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Evaluation of Sugarcane Varieties: Investigating Resistance and Susceptibility to Herbicides (2,4-D; Diuron; Glyphosate) at Germination and Tillering Stages

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Abstract

In an endeavor to optimize weed management practices in sugarcane cultivation while maintaining an intricate balance with overall plant health, this study undertakes a thorough screening of various sugarcane varieties to assess their responses to different herbicides (2,4-D; Diuron & Glyphosate). The performance of sugarcane varieties to herbicides during the germination and tillering stages indicates diverse responses to 2,4-D and Diuron. 62% and 79% of the genotypes showed resistance or no noticeable influence, indicating a high tolerance to 2-4, D in the germination and tillering stage, respectively. Moreover, most of the varieties, precisely 42% during the germination stage and 34% during the tillering stage exhibited resistance to the application of Diuron. In the initial stages of growth, sugarcane varieties typically exhibit a positive response to 2,4-D and Diuron, suggesting favorable tolerance. In contrast, Glyphosate application exhibited a consistent and pronounced impact, with none of the varieties considered resistant or slightly sensitive in germination and tillering stages. The majority of the varieties were in the range of highly to severely sensitive to Glyphosate. These findings highlight the importance of careful consideration when using glyphosate herbicide during the germination and tillering stage of sugarcane development.

The varied responses observed in herbicide sensitivity at the germination and tillering stages emphasize the diversity among sugarcane varieties. This highlights the need for an in-depth understanding of herbicide management, considering the specific sensitivities of different varieties. Understanding the varying levels of tolerance and susceptibility among different varieties helps identify and select cultivars most suited for specific herbicides, thereby enhancing weed management effectiveness, minimizing the risk of crop damage, and ultimately improving overall yield.

INTRODUCTION

Sugarcane plays a vital role in the agricultural landscape of the Philippines, contributing significantly to the country's economy. However, the cultivation of sugarcane faces challenges, notably weed infestations that can have a substantial impact on crop growth and productivity. In response to these challenges, effective weed management becomes crucial not only to safeguard the health of sugarcane plants but also to ensure the sustainability of farming practices. An emerging trend in sugarcane farming is the increasing reliance on herbicide application. The scarcity of the workforce primarily drives this shift, as many farmers find it challenging to secure an adequate workforce for manual weeding. Herbicides have emerged as a practical solution, offering an efficient means of weed control without the labor-intensive demands of manual removal of weeds.

Efficient weed control and maintaining crop health are paramount considerations in sugarcane cultivation, especially given the diverse responses exhibited by different varieties (Aekrathok et al., 2021). Weed control is fundamental to prevent unwanted plants from competing with sugarcane for vital resources such as sunlight, water, and nutrients, which could jeopardize overall growth and health. Achieving a balance in crop health requires a nuanced approach, tailoring weed management strategies

to the specific characteristics and responses of each sugarcane variety. Some varieties may show susceptibility to certain herbicides, while others may exhibit resistance (Simões et al., 2016).

The focus of this study is to determine how sugarcane varieties respond to various herbicides, considering their susceptibility or resistance. This investigation aims to empower farmers with insights for informed decision-making in weed management, including the strategic selection of herbicides and the integration of resistant varieties. The study particularly in the germination stage and tillering stage, recognizing these as the most vulnerable stage for sugarcane plants. By focusing on these critical stages, the research seeks to contribute to a sustainable and balanced environment for sugarcane growth, ultimately enhancing the efficiency of weed control practices and safeguarding the overall health and productivity of sugarcane crops.

Materials and Methods

Experimental Site

The study was laid out in the experimental area of the SRA-Luzon Agricultural Research and Extension Center (SRA-LAREC), Paguiruan, Floridablanca, Pampanga, located at 14°59'20.04" N and 120°31'39.04" E with an elevation of 27 meters above sea level and under sandy loam soil. The study was conducted in the plant cane from February 2021-February 2022.

Materials

Varieties

The study used a total of 90 sugarcane varieties, old and recently introduced clones/varieties and exhibiting diverse characteristics (Appendix Table 1).

Herbicides

The study used three widely utilized active ingredients in herbicides for weed control in sugarcane fields, namely 2,4-D, Diuron, and Glyphosate. These herbicides play a crucial role in managing weed infestations in sugarcane cultivation. The inclusion of 2,4-D, Diuron, and Glyphosate reflects their common application and prevalence in agricultural practices, particularly in sugarcane farming. Below are descriptions of the herbicide used and its characteristics.

