that sustain them. These systems are highly productive yet fragile and marked by deep inequalities. Rather than framing pesticide adoption as either entirely constrained or a product of free, rational choice, we examine the circumstances that underlie these decisions. As Luna (2019, 450) aptly puts it: 'farmers are making choices, but (as Marx famously wrote) not in conditions of their own choosing'. In what follows, drawing on political ecology and agrarian studies scholarship on pesticide use and agrarian change, we will first analyze some key drivers of pesticide adoption, then discuss this in light of the challenges farmers face and the complex subjectivities that arise from constrained agrarian political economies (Galt 2013; Luna 2019, Shattuck 2021). Building on previous analysis by Shattuck (2021), Shattuck et al. (2023b), and Thrupp et al. (2015), we grouped key drivers into four major areas: transformation in agricultural commodities and supply chains, changes in crop diversity and ecological relationships, shifts in labor dynamics, and market constraints.

### *3.1. Agricultural commodities and supply chains*

The transformation of agricultural commodities and supply chains encompasses the rise of generic pesticides, the growth of export commodities, the increasing role of agricultural extension services provided by input suppliers, and the consolidation of contract farming schemes. These shifts have reinforced structural barriers to the FS pillar of *localizing food systems*.

As discussed earlier, China is currently the world's largest producer of pesticides, particularly active ingredients (AIs) (Xu and Chen 2024; Zhao and Rogers 2024). Following the successive expiration of patents held by international corporations, generic producers in China lowered the price of pesticides, particularly glyphosate-based herbicides (Huang, Wang, and Xiao 2017; Shattuck 2021; Werner, Berndt, and Mansfield 2022). These abundant and inexpensive pesticides became widely accessible to farmers in China and Latin America (Berndt et al. 2025; Chen 2018; Shattuck 2021). In Latin America, in the contemporary food regime, neoliberal agriculture policies have shifted state support toward the private sector (e.g. agribusiness), resulting in the substitution of previous extension services with pesticide sales by the industry (Castro-Vargas and Werner 2025). As Aga (2018) argued, 'agrichemicals marketing brings partial technical expertise to farmers, appropriating the styles of public agricultural extension in its heyday.' In Costa Rica, for instance, the generic industry absorbed pre-existing commercial infrastructures installed by the R&D industry, reaching farmers through efficient and localized retailer markets and supply systems, encouraging pesticide usage. This has resulted in a smooth adoption of generics (Castro-Vargas and Werner 2025).

Similarly, in China, pesticides are sold through a deeply embedded local sales network, which was transformed from the previous 'Agricultural Technology Extension System' at

the county and township levels during the collective era (Chen 2018). Under this network, the salesmen/women at the village level are usually the village elites, and free training sessions are frequently offered in villages by retailers. Such training is a key channel for smallholders to learn about pesticide use. This tends to encourage overuse, as it is a sales-driven system (Hu and Rahman 2016).

In Latin America, the boom in generics and the rise of domestic formulation have been ongoing for at least two decades. The market continues to expand as more active ingredients lose patent protection. Globally, between 2023 and 2024, fifteen active ingredients came off patent, and four others will do so before 2028 – eleven fungicides, four herbicides, and four insecticides (Hopkins 2023). In Mexico, for instance, it is estimated that the government, through the Federal Commission for Protection against Sanitary Risks (COFEPRIS), authorizes the use of highly hazardous active ingredients in more than 3,000 herbicides, insecticides, and fungicides, many of which are now available as generics. It is estimated that 111 active substances banned in other countries are currently being applied in the Mexican fields (Lopez-Carmen et al. 2022).

This situation coincides with a presidential decree aimed at banning glyphosate and genetically modified (GM) corn for human consumption, while adopting agroecology as a national policy (Nelson, Gomez Tovar, and Gómez Cruz 2024). The decree, expected to take effect by the end of 2024, has been suspended amidst the ongoing maize-corn dispute with the United States (US) (PAN 2024). Although glyphosate importations have been reduced, it remains unclear whether Mexico continues to produce generic glyphosate-based pesticides, and an informal or illicit market appears to be emerging (Agri-Brasilis 2023). According to participatory observations from one of the authors, it remains uncertain if the ban to glyphosate will simply lead to farmers' adoption of other pesticides, to the consolidation of an illicit market, or if the government will indeed have the capacity to promote agroecology at a national scale and reverse, at least across peasant communities, the chemicalization of Mexican agriculture. What is clear is that the generic market is broad, growing, and difficult to regulate effectively. As in other countries, local pesticide retailers are key in training peasants and farmers on how and in what quantities to apply these products.

However, the increase in pesticide adoption should not be interpreted solely as a top-down imposition. Small farmers themselves tend to demand access to cheap generic pesticides and embrace them quickly if accessible. In this sense, a very significant number of small farmers perceive generics as limited but useful inputs that have reduced drudgery and crop losses. A politically savvy FS agenda should consider how the so-called 'generics revolution' has triggered pesticide adoption in rural areas, and how, depending on the context, this reflects demands from below.

### *3.2. Crop diversity and ecological relationships*

The rise of commodity crops, the loss of crop diversity, and the alteration of ecological relationships constitute structural constraints that challenge the six pillars of FS and have contributed to growing pesticide use. The emergence of generics in the 2000s happened simultaneously with the land rush and the rise of commodity crop production, which led to smallholder production under more intensive farming practices (Borras

and Franco 2012; Borras et al. 2016; Shattuck 2020). These high-value crops often require intensive pesticide applications (Castro-Vargas and Werner 2025; Galt 2020).

The boom of commodity crops also paralleled the proliferation of contract farming schemes, which can directly and/or indirectly impose pesticide use. In Bolivia, for instance, small farmers have been locked in a 'hybrid' contract farming model (Little and Watts 2022) where local traders serve as intermediaries between farmers and agribusiness firms. These informal traders often smuggle generic pesticides from Paraguay and have been accused of diluting products and/or selling expired ones. Small farmers repeatedly claimed that the questionable quality of the products is one of the main reasons they have tripled pesticide use over the past decades (Castañón Ballivián 2025, forthcoming).

