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MECHANICAL ALTERNATIVES TO ELIMINATE THE USE OF GLYPHOSATE IN WEED CONTROL IN MEXICO'S SEMBRANDO VIDA PROGRAM

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Abstract: Weed control in our country has always been conditioned by the moment when a site is to be used for crop establishment. In other words, there is no culture of planning for sowing, much less a culture of proper weed management, resulting in production losses ranging from 15 to 80%. It is important to note that weed control is defined according to the type of producer. Based on this approach and considering that Mexico's Sembrando Vida (PSV) program is for small producers, preferably in marginalized areas, the federal government issued a national decree eliminating the use of GLYPHOSATE as a chemical control agent, given its harmful effects and consequences for human health. In the search for alternatives, the National Council for Science, Humanities, and Technology (CONAHCYT) recently published that mechanical control is a viable option and recommends four alternatives, including mechanical brush cutters and rotary tillers. Therefore, the objective of this study was to conduct a technical evaluation of two commercial mechanical alternatives used for weed control. The test conditions were based on Mexican standards NMX-O-233-SCFI-2019 and NMX-O-226-SCFI-2015, respectively. The results for the rotary tiller showed an effective yield per hectare of 3 hours and 18 minutes, fuel consumption of 8.33 liters, and a cutting height of 4 centimeters. For the brush cutter, an effective performance of 17.65 hours and a fuel consumption of 25 liters per hectare when the person is trained. It is concluded that the rotary tiller evaluated is an efficient alternative for weed control in areas of one to three hectares, as is the case with the brush cutter, but in areas of up to one hectare.

Keywords: Rotary tiller, mower, brush cutter.

INTRODUCTION

Effective weed management is a crucial challenge for the productivity and sustainability of agricultural systems worldwide. In small-scale agricultural production systems such as those promoted by the Sembrando Vida (PSV) Program in Mexico, weed management is often reactive and unplanned, resulting in losses of up to 80% in some sensitive crops (Martínez et *al.*, 2019).

On the other hand, the ban on glyphosate by national decree has prompted the search for effective and less harmful chemical and non-chemical alternatives for weed control (Sánchez & Wyckhuys, 2019), which guarantee effective weed control, especially in national social programs such as the PSV, which promote sustainable agriculture among small producers in marginalized areas (Ramírez & Delgado, 2023; García *et al.*, 2021).

The transition to sustainable agriculture in Mexico, driven by public policies such as the Sembrando Vida Program (PSV), requires replacing traditional management practices, such as those based on agrochemicals or manual tools, with agroecological approaches or mechanical alternatives that are culturally and socioeconomically appropriate. One of the main technical barriers identified in this process is effective weed control, especially in light of the progressive elimination of glyphosate, decreed by the Federal Government (DOF, 2021). This situation creates significant operational and technical gaps for small producers, who lack practical, affordable alternatives adapted to their production conditions. Mechanical alternatives represent a viable option to replace the use of herbicides in the short and medium term, provided they are implemented holistically to reduce dependence on agrochemicals without compromising productivity (Altieri et al., 2018; Vázquez *et al.*, 2020) with appropriate and contextualized technical criteria. Unlike chemical control, mechanical management has the potential to reduce negative impacts on human health, preserve soil biodiversity, and strengthen the technological sovereignty of rural communities (SEMARNAT, 2022; *González et al.*, 2022). Furthermore, as these are labor-intensive practices, they can be integrated as a strategy to reduce costs and labor shortages, one of the problems that most threaten the success of the PSV's MIAF system. Despite the advantages, the implementation of mechanical control still faces multiple challenges: limited technical information available, lack of systematization of local experiences, and insignificant training in the use of tools adapted to intercropping systems such as MIAF. Added to this is a wide variety of agro-soil-climatic and socioeconomic conditions, as well as crops and fruit trees that vary between regions, which affects the applicability of standardized h al solutions. Most of the states belonging to the PSV, and in particular some entities in the center and throughout the south of the country, such as Campeche, Chiapas, Guerrero, Oaxaca, Puebla, Quintana Roo, Tabasco, Tamaulipas, Tlaxcala, and Veracruz, have conditions that require differentiated and field-validated solutions. On the other hand, the National Council for Humanities, Science, and Technology (CONAHCYT, 2022) has spent the last three years of this administration pointing out a constellation of these practices, which it describes as Integrated Ecological Weed Management (MEIA) and which are classified according to (Ramírez, 2021) and (Escalona *et al.*, 2021) into seven groups: preventive, cultural, physical, **mechanical,** plant cover, biological control, and natural herbicides or bioherbicides. Of the 42 practices in the seven MEIA groups identified, CONAHCYT (2021) considers 12 that are already applied in Mexico to be "very important": false planting, non-living plant cover, living plant cover, brush cutters, rototillers, grazing in orchards, crop rotation, and mulching. that are already applied in Mexico: false planting, non-living plant cover, living plant cover, **brush cutters, rotary tillers,** grazing in orchards, crop rotation, high-density planting, annual polycultures, agroforestry polycultures, bioherbicides, and plastic coverings. (Gómez, 2017).

