

Pesticide use in Mexico and the reverse logistics approach: a literature review

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Abstract

A literature review on the use of pesticides in agriculture in Mexico and the reverse logistics approach was conducted to understand their current use and the potential for applying this approach in the sector. Content analysis was performed using academic search engines, artificial intelligence, and official statistics. The pesticide industry in Mexico represents a market of great economic importance; nevertheless, information on their use and usage characteristics is limited. Pesticides have contributed to agricultural productivity but have also generated negative externalities in health and the environment. Reverse logistics has few papers in agriculture, as most studies are simulations or specific cases, without applicable standardized methods, which represents an area of economic opportunity and academic research.

Keywords:

artificial intelligence, containers, reuse.



Introduction

With the green revolution, the use of agrochemicals and pesticides intensified, which generated growth in production and the economy; however, in the seventies, the negative impacts on the environment and people's health were not considered (Dias *et al.*, 2017) nor was the fate of pesticide containers questioned (Marques and Vieira, 2015); they, according to FAO (2014), are substances intended to control pests and the growth of weeds in crops. The management of pesticide containers (PCs) should be considered of interest among the topics of study of reverse logistics (RL), for their reuse or elimination, which influences public health in rural areas and the environment (Ballesteros and Ballesteros, 2007; Contreras and Silva, 2014).

There is a relationship between RL and corporate social responsibility (CSR) in terms of the implementation of environmentally friendly practices and benefits to society (Gómez *et al.*, 2012), as it represents a competitive advantage (Reyes *et al.*, 2008). RL has focused more on the industrial sector than on agriculture (Contreras and Silva, 2014); therefore, it is important to create and design methodologies for the collection, treatment, and destination of PCs.

In Mexico, statistics on pesticide use are limited, as the available data come from national censuses and surveys of the agricultural and industrial sectors, which, although useful, do not offer regionalized or specific information by crop (Silveira-Gramont *et al.*, 2018; OCDE, 2021). The objective was to conduct a literature review on the use of pesticides in Mexico and RL to identify their overall situation and the application of this approach in the primary sector.

Methodology

The methodologies applied were those of Campoverde *et al.* (2022); Contreras and Silva (2014), who focused on literary and content analysis. Indexed academic papers were reviewed, along with the Agricultural Census, the National Agricultural Survey (ENA, by its Spanish acronym), the Monthly Survey of the Manufacturing Industry, OCDE and FAO reports, as well as portals of specialized consulting companies.

Through website taxonomy, Google Scholar, Scopus, DOAJ and Redalyc were used and 117 000 results were obtained for 'reverse logistics', 48 000 for 'pesticides in Mexico' and 2 620 when combined; when narrowing the search interval for any type of document, the result decreased to 455 (years 2020-2024) and when specifying papers related to agriculture and RL, it decreased to 14. In the first stage, the approach, concepts, and models of RL were reviewed, with a later focus on pesticides.

More than 100 sources were reviewed, of which just over fifty were selected for the study, considering the relationship between agriculture and RL as a criterion that is, both were present and related in the documents found. Artificial intelligence (Chat GPT 3.5) was utilized through questions about the following: the volume of pesticides in Mexico, RL processes in containers, the concept of RL in agriculture, and companies specializing in this activity within the sector. The search for information was conducted in 2024.

Pesticides in Mexico

According to the 2022 Agricultural Census, Mexico has 32 million agricultural hectares (64% are planted and 17% are not cultivated); in national agriculture, the main problems are high production costs and climatic factors (82%), low sales price (65%), loss of soil fertility (37%), and insecurity (21%) (INEGI, 2023).

The use of pesticides has caused damage to soils, contamination of water tables, effects on the health of operators, and resistance to pests, since technical and economic criteria have been prioritized over environmental ones (Albert, 2005; Ortiz *et al.*, 2014; SAGARPA, 2015; García *et al.*, 2018; Silveira-Gramont *et al.*, 2018); additionally, the lack of specific data by region or crop makes it challenging to assess their negative externalities (Moo-Muñoz *et al.*, 2020; González-Bedoya *et al.*, 2023). These products are classified by pest type, formulation, and toxicity, among others (SADER, 2019).

Although Mexico has a legal framework (DOF, 1988; 1993; 1994; 2009), its implementation is limited by institutional dispersion and the lack of a product life-cycle approach (OCDE, 2021; Mordor Intelligence, 2023). The Mexican laws that regulate them are the General Law of Ecological Balance and Environmental Protection (DOF, 1988), the Federal Law of Plant Health (DOF, 1994) and the official standards NOM-045-SSA1-1993 (DOF, 1993) and NOM-232-SSA1-2009 (DOF, 2009).

