Efficiency of reduced rates of 2,4-D in mixture with wood vinegar in weed control

Eficiencia de redução de doses de 2,4-D em mistura com extrato pirolenhoso no controle de plantas daninhas

Eficiencia de la reducción de dosis de 2,4-D en mezcla con extracto piroleñoso en el control de malezas

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ABSTRACT
Chemical control is the most efficient method in weed management. However, given the societal demand for reducing pesticide use and mitigating production costs, alternatives for reducing herbicide doses should be considered. Among the alternatives that can contribute to the sustainable management of weeds is wood vinegar, a bio-input that has several applications in agriculture. In light of this, the objective of this study was to evaluate the reduction of doses of 2,4-D herbicide by mixing it with wood vinegar (WV). The experiments were conducted in a greenhouse at the Campus of Engineering and Agricultural Sciences (CECA/UFAL). The experimental design was completely randomized in a 4x2 factorial scheme, with 4 herbicide-WV mixtures (Distilled water; 0.5 L ha-1 of 2,4-D + 1 L ha-1 of WV; 1 L ha-1 of 2,4-D + 0.5 L ha-1 of WV; and 1.5 L ha-1 of 2,4-D (recommended commercial dose), and the spray solution with water only and with mineral oil (0.5% v/v). The receptor plants were Crotalaria juncea, Senna obtusifolia, and Bidens spp., and each weed species constituted an experiment, where phytotoxicity scale, control (%), and relative dry mass (%) were evaluated. The reduction of 2,4-D doses was not effective in controlling Crotalaria juncea, which showed satisfactory control only at the commercial dose of the product with mineral oil. The species Senna obtusifolia and Bidens spp. were effectively controlled in all treatments of the experiments regardless of mineral oil.

Keywords: Pyroligneous Acid. Auxinic Herbicides. Chemical Control. Bioimpult.
RESUMO
O controle químico é o método de controle mais eficiente no manejo de plantas daninhas, porém diante do apelo da sociedade para redução do uso de defensivos, e para mitigar os custos de produção, deve-se pensar em alternativas para a redução de doses dos herbicidas. Dentre as alternativas que pode contribuir para o manejo sustentável de plantas daninhas, esta o extrato pirolenoso, um bioinsumo que possui diversas aplicações na agricultura. Diante do que foi apresentado, o objetivo deste trabalho, foi avaliar a redução de doses de herbicida a base de 2,4-D a partir da mistura com extrato pirolenoso (EP). Os trabalhos foram realizados em casa de vegetação no Campus de Engenharia e Ciências Agrárias (CECA/UFAL). O delineamento experimental foi inteiramente casualizado em esquema fatorial 4x2, sendo 4 misturas do herbicida com EP (Água destilada; 0,5 L ha-1 de 2,4-D+1 L ha-1 de EP; 1 L ha-1 de 2,4-D+ 0,5 L ha-1 de EP; e 1,5 L ha-1 de 2,4-D (dose comercial recomendada), e a calda apenas com água e com óleo mineral (0,5% v/v). As plantas receptoras foram Crotalaria juncea, Senna obtusifolia e Biddens spp., e cada espécie de planta daninha constituiu um experimento, onde foram avaliados a escala de fitointoxicacao, o controle (%) e massa seca relativa (%). A redução de doses de 2,4-D não foi eficiente no controle de Crotalaria juncea, onde apresentou controle satisfatório apenas na dose comercial do produto com óleo mineral. As espécies Senna obtusifolia e Biddens spp. foram controladas de maneira eficiente em todos os tratamentos dos experimentos independente de óleo mineral.