In this context, this research seeks to provide two mechanical alternatives that contribute to improving the efficiency of weed control in the Milpa Intercalada en Árboles Frutales (MIAF) system in highly marginalized rural areas belonging to the PSV, taking the central region of Veracruz as a case study given its natural conditions. By evaluating the effectiveness and operability of various mechanical tools used by PSV producers, the aim is to validate accurate technical information that improves decision-making in the agroecological transition. While the ultimate goal is to move towards agroecological systems, it is essential to have viable intermediate solutions during the transition period that ensure the productivity and sustainability of the PSV without compromising the health of communities or the environment.

MATERIALS AND METHODS

This research was carried out in the Mechanization program belonging to the

National Institute of Forestry, Agricultural and Livestock Research (INIFAP) Cotaxtla Experimental Field, located at coordinates s (18° 56´24´´ N and 96° 11´ 52´´ W), in the central area of the State of Veracruz, Mexico. The climate is classified as AW1: warm subhumid with rainfall in summer, higher humidity (68.67%) and warm subhumid with rainfall in summer, medium humidity (31.33%) and an average annual precipitation of 1,417.8 mm. The average annual temperature is 25.3°C and the average altitude is 20 meters above sea level. Narrow-leaved weeds or grasses predominated in the evaluation area, especially Dichantium annulatum, which covers almost 60% of the land. Other weeds present were Tridax procumbens, Megathyrsus maximus, Ruellia blechum, Emilia sonchifolia, Lagascea mollis, Commelina erecta, Digitaria eriantha, Melochia pyramidata, Priva lappulacea, Cynodon dactylon, Sorghum halepense, Heliotropium indicum, Malvastrum coromandelianum, and Euphorbia heterophylla.

The research carried out is classified as applied experimental, since two teams were evaluated in a controlled and systematic manner under field conditions in the fall-winter cycle of 2024, a period when weeds express their greatest complexity. The sources of information are databases with records from the experiment itself, and the variables to be measured were based on Mexican testing standards. This methodological approach facilitates the generation of useful results for decision-making in agricultural public policies such as Mexico's PSV.

Evaluation 1

The objective of this test was to evaluate the field performance of a rotary tiller with a mower for cutting weeds, analyzing different parameters such as working speed, fuel consumption, cutting height, effective operating time, and effective performance.

Rotary tiller

Various tests were carried out to evaluate the rotary tiller as an alternative for weed control and to determine its effective working performance, based on Mexican standard NMX-O-233-SCFI-2019 for tractors, implements, and agricultural machinery—rotary tillers, motor hoes—specifications and test methods.

Description

Parazzini brand rotary tiller, model MCP7HP, with two forward speeds and one reverse speed, powered by two drive wheels, a 7 horsepower gasoline engine with a category III rating, a fuel tank with a capacity of 3.5 liters, and a weight of 57 kg. It is coupled with an agricultural mower with a cutting height of between 2 and 6 cm, a working width of 0.97 m, and a weight of 30 kg (Figure 1).

Figure 1. Parazzini brand rotary tiller (online): https//www.todopartes.mx/articulos/tp--14973-kmpsk-motocultor-Parazinni-7-hp-con segadora-agrícola).

Speed

Forward speed

This test was carried out on a plot measuring 50 m long by 1 m wide, with each end as the starting and finishing point (Figure 2). The travel time was measured, for which three repetitions were carried out per forward speed: high, medium, and low; and with two working speeds, first and second.

Figure 2. Speed test under field conditions with a Parazzini rototiller.

