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ENVIRONMENTAL ATTITUDE DUE TO THE USE OF GLYPHOSATE IN AGRICULTURE IN THE LOWER BASIN OF THE JAMAPA RIVER IN VERACRUZ, MEXICO

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ABSTRACT

Currently, there is a debate about the toxicity and consequences of glyphosate use on human health and the environment. The objective of this work was to estimate the level of use of this herbicide and the environmental attitude of farmers. The hypothesis was that glyphosate use is low in agriculture and the environmental attitude is unclear. For this purpose, a total of 103 questionnaires were distributed to farmers in Jamapa and Medellín in Veracruz, Mexico, to gather socioeconomic, technical-productive, and attitude data. The information was analyzed through descriptive statistics and parametric (*t*-student) and non-parametric (X^2) tests. According to the findings, farmers have an average age of 60 to 63 years, work in agriculture, and have an average level of education equivalent to incomplete primary school. The type of tenure of the production unit between municipalities was found to be statistically different ($p < 0.05$). In Jamapa and Medellín, the average land extension was 6 and 9 ha, respectively. The predominant crops are maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), and grass (*Panicum maximum* Jacq. cv. Tanzania), mainly rainfed and for self-consumption or local and/or regional sale. Weeds are moderately affected when chemical herbicides are used, with glyphosate being the main herbicide for both agricultural and non-agricultural use. It was found that 94–98 % of farmers do not use safety measures and do not receive technical training. Glyphosate is used sparingly by farmers in agricultural practices. However, the general perspective is that it has a negative impact on the environment and people's health. There is a difference of opinion regarding the risk in the use of glyphosate and the environmental attitude in the disposal of containers and application of personal prevention measures.

Keywords: herbicide, agroecosystems, weeds, contamination.

INTRODUCTION

The use of agrochemicals such as fertilizers and pesticides is widely accepted in agriculture and has increased significantly since the "Green Revolution" model, which aimed to boost agricultural productivity and profitability. However, its externalities caused serious consequences, including environmental degradation, human diseases, and socioeconomic effects, primarily on small farmers (Ceccon, 2008; Martínez-Centeno and Huerta-Sobalvarro, 2018).

Inadequate management and constant pesticide abuse endanger human and wildlife health. If this trend continues, it may lead to a food crisis and imminent damage to human health. The social and environmental damage caused by pesticide contamination was first described by Rachel Carson in her book "Silent spring," published in 1962, and today we face the problems described by this author as a result of the excessive and uncontrolled use of different types of pesticides. Soil degradation, loss of biodiversity, increase in human diseases, and contamination of food and water are notorious (Díaz-Vallejo *et al*., 2021).

Pesticide contamination is a global problem that persists. Products such as dichlorodiphenyltrichloroethane (DDT), chlorpyrifos, and paraquat are banned in some countries. In the case of Mexico, DDT is classified as a "restricted use" compound, while paraquat and chlorpyrifos are not restricted (COFEPRIS, 2024). In contrast, new pesticides are entering the market or are in the process of approval and/or prohibition due to the risk they represent. An example of this is glyphosate (N-phosphonomethylglycine, $C_3H_8NO_5P$), which was marketed under the trade name Roundup® in the 1970s and is now being debated globally due to its toxic effects (Fernández-Peña *et al*., 2023; Novotny, 2023).

Glyphosate has been associated with a decrease in soil microorganisms and pollinating insects such as bees (Cullen *et al*., 2023), which may have repercussions on the alteration of biogeochemical cycles and food production. In addition, several toxicological studies have identified damage to the development of aquatic organisms (Kale *et al*., 2023; Bellot *et al*., 2023). Glyphosate contamination alters both surface and groundwater quality; in addition, the use of this herbicide is a precursor of diseases, mainly in agricultural workers through direct contact (Rydz *et al*., 2021). However, another route of contact with the population is the consumption of contaminated food or drinking water (Gomes *et al*., 2020; Rampazzo *et al*., 2023). Glyphosate concentrations have been reported in the urine of workers and pregnant women, which is alarming because of the effects it could cause (Dou *et al*., 2023; Fuhrimann *et al*., 2023).