2,4-D

2,4-Dichlorophenoxyacetic acid, more commonly known as 2,4-D, is one of the most commonly used herbicides in sugarcane farming. This herbicide is selective, systemic and plant growth regulator affective against numerous annual and perennial broadleaf weeds but not most grasses (Minnesota Department of Agriculture, 2023). Its mechanism involves inducing uncontrolled division and growth in the cells responsible for transporting water and nutrients within the plant tissues. Herbicides employing this mode of action are classified as auxin-type herbicides (2,4-D General Fact Sheet, n.d.).

Diuron

Diuron, also known as 1,1-dimethyl, 3-(3',4'-dichlorophenyl) urea, is a broad-spectrum residual herbicide that is applied to grass and broadleaved weeds in agriculture for pre-emergent and post-emergen. It is absorbed by roots and translocated to the leaves where it interferes with photosynthesis.

Glyphosate

Glyphosate is a broad-spectrum, nonselective herbicide used to control annual and perennial grasses, which means it will kill most plants. It prevents plants from producing certain proteins required for plant growth and inhibits a particular enzyme pathway (Jervais et al., 2008)

Method of Experimentation:

The experiment involved two studies, one conducted in the germination stage and the other in the tillering stage.

In Study 1, the primary objective is to evaluate the response of various sugarcane varieties to herbicides during the germination stage. This study is thoughtfully structured, consisting of three layouts to assess the impact of different herbicides. One layout is specifically dedicated to the application of 2-4, D, while the other two layouts focus on the herbicides Diuron and Glyphosate (**Figure 1**), respectively. Also, as a reference for healthy plants, no herbicide application was utilized, serving as the control. This control group serves as a baseline, allowing researchers to assess the natural development and health of the plants in the absence of herbicidal influence. The inclusion of these layouts allows for a comprehensive examination of how different sugarcane varieties respond to distinct herbicidal active ingredient, providing valuable insights into herbicide efficacy and potential variations in tolerance among the 90 sugarcane varieties under investigation.

Each of the 90 sugarcane varieties is systematically planted in rows, with a measurement of 3 meters in length and 1.3 meters between rows. Three-eye canepoints, with a density of five canepoints per linear meter, are employed for planting, ensuring consistency in planting material across the varieties. The arrangement of varieties in a sequential pattern from the latest to newly developed varieties, replicated three times, enhances the robustness of the study by accounting for potential variations in environmental conditions. Additionally, the dosage of herbicide application is carefully determined based on recommended levels, contributing to the reliability of the screening process and providing relevant insights into the herbicidal responses of sugarcane varieties during the germination stage. The spraying of herbicide was done only once and prescribed cultural management practices, covering activities from land preparation to planting and cultivation were followed.

In Study 2, the emphasis shifts to evaluating the response of different sugarcane varieties to herbicides during the tillering stage. Notably, the study maintains consistency with Study 1 by utilizing the same set of sugarcane varieties and following the same methodology. The key difference in Study 2 lies in the developmental stage under investigation, which is the tillering stage.

This stage is crucial in the growth cycle of sugarcane as it involves the development of lateral shoots or tillers from the main stalk. Assessing herbicide responses at this specific stage provides insights into how different sugarcane varieties react to herbicides during a critical phase of their development. By employing the same set of varieties and maintaining methodological consistency between Study 1 and Study 2, researchers can draw meaningful comparisons between the germination

Herbicide application at germination stage | Herbicide Application at Tillering stage

Figure 1: Herbicide application at germination and tillering stages

and tillering stages, offering a comprehensive understanding of herbicide effects across various stages of sugarcane growth. The continuity in methodology ensures the reliability and relevance of the findings, contributing to a more comprehensive and nuanced assessment of herbicide impacts on sugarcane varieties throughout their growth cycle.

The practice of applying herbicides involves the systematic spraying of the complete plant with a herbicidal solution. This method is specifically designed to achieve comprehensive coverage across all exposed surfaces of the plant, which includes leaves, stems, and other above-ground structures. The intention behind this thorough application is to evaluate the plant's susceptibility to the herbicide. By subjecting the entire plant to the treatment, researchers or practitioners aim to gain insights into how different components of the plant, such as leaves and stems, respond to the herbicidal agent. It also allows for a holistic assessment of the plant's response, providing a more accurate understanding of its susceptibility to the herbicide across various parts.