In addition, there are agencies related to their regulation, production, and distribution, such as the Secretariat of Health (SSA, by its Spanish acronym), the Federal Commission for the Protection against Sanitary Risks (COFEPRIS, by its Spanish acronym), the Secretariat of Environment and Natural Resources (SEMARNAT, by its Spanish acronym), the Secretariat of Agriculture and Rural Development (SADER, by its Spanish acronym), and the National Service of Health, Safety, and Agrifood Quality (SENASICA, by its Spanish acronym) (DOF, 2009; SADER, 2019). In other words, the country has a legislative and regulatory framework, but the absence of transversality in them, as well as the “life-cycle approach to pesticide management”, has limited its operability (OCDE, 2021; Mordor Intelligence, 2023).

According to data from the INECC (2019); OCDE (2021), the states of Sinaloa, Veracruz, and Oaxaca are the ones that use the highest amount of pesticides; this is caused, among other factors, by monoculture, high yields and intensity in management; some of these crops are corn, sugarcane, tomato, chili, avocado, orange, lemons and grape (Barba and Vázquez, 2021; Mordor Intelligence, 2023). In 2019, pesticide sales exceeded 17 billion pesos (approximately 898 million USD), with an annual growth of 3% between 2013 and 2018. Insecticides are the best sellers, followed by herbicides and fungicides (INEGI, 2019).

It is projected that by 2028, the market will reach 1.61 billion dollars (Mordor Intelligence, 2023); in the country, only 12 of 119 companies are producers; around 80% of the market is controlled by transnationals such as Bayer, BASF and Syngenta (COFECE, 2015; Bejarano, 2018).

Reverse logistics: concepts and their interdisciplinarity

The RL process requires design, collection centers, classification, information systems, and budgeting (Ballesteros and Ballesteros, 2007), so it entails planning, systematization, and integration of resources (Díaz *et al.*, 2004; Reyes *et al.*, 2008). Currently, business competitiveness is related to both productive factors and socioeconomic and environmental impacts (Hurtado, 2020); therefore, production must consider quality and costs, as well as the reduction of negative externalities, where reverse logistics (RL) could be a strategy (Autry, 2005; Bustos, 2015).

Initially, logistics focused on efficiency and specific certifications, such as just-in-time and ISO (International Organization for Standardization), but its focus has evolved towards environmental issues, consumption habits, and climate change (Alshamrani *et al.*, 2007; Bustos, 2015). The initial proposal was put forward by Stock (1992), which focused on the recycling and management of hazardous waste (Campoverde *et al.*, 2022); the most significant contributions on the use of this approach have been in case studies and simulations, particularly in the automotive, electronics, software, and construction sectors; in contrast, in agriculture, the first works emerge until 2005 (Contreras and Silva, 2014).

Reverse logistics in agriculture

Artificial intelligence (Chat GPT 3.5) was used not as a source of authorship but in order to identify the concepts that this tool handles on the subject; in this sense, the AI considers the RL in pesticides “as the process of efficient management and return of empty containers of chemical products used in agriculture”. It focuses on the collection, transport and proper treatment of empty containers to minimize environmental impact and promote sustainability in the agricultural industry: ‘it involves the efficient and safe return of these containers from end users to their final disposal’ (Chat GPT 3.5).

When questioned about the number of companies with RL in agriculture, AI's response was: 'as of my last update in January 2022, I do not have specific information on the exact number of reverse logistics companies in agriculture in Mexico'. Similarly, when inquiring in the AI about the amount of pesticides used, it was found that there are no specific figures on the amount used in Mexican agriculture for a given year, which shows that a problem for the use of pesticides in Mexico is the lack of official information and statistics either by crop or region, since the data that can be accessed are general and come from the Agricultural Censuses, the National Agricultural Survey (ENA), by its Spanish acronym and the monthly survey of the manufacturing industry; although these have data on volume and prices, they lack information by regions, forms of use by crops and quantities, among others (Silveira-Gramont *et al.*, 2018; OCDE, 2021).

By citing this paper in Chat GPT 3.5 and requesting a 120-word abstract, the AI states that: the Green Revolution in the 60s increased the use of pesticides in Mexican agriculture, boosting economic growth. However, the environmental and health impacts were neglected. The management of pesticide containers becomes a critical issue, being fundamental in reverse logistics (RL). Although RL in agriculture has received less attention, its importance lies in public health, the environment, and corporate social responsibility. The lack of official information on the use of pesticides in Mexico is a challenge. The literature review addresses pesticide use and RL, identifying the need for further research in this field (Chat GPT 3.5).

Similarly, the AI establishes that the research needs in Mexican agriculture are focused on eight topics: impact of pesticides on health and the environment, data collection on pesticide use, design of standardized methodology of RL in agriculture, analysis of negative externalities, sustainability and competitiveness, sustainable technologies, inter-institutional coordination, training, and awareness-raising. In addition, the AI establishes as needs for RL the standardization of processes, adoption and adaptation of emerging technologies, design of collection networks, life cycle assessment, inter-industry collaboration, research on circular economies, education and awareness, regulation and policies, social impact assessment, adaptation to e-commerce, and awareness raising (Chat GPT 3.5).