In Mexico, the presence of this compound has been reported in surface and groundwater, as well as commercial bottled water (Rendón-von Osten and Dzul-Caamal, 2017; Reynoso *et al*., 2020). Although its application is designed to increase agricultural efficiency, its presence can alter several natural processes in the ecosystem, affecting biodiversity and the quality of natural resources. In 2019, the Ministry of Environment and Natural Resources (SEMARNAT) of Mexico applied the "precautionary principle" to stop the importation of glyphosate. In 2020, a presidential decree was published, indicating the "gradual substitution" of glyphosate, which would conclude with its total ban by January 2024. However, in April of that year, the ban was postponed until a viable substitution could be found.

Therefore, the objective of this research was to estimate the level of glyphosate use and to statistically characterize the environmental attitude (degree of knowledge, perception, and behavior) expressed by farmers regarding the impact of glyphosate use on the environment and human health. It was hypothesized that glyphosate use in agriculture is low in the lower Jamapa River basin, and farmers' perceptions of the negative effects on the environment and human health are unclear.

MATERIALS AND METHODS

Study area

The Jamapa River basin is located on the Gulf of Mexico slope in the states of Veracruz and Puebla, between the La Antigua and Papaloapan River basins. It covers an area of 3918 km^2 and partially or totally covers 31 municipalities in the state of Veracruz. It includes two important streams, the Jamapa River as the main watershed and the Cotaxtla River as the main tributary. The watershed is divided into three zones according to its altitude and function: high (catchment zone), medium (accumulation-transport zone), and low (discharge zone) (PAMIC, 2017).

The lower basin covers an area of 1355 km^2 and has altitudes ranging from 0 to 400 m. It has a predominantly warm sub-humid climate with an average annual temperature of 26 °C. The region is characterized by its eminently agricultural activity, and to a lesser extent, subsistence fishing (INEGI, 2019). This work was carried out in the municipalities of Medellín de Bravo and Jamapa, located within the lower basin of the Jamapa River in the state of Veracruz, Mexico (Figure 1).

Questionnaire design and application

A questionnaire was created to collect information, and it was divided into four sections: the first one made a brief exposition of the purpose of the research, the second registered aspects related to the socioeconomic profile of the interviewee, the third compiled technical-productive characteristics of the production unit, and finally, the fourth consisted of a series of items established in an ordinal Likert scale to identify the attitude of farmers in relation to the environmental and human health impacts caused by the use of glyphosate, evaluating the cognitive (level of knowledge), affective (perception), and behavioral (way of acting in the face of certain events) components. Five response options were used for each item, assigning a numerical value for analysis: strongly disagree (1), disagree (2), neutral (3), agree (4), and strongly agree (5).

The questionnaire consisted of a total of 48 open and closed questions. Previously, a pilot test of the questionnaire was carried out (December 2021), and some pertinent adjustments were made. Finally, the questionnaire was validated by means of expert judgment, taking coherence, clarity, scale, and relevance as evaluation indicators (Escobar-Pérez and Cuervo-Martínez, 2008). The questionnaire was applied through personal interviews during the months of March to June 2022.