The 'supermarket revolution' took off in Latin America in the 1990s, characterized by the rapid spread of retail formats – especially supermarkets – which reshaped food distribution, consumer habits, and agricultural supply chains (Reardon et al. 2003). Supermarkets imposed cosmetic aspects and logistical standards to satisfy an increasing demand for fresh fruits and vegetables, which can only be achieved through pesticide applications to reduce the possible losses due to pests, weeds, and pathogens (Reardon & Hopkins 2006; McMichael 2009; Shattuck 2020). The demand for fresh produce also generated a vegetable production boom in Latin American markets, which, under humid conditions, can lead to even higher pesticide use (Galt 2014). Dietary change has also been a driver of pesticide use. For instance, there is a diet transformation in China towards more value-added food consumption with the rise of the middle class during rapid urbanization and industrialization. This diet implies an increased demand for animal feeds, vegetables, and fruits, thus increasing pesticide use (Qiu and Hu 2020). This shift has pushed farming in China towards a more capital-intensive mode, referred to as China's Hidden Agricultural Revolution by Huang (2016).

The increased demand for animal feeds in China and cheap exports of pesticides from China, in turn, fueled the chemical and capital-intensive 'soy boom' in Latin American countries, including Brazil and Argentina, with cascading effects on pesticide use in other agricultural sectors. Since GM soybeans were introduced in 1996, the use of glyphosate-based herbicides has spiked in the country: from 28 million liters used in the late 1990s, to more than 200 million liters currently sprayed annually (together with 2,4-D and, more recently, glufosinate ammonium) (Lapegna, Kunin, and Palmisano 2024). Caught between urban growth and expanding soy fields, small family farmers in the fresh vegetable sector have turned to labor and chemical-intensive techniques to extract value from smaller areas of land through investments in greenhouse technology (Marini 2020). Greenhouse cultivation entails the use of neurotoxic methyl bromide, a substance with a dubious regulatory status. Although banned in concentrations over 70% of the active ingredient, it is widely used in formulations under this percentage. A wide range of restricted pesticides due to their high toxicity and health hazards are also applied in the vegetable sector. In 2022, the National Service of Agri-food Health and Quality (SENASA) reported a total of 83 active ingredients in fruits and vegetables, among them highly toxic fungicides and insecticides, including banned ones such as metamidofos, carbofuran and chlorpyrifos (Mangia and Cabaleiro 2024).

Ecological pressures also shape the growing use of pesticides. In Mexico, factors such as land scarcity, soil degradation, and increasing pest pressure and crop diseases have intensified pesticide dependence. One of the key benefits of agrochemical use has

been the capacity of households to maintain their traditional farming systems, such as the Mayan *milpa*, despite increasing land scarcity and soil deterioration (Hernández Rodríguez 2023; Hernández Rodríguez, Perales Rivera, and Jaffee 2020). Traditionally, the *milpa* required the rotation of farming plots to allow for the regeneration of soils and secondary forests (Nigh and Diemont 2013), a practice that has become difficult or even impossible to carry on, coupled with the limits of land reform and other pressures such as population growth. Chemical fertilization has become essential for keeping production in degraded soils without requiring land rest. Pesticides and herbicides have, in turn, helped peasant households to save labor and time while preserving their milpas. In addition to food security and peasant autonomy, the reproduction of the milpa has been key for agrobiodiversity conservation of native varieties, reinforcing the centrality of peasant communities in the process of crop evolution in their centers of origin and diversity, as the case of Mexico made evident when the government approved early in 2025 a constitutional reform to recognize maize as 'an element of national identity' and as the subsistence base of Indigenous and Afro-American peoples (INPI 2025).

Paradoxically, among Mayan communities, it is common to find alongside chemicalized subsistence agriculture and conventional cash crops/greenhouses, organic production of coffee, cacao, or honey for fair-trade international markets. It may indicate that alternative markets with higher prices and collective organization (e.g. cooperatives) are crucial in supporting communities' engagement with more labor-intensive, agrochemical-free agriculture (Hernández Rodríguez 2023). Environmental constraints from past and present plantations have led to increased pesticide applications in Central America. In the Southern Pacific of Costa Rica, for instance, smallholders cultivating former plantation lands are often conditioned to use pesticides to manage the inherited pests and pathogens from the banana enclave (Castro-Vargas and Werner 2025). Meanwhile, pesticide use in the agroindustry has been steadily increasing, reaching unprecedented highs and resulting in frequent aerial applications, above 60 cycles of fumigation per year (Brühl et al. 2023).

### *3.3. Changes in labor dynamics*

Changing labor dynamics and access to capital have enhanced pesticide use, especially herbicides, which serve as lock-in technologies tied to glyphosate-resistant crops (Clapp 2021). Pesticide adoption in eastern Bolivia illustrates this, where herbicides have been intimately associated with disputes around the labor regime. Back in the 1990s, soybean cultivation demanded substantial amounts of wage labor. While the sowing and harvesting of soybeans were largely mechanized, manual work was necessary for the crucial task of weed management. Weeding the soybean at the right moment of the crop's development made the difference between generating surpluses and facing losses. Aware of the urgency, agricultural laborers used it to their advantage and often managed to negotiate higher prices for their labor. Once taken to the field, they usually claimed that the amount of weed did not correspond to the payment offered and so refused to start with the work. To resolve disputes, managers of agricultural enterprises often had no choice but to concede to workers' demands. The solution to this so-called 'labor problem' came in the form of transgenic soybean seeds resistant to glyphosate. The adoption of glyphosate-based herbicides made 95% of the soybean workforce

redundant (Castañón Ballivián 2024). Herbicides, and particularly glyphosate-based products, make up the bulk of Bolivia's pesticide imports (67.6%), which have been increasing dramatically over the last decades, from 2,000 tons in 1995 to more than 43,600 tons in 2023 (SENASAG 2024).

Rural-urban migration generates labor shortages and increased wages, which make herbicides a viable option to replace labor. In the case of China, rural labor dynamics are shaped by massive rural-to-urban migration that started in the 1980s. Such migration is often cyclical due to the restriction of China's household registration system, known as the *Hukou* system (Andreas and Zhan 2016; Chan and Zhang 1999). Typically, the strong household members of rural communities migrate to urban areas for wage jobs, serving as cheap labor that supports China's rapid industrialization (Chuang 2020), while the elderly, children, and women are left behind and do farm work (Ye et al. 2013; 2016). Such migration has two impacts on the smallholders' pesticide use (Xu and Chen 2024). On the one hand, this causes a labor shortage for farming, making pesticides a substitute for manual labor in weed and pest control. On the other hand, the income gained from the migration enables smallholders to afford chemical inputs, as observed in the case of industrial tree plantations in Southern China (Xu 2020).