Reverse speed

This test was carried out on a plot measuring 10 m long by 1 m wide, with each end as the starting and finishing point. The travel time was $v = \frac{d}{t}$ measured, for which three repetitions were performed for each reverse speed: high and low; and with two working speeds, first and second. The speed was calculated using the distance over time formula, represented mathematically as follows:

Where:

d: distance in meters or kilometers

t: time in seconds or hours.

Fuel consumption

Fuel consumption at idle

This test consisted of evaluating fuel consumption over a period of time at different forward speeds (high, medium, and low). To do this, 500 ml of gasoline was added to the tank and the engine was started,

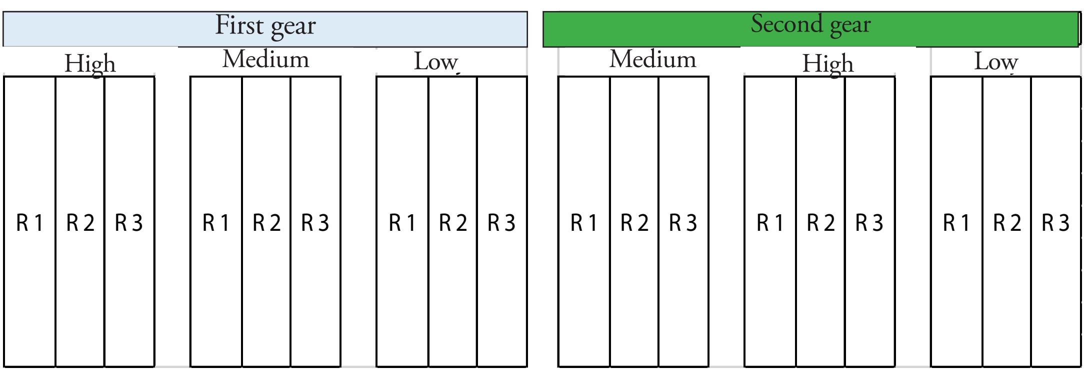

Figure 3. Route diagram for evaluating the fuel consumption of the rotary tiller during operation

keeping the rototiller idling (without any working speed) until it stopped on its own. The excess fuel in the tank was then removed to obtain the equipment's consumption over a given time.

Where: fuel consumption l/h or ml/s.

Fuel consumption during operation

This test consisted of evaluating fuel consumption when the equipment was put into operation at different forward speeds (high, medium, and low) in its first and second working speeds. To do this, two liters of gasoline were added to the tank and the engine was started at the respective speeds. Three repetitions were performed for each of the two forward positions of the rotary tiller and at three operating speeds, making a total of 18 repetitions for this evaluation (Figure 3). The area used per repetition was 2 x 20 m.

Effective operating time

This is the time required to complete the work being done with the equipment, not including the time spent turning around at the headlands or downtime due to breakdowns. A stopwatch is used to read or measure this time.

Cutting height

For this evaluation, I used a plot measuring 25 m long by 1 m wide in an area identified as having tall weeds (> 0.30 m and abundant total coverage). To do this, a loop was stretched in one of the areas with the greatest abundance of each repetition and, with the help of a flexometer, the average initial and final height of the weeds was measured, from the base of the stem to the top of the erect plant. With the mower attached to the rototiller, three repetitions were performed per forward speed (high, medium, low) and working speed (first and second), and the travel time was measured in each repetition.

This is the area worked per unit of time (hectares per hour) and is obtained by the working width indicated by the manufacturer and the recommended speed.

$$R_t = 0.1(B_f * V_{mt})$$

Where:

R_t = Theoretical performance, ha/h

$B_{(f)}$ = Theoretical width, m

V_{mt} = Average working speed recommended by the manufacturer, km/h

0.1: Dimension conversion factor

Effective yield

Also known as the amount of work in the field, it is expressed in hectares per hour and is obtained by dividing the actual working area by the effective working time.

$$Re = \frac{Sr}{T_{(e)} * 10^{(4)}}$$

Where:

Re= Effective yield, ha/h

Sr = Actual working area, m^2

Te = Effective working time, h

$1*10^4$ = Conversion from m^2 to ha

Evaluation 2

The objective of this test was to verify that the brush cutter is an alternative for weed control, evaluating its performance and ease of use. The evaluation parameters are the same as for the rotary tiller, although because they are different pieces of equipment, they are categorized under a different Mexican standard.