After the application of herbicides, the responses of each sugarcane variety were closely monitored, and their evaluation was based on a rating system utilizing specific criteria. The rating scale is structured as follows:

Rating 1 (No Effect/resistance): Plants receiving a rating of 1 exhibit no observable damage, or adverse effects, indicating a high level of resistance that the herbicide has not caused any discernible negative impact on the plants. This category serves as a standard for unaffected plant health.

Rating 2 (Slightly Sensitive): A rating of 2 suggests that the plants display slight or minimal damage with slight yellowing, but no significant drying, estimating around 25% of the foliage is affected. This indicates mild herbicide impact without reaching a critical level of harm to the foliage or plant structure.

Rating 3 (Moderately Sensitive): Plants with a rating of 3 exhibit moderate damage, with roughly 50% of the foliage affected. This level of damage signals a more substantial impact on plant health with noticeable yellowing and some drying of leaves, indicating intermediate sensitivity to the herbicide.

Rating 4 (Highly Sensitive): A rating of 4 indicates that the plants are highly affected with significant yellowing and drying of leaves. Substantial damage of around 75% to the plant, highlighting a high level of sensitivity to the herbicide.

Rating of 5 (Severely Sensitive): (Rating 5 – >75% Damage, Almost Die): The highest rating of 5 signifies severe damage with the plants experiencing >75% damage, and they are on the verge of dying. This category underscores a critical level of herbicide impact that nearly jeopardizes the survival of the plants with extensive yellowing and complete drying of leaves, indicating an extremely high sensitivity to the herbicide.

This rating scale (**Figure 2**), considering the percentage of damage and specific symptoms like yellowing of leaves, provides a comprehensive and quantitative framework for evaluating the herbicide effects on plants in the screening process.

Figure 2: Rating scale illustration for the sensitivity of sugarcane varieties to herbicides

RESULTS AND DISCUSSION

Study 1: Sensitivity of Sugarcane Varieties to Herbicides at Germination Stage

To better understand the most critical stage of sugarcane development, this study examines how sensitive sugarcane varieties are to herbicides during the germination stage. This study aims to explore and understand how different sugarcane varieties respond to herbicide applications during the germination stage, providing insights into potential variations in sensitivity across diverse cultivars. The germination stage is an essential stage that sets the foundation for the entire crop lifecycle, making it necessary to assess herbicide effects at this early growth phase.

Sensitivity screening for 2-4, D at germination stage

The data on sugarcane varieties regarding 2,4-D herbicide sensitivity at the germination stage reveals a notable range of responses. A significant proportion of the varieties, accounting for 62%, demonstrated resistance or had no noticeable effect when subjected to 2,4-D application (**Figure 3**). These findings indicate that the majority of sugarcane cultivars being studied have a strong ability to

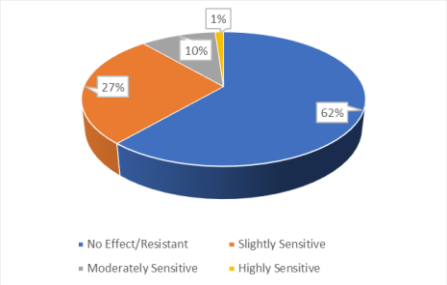

Figure 3: Responses of sugarcane varieties to 2,4-D application at germination

withstand and tolerate 2-4,D application during germination. Additionally, 27% of the varieties showed slight sensitivity, indicating a mild response to the herbicide. A smaller proportion, 10%, exhibited a moderate sensitivity, fortunately, only a minimal percentage of varieties showed a high sensitivity.

Remarkably, none of the examined varieties fell into the category of severely sensitive, indicating a generally favorable tolerance to 2,4-D herbicide at the germination stage. Below are the list of varieties along with their respective reactions to 2-4,D application.