RESUMEN
El control químico es el método más eficiente en el manejo de las malezas, sin embargo, ante la demanda de la sociedad de reducir el uso de pesticidas y para mitigar los costos de producción, se debe considerar alternativas para reducir las dosis de herbicidas. Entre las alternativas que pueden contribuir al manejo sustentable de malezas se encuentra el extracto piroleñoso, un bioinsumo que tiene varias aplicaciones en la agricultura. En este contexto, el objetivo de este trabajo fue evaluar la reducción de dosis del herbicida a base de 2,4-D mediante la mezcla con extracto pirolenoso (EP). Los trabajos se realizaron en un invernadero en el Campus de Ingeniería y Ciencias Agrarias (CECA/UFAL). El diseño experimental fue completamente aleatorizado en un esquema factorial 4x2, con 4 mezclas del herbicida con EP (Agua destilada; 0,5 L ha-1 de 2,4-D + 1 L ha-1 de EP; 1 L ha-1 de 2,4-D + 0,5 L ha-1 de EP; y 1,5 L ha-1 de 2,4-D (dosis comercial recomendada), y la solución de pulverización solo con agua y con aceite mineral (0,5% v/v). Las plantas receptoras fueron Crotalaria juncea, Senna obtusifolia y Biddens spp., y cada especie de maleza constituyó un experimento, donde se evaluaron la escala de fitotoxicidad, el control (%) y la masa seca relativa (%). La reducción de las dosis de 2,4-D no fue eficaz en el control de Crotalaria juncea, donde solo se mostró un control satisfactorio en la dosis comercial del producto con aceite mineral. Las especies Senna obtusifolia y
Bidens spp. fueron controladas de manera eficiente en todos los tratamientos de los experimentos, independientemente del aceite mineral.


1 INTRODUÇÃO

Weeds are among the main factors responsible for productivity loss in agroecosystems. These plants cause direct and indirect damage, competing for resources such as water, light, and nutrients, hosting pests and diseases, and interfering with cultural practices and harvest, thereby increasing production costs and final crop yield (Yamashita et al. 2018; Furquim et al. 2019, Rigon et. al. 2020).

Due to its high efficiency, speed of operation, and practicality, chemical control has been the most widely used alternative in weed management. Among the herbicides used, auxin mimics stand out, belonging to a group with systemic action, used in the management of dicotyledonous plants, which includes molecules like 2,4-D widely used in sugarcane crops and pastures (Pinheiro, 2020; Silva, 2022).

Despite its efficiency, the use of herbicides has generated a series of discussions due to the different effects on humans and the environment, mainly due to misuse. Additionally, there is the economic point of view, where global demand and competition from internal and external markets, as well as weed resistance to different molecules, have increased application costs. Thus, it is necessary to administer correct doses and implement adjunct technologies to reduce doses, mitigate application costs, reduce damage to human health and the environment, without compromising control efficiency (Ash 2010; Brussasrd et al. 2010; Cordeau et al. 2016; Silva 2022).

The reduction of herbicide doses can and should be achieved through strategies that increase the efficiency of molecule absorption. Among these strategies, the use of adjuvants stands out. Adjuvants are chemical products added to the spray solution that not only reduce losses due to drift, runoff, or
evaporation but also facilitate herbicide entry into plants by aiding in cuticle penetration (Caixeta, 2020).

Adjuvants can have various origins and can be either synthetic or natural. Among natural products with potential for use as adjuvants are wood vinegar (WV), which are bioinputs composed of a complex carboxylic chain, produced from the burning of wood and other components rich in cellulose, lignin, and phenolic compounds. Pyroligneous extracts have been used in agriculture for pest and disease control, seedling growth conditioning, and as a chelating agent (Barbosa et al., 2023; Campos 2018).

Based on the foregoing, the objective of this study was to evaluate the reduction of doses of 2,4-D herbicides through the mixture of pyroligneous extract in the application solution for weed control.

2 MATERIAL AND METHODS

The experiments were conducted in a greenhouse located at the Campus of Engineering and Agricultural Sciences (CECA) of the Federal University of Alagoas – UFAL, situated in the municipality of Rio Largo, Alagoas (latitude 9° 29' 45" S, longitude 35° 49' 54" W, altitude 127 meters).

For the execution of the work, three weed species were selected: Crotalaria juncea Lineus, Senna obtusifolia (L.) Irwin & Barneby, and Bidens spp. The seeds of Crotalaria and Bidens were collected from the Center for Agricultural Sciences, in sugarcane production areas, while the seeds of Senna obtusifolia were obtained from a specialized company. The seeds were sown in 500 cm³ pots filled with substrate until reaching a weight of 420 g per pot. After germination, 10 plants per plot were maintained.

For the application of treatments, a commercial wood vinegar (WV) named SDM Pyroligneous Extract® from SDM Fertilizers company and the herbicide U46 BR® from Sumitomo Chemical company, which is based on the molecule 2,4-D (80.6% m/v)

Three experiments were conducted, with each experiment consisting of one weed species. The methodologies for execution were standardized, with a
completely randomized experimental design established in a 4x2 factorial scheme. The first factor consisted of 4 mixtures of WV and 2,4-D (as shown in Table 1), and the second factor included treatments with and without mineral oil (0.5% v/v).