In Mexico, similar trends exist. Agrochemicals have contributed to partially resolving labor scarcity due to migration and reducing production costs. They allow households to significantly cut back on both hired labor (*jornaleros*) and unpaid family labor – a defining feature of peasant agriculture. As family labor is freed from subsistence production, more household members can engage in cash-crop agriculture, wage labor, education, or time-intensive community activities, including participation in social movements. These shifts have been particularly impactful for women and youth, who now enjoy greater access to cash economies, education, and political representation (Hernández Rodríguez 2018).

### 3.4. Market constraints

Influential factors also include market constraints within the food system, as farmers in the Global South increasingly shift from subsistence-based production to market-oriented agriculture, they face new pressures that entrench pesticide use (Thrupp et al. 2015). As Thrupp (1991) has analyzed, access to credit works as an incentive to pesticide use, promoting it as a safeguard of investment. In our study areas, we have seen how credit systems push farmers to adopt pesticide-based technological packages. Farmers enter into pesticide use to comply with conditions imposed by credit systems. Since the 1980s, state-managed credit programs have been gradually replaced by private schemes often linked to input suppliers. These arrangements condition farmers' access to financing on the purchase and use of chemical inputs. In such contexts, pesticides become not just tools for increasing yields but also obligatory components of participating in commercial agriculture. This deepens the structural entrenchment of pesticide use and displaces less chemicalized alternatives.

### 3.5. Farmers' challenges within chemicalized agriculture

The drivers previously described have pushed farmers into adopting pesticides, producing a series of challenges that entrap them within industrial agriculture. Farmers are

strongly constrained by informational, political, economic, cultural, individual, and environmental contexts that render pesticide avoidance almost impossible (Galt 2013). To reiterate: farmers make decisions in conditions that they do not control. One of the most pressing conditions is dependency, expressed in multiple ways. A key mechanism that enhances entrapment is the pesticide treadmill- the ecological feedback loop that occurs after the disruption of agroecosystems through pesticide use, the emergence of biocide resistance, and pest outbreaks, resulting in a constant increase in pesticide use (Nicholls and Altieri 1997; Thrupp 1988).

In Bolivia, the use of herbicides has become so dominant that it forecloses any alternative way of producing soybeans. Virtually all farmers who tried out organic soybean production were quickly forced to resort back to glyphosate-resistant varieties. The materiality imposed by the extensive use of pesticides rendered farmers' desire for organic production futile. For example, a small farmer who had decided to go organic with the support of an NGO explained:

> With the organic seed, you have to wait more than five years to see results. But, more than that, it is very difficult to control pests, and even if you manage to do that, any time a wind [current] will bring poison [herbicide] from a neighbouring farm. It is impossible. One is forced to produce transgenic. (Castañón Ballivián 2020)

The rise of different crop mixes and dietary changes, previously described, poses significant challenges for vegetable-producing farmers. In Costa Rica, for instance, vegetable production in the Northern area of Cartago has one of the highest uses of pesticides globally (Galt 2014). As a result of decades of highly chemically intensive agriculture, local entities detected contamination of drinking water intended for human consumption with metabolites derived from the fungicide chlorothalonil. It was later found that the contamination spanned a larger area than initially estimated, revealing how agriculture and access to clean water are at a crossroads (Gobierno de Costa Rica 2024). According to recent fieldwork in this area by Castro-Vargas (2025), farmers who live in these communities grapple with the contradiction, in some cases with pain, guilt, and remorse, of applying pesticides that allow them to maintain their livelihoods, even though this affects the well-being of their families and communities. Similarly, in Indigenous communities in Mexico, peasants associate agrochemical use within their communities with water contamination, soil and seed deterioration, and human diseases such as skin cancer (Hernández Rodríguez, Perales Rivera, and Jaffee 2020).

Not only environmental factors, but also cyclical economic pressures, accompany the pesticide treadmill, as rising expenditures on chemical inputs generate the need to increase income. This can trigger what Henry Bernstein (1994, 56) calls the 'simple reproduction squeeze' and lead to downward spirals of debt, which, in turn, put ever more pressure on making money (Luna 2019). We have observed how credit and debt operate in perverse ways, pushing farmers into entrapment.

Conversely, we consider it essential to acknowledge that using pesticides can bring benefits to farmers, such as class mobility, which could align with the FS pillar, *making decisions locally* (Aga 2018; Luna 2019; Shattuck 2020). The use of pesticides in specific contexts enables farmers to organize collectively and demand access to the means of production, mainly land. For instance, in Argentina, Bolivian-Argentine family farmers (including both recent migrants from Bolivia and established families with second and third

generations of Argentine descendants) rely on a wide range of pesticides to cultivate peri-urban farms, supplying cities with fresh produce. In a context dominated by GM soy cultivation for export, Bolivian-Argentine farmers have organized to demand the democratization of access to land and permanent housing for small farmers, recognizing this as a necessary precondition for grassroots agroecological production (Marini 2023). In rural China, rural land was previously collectively owned (Ye 2015). Following the implementation of the household responsibility system (HRS) reform, smallholders have gained control over farmland use and have easy access to inexpensive chemical inputs under a localized sales network, contributing to the intensive use of pesticides (Xu and Chen 2024).