Rating 1 (No Effect/resistance): Phil 2012-0537, Phil 2012-0475, Phil 2011-1683, Phil 2011-1121, Phil 2011-0449, 2011-J47, 2010-G6, Phil 2010-01107, Phil 2009-1867, Phil 2009-1969, Phil 08-0909, Phil 07-243, Phil 07-221, Phil 06-2289, Phil 06-1899, Phil 05-1197, Phil 05-0645, Phil 04-1011, Phil 03-0021, Phil 02-0421, Phil 02-0359, Phil 00-2569, Phil 00-2417, Phil 00-2155, Phil 00-1491, Phil 00-1419, Phil 00-0881, Phil 97-3933, Phil 97-3501, Phil 97-1123, Phil 97-0693, Phil 97-1215, Phil 94-0913, Phil 93-3849, Phil 92-0751, Phil 92-0577, Phil 92-0051, Phil 91-1091, Phil 90-1237, Phil 88-35, Phil 88-29, Phil 87-27, Phil 85-83, Phil 84-77, Phil 83-61, Phil 80-93, Phil 80-13, Phil 78-1440, Phil 75-44, Phil 74-64, Phil 72-70, Phil 67-23, PSR 00-343, VMC 71-39

Rating 2 (Slightly Sensitive): Phil 2012-1263, Phil 04-0827, Phil 04-0081, Phil 03-1727, Phil 00-1893, Phil 00-0791, Phil 99-2541, Phil 99-1793, Phil 99-1427, Phil 99-0925, Phil 98-0255, Phil 93-3727, Phil 93-3155, Phil 93-2349, Phil 88-39, Phil 87-15, Phil 77-79, Phil 72-28, Phil 66-0, Phil 65-53, Phil 50-01, VMC 87-559, VMC 84-524, VMC 86-550

Rating 3 (Moderately Sensitive): Phil 05-1763, Phil 05-0483, Phil 05-0055, Phil 01-0295, Phil 93-1601, Phil 89-43, Phil 62-120, PSR 00-034, PSR 00-161,

Rating 4 (Highly Sensitive): Phil 03-1389

Rating of 5 (Severely Sensitive): None

Sensitivity screening for Diuron at germination stage

The data on sugarcane varieties concerning Diuron herbicide sensitivity at the germination stage highlights diverse responses among the cultivars. Approximately 19% of the varieties demonstrated resistance to Diuron, indicating a high tolerance level within this subset (**Figure 4**). A significant portion of the varieties, the majority at 42%, exhibited a slight sensitivity to Diuron application, suggesting a mild response. Moreover, 31% of the varieties fell into the category of moderately sensitive, reflecting a more pronounced reaction to the herbicide. In addition, 8% of the varieties were classified as highly sensitive, indicating a notable degree of susceptibility. Interestingly, none of the varieties tested were considered susceptible (severely sensitive) to Diuron at the germination stage. The following is a list of varieties accompanied by their corresponding responses to the Diuron application.

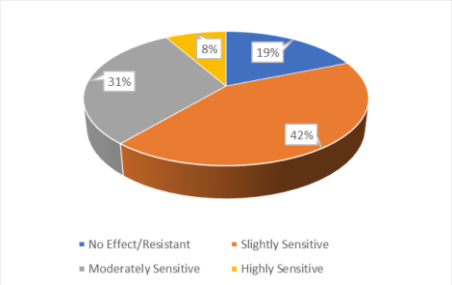

Figure 4: Responses of sugarcane varieties to Diuron application at germination stage

Rating 1 (No Effect/resistance): Phil 2012-0475, Phil 08-0909, Phil 07-243, Phil 05-1763, Phil 05-1197, Phil 03-1727, Phil 03-1389, Phil 00-2155, Phil 99-2541, Phil 99-0925, Phil 98-0255, Phil 97-3501, Phil 97-1123, Phil 97-0693, Phil 88-35, Phil 84-77,

Rating 2 (Slightly Sensitive): Phil 2011-1683, Phil 2011-1121, Phil 07-221, Phil 06-2289, Phil 06-1899, Phil 04-0827, Phil 04-0081, Phil 02-0359, Phil 00-2417, Phil 00-1893, Phil 00-1491, Phil 00-0791, Phil 99-1427, Phil 97-3933, Phil 94-0913, Phil 93-3727, Phil 93-2349, Phil 93-1601, Phil 92-0751, Phil 92-0051, Phil 91-1091, Phil 90-1237, Phil 88-29, Phil 87-27, Phil 87-15, Phil 83-61, Phil 80-93, Phil 80-13, Phil 78-1440, Phil 72-70, Phil 72-28, Phil 67-23, PSR 00-034, PSR 00-343, VMC 84-524, VMC 86-550