<table>
<thead>
<tr>
<th>Treatments – Factor 1</th>
<th>L. C. P. ha-1*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1 – Without herbicide and WV</td>
<td>-</td>
</tr>
<tr>
<td>Treatment 2 – 335 g a.i ha⁻¹**+ 1 liter of WV</td>
<td>0.5 L</td>
</tr>
<tr>
<td>Treatment 3 – 670 g a.i ha⁻¹ + 0.5 liter of WV</td>
<td>1 L</td>
</tr>
<tr>
<td>Treatment 4 – 1005 g a.i ha⁻¹ (Commercial dose)</td>
<td>1.5 L</td>
</tr>
</tbody>
</table>

*Liters of commercial product per hectare
**Grams of active ingredient per hectare

Source: The authors (2024)

For the application of treatments, a pressurized backpack sprayer with CO2 was used, equipped with Teejet XR 110 02-VS flat fan nozzles, operating at a constant pressure of 200 kPa, providing a spray volume of 120 L/ha.

The effects of phytotoxicity from the mixtures of WV and 2,4-D were evaluated at 3, 7, and 15 days after application (DAA) according to the visual damage scale with scores ranging from 0 to 100, where 0 represents no damage and 100 represents plant death (SBPD, 1995).

On the 15th DAA of the treatments, the control (%) and relative dry mass (%) of the studied weeds were evaluated, with the latter conducted in a forced-air circulation oven at 60°C for 72 hours, with the plants placed in kraft paper bags.

The obtained data underwent analysis of variance, and the means were compared using the Tukey test at a 5% probability level, with the assistance of the SISVAR software (Ferreira, 2011).

3 RESULTS AND DISCUSSION

The result of the analysis of variance indicated that there was a significant difference in the evaluated variables. In Figure 1, we can visualize the phytotoxicity effect for the Crotalaria juncea species at 3, 7, and 15 DAA.
The species did not show significant phytotoxicity symptoms during the first DAA when compared to the other studied species. However, by 3 DAA, it began to exhibit typical symptoms of 2,4-D phytotoxicity, such as delayed growth, etiolated shoots, stem swelling, and young leaves becoming wrinkled. It is worth noting that despite the mentioned symptoms, the level of control of the species was not satisfactory.

Figure 1. Phytotoxicity (%) of Crotalaria juncea after 3, 7, and 15 days after application (DAA). Different uppercase letters among treatments, and lowercase letters within the same level, differ from each other by the Tukey test at 5% probability.

According to Table 2, the species Crotalaria juncea did not show effective control in the tested mixtures, with plants subjected to the recommended dose (T4) not statistically differing from T3, which corresponds to 1 liter of the commercial product + 0.5 L of WV in treatments without the addition of mineral oil.

With the addition of mineral oil (0.5% v/v), it was observed that there was an increase in the control of the species in all treatments. However, the dose recommended by the manufacturer showed better results than all the tested
mixtures, indicating that for this species, the main factor involved in the effectiveness of phytotoxicity may be related to the mineral oil associated with the treatments.

Table 2. Weed control of *Crotalaria juncea* at 15 DAA. Treatment means followed by different uppercase letters in the column and lowercase letters in the row differ from each other by the Tukey test at 5% probability.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adjuvant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without mineral oil</td>
</tr>
<tr>
<td>T1 - Without herbicide and WV</td>
<td>00,00 Aa</td>
</tr>
<tr>
<td>T2 – 0,5 L of 2,4-D + 1L of WV</td>
<td>10,00 Aa</td>
</tr>
<tr>
<td>T3 – 1 L 2, 4-D + 0,5 L of WV</td>
<td>27,50 Ba</td>
</tr>
<tr>
<td>T4 – 1,5 L 2,4-D</td>
<td>25,00 Ba</td>
</tr>
<tr>
<td>CV</td>
<td></td>
</tr>
</tbody>
</table>

Source: The authors (2024)

Although plants of the genus Crotalaria are of interest in agriculture for green manure and nematode management purposes, they present a great difficulty in control at the desiccation stage when aiming for succession with the target crop (*Espanhol et al.*, 2011; Inoue *et al.*, 2012).

Several studies have reported the difficulties in managing plants of this genus using herbicides, precisely because these plants exhibit some degree of tolerance attributed to morphological characteristics inherent to this group, such as the presence of a thick cuticle on both leaf surfaces, with a high content of epicuticular wax, which can hinder the absorption of sprays (*Concenço; Silva, 2015; Procopio, *et al.*, 2003).