A more nuanced conceptualization of farmers' 'complex subjectivities' helps to move beyond the idea of farmers as self-responsible individuals making choices and prioritizing economic wealth above everything else. Farmers are constrained within an agrarian political economy that threatens lives and livelihoods and, therefore, technocratic regimes of protection (i.e. educating pesticide users) do not translate into greater protective gear use (Galt 2008). On top of structural limitations, farmers' capacity for self-determination and inventiveness also shape subjectivities. Farmers can be, at the same time, pesticide users and agroecology advocates. In the Argentine case, for instance, organized Bolivian-Argentine farmers, coalesced under the banner '*el otro campo*' (the other countryside), are challenging the politics of land and citizenship in the country. Their vital strategies mix communitarian and profit-maximizing logics, and combine the use of pesticides with the development of agroecological colonies, participatory certification, and the autonomous manufacturing of biofertilizers, rationalities and practices often considered incompatible. While subject to a toxic, extractivist landscape that continually undermines their conditions for survival, they deploy their own collective subjectivity, 'the other countryside' as a necessary act of resistance, allowing racialized farmers to assert their difference from corporate agribusiness while navigating entrenched inequalities (Marini 2021). *Valuing food providers* and *making decisions locally,* as FS pillars, implies respecting how farmers navigate these apparent contradictions.

## 4. Navigating everyday life in pesticide-contaminated environments

Although primarily promoted as crop protectants, pesticides are toxic substances produced to kill living organisms; consequently, they often endanger human health, biodiversity, and the well-being of communities exposed to their harmful effects (Maggi et al. 2020). As noted for the cases of Costa Rica and Mexico, local communities are not unaware of the risks associated with pesticide use. On the contrary, they recognize clear links between agrochemicals and water contamination, soil and seed degradation, as well as human health impacts. However, this awareness does not necessarily translate into a shift away from the use of pesticides. Bringing the FS pillar of *harmony with nature* into the discussion, this section explores the tensions between pesticide use and ecological sustainability within a broader political economy context. It emphasizes the challenges faced by local communities using pesticides and living in areas impacted by pesticide exposure, as well as the harmful effects of these practices.

According to the World Health Organization (WHO), pesticide contamination is a growing global public health concern (WHO 2010). Although the exact number is

difficult to determine, the Pesticide Atlas estimates that 385 million people suffer from pesticide poisoning every year (2022). Regarding chronic illnesses, the number is much more difficult to track, but authors have evidenced that long-term exposure to pesticides significantly increases the risk of Parkinson's disease, infertility, miscarriages, and cancer (Ahmad et al. 2024 ). Prenatal and breastfeeding-related exposure can also cause intergenerational effects (Zhang et al. 2024).

Direct exposure via inhalation, skin contact in the fields, or ingestion of contaminated water can lead to serious health outcomes, such as respiratory problems, neurological disorders, and different types of cancers. Beyond their target locations and occupational exposure during production, handling, and application, pesticide drift can lead to pollution of water, air, and soil, affecting not only directly exposed communities but also those living miles away (Harrison 2011). Additionally, bioaccumulation in the food chain magnifies their reach.

Ecologically, pesticide pollution has been identified as a significant driver of environmental disruption and biodiversity loss (Naz et al. 2023; Sharma et al. 2019). More recently, pesticide use has increasingly been recognized as a threat to the stability of several planetary boundaries, particularly those related to biosphere integrity, biogeochemical flows, ocean acidification, and the emergence of novel entities. The accumulation of synthetic chemical pollutants, such as persistent pesticides, can push ecosystems beyond their capacity to adapt, potentially triggering irreversible environmental change (Richardson et al., 2023). Adding to the human health and ecological impacts, pesticides, like other forms of toxic pollution, can produce environments of dispossession in various ways. In the context of food sovereignty, pesticides can lead to dispossession by undermining livelihoods, contaminating soil and water sources, and eroding traditional agricultural practices. Empirical cases illustrate how these dynamics displace communities, marginalize small-scale farmers, and restrict access to healthy, autonomous food production (Vélez-Torres, Lugo-Vivas, and Swistun 2024).

Due to the fact that geographies of harm and exposure are highly uneven across the globe (Jørs, Neupane, and London 2018; London 2003), pesticide pollution often raises concerns about social and environmental justice as it affects to a greater extent marginalized communities (Harrison 2011). Furthermore, concerns about colonialism, racism, and economic exploitation are especially pronounced in postcolonial contexts where the continuation of imperial power becomes evident through pollution and bodily harm (Agard-Jones 2013; Ferdinand 2015; Marya and Patel 2021). For instance, Agard-Jones explores how toxic exposures in postcolonial contexts reflect ongoing forms of imperial domination through the regulation and contamination of bodies (Agard-Jones 2013). Ferdinand extends this critique by arguing that environmental degradation in the Caribbean Islands reinforces racial and economic hierarchies rooted in colonial history (Ferdinand 2015; 2024). Also, Marya and Patel (2021) discuss how socioeconomic background, racism, and trauma determine health outcomes.

Within this unevenness of exposure, farmers and agricultural workers from low- and lower-middle-income countries are particularly vulnerable. Migrant workers with a more precarious job status face the highest levels of pesticide exposure (Holmes 2013). Tang et al. (2021) conducted a global-scale analysis of the environmental risks associated with pesticide pollution on agricultural lands. Their findings indicate that approximately 75% of agricultural land worldwide is at risk of pesticide contamination. In those areas,

pesticide residues (containing at least one active ingredient) in the water or air are higher than the considered safe levels by the WHO.

Pesticides are rarely used alone but often applied in combination with others, which can intensify their toxicological effects (Hernández et al. 2013). While much attention has been given to individual active ingredients, the potential impact of low-dose combinations of multiple pesticides is also a major concern. When two or more pesticides are combined, their effects can work separately, add up, or interact with each other (Hernández et al. 2013). Hence, the traditional toxicological principle that 'the dose makes the poison' is increasingly being challenged in the case of pesticides. This is partly because some substances can be harmful even at low doses over the medium and long term, and also because interactions between two or more pesticides can amplify their consequences (Hernández et al. 2013; Zeliger 2011). This uncertainty introduces a situation where not only are the outcomes unpredictable, but the risks themselves cannot be fully known or quantified. A FS agenda must therefore prioritize the precautionary principle and advocate for forms of knowledge production that acknowledge complexity, long-term effects, and the interplay of multiple chemical exposures. At the same time, a FS agenda must call for increased transparency and accountability in pesticide regulation, especially concerning the continued use of pesticides in the Global South that are banned or heavily restricted in the Global North (Jors and London, 2108). This regulatory double standard places marginalized communities at risk by exposing them to chemicals considered too dangerous for use elsewhere, thereby deepening global inequalities (Chukwrah 2021).