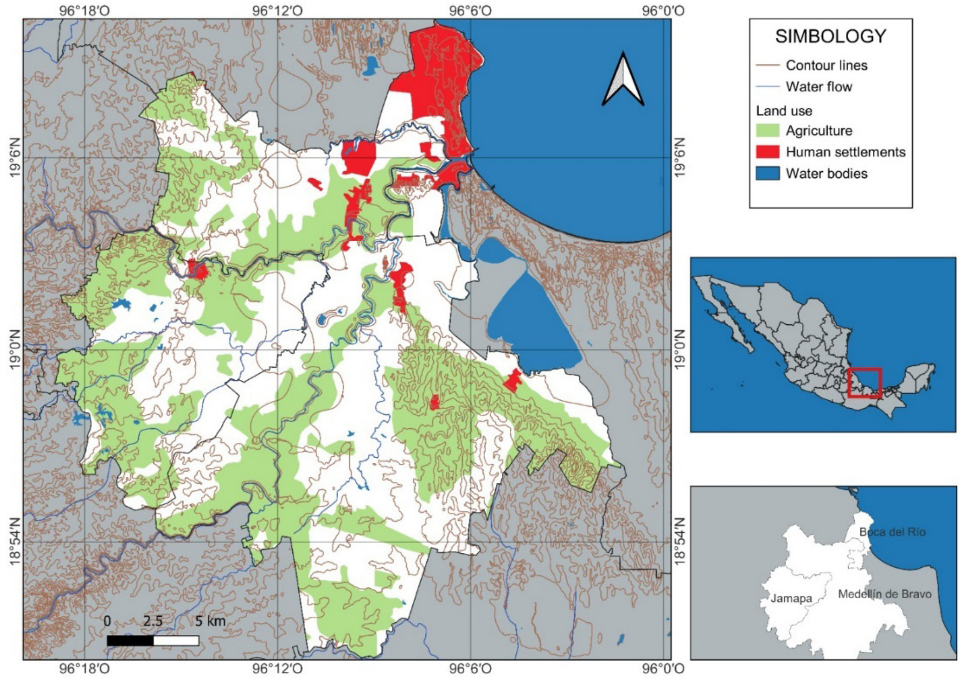

Figure 1. Location of the study area in the lower basin of the Jamapa River in the state of Veracruz, Mexico.

Sample size determination

To determine the sample size for the municipalities of Medellín de Bravo and Jamapa, the number of farmers registered in the Rural Development District (DDR) Veracruz was considered, which was 492 in both municipalities. The estimated sample size was 103 farmers with a confidence level of 95 %. The type of sampling was non-probabilistic, using the snowball technique (Hernández-Ávila and Carpio, 2019); therefore, initial information was obtained from one farmer and other farmers of interest were identified.

Data processing and analysis

The information was captured using Microsoft Excel. Subsequently, the data were analyzed using descriptive statistics and parametric (*t*-student) and non-parametric (chi-squared test) tests. The statistical programs used were Statistica version 7.0 (StatSoft Inc.), IBM SPSS V25 (IBM Statistics; Cary, NC, USA), and Microsoft Excel 2016. Through frequency analysis, the attitude graph by municipality was constructed.

RESULTS AND DISCUSSION

Farmer characterization

A total of 103 farmers were interviewed in both municipalities: Medellín de Bravo (50.4 %) and Jamapa (49.6 %). The farmer profile corresponded to people belonging to the elderly group. The average age in Medellín was 60 years (33–88), while in Jamapa it was 63 years (42–98). No statistically significant differences ($p > 0.05$) were found in the age of farmers between municipalities.

In terms of schooling, more than 60 % have not completed primary school. Most of their working lives have been dedicated to activities related to agriculture and livestock as their main activity, both in Jamapa (80.4 %) and Medellín (90.4 %). A small proportion reported that their primary work activity was permanent jobs in the region or their own businesses (sales of various products), with no statistical differences found between locations ($p > 0.05$).

Both municipalities were mostly represented by the male gender (> 90 %). In terms of agricultural activities, the participation and role of women is very low. However, Leyva-Trinidad (2019) noted that women participated significantly in agricultural activities, despite some social inequality between men and women.

Level of glyphosate use

The type of tenure of the production unit between municipalities was statistically different ($p < 0.05$). In Jamapa, the ejido type is predominant (74.5 %), while in Medellín de Bravo, the small property prevails (65.4 %). The average land area of farms in Jamapa was 6.3 ha and 9.7 ha in Medellín de Bravo. However, statistically, there were no differences ($p > 0.05$). Farmers in both municipalities use their agricultural land for planting and livestock management, mainly cattle.