As evidenced in the phytotoxicity and control results (%), treatments with mineral oil showed the best results, regardless of the tested mixtures. This can be explained by the direct action of mineral oil on the plant’s cuticle, which dissolves the epicuticular wax, thereby facilitating the absorption of the applied products (*Rodrigues Neto, *et al.*, 2019; Vargas; Roman, 2006).

Several strategies for efficient chemical management have been tested in Crotalaria species, including the combination of herbicides, including 2,4-D (*Paula, 2015; Inoue, *et al.*, 2012). *Espanhol et al.* (2011), when evaluating the combination of 2,4-D with glyphosate in the desiccation of Crotalaria juncea, did not obtain satisfactory results, as the combination allowed the plants to regrow. This result confirms the difficulties encountered in the present study with control using the mixture of wood vinegar with 2,4-D.
In the dry mass variable (Table 3), the mixtures showed a reduction in dry mass assimilation starting from T2, with more pronounced results than the control variable.

Table 3. Dry mass of *Crotalaria juncea* at 15 DAA. Treatment means followed by different uppercase letters in the column and lowercase letters in the row differ from each other by the Tukey test at 5% probability.

<table>
<thead>
<tr>
<th>Treatant</th>
<th>Adjuvant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without mineral oil</td>
</tr>
<tr>
<td>T1- Without herbicide and WV</td>
<td>100,00 Aa</td>
</tr>
<tr>
<td>T2 – 0,5 L of 2,4-D + 1L of WV</td>
<td>66,59 Ba</td>
</tr>
<tr>
<td>T3 – 1 L 2, 4-D + 0,5 L of WV</td>
<td>52,04 Ba</td>
</tr>
<tr>
<td>T4 – 1,5 L 2,4-D</td>
<td>25,34 Ca</td>
</tr>
<tr>
<td>CV</td>
<td></td>
</tr>
</tbody>
</table>

Source: The authors (2024)

Despite showing low control of *Crotalaria juncea*, even at the commercial dose, the mixture of 2,4-D with wood vinegar resulted in a significant reduction in dry mass percentage in this species. The accumulation of dry mass is important for plants to establish themselves effectively and reflects the allocation of nutrients and other environmental elements necessary for the plant to fully carry out its metabolic activities and compete for resources until its reproductive phase. Thus, the perpetuation of the plant is compromised when this increment is interrupted or decreased (Carvalho *et al.*, 2007; Braz, 2019).

The species *Senna obtusifolia* already presented the mentioned symptoms from the first treatments on the 3rd DAA (Figure 2). For this species, there was no significant interaction in treatments with the presence of mineral oil, not statistically differing from the other treatments at the same control level (Table 4).

From the 1st day, the plants already showed phytotoxicity symptoms on the leaves, such as wilting, burning, and chlorotic lesions, similar to contact herbicides. These lesions may possibly be attributed to the action of wood vinegar in the mixture. Liu *et al.* (2020) reported similar symptoms in *Geranium carolinianum*, *Oxalis corniculata*, and *Perilla frutescens* plants when subjected to treatments with wood vinegar.

The symptoms presented in the early days were quite characteristic of the action of the 2,4-D molecule, such as the atrophy of new shoots and leaf curling. Unlike what happened with *Crotalaria juncea*, there was no stem swelling, but
rather a darkening that resulted in increased fragility of the plant attachment. This darkening can also be associated with the action of the 2,4-D molecule, which can generate oxidative stress in the plant, leading to high concentrations of ethylene and abscisic acid (Grosmann et al., 2009).

In treatments without the presence of mineral oil, there was no significant difference in the control of Senna obtusifolia in mixtures T2 and T3, which showed control levels of 82.5% and 97.5%, respectively. Mixture T3 did not differ statistically from the recommended commercial dose, which achieved 100% control (Table 4).

In treatments with the addition of mineral oil (0.5%), there was no significant difference between T2, T3, and T4, which corresponds to the recommended commercial dose, with an average control of 87.5%, 97.5%, and 100%, respectively (Table 4).

Figure 2. Phytotoxicity (%) of *Senna obtusifolia* after 3, 7, and 15 days after application (DAA). Different uppercase letters between treatments, and lowercase letters within the same level, differ from each other by Tukey’s test at 5% probability.