Brush cutter

Various tests were carried out to evaluate the brush cutter as an alternative for weed control and to determine its effective work performance, based on Mexican standard NMX-O-226-SCFI-2015 agricultural and forestry machinery – tests for portable, manual, and motorized brush cutters – machines equipped with internal combustion engines.

Descriptive sheet

STIHL brush cutter, model FS 55 R, with a 0.33-liter gasoline engine, weighing 4.4 kg, equipped with a cutting head with string (Figure 4).

1 . STIHL FS 55 R brush cutter (author: STIHL distributor).

RESULTS AND DISCUSSION

Evaluation results 1. Rotary tiller

Forward speed evaluation

Table 1 shows that the high and second transmission speeds recorded the highest working speed at 2.79 km/h, followed by the medium working speed in second and low working speed in second at 2.55 and 2.07 km/h, respectively. It can also be seen that all transmission speeds in second gear were higher than the first gear in their low, medium, and high positions.

The same table also shows the average reverse speed values obtained under the same test conditions as for forward speed. The results show similar behavior, with the second transmission position obtaining the highest speed at any speed (low, medium, and high, respectively). It is important to mention that reverse speed was only tested at two conditions, low and high speed, since the technical team considered that this speed was only necessary to position the equipment before operating it.

Fuel consumption assessment results

Fuel consumption at idle

Table 2 shows that 250 ml of gasoline is consumed in an average operating time of 17.44 min at high speed, 24.28 min at medium speed, and 48.64 min at low speed ( ). We can conclude that higher operating speeds result in shorter operating times and, consequently, lower fuel consumption.

Adjustment		Forward speed			Reverse speed		
Forward speed	Transmission position	Average time (s)	Average speed (m/s)	Average speed (km/h)	Average time (s)	Average speed (m/s)	Average speed (km/h)
Low	First speed	167	0.29	1.07	44.28	0.22	0.81
	Second gear	86.67	0.57	2.07	22.89	0.43	1.57
Average	First gear	135.67	0.36	1.32	NA	NA	NA
	Second gear	70.33	0.71	2.55	NA	NA	NA
High	First gear	121.67	0.41	1.47	28.85	0.34	1.24
	Second gear	64.33	0.77	2.79	16.08	0.62	2.24

***Table1* . Average forward and reverse speed values during operation , and transmission position of the rototiller.**

Idle	Average engine running time (min)	Start fuel (ml)	fuel at end (ml)
High speed	17.44	500	250
Medium speed	24.28	500	250
Low speed	48.64	500	250

Table 2. Average engine running time and fuel consumption at different speeds under idle operating conditions.

Transmission speed	**Working speed**	**Average in (ml) per 40 m^2**	**Average in (l/ha)**
First speed	**Low**	63.33	15.83
	Medium	50.00	12.50
	High	33.33	8.33
Second gear	**Low**	100.00	25.00
	Medium	93.33	23.33
	High	33.33	8.33

Table 3. Fuel consumption values for weed cutting with the rotary tiller.

Transmission speed	Working speed	Average test time (s)	Average test time (hr/ha)
First speed	High	90.33	6.27
	Medium	96.66	6.71
	Low	104.66	7.26
Second gear	High	47.77	3.31
	Medium	66	4.58
	Low	76.66	5.32

Table 4. Average operating time values for the rotary tiller when cutting weeds.

Transmission position	Working speed	Travel time (s)	Average weed height (cm)	Average cutting height (cm)
First speed	Low	91.03	58.33	4.33
	Medium	72.1	56.33	4.33
	High	55	46.66	4.00
Second gear	Low	43.47	38.33	4.66
	Average	39.58	58.33	4.66
	High	28.8	50.00	4.0

Table 5. Average values for travel time, weed height, and cutting height with a rotary tiller and mower in weed cutting operation.

Figure 5. Weed control a) before tillage and b) after tillage with a rotary tiller in first gear.

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Test observation: the minimum fuel volume required to operate the rotary tiller must be greater than 250 ml, otherwise the equipment will shut down.