The predominant crops in the Jamapa and Medellín region are maize (*Zea mays* L.), beans (*Phaseolus vulgaris* L.), and grass (*Panicum maximum* Jacq.), and to a lesser extent, fruit species such as pineapple (*Ananas comosus* (L.) Merr.), mango (*Mangifera indica* L.), and apple (*Byrsonima crassifolia* (L.) Kunth), and vegetables such as papalo (*Porophyllum ruderale* (Jacq.) Cass.) and chili (*Capsicum annuum* L.). However, the position of the predominant crops is reversed in the municipalities. In Jamapa, the main crop is maize, while in Medellín it is grass (Figure 2). The main cropping regime is rainfed. In June 2024, 757.52 ha of corn were planted in Jamapa and 100.18 ha in Medellín (SIAP, 2024). This may be related to the type of tenure of the production unit, the agricultural vocation, and the fact that the number of hectares per farmer is greater in Medellín than in Jamapa. It is important to note that much of what is harvested is for self-consumption and/or local or regional sales in smaller proportion.

The main herbicides used by farmers to control weeds in production units (agricultural use), as well as on the edges of plots, gaps, or roads (non-agricultural use) in both municipalities, are chemical herbicides, including glyphosate, paraquat (1,1′-dimethyl-4,4′-bipyridyl dichloride), and 2,4-D (2,4-dichlorophenoxyacetic acid) (Figure 3). Glyphosate is marketed under the names LaFam®, Faena Fuerte, Durango,

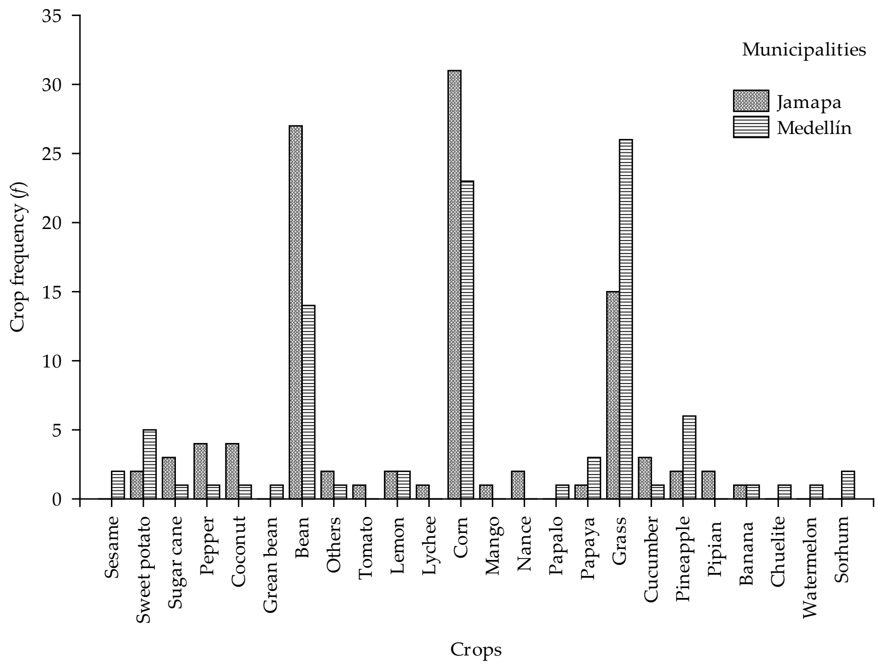

Figure 2. Frequency of predominant crops in the municipalities of Jamapa and Medellín de Bravo in Veracruz state, Mexico.