Rating 3 (Moderately Sensitive): Phil 2012-1263, Phil 2012-0537, Phil 2011-0449, 2011-J47, Phil 2010-01107, Phil 2009-1969, Phil 05-0645, Phil 05-0055, Phil 03-0021, Phil 02-0421, Phil 01-0295, Phil 00-2569, Phil 00-1419, Phil 00-0881, Phil 99-1793, Phil 97-1215, Phil 93-3849, Phil 93-3155, Phil 92-0577, Phil 89-43, Phil 85-83, Phil 74-64, Phil 65-53, Phil 62-120, Phil 50-01, PSR 00-161

Rating 4 (Highly Sensitive): 2010-G6, Phil 04-1011, Phil 88-39, Phil 77-79, Phil 75-44, VMC 87-559, VMC 71-39

Rating of 5 (Severely Sensitive): None

Sensitivity screening for Glyphosate at germination stage

The data on sugarcane varieties regarding glyphosate herbicide sensitivity at the germination stage suggests minimal variation in responses. Notably, none of the varieties were categorized as resistant to slightly sensitive, indicating a consistent lack of tolerance or mild response to glyphosate among the examined cultivars. However, 5% of the varieties fell into the moderately sensitive category, signifying a more pronounced reaction to glyphosate application (**Figure 5**). Most of the varieties (57%) were considered highly sensitive to glyphosate, suggesting a substantial vulnerability to this herbicide. Furthermore, a significant portion of the varieties were classified as severely sensitive (38%). These findings highlight a predominant high sensitivity of sugarcane varieties to glyphosate application at the germination stage, emphasizing the importance of careful consideration and tailored approaches in glyphosate use during this critical phase of sugarcane development. The following is a list of varieties, along with their responses to the Glyphosate application.

Rating 1 (No Effect/resistance): None

Rating 2 (Slightly Sensitive): None

Rating 3 (Moderately Sensitive): Phil 2009-1867, Phil 2009-1969, Phil 08-0909, Phil 07-243

Rating 4 (Highly Sensitive): Phil 2012-1263, Phil 2012-0537, Phil 2012-0475, Phil 2011-1121, 2010-G6, Phil 2010-01107, Phil 07-221, Phil 06-1899, Phil 05-1197, Phil 05-0645, Phil 04-1011, Phil 03-1389, Phil 02-0359, Phil 00-2417, Phil 00-2155, Phil 00-1419, Phil 00-0881, Phil 00-0791, Phil 99-2541, Phil 99-0925, Phil 97-3933, Phil 97-3501, Phil 97-0693, Phil 97-1215, Phil 94-0913, Phil 93-3849, Phil 93-2349, Phil 92-0577, Phil 91-1091, Phil 88-39, Phil 88-35, Phil 88-29, Phil 87-27, Phil 87-15, Phil 83-61, Phil 78-1440, Phil 77-79, Phil 74-64, Phil 72-70, Phil 50-01, PSR 00-034, PSR 00-343, VMC 87-559, VMC 84-524, VMC 71-39, VMC 86-550

Rating of 5 (Severely Sensitive): Phil 2011-1683, Phil 06-2289, Phil 05-1763, Phil 05-0483, Phil 05-0055, Phil 04-0827, Phil 04-0081, Phil 03-1727, Phil 03-0021, Phil 02-0421, Phil 01-0295, Phil 00-2569, Phil 00-1893, Phil 00-1491, Phil 99-1793, Phil 98-0255, Phil 97-1123, Phil 93-3155, Phil 93-1601, Phil 92-0751, Phil 92-0051, Phil 90-1237, Phil 89-43, Phil 85-83, Phil 84-77, Phil 80-93, Phil 75-44, Phil 72-28, Phil 67-23, Phil 62-120, PSR 00-161

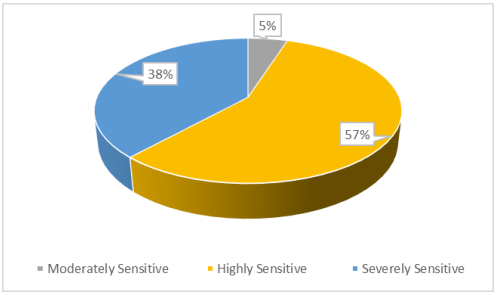

Figure 5: Responses of sugarcane varieties to Glyphosate application at germination stage

The comprehensive examination of sugarcane varieties' responses to herbicides during the germination stage provides crucial insights into their ability to withstand and tolerate specific herbicide applications. In the case of 2,4-D, a substantial 62% of varieties exhibit resistance or no noticeable effect, showcasing a robust tolerance to this herbicide. Moreover, the absence of severely sensitive varieties indicates an overall favorable tolerance across the cultivars studied.