Fuel consumption results during operation

Table 3 shows the average fuel consumption values during operation of the rotary tiller when cutting weeds, where the lowest fuel consumption per hectare was in first and second transmission speeds and at the same high working speed. In the variable average fuel consumption in liters per hectare, the highest fuel consumption recorded was 8.33 liters per hectare. We can conclude that higher operating speeds result in lower fuel consumption. The optimal speed for cutting weeds in the field was second transmission speed and high working speed.

Table 4 shows the average values for the operating time of the rotary tiller when cutting weeds, where the lowest average time recorded per hectare was 3.31 hours per hectare in second transmission speed and with the working speed set to high. The optimal speed for cutting weeds in the field with respect to the time variable was second transmission speed and high working speed. It is important to mention that the rotary tiller must be stopped for a rest period to avoid failure or damage due to overheating. Therefore, the actual time per hectare may increase the effective time evaluated.

Cutting height assessment

In Table 5, we can see the average cutting height. According to the supplier's technical specifications, the mower attached to the rototiller has a cutting height of between 2 and 6 cm. the data presented in the evaluation show that for the first transmission speed, the low and medium working speeds were the same with a cutting height of 4.33 cm, but not so for the high working speed, which registered 4 cm. The evaluation showed the same trend, with the low and medium speeds registering 4.66 cm and the high working speed registering 4 cm. This variation for both transmission speeds may be due to the terrain conditions and may also be due to the vibrations caused by the machine, which forced the operator to lift the front part by inertia when leaning on the handles of the equipment. In addition, at high speed, both in second and first transmission speeds, greater support force was applied due to the vibrations produced by the rototiller. It is important to mention that all the green matter or residues from the cut weeds remain as a cover, and that the volume of this cover depends on the height and number of weeds on the surface to be worked.

Figures 5a, 5b, 6a, and 6b show a comparison of the areas before and after weed cutting with the rotary tiller with mower attachment. The equipment does a very good job, removing weeds with a high cutting efficiency of over 95%, leaving a cover or mulch on the ground after cutting, which must be removed manually. These results are what the PSV requires to contribute to labor use, as studies report that if weeds are not controlled, it can mean up to 42% damage to crop production (CESAVEM, 2015).

Trotary tiller theoretical performance

In Table 6, we can see the theoretical work performance values projected from the calculation of the average speed of the rotary tiller in a specific test area. The best theoretical performance of 0.2714 hectares per hour

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was obtained with the second transmission speed in high gear. We can conclude that higher speeds result in higher theoretical performance.

Effective performance of the rotary tiller

Table 7 shows the effective work performance values projected from the calculation of the rototiller's working time in a given test area. The best effective performance was 0.2798 hectares completed in one hour, with the second transmission speed in high gear. We can conclude that higher speed results in higher effective performance.

Evaluation results 2. Brush cutter

Table 8 shows the values of the evaluation at idle speed, showing that in the test repetitions carried out at the same time, there were no changes in the fuel consumption variable. Likewise, we can observe the fuel consumption of the brush cutter under operating conditions carried out by three different people, of different ages and both genders (male, female). The person with the lowest fuel consumption was the older adult male, as he already had training and knowledge of the equipment. The other two people had not worked with this type of equipment before, so they took longer to operate it. Under these same operating conditions, we also observed that the person who took the least time to operate the brush cutter was the older man, as he already had training and knowledge of the equipment. The other two people had not worked with this type of equipment before, so they took longer to operate it. We can conclude that the longer the working time, the greater the fuel consumption.

Theoretical performance of the brush cutter

This parameter was not considered, as the manufacturer did not specify a working width, and it is also known that the working width depends on the operator's skill and the length of the cutting line selected by the operator.

Effective performance of the brush cutter

Table 9 shows the effective work performance values projected from the calculation of the brush cutter's operating time in a specific test area. We can argue that the projected effective work performance of the brush cutter operation was 85% and 94% higher when used by the older adult man compared to the young man and woman, respectively. This difference may be due to the fact that the older adult male operator is a person who habitually performs this work, unlike the other two operators, who do not perform this work. Figures 7a and 7b show a comparison of the area before and after weed cutting with the brush cutter. This equipment cuts the weeds into small pieces and does not leave such dense vegetation cover in theworked area.