On the other hand, when requesting information on global companies dedicated to the sale of pesticides in Mexico, the result was: Syngenta, Corteva Agriscience, and FMC. Regarding only the world's leading companies related to RL, it includes Walmart, Coca-Cola, and Dell, and among the organizations, the Council of Supply Management Preprofessionals (CSCMP), the Institute for Supply Management (ISM), and the Reverse Logistics Association (RLA).

Discussion

RL has been based more on the secondary sector of the economy (transformation) (Contreras and Silva, 2014), and many of the studies focus on design, planning, and simulation (Castelblanco *et al.*, 2012; Contreras *et al.*, 2013; Días *et al.*, 2017; Silva-Rodríguez and Contreras, 2022; Silva, 2022); on case studies in specific regions or areas (Contreras *et al.*, 2013; Silva-Rodríguez, 2017; Mejía, 2018); in several cases, it is an empirical process that cannot be considered as RL (Contreras *et al.*, 2013; Silva and Contreras, 2015; Chapoñan and Portugal, 2019; Silva, 2022); therefore, an area of research opportunity could be opened if it were related to agriculture.

Mexico has established a legal framework for the use and utilization of pesticides; nonetheless, its operation is limited as it is divided into several agencies, so transversality is required (Ortiz *et al.*, 2014; Esquivel-Valenzuela *et al.*, 2019). Due to the lack of clear information on the use of these products either by crop or region, it is essential to estimate the potential based on the type of pesticides, characteristics of the containers and specific periods of use in the different agroecological regions of the country.

According to (Días *et al.*, 2017; Silveira-Gramont *et al.*, 2018; Moo-Muñoz *et al.*, 2020; OCDE, 2021), this aspect would allow the externalities and the application of RL in the primary sector to be measured and quantified (Ramírez, 2007; Montes-Castillo and Rodríguez-López, 2021). Thus, the documented efforts of RL in agriculture have been empirical case studies lacking methodology or systematization; therefore, it may represent an area of economic and environmental opportunity (Ramírez, 2007; Salas, 2020).

It has been documented that 88% of companies that market agrochemicals and pesticides offer some training to their employees to encourage their customers to return the packaging and dispose of it properly; however, only 38% dispose of it correctly (De Almeida and De Souza *et al.*, 2023). In this sense, it is equally important to create regulatory and control schemes that are easy to access, operate, and apply, taking advantage of institutional support, and the 'life-cycle approach to pesticide management' has limited their operability (OCDE, 2021; Mordor Intelligence, 2023) since in Mexico, there has been no discussion and analysis on co-responsibility in the use of pesticides, which should be quadripartite, between government, companies, input distributors, and producers, as each component must assume its responsibility.

When searching for companies dedicated to RL in agriculture, the AI does not have any type of information, which could be the result of little or no legal obligation to return containers, the lack of adequate structure, and the lack of supervision (Días *et al.*, 2016). It has been documented that most PCs are disposed of incorrectly and that the RL process is poorly applied since many of the containers are burned and discarded in the same agricultural fields (CCA, 2014); in addition, Días *et al.* (2017) mention that about 83% of farmers do not return containers and do not comply with environmental and use recommendations due to lack of training, motivation, and awareness. RL is a recent approach, which is likely the reason why there is no standard definition of it (Baranau and Lisec, 2020).

Research and public policy needs

The first need for research is the exact quantification of the amount of agrochemicals and pesticides used in the country, their spatial distribution, and by crop. This is to have more information when making decisions. The methodology would be mainly through the producers and distributors of agrochemicals.

The second is the quantification close to reality of nature's assimilation capacity, that is, the biodegradation capacity of agrochemicals, to stipulate in public policies actions not to exceed that limit. The third would be to economically assess the negative effect of the excessive use of pesticides and agrochemicals in order to internalize the negative externalities of their use; that is, that the main users (producers) take responsibility for the negative cost of the use of these products under government regulation and supervision, either through taxes or through a specific type of activities that give back to the environment.

The fourth would be to establish inter-institutional coordination for the registration, control, and distribution of agrochemicals and pesticides used in food production. Finally, designs of public policies that contemplate the needs of agricultural producers and the demands of final consumers of agricultural goods and services to reflect the willingness to pay for healthier products for humans and nature. In general, it is necessary to develop the capacity for scientific and technological research in Mexico for decision-making based on the results of *in situ* research, and for each of the actors to assume their responsibility.

Conclusions

In Mexico, pesticides and agrochemicals are conventionally used in commercial agriculture; therefore, it is necessary to estimate, through regional and state information, their mode of use, use and volume, which would allow us to model the destination and reuse of containers, which are generally non-biodegradable and highly polluting plastic containers, their disposal can become a polluting axis of the environment and health in the operators.

Reverse logistics (RL) can be an approach and strategy that helps to solve this problem; nevertheless, it lacks a standardized and adequate model for the containers and packaging of these pesticides, so it is necessary to generate and develop models applicable to the primary sector, which would represent an area of economic, environmental, and research-development opportunity.

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