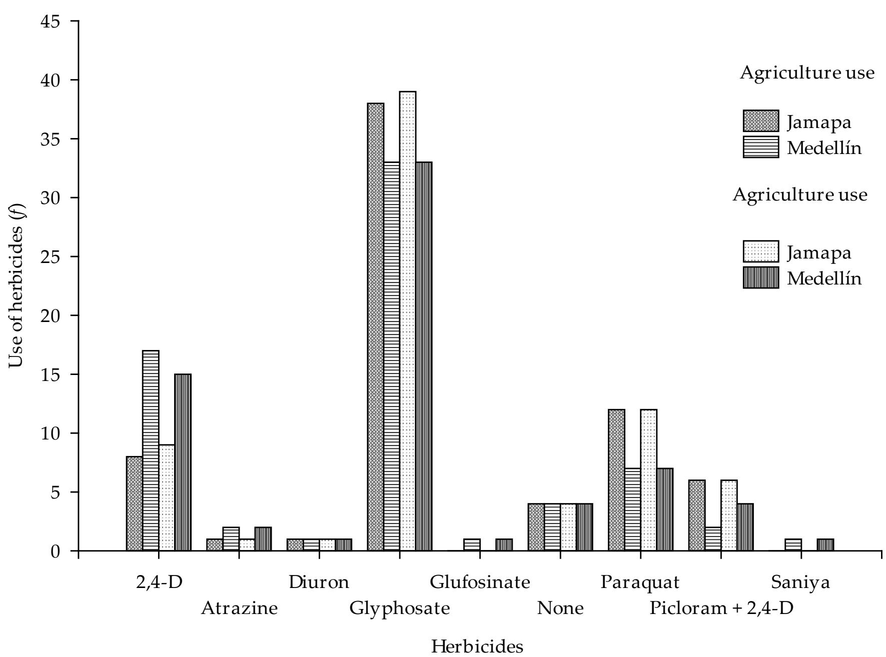

Figure 3. Herbicides used in production units for agricultural and non-agricultural use in the municipalities of Jamapa and Medellín de Bravo in Veracruz state, Mexico.

Glyphosate Technical, Glyfos, or Velfosate. The average dose they use is 1.8 L ha^{-1}, and the season they apply the most is during the rainy season (90 %), where the number of applications is one to three times per crop cycle, and, in general, the application is made in the morning (6 to 8 a.m.).

Farmers emphasize that herbicide applications depend on the growth and resistance of weeds, which are increasingly aggressive and present greater resistance to eliminate them. Alcántara-de la Cruz (2022) points out that the application of herbicides several times during an annual cycle generates the modification of genes in weeds that confer resistance. Therefore, it is important to take into account the type of weeds to be eliminated, rotate herbicides, and try alternatives that allow eliminating dependence on these products. One option could be intercropping, which, although some farmers in the municipalities report using it, there are still very few cases (15–20 %).

The glyphosate dose they apply is lower compared to that reported in northern states of the country or Campeche and Yucatan, where 3 to 5 L ha^{-1} and even more is applied, mainly in soybean, corn, citrus, and vegetable crops (Polanco-Rodriguez *et al*., 2019). However, it continues to be used despite the presidential decree published on December 31, 2020, establishing the gradual substitution and regulation of the acquisition, distribution, promotion, and importation of glyphosate (DOF, 2020). Ramírez-Mora *et al*. (2018) identified glyphosate as the primary herbicide used in the La Antigua irrigation district (DR035) near the study area, where sugarcane cultivation is prevalent. This herbicide has been used since 1995.

Inappropriate and excessive use of herbicides such as glyphosate leads to occupational exposure to pesticides. The safety of agricultural workers is inadequate when handling and applying pesticides. This issue is of vital relevance to human health, given that farmers do not receive training in the proper use of pesticides and measures to reduce the risk of exposure and intoxication. In Jamapa, 16 % of farmers have received technical assistance, while in Medellín only 12 % have received it. Most farmers report that they rely on the experience of other farmers, their own experience, or what is suggested to them in agrochemical stores regarding the type and amount of herbicide to use. This shows that training on the safe use of agrochemicals is a neglected issue where there is still much work to be done.

Regarding the safety measures used by farmers and/or agricultural workers, according to the indications on most pesticide labels and the International Code of Conduct on the Distribution and Use of Pesticides (FAO, 2013), at least a mask, gloves, overalls, and boots should be used. However, of the total number of interviewees, only 2 to 6 % follow what is established in the safety labels and the use of protective measures; the remaining group (94–98 %) only use one or two safety measures (mask covers and/or boots).

In the case of glyphosate, interviewees stated that they do not use safety precautions because it does not have unpleasant odors like other pesticides and that they have been using it for years with no health problems. Farmers reported headaches or rashes, but no other symptoms. Ramírez-Mora *et al*. (2019) reported that 50 % of farmers interviewed in DR035 have presented symptoms of acute intoxication during pesticide application and that most (90 %) do not use safety measures. Sánchez-Alarcón *et al*. (2023) reported that a group of agricultural workers exposed to pesticides without the necessary protection at the time of preparation and/or application presented significant genotoxic damage.