As a solution to reduce pesticide exposures, technocratic approaches have promoted the use of protective equipment; however, studies have shown that pesticide users' behaviors are not merely guided by rational choices alone. Instead, their choices on protection gear are mediated by 'complex subjectivities' (see Section 3). The decision of whether to use or not to use protection is shaped by the broader political economy and cultural aspects (Galt 2008; Senanayake 2022; Wilson and Tisdell 2001). In other words, promoting top-down policies and models of an 'individualized and rational pesticide user' is blind to the deep, contextualized realities that keep pesticide users, including farmers, reliant on pesticides.

But pesticides are not only villainous inputs to sustain industrial agriculture. Pesticides are a driver of farmers' autonomy, economic stability, cultural resilience, and even a source of social reproduction sustainability (Evia et al. 2024; Senanayake 2022). Farmers who rely on pesticides confront the paradox that maintaining their livelihoods as small-scale commodity producers often entails absorbing hidden costs, including the harms these chemicals inflict on their bodies and their families. Pesticides, as both inputs for agricultural productivity and vectors of harm, must be understood within a broader epistemic terrain marked by scientific uncertainty, contested knowledge claims, and the politicization of risk (Shattuck 2019, 2020; Navas 2022). A reductive framing of users as mere victims eclipses the more complex entanglement whereby agrochemicals function dually as toxic agents implicated in environmental injustices and as indispensable technologies within socio-economic systems of food production, thereby raising intersecting concerns of both environmental and social justice.

A key concept for understanding the situated nature of relationships between agrochemicals, harm, and health is that of 'agrochemical kinship' (Senanayake 2022). In her research, Senanayake illustrates how chemical inputs are not solely perceived as

hazardous substances contributing to adverse health outcomes among agricultural workers but also as indispensable to economic survival within contexts marked by rural stagnation and constrained labor opportunities. Grounded in the framework of social reproduction, Senanayake argues that pesticide use cannot be reduced to individual choice or framed solely as a health or ecological concern; rather, it must be situated within the broader dynamics of political economy, social reproduction, and the identity politics inherent to agrarian life.

The global pesticide industry is deeply rooted in agrarian production and reproduction, and the realization of food sovereignty and agroecology in such a scenario has been a driving force behind mobilizations for various movements worldwide. The following section explores this further.

## 5. Contesting pesticides: movements, strategies and tensions

This section explores how grassroots mobilizations, community-led initiatives, and social movements confront the ecological, social, and health harms of pesticide use from an agrarian justice perspective. We examine the strategies, contradictions, and dilemmas faced by these movements, paying particular attention to the interplay between scientific evidence, the politics of knowledge production, legal accountability, corporate power, and lived experience, the differentiated exposures, and the politics of transition away from pesticide dependence. In doing so, we emphasize the need for a nuanced understanding of movement dynamics – one that acknowledges internal contradictions, diverse political subjectivities, and the uneven capacity of communities to mobilize and take forward transformations. Drawing from different cases, we trace how struggles over pesticides are deeply entangled with broader questions of knowledge production, ecological repair, and political commitments.

The struggles against pesticide harm and those advancing food sovereignty (FS) share important common ground, yet they are often articulated through distinct priorities, definitions of problems, and horizons. Movements against pesticides –those advocating for reducing or eliminating the use of synthetic pesticides and other agrochemicals in agriculture and other contexts– and the Food Sovereignty movement both challenge the dominant influence of corporate agribusiness. While FS is grounded in the rights of peasants and communities to control their food systems, anti-pesticide movements foreground the environmental, health, and socio-economic harms caused by pesticides, particularly affecting vulnerable and marginalized communities in rural and urban settings. As Borras emphasizes, alliances are foundational to strengthen collective action and build bridges among agrarian, rural and rural-urban spheres (Borras 2023a).

In general terms, the anti-pesticide movements gained significant momentum following the publication of the American biologist Rachel Carson's Silent Spring in 1962. This groundbreaking book exposed the environmental dangers of pesticides like DDT, sparking widespread concern over their persistence, systemic contamination, and the need for regulatory shifts in the US. Carson's book also brought attention to the ethical issues arising from corporate-financed chemical research and the lack of transparency and freedom of scientific research. After its publication, the US modified its policies on the use of agrochemicals, banned the use of DDT in agriculture, and created the Environmental Protection Agency in 1970 (DeMarco 2017).

Two key examples of international anti-pesticides civil society initiatives are the Pesticide Action Network (PAN) and the International Monsanto Tribunal (IMT). Created in 1982 in Malaysia, PAN is a coalition of more than 600 NGOs working in 90 countries to raise public awareness and promote the transition from hazardous pesticides to safer, socially just, and ecologically sound alternatives. PAN was an important voice leading to the Stockholm Convention on Persistent Organic Pollutants, signed in 2001 (PAN 2022). More recently, the IMT, a legal opinion tribunal, was created by a coalition of organizations and activists, including Vandana Shiva and Marie-Monique Robin. It took place in 2016–2017 in The Hague and integrated five judges who, after assessing evidence and testimonies on glyphosate, concluded that Monsanto (now Bayer) does not act in conformity with the human rights to a healthy environment, health, food, and the freedom of scientific research. The Tribunal recommended that the crime of ecocide –the crime against ecosystems– be included in the Rome Statute alongside crimes against humanity, genocide, war, and aggression. The judges determined that if ecocide were recognized by international law, glyphosate could be considered a tool of this crime. As a conclusion, the IMT highlighted the need for better regulations to protect both the victims of multinational corporations and the environment (IMT 2017).

From these initiatives, we identify two major challenges that independent scientists and movements face. One is the 'politics of knowledge production', meaning how the knowledge about pesticides is created, accepted, circulated, or ignored. A second one is the lack of legal channels to achieve compensation or reparations from corporations and governments for health and environmental damages (Brisbois, Spiegel, and Harris 2019; Shattuck 2021; Welz 2020). And even when court cases are successful for movements, companies often fail to comply with judicial orders (Conde et al. 2023). The use of compensation as a means of delivering justice and repairing affected communities raises critical questions about the incommensurable value of harms such as cancer, giving birth to a child with a malformation, or ecocide. The persistent impacts of pesticide exposure further challenge the adequacy of such compensatory approaches, highlighting the need to rethink what justice entails and how it can be achieved (Navas, D'Alisa, and Martínez-Alier 2022).