Source: The authors (2024)
Table 4. Weed control of *Senna obtusifolia* at 15 DAA. Treatment means followed by different uppercase letters in the column and lowercase letters in the row differ from each other by the Tukey test at 5% probability.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adjuvant</th>
<th>Without mineral oil</th>
<th>Without mineral oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1- Without herbicide and WV</td>
<td>00,00 Aa</td>
<td>00,00 Aa</td>
<td></td>
</tr>
<tr>
<td>T2 – 0,5 L of 2,4-D + 1L of WV</td>
<td>82,50 Ba</td>
<td>87,50 Ba</td>
<td></td>
</tr>
<tr>
<td>T3 – 1 L 2, 4-D + 0,5 L of WV</td>
<td>97,50 BCa</td>
<td>97,50 Ba</td>
<td></td>
</tr>
<tr>
<td>T4 – 1,5 L 2,4-D</td>
<td>100,00 Ca</td>
<td>100,00 Ba</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td></td>
<td>11,19%</td>
</tr>
</tbody>
</table>

Source: The authors (2024)

In addition to effective control, mixtures of wood vinegar with the 2,4-D molecule also contributed to a reduction in dry mass (%) in the tested species (Table 5), regardless of the presence of mineral oil as an adjuvant. Similar to what happened with the control variable, there was no significant difference when compared to treatments without oil.

Table 5. Dry mass of *Senna obtusifolia* at 15 DAA. Treatment means followed by different uppercase letters in the column and lowercase letters in the row differ from each other by the Tukey test at 5% probability

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Adjuvant</th>
<th>Without mineral oil</th>
<th>Without mineral oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1- Without herbicide and WV</td>
<td>100,00 Aa</td>
<td>83,41 Ab</td>
<td></td>
</tr>
<tr>
<td>T2 – 0,5 L of 2,4-D + 1L of WV</td>
<td>14,31 Ba</td>
<td>16,02 Ba</td>
<td></td>
</tr>
<tr>
<td>T3 – 1 L 2, 4-D + 0,5 L of WV</td>
<td>4,01 Ba</td>
<td>3,07 BCa</td>
<td></td>
</tr>
<tr>
<td>T4 – 1,5 L 2,4-D</td>
<td>1,14 Ba</td>
<td>0,97 Ca</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td></td>
<td>25,40%</td>
</tr>
</tbody>
</table>

Source: The authors (2024)

The reduction in dry mass was quite effective when compared to the controls. In mixture T2 without mineral oil, the mean assimilated dry mass was only 14.31% when compared to the mean of the controls and did not differ statistically from T3 and T4, which had means of 4.01% and 1.14%, respectively.

In the mixtures that had the presence of mineral oil (5% v/v), T2 had a mean of 16.02%, and did not differ from T3, with a mean of 3.07%, which in turn did not differ from the commercial dose of 2,4-D, which was 0.97%.

The results obtained for the management of *Senna obtusifolia* show that the mixture of wood vinegar with the herbicide 2,4-D can be a viable alternative for the management of this species in post-emergence, and opens up
opportunities for further investigations that can contribute to the management of this species using wood vinegar.

In the management of the weed *Bidens spp.*, phytotoxicity in plants of T2 and T3 was observed after 4 hours of application, with the plants showing symptoms such as wilting and burning of the leaves. These rapid results can be attributed to the wood vinegar present in the mixture, as wood vinegar exhibits phytotoxic action with herbicidal potential (Liu *et. al.*, 2021).

The species *Bidens pilosa* has been studied as a target organism for the herbicidal action of wood vinegar, showing an LC50 of 2% in the management of newly germinated seedlings and 50% control in mature plants when using 653 L/ha, exhibiting symptoms such as chlorosis, leaf burning, and reduction in dry mass (Chu, *et. al.*, 2022). These results are consistent with the effects observed in this research, as the rapid onset of phytotoxic effects was only observed in treatments containing wood vinegar (T2 and T3).

At 3 DAA, the visual effects of phytotoxicity indicated that the treatments had an effect on the plants (Figure 3). In all treatments, including the adjuvants, the visual phytotoxic effects increased as the concentration of 2,4-D increased, with the commercial treatment showing greater effects than the others at 3 and 7 DAA.

Among the treatments without the presence of mineral oil, there was a significant difference only in treatments T2 at 3 DAA, which showed 44.25 without oil and 46.25 with mineral oil, and in T3 at 7 DAA, with averages of 82.75 without oil and 84.5 with oil.