The gradual reduction that would conclude with a total ban on the use of glyphosate in Mexico was postponed. Therefore, the use of glyphosate in agricultural fields will not be eliminated, and its application will continue despite the risks involved in its use. It is important to join efforts and implement training and orientation programs for farmers, since the risk of intoxication during exposure to herbicides such as glyphosate is serious. In addition, it is necessary to work and implement alternatives to reduce dependence on this and other types of pesticides, which will ultimately lead to a reduction in the impact on health and the environment.

Environmental attitude

A general Likert index value close to five indicates a favorable or positive attitude, while values close to one indicate an unfavorable or negative attitude. In the case of both municipalities, the attitude analysis indicates that farmers had a slightly positive attitude (Table 1) based on what they know, observe (cognitive component),

Table 1. Attitudes toward the impact of glyphosate in Jamapa and Medellín de Bravo, Veracruz, Mexico, measured using a Likert index.

Aspects on the impact of glyphosate	Key	Jamapa	Medellín
		IL*	IL*
1. The use of herbicides (glyphosate) affects the biodiversity of agricultural fields.	IGBIO	4.0	3.9
2. The use of herbicides (glyphosate) affects soil quality and fertility.	IGCFSUE	4.2	3.8
3. The use of herbicides (glyphosate) affects air quality.	IGCAIRE	4.0	3.8
4. The use of herbicides (glyphosate) affects water quality and properties.	IGCAGUA	4.0	3.7
5. Herbicide use affects people's health.	IGSALUDH	4.2	4.0
6. Herbicide use has a direct impact on the health of field workers.	IGSALUDTRA	4.2	4.0
7. The use of herbicides has a direct impact on the health of those who apply them.	IGSALUDAPLI	4.2	4.2
8. The water in the Jamapa River is clean and safe for domestic use.	PAUSODOM	4.2	4.0
9. The water in the Jamapa River is clean and suitable for irrigation.	PAUSORIEG	2.1	2.3
10. The water in the Jamapa River is clean and safe for livestock consumption.	PAUSOGAN	2.1	2.6
11. The water of the Jamapa River contains pesticide and herbicide residues from the surrounding area.	PCONTAPLAG	3.6	3.3
12. The water of the Jamapa River carries pesticide and herbicide residues that can be toxic if used for animal consumption.	PERTOXANIM	3.7	3.6
13. Glyphosate (herbicide) residues in the water reduce and eliminate aquatic organisms in the Jamapa River.	PERPERBIO	4.1	4.2
14. By discontinuing the use of glyphosate (herbicides), environmental and human health impacts are eliminated.	PERRESPROB	1.7	1.8
Overall Likert index		**3.5**	**3.7**

IL*: Likert index.

and perceive (affective component) of the negative impacts of glyphosate and other pesticides on human health and the environment (Figure 4).

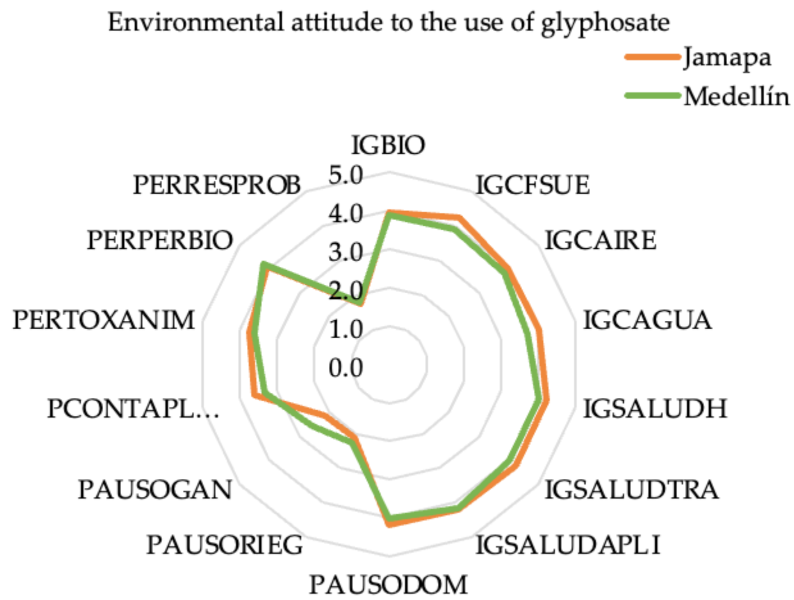

Figure 4. Environmental attitude of the farmers interviewed in the study municipalities in Veracruz, Mexico, by item evaluated (Table 1).