Corporate interests often shape scientific and political agendas, regulatory frameworks, and public discourse, as illustrated in the European Union's report, 'Late Lessons from Early Warnings' (Gee et al. 2013). A clear example is given by Bayer, which has come under pressure in Europe as several scientists have argued that neonicotinoids are the most toxic insecticides ever produced and that they must have been banned years ago. Although a growing body of scientific research documents the ecological impacts of these substances – including their effects on insects, birds, and broader ecosystems – corporate actors have frequently downplayed or countered these findings through selective research funding and public relations campaigns, while questioning the credentials of independent researchers, which represents an open violation of information and freedom of scientific research (Welz 2020).

For their part, movements use diverse strategies to document the health impacts of pesticides and push for greater accountability. In Argentina, 'popular epidemiology', as a form of mobilization, is a good example. Local communities, particularly women, established a connection between the health impacts identified in their communities (cancer, birth defects, miscarriages, respiratory problems) and the proximity of fumigations

through the creation of handmade maps. While the agribusiness sector still questions the toxicity of glyphosate, and local and national authorities delay action on the matter, their findings led to legal restrictions on pesticide spraying near homes and schools (Arancibia and Motta 2019). In collaboration with scientists and experts, affected peri-urban communities prompted a provincial justice to sentence contamination with agrochemicals as a criminal offense of willful pollution to the environment and public health. Following this emblematic case in 2009, another provincial justice inverted the responsibility of providing proof by requesting the government to prove that glyphosate is not harmful to human health (Arancibia 2013).

In Mexico, peasant communities have established their own health and agroecology committees, which collectively aim to identify the connection between the use of agrochemicals, environmental degradation, and human diseases (Hernández Rodríguez 2018). The overuse of pesticides without protection, the fumigations in communal areas such as collective gardens or household backyards, the pollution of water bodies, and the consumption of contaminated foods are considered to be the main causes leading to the sharp increase in diseases among these communities (Hernández Rodríguez 2018; Ponce-Caballero et al. 2022). Although the federal government has itself advanced a political agenda to ban glyphosate, which has been indefinitely postponed among the maize-corn controversy with the US, the issue of reparation to communities is lacking (Nelson, Gomez Tovar, and Gómez Cruz 2024). The Mexican case exemplifies that, beyond the rise of a collective awareness about the impacts of pesticides, it has been difficult for communities to figure out how their knowledge can be formulated in legal terms, mainly because of the difficulties in establishing clear causation between exposure and damage that can be presented in a tribunal. This situation raises the question of what kind of knowledge is valid for engaging in legal battles, particularly when compensation and recognition are needed. As Navas (2022) points out for the case of Dibromochloropropape (DBCP) in Nicaragua, sometimes the evidence remains 'undone', rendering invisible not only the harm itself, but also the possibility of demanding accountability and reparation. Collaborations among lay people, scientists, lawyers, and physicians in the Argentine case speak to the need for multiple forms of knowledge and coordination among different actors to influence decisions regarding risk.

The targeted campaigns that concentrate efforts on contesting a single corporation (i.e. Monsanto, Bayer) or a single active ingredient (i.e. glyphosate, neonicotinoids) illustrate another challenge for movements opposing the pesticide industry. These campaigns have yielded key victories and made evident the systemic nature of agrochemical corporations and pesticide dependence. Although Monsanto's glyphosate has been successfully targeted by grassroots movements, governments, and international agencies, the merger with Bayer in 2018 did not imply the collapse of this pesticide market. The Mexican case suggests that focusing solely on one pesticide, in this case glyphosate, is becoming more a political move from the government to strengthen alliances with social movements and environmentalists than a realistic approach to regulating the growing generic market and promoting the agroecology national agenda (Fox and Garcia Jimenez 2024; Nelson, Gomez Tovar, and Gómez Cruz 2024). In Costa Rica, according to Castro's research on pesticide regulation, anti-pesticide movements also hold a critical reflection on this issue. Although important victories have been achieved in banning pesticides such as the herbicide bromacil and the fungicide chlorothalonil, movements reflect on the scope and

results of these bans. Even though these molecules are no longer in circulation, they persistently appear in chemical water analysis, and there has not been a change towards less chemicalized agriculture systems following these bans. In the opposite direction, there has been considerable uncertainty about which pesticides are being used as substitutes, and frequent doubts whether bromacil and chlorothalonil are still being available through illicit markets, and thus still applied (Castro-Vargas 2025; Castro-Vargas and Werner 2022;).

In response to the structural nature of the corporate agrochemical-seed system, communities and movements have successfully articulated campaigns that confront multiple dimensions. Struggles for national sovereignty and against giant corporations have manifested in opposition to the coupling of GMs and pesticides. In the case of Mexico, for instance, food sovereignty first crystallized as a defense of Mexican maize in the context of the free trade agreement with the US and Canada, which required the opening of the Mexican maize market to imports of GM corn (Richard 2012). Soon after, the opposition expanded to GM soy and glyphosate, allowing the struggle to focus against Monsanto (Gómez González 2016). Although Mexico has become the largest market of American GM corn and glyphosate continues to be the most used herbicide in the country, nonetheless there have been important achievements for food sovereignty movements regarding four issues: the ban of cultivating GM corn and soy in Mexican territory, the implementation of measures to protect native maize varieties, and the government intention to ban glyphosate and advance agroecology as a national agenda (Barrera 2025; Fox and Garcia Jimenez 2024; INPI 2025; Wise 2024). Argentina is another case in which the battle against GM soy and glyphosate is closely linked and has become central to the national debate, as GM soy is the country's most important agricultural commodity for export and tax revenue.