At 15 DAA, except for the control group, there was no significant difference between the treatments, showing a high level of control in the visual phytotoxicity scale (Figure 3).
Figure 3. Phytotoxicity (%) of *Biddens* spp. after 3, 7, and 15 days after application (DAA). Different uppercase letters between treatments, and lowercase letters within the same level, differ from each other by Tukey's test at 5% probability.

In the control variable (Table 6), except for the control groups, all treatments did not vary statistically from the recommended commercial dose, regardless of the adjuvant. These results suggest that the mixture of wood vinegar with 2,4-D could be a viable alternative for post-emergence management of *Bidens* spp.

Table 6. Weed control of *Biddens* spp. at 15 DAA. Treatment means followed by different uppercase letters in the column and lowercase letters in the row differ from each other by the Tukey test at 5% probability.

<table>
<thead>
<tr>
<th>Treatament</th>
<th>Adjuvant</th>
<th>Without mineral oil</th>
<th>Without mineral oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 - Without herbicide and WV</td>
<td>00,00 Aa</td>
<td>00,00 Aa</td>
<td></td>
</tr>
<tr>
<td>T2 – 0,5 L of 2,4-D + 1L of WV</td>
<td>95,00 Ba</td>
<td>100,00 Ba</td>
<td></td>
</tr>
<tr>
<td>T3 – 1 L 2, 4-D + 0,5 L of WV</td>
<td>100,00 Ba</td>
<td>100,00 Ba</td>
<td></td>
</tr>
<tr>
<td>T4 – 1,5 L 2,4-D</td>
<td>100,00 Ba</td>
<td>100,00 Ba</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>4,75%</td>
<td></td>
</tr>
</tbody>
</table>

In the relative dry mass (%) variable (Table 7), there was a significant difference between T1 (treatments without herbicide and without wood vinegar) regarding the presence of mineral oil, where the treatment with 0.5% mineral oil...
concentrations of Monochoria vaginalis, Aneilema keisak, Ludwigia prostrata, and Eleocharis kuroguwai, which did not differ from the recommended commercial dose.

The use of wood vinegar as an herbicide adjuvant was also tested in association with oxyfluorfen at half the recommended commercial dose, using concentrations of 100% (V/V) and 0.4% (V/V) of wood vinegar in a spray volume...
of 498 L ha\(^{-1}\). *These concentrations inhibited the germination of seeds of Brachiaria decumbens, Bidens spp., and Amaranthus viridis,* showing better results than the commercial dose of the product (Zeferino; Lima; Vieira, 2018).

Wood vinegar can exhibit herbicidal action depending on the concentration and the phenological stage of the target plant species. This variability can be attributed to the high complexity of its chemical composition, which can vary according to the plant material used and the temperature and pyrolysis time (Deng *et al*., 2023; Iacomino *et al*., 2024; Maliang *et al*., 2023).

Among the most abundant components of wood vinegar composition is acetic acid, an open-chain ethanoic carboxylic compound that exhibits herbicidal action upon contact with leaf surfaces (Benvenuti; Tardivo, 2018). However, it is worth noting that wood vinegar contains a range of other compounds such as phenols, ketones, aldehydes, and furans, which may contribute to phytotoxic action to varying degrees. Additionally, these organic compounds can aid in better fixation of products on the leaf surface, enhancing the action of herbicides (Aguirre *et al*., 2020; Grew; Abbey; Gunupuru, 2018; Liu *et al*., 2021).

4 CONCLUSIONS

The species Crotalaria juncea did not yield satisfactory control results even at the recommended dose of 2,4-D, except for the treatment with mineral oil.

The weed species Senna obtusifolia and Bidens spp. showed excellent control in all treatments with a mixture of wood vinegar and 2,4-D, regardless of the presence of mineral oil.

The mixtures of wood vinegar with 2,4-D reduced the assimilation of dry matter in the species *Crotalaria juncea*, *Senna obtusifolia*, and *Bidens spp*.

The present research, as a pilot study, suggests that the combination of 2,4-D mixed with wood vinegar increased its effectiveness. These findings highlight the potential of wood vinegar as an adjuvant in herbicide formulations, offering a sustainable and cost-effective approach to weed management.

Further research is needed to explore the effectiveness of this combination with a wider range of doses, target plants, field conditions, and in combination
with other herbicides, as well as its broader implications for agricultural practices and environmental sustainability.

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