The interviewees have the notion that glyphosate and other herbicides negatively affect ecosystems in the short, medium, or long term, and even emphasized that in previous years (more than 20 years ago), the Jamapa Riverbed had a greater richness and abundance of fauna and flora species; in addition, the water was of good quality and was more reliable for human consumption and recreational activities. Unfortunately, today it can no longer be consumed, and there are fewer and fewer species for human consumption (mojarras, shrimp, among others).

Item 14 (Table 1) reflects that glyphosate is not the only agrochemical that harms the environment, since farmers perceive that there are other contaminants that trigger human health and environmental impacts and that eliminating the use of glyphosate will not end the negative impacts on the environment. Regarding the actions taken to avoid the use of chemical herbicides in Jamapa, 72 % answered that they use agricultural tools (machete, hoe, tarpala) and even weeding by hand; 23 % said none, and 5 % sometimes use agricultural machinery. In the case of Medellín, 60 % use agricultural tools, 23 % use no alternative, and 17 % use agricultural machinery.

They were asked, “What is the final disposal of empty agrochemical containers?” In both municipalities, producers first highlighted “burning,” then “burying or throwing away," and finally, only 20 % of farmers in Medellín and 2 % in Jamapa indicated that they collect them and take them to a special container located in the municipality of Manlio Fabio Altamirano. This practice is of concern in environmental and public health terms, so it is necessary to work and implement actions to mitigate this problem. One example is the placement of special collection containers (Clean Field Program) located in the municipalities of La Antigua and Ursulo Galván in the state of Veracruz, where bins are placed on the roadsides where farmers deposit the containers, and later, personnel from the Ministry of Agriculture collect them for proper disposal.

Both municipalities had similar attitudes toward the environment. Farmers demonstrated a level of knowledge and positive opinion, indicating that they are aware of and perceive the negative impact of glyphosate on the environment and even human health. It was found that there is a dissonance between the opinion and the way of acting, since their behavior is contrary to what was expressed, referring to the incorrect final disposal of empty agrochemical containers and the scarce personal prevention measures when handling and applying this or other products.

The results of this research regarding the environmental attitude towards the negative impacts of glyphosate, the disposal of empty containers, and farmer safety are similar to those reported by Ponce-Caballero *et al*. (2022), who pointed out that farmers do perceive the negative impacts of pesticides; however, they present deficiencies in terms of personal protection and disposal of empty containers, which they associate with age, level of schooling, lack of information, and technical training.

CONCLUSIONS

Farmers in the municipalities of Jamapa and Medellín are small-scale producers and use chemical herbicides to control weeds, with glyphosate being the most commonly utilized. Although the application rate is relatively low, it may be related to what they know or observe of the impacts of this or other pesticides. Based on their years of experience in the field, farmers know and have a positive and favorable environmental attitude. In terms of knowledge or perception of the impact of glyphosate or other agrochemicals, they are willing to use alternative methods (such as agricultural tools and machinery) to combat weeds in order to reduce the use of chemical herbicides. Although the problem may not be solved quickly, these actions could lead to gradual but significant progress in reducing the use of this herbicide.

On the other hand, despite being clear about the negative effects of glyphosate and other herbicides, farmers carry out unfavorable actions such as improper disposal of containers and do not use preventive personal protection measures when handling and applying this type of agrochemical. It is necessary for the sector's institutions to reach out to farmers and inform them of the risks they face. Given that agricultural workers are the most vulnerable to intoxication and disease, technical training programs and safety precautions must be implemented. To reduce the impact and contamination of natural resources, an environmental education program should be developed or expanded, similar to the Clean Field Program.

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