The results of this study confirm that both the rotary tiller and the brush cutter are viable alternatives for mechanical weed control in small production units, such as those integrated into the Sembrando Vida Program. The rotary tiller, with a performance of 3.18 h/ha and lower fuel consumption, demonstrated greater operational efficiency, in line with the findings of Gaytán-Campos (2023) and Rodríguez-Hernández et al. (2022), who highlight the superiority of traction equipment over portable tools. The

Figure 6. Weed control a) before tillage and b) after tillage with a rotary tiller in second gear.

Working speed	Transmission speed	Average speed (km/h)	Theoretical width (m)	Theoretical performance (ha/h)
Low	First speed	1.0779	0.97	0.1046
	Second gear	2.0779		0.2016
Average	First gear	1.327		0.1287
	Second gear	2.5594		0.2483
High	First gear	1.4795		0.1435
	Second gear	2.7981		0.2714

Table 6. Theoretical performance values in hectares per hour with different working speeds and transmission speeds of the rotary tiller

Working speed	Transmission speed	Actual working area (m^2)	Effective working time (h)	Effective performance (ha/h)
Low	First speed	50	0.0464	0.1078
	Second gear		0.0241	0.2077
Average	First gear		0.0377	0.1327
	Second gear		0.0195	0.2559
High	First gear		0.0338	0.1479
	Second gear		0.0179	0.279

Table 7. Effective performance values in hectares per hour at different working speeds and transmission speeds

Test condition	Idle		In operation		
Operator	Operating time (min)	Fuel consumption (ml)	Working area (m^2)	Operating time (s)	Fuel consumption (ml)
Elderly man	10	50	20	127.07	50
Young male	10	50	20	246.56	100
Young woman	10	50	20	235.04	80

Table 8. Average values for the evaluation of fuel consumption, time, and areas at idle speed and under operating conditions.

<table>
<tr><th>Operator</th><th>Effective working area (m^2)</th><th>Projected effective working area (ha)</th><th>Effective working time (h)</th><th>Effective work performance (ha/h)</th><th>Effective projected work output (h/ha)</th></tr>
<tr><td>Older adult male</td><td rowspan="3">20</td><td rowspan="3">1</td><td>0.0353</td><td>0.0567</td><td>17.65</td></tr>
<tr><td>Young woman</td><td>0.0685</td><td>0.0292</td><td>34.25</td></tr>
<tr><td>Young male</td><td>0.0653</td><td>0.0306</td><td>32.65</td></tr>
</table>

Table 9. Effective working performance values determined on the test surface and effective working performance projected in hours per hectare

Figure 7. Weed control a) before work and b) after work with a brush cutter.

brush cutter, although less efficient (17.65 h/ha), can be useful in areas smaller than one hectare if the operator is trained, as suggested by Pérez-García et al. (2021). These findings support the recommendations of CONAHCYT (2023) on replacing glyphosate with mechanical means, although they emphasize the importance of considering the specific conditions of the terrain and crop for its effective adoption (Espinoza--Hernández et al., 2021). By using these tools during the critical period of competition between weeds and crops, i.e., the time when the presence of weeds causes a loss of yield and also when intervention is easiest, great efficiency in weeding is achieved (Ramírez, 2021b; Escalona et al., 2021b). There are reports of the successful use of brush cutters for weed control in orange and avocado cultivation, forest management, and fruit orchards in general (Duarte and Martins, 2005; Godínez, 2022; Gómez Tovar and Gómez Cruz, 2022).

CONCLUSIONS

The results of this research confirm that the Parazzini rotary tiller represents a technologically viable and efficient alternative for mechanical weed control in small production units of one to three hectares, in the context of the Sembrando Vida Program. Its technical performance, with an average operating time of 3 hours and 18 minutes per hectare, fuel consumption of 8.33 liters, and a cutting height adjusted to the terrain of 4 centimeters, positions it as an appropriate tool for intercropped agroforestry systems, provided that the terrain allows it.

For its part, the STIHL brush cutter also proved to be an effective option for weed control, particularly on areas smaller than one hectare. Its efficiency, at 17.65 hours per hectare under conditions of adequate operator training, indicates that its implementation can be useful in areas that are difficult to access or have steep slopes, where the use of rototillers is limited. However, the operational efficiency of both pieces of equipment is significantly influenced by the technical skills of the operator and the morphological and ecological characteristics of the weeds present. In this regard, the need for continuous technical training and the appropriate selection of mechanical equipment and tools is emphasized in order to achieve an effective transition to agroecological weed management without the use of glyphosate.

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