However, there are still important issues that have yet to be addressed by anti-pesticide movements. One is the racial geographies of pesticide use and exposure and the structural violence in national agricultural markets (Slocum, Cadieux, and Blumberg 2016). Taking the Argentine case to illustrate this point, given the economic and cultural dominance of industrial agriculture for export in the country, anti-pesticide activist groups have neglected to engage with the exposure of migrant farmers to pesticides used in fresh vegetable cultivation, a marginalized agricultural sector in the country (Marini 2023). To advance their goals, anti-pesticide groups deploy discourses that flatten pesticide users when farmers' racial, migrant, and legal status significantly differ in GM soy and fresh vegetable cultivation. The kind and toxicity of pesticides used, the application methods, the frequency of fumigation, and the spatial concentration of chemicals in soy agribusiness and fresh vegetable cultivation also differ greatly. Moreover, relying on national and provincial environmental protection legislation to demand the fulfillment of their right to a clean environment, anti-pesticide actors leave migrant farmers unseen and unprotected. Despite well-intentioned efforts towards socio-environmental justice, exclusionary strands of anti-pesticide and agroecology activism risk perpetuating a double standard in food systems – one that privileges access to uncontaminated food and environments for some, while ignoring the toxic burdens borne by others. Alternatively, by engaging with the use and exposure to toxicity of marginalized farmers, the mainstream agroecological project would be capable of denaturalizing patterns of exclusion while establishing crucial collaborations with subaltern actors already pushing for the expansion of grassroots agroecology as a means for social transformation (Marini 2023).

Another question that requires further research is how communities envision and move from conventional, pesticide-intensive agriculture toward less chemicalized production systems and/or agroecological alternatives, especially when existing systems have been shaped by decades of chemical dependency and labor restructuring. As we have discussed, agrochemicals have contributed to reducing labor, allowing peasants to minimize production costs, work in highly degraded soils, and engage in non-subsistence activities. It is still necessary to discuss how these issues will be resolved and what the roles of markets and governments are in supporting communities throughout this transition, without ignoring the need to acknowledge, repair, or compensate for the health and environmental damages caused by the long-term exposure to agrochemicals.

We also want to highlight the different meanings of agroecology as the productive basis for food sovereignty**.** In some contexts, agroecology is framed primarily as a set of environmentally sound agricultural techniques, similarly to organic farming, a perspective that can obscure the structural political-economic forces shaping agrarian systems and fail to challenge broader capitalist dynamics essential for FS (Guthman 2014). In Costa Rica, for example, some agroecology-inspired initiatives operate as isolated enclaves of privilege, situated within broader rural landscapes dominated by large-scale, pesticide-intensive monocrops. These spatial disparities contribute to entrenched patterns of environmental injustice and rural health inequality (Castro-Vargas 2025). In contrast, the Mexican case illustrates that communities' understanding of agroecology can go beyond agrochemical-free agriculture and is broadly construed as the collectivization of labor and resources. Collective production, however, has proven to be an efficient way for communities to produce organically without the burdens of increased labor and time use (Hernández Rodríguez 2023). Not surprisingly, cooperatives working with fair trade, solidarity, and/or organic markets seem to be the ones benefiting the most in the long term (Jaffee 2007). This suggests that solidarity markets, which pay higher and/or better prices to farmers, are significant incentives for communities to transition towards a type of agroecology characterized by agrochemical-free, agrodiverse, and ecosystem- and soil-health-focused agriculture. Still, it is important to emphasize that for these communities, collectivization and political organization are at the core of agroecology (Orozco-Meléndez and Paneque-Gálvez 2022). The multiple definitions, horizons of collective memory struggle, degree of collectivization, and reliance on external chemical inputs require sidelining a plain understanding of agroecology-based food sovereignty as agrochemical-free agriculture.

## 6. Conclusions

Pesticide use poses one of the most intractable challenges for agrarian movements committed to food sovereignty. This paper has explored the intricate (dis)connections between pesticide use and food sovereignty. As we have shown, pesticide use is not only a hallmark of industrial agriculture but also deeply entangled in the everyday practices and survival strategies of smallholders and peasant communities, often not by choice. Through examining structural drivers, farmer challenges and subjectivities, politics of exposure and harm, and movement responses, we argue that pesticide use must be critically situated within food sovereignty debates rather than simplistically condemned.

By foregrounding the complex realities of agrarian life in chemical-dependent agroecosystems, this paper intends to contribute to a more nuanced and inclusive perspective of food sovereignty.

To sharpen FS's critical focus and alliance-building capacity, we revisit its six pillars, informed by the previous sections. Regarding the *food for people* pillar, we recognize that pesticide use has played an important role in food production. Pesticides' role in augmenting labor productivity should not be understated. Reconciling this fact with the tenets of the FS project represents a key challenge. Yet, in the long run, it is clear that agro-food systems reliant on pesticides undermine the social and ecological basis that is key to advancing FS. Hence, pesticide use, especially highly hazardous ones, is indeed incompatible with the FS pillar *working in harmony with nature*. The intrinsic toxicity of pesticides and the dependency of farming on fossil fuels make them ecologically unsustainable. And yet we ask, to what extent do certain pesticides used under specific circumstances play a role in building farmers' autonomy? In this sense, more multidisciplinary research is needed to assess which specific pesticides, and in what contexts, can support the political commitment of the FS movement to prioritizing people's food needs. This research must go hand in hand with recognizing traditional knowledge and agroecological practices as vital foundations and a transition towards just and sustainable food systems.

When considering the *localizing food systems* pillar, pesticides play a crucial role in industrialized food systems, which are rooted in export-oriented agriculture commodities and global supply chains. Still, pesticides also have the potential to contribute to a vision of sovereignty that prioritizes domestic over non-domestic production, as they can be part of agriculture programs aiming to strengthen food security. However, as smallholders' dependence on pesticides deepens, the pillar *making decisions locally* is increasingly challenged by the top-down transfer of knowledge and the structural constraints imposed by the global pesticide complex on farmers' choices and decisions. Recognizing how small farmers navigate constrained choices on pesticide use is essential to respecting their decisions as agricultural producers.

Regarding *building knowledge and skills*, in general terms, the technological package of conventional agriculture, including pesticides, has contributed to erasing traditional agricultural knowledge and practices. In contemporary food systems, the industry primarily leads knowledge transfer on pesticide use, as shown in section 3. However, smallholders also practice a 'combination' of expertise and skills, drawing from pesticide use practices, traditional knowledge, and agroecological techniques, due to a series of factors we discussed above. Recognizing such an ongoing knowledge shift among farmers is a critical step toward advancing the construction of food sovereignty today. Instead of understanding traditional knowledge as fixed in the past, we consider that it still needs to be empirically and theoretically addressed: the question of how farmers' knowledge is evolving and will continue to evolve amidst the climate and biodiversity crisis, where it is expected that the virulence and resistance of diseases, pests, and weeds will increase. In this sense, we urgently need to create alliances among scholars, communities, and social movements to develop skills and methods for mitigating the climate and environmental crises while reinforcing environmental justice. *Building knowledge* also intersects with research and documentation on pesticide health effects. It is key to develop mechanisms that validate and incorporate popular and lay knowledge, not just scientific

research, as credible evidence in addressing pesticide exposure, contamination, and associated health consequences. The 'embodied knowledge' of pesticide harm has been essential for local communities in seeking reparations, as shown in section 5, but it is often dismissed as incomplete and rarely considered valid evidence (Shattuck 2019). Another dimension of building knowledge and skills involves demanding transparent access to data on pesticide imports, exports, and use on a country, regional, and global level, which would enable scholars and activists to evaluate agricultural dynamics and trends.

*Valuing food providers* could benefit from a broader framing that includes landless farmers and smallholders who actively (and even eagerly) participate in agribusiness structures and not just those who reject them. Earnest attention to these efforts can also elucidate the ways that pesticides may simultaneously underwrite and undermine smallholder livelihoods and local food production. Valuing food providers also means to fight for stricter regulations of pesticide use and exposure, both in industrial and small farmer agriculture, and to demand adequate access to health, taking into account the structural inequalities posed by race, ethnicity, gender, and migratory status – issues closely related to social movements for the rights of undocumented immigrant agricultural labor. It is also necessary to better understand the health consequences of pesticide exposure to advance national health policies and prevent pesticide-related diseases. We also consider that food sovereignty movements must demand the right to information about the environmental and health impacts of pesticides. Achieving these goals requires safeguarding the freedom of research as a fundamental condition.

Instead of providing concrete answers, the paper calls for initiating an open discussion on whether pesticide usage can be critically considered in a food sovereignty project that acknowledges the reliance of contemporary agrarian capitalism on pesticide inputs. We propose a more inclusive framing of the FS agenda that would allow the integration of farmers involved in more conventional input-dependent agriculture. Conceiving the use of pesticides as part of a multifaceted set of vital strategies for sustaining livelihoods, albeit with its contradictions, offers fertile ground for alliance-building across rural and urban agrarian actors located at different intersections of power asymmetries in the global pesticide complex. However, as rural communities have experienced firsthand, in their bodies and environments, pesticides have harmful effects and undermine the conditions necessary for long-term subsistence. Awareness of the scope and intricacy of the current configuration of the pesticide complex, which we have analysed in this article, is key for movements struggling for a systematic change. Alliances between scholars studying pesticides, anti-pesticide movements, and agrarian movements could contribute to pushing back the entrenched chemicalization of agriculture, considering the multiple lessons learned from different movements and how victories and achievements, even those that may seem small, matter on the ground.

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## Author contributions

CRediT: **Soledad Castro-Vargas:** Conceptualization, Formal analysis, Investigation, Supervision, Writing – original draft, Writing – review & editing; **Carol Hernández Rodríguez:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing; **Grettel Navas:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing; **Enrique Castañón Ballivián:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing; **Yunan Xu:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing; **Daniela Ayelén Marini:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing.

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## Notes on contributors

***Soledad Castro-Vargas*** is a postdoctoral researcher at the Department of Geography of the University of Zurich, Switzerland. She holds a PhD in Environmental Science and Technology from the Institute of Environmental Science and Technology (ICTA) of the Universidad Autónoma de Barcelona. Her research focuses on plantations, pesticides, and waterscapes from a multidisciplinary perspective, integrating approaches from political ecology, critical agrarian studies, and tropical ecotoxicology.

***Carol Hernández Rodríguez*** is an environmental sociologist and Assistant Professor at the University Program of Bioethics of the National Autonomous University of Mexico. Her research examines the intersections between Indigenous agrobiodiversity, climate change and climate justice, agrifood systems, seed sovereignty movements, and environmental ethics.

***Grettel Navas*** is an Assistant Professor at the Department of Political Studies, Facultad de Gobierno, Universidad de Chile. Her research focuses on political ecology, environmental conflicts, critical agrarian studies and toxic pollution. She is an active member of the Latin American Political Ecology Group (CLACSO-Abya Yala) and part of the Direction and Coordination Group of the Global Environmental Justice Atlas (EJAtlas).

***Enrique Castañón Ballivián*** is a Lecturer in International Development at the Institute of the Americas, University College London. He researches the dynamics, theory and politics of agrarian change and environmental governance in Latin America, with a focus on agribusiness expansion and resource politics.

***Yunan Xu*** is an Assistant Professor at the Centre of Development Studies in the Department of Politics and International Studies (POLIS) at the University of Cambridge. Her research experience and interest revolve around the agro-food system and land politics underlying a China-world interconnection lens. Email: xuyunancindy@gmail.com, yx428@cam.ac.uk

***Daniela Ayelén Marini*** is an Assistant Professor in the School of Interdisciplinary Studies at Grand Valley State University in Allendale, MI. She completed her PhD in Geography at the University of Colorado, Boulder, in 2020. She holds a degree in Biological Sciences from the National University of Río Cuarto, Córdoba, Argentina (2008) and a Master of Science in Forestry from the Yale School of the Environment (2012). Her academic work mobilizes a political-ecological analysis to investigate racial, class and gender dynamics operating in and through food and environmental activism in Argentina and the U.S. She is a member of the Collective of Agrarian Scholar-Activists from the South (CASAS) since 2019.

## ORCID

*Soledad Castro-Vargas* http://orcid.org/0000-0002-1040-0580
*Carol Hernández Rodríguez* http://orcid.org/0000-0002-6180-8164
*Grettel Navas* http://orcid.org/0000-0002-4727-8259
*Enrique Castañón Ballivián* http://orcid.org/0000-0003-4443-6845
*Yunan Xu* http://orcid.org/0000-0002-4520-1207
*Daniela Ayelén Marini* http://orcid.org/0000-0001-5128-0872

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