Conversely, Diuron application elicits diverse responses, with 19% displaying resistance and 31% demonstrating a mild sensitivity. The notable absence of severely sensitive varieties suggests a manageable impact of Diuron during germination. Given the widespread tolerance to 2,4-D, optimize its application during germination to capitalize on the majority of varieties exhibiting resistance or minimal effects. This can contribute to effective weed management without compromising crop development.

Glyphosate application, however, reveals a consistent high sensitivity among 57% of varieties, emphasizing the need for cautious use during this critical stage. These findings underscore the importance of tailored herbicide strategies based on the specific sensitivities of sugarcane varieties, especially during the germination phase, to optimize crop development and yield. Important to note that, exercise caution when using glyphosate during germination due to the prevalent high sensitivity among sugarcane varieties.

Study 2: Sensitivity of Sugarcane Varieties to Herbicides at Tillering Stage

The exploration into the sensitivity of sugarcane varieties to herbicides at the tillering stage offered an essential understanding of how various genotypes respond to herbicide treatments during the tillering stage. Tillering is a crucial stage in sugarcane development, marked by the initiation of additional shoots from the base of the primary tillers.

Sensitivity screening for 2,4-D at tillering stage

A significant trend can be observed in the findings on sugarcane varieties' sensitivity to 2,4-D herbicide during the tillering stage (**Figure 6**). A majority of the varieties, or 79% of them, either showed no effect at all or showed resistance to the application of 2,4-D. This implies that a considerable proportion of the sugarcane cultivars that are being examined exhibit a strong tolerance. Furthermore, 19% of the varieties showed slight sensitivity to the herbicide, indicating a mild response to the application. Interestingly, none of the sugarcane varieties under study showed signs of high or severe sensitivity to 2,4-D, suggests that during the tillering stage, the assessed cultivars demonstrated considerable resistance to this herbicide during the tillering stage. These findings provide valuable insights into the different responses of sugarcane varieties to 2,4-D herbicide, offering important considerations for weed management practices in sugarcane cultivation. The following varieties and their 2,4-D application responses are listed below.

Rating 1 (No Effect/resistance): Phil 2012-1263, Phil 2011-1121, 2011-J47, 2010-G6, Phil 2010-01107, Phil 2009-1969, Phil 08-0909, Phil 07-243, Phil 06-1899, Phil 05-1763, Phil 05-1197, Phil 05-0055, Phil 03-1389, Phil 03-0021, Phil 02-0421, Phil 00-2569, Phil 00-2417, Phil 00-2155, Phil 00-1893, Phil 00-1491, Phil 00-1419, Phil 00-0881, Phil 00-0791, Phil 99-2541, Phil 99-1793, Phil 99-1427, Phil 99-0925, Phil 98-0255, Phil 97-3933, Phil 97-0693, Phil 97-1215, Phil 94-0913, Phil 93-3849, Phil 93-3155, Phil 93-2349, Phil 93-1601, Phil 92-0751, Phil 92-0577, Phil 92-0051, Phil 90-1237, Phil 89-43, Phil 88-39, Phil 88-35, Phil 88-29, Phil 87-27, Phil 87-15, Phil 85-83, Phil 84-77, Phil 83-61, Phil 80-93, Phil 80-13, Phil 78-1440, Phil 77-79, Phil 75-44, Phil 74-64, Phil 72-70, Phil 72-28, Phil 67-23, Phil 66-07, Phil 65-53, Phil 62-120, Phil 53-33, Phil 50-01, PSR 00-034, PSR 00-343, PSR 00-161, VMC 87-559, VMC 84-524, VMC 71-39, VMC 86-550.

Rating 2 (Slightly Sensitive): Mild- Phil 2012-0537, Phil 2012-0475, Phil 2011-0449, Phil 2009-1867, Phil 07-221, Phil 06-2289, Phil 05-0645, Phil 05-0483, Phil 04-1011, Phil 04-0827, Phil 04-0081, Phil 03-1727, Phil 02-0359, Phil 01-0295, Phil 97-1123, Phil 93-3727, Phil 91-1091

Rating 3 (Moderately Sensitive): Phil 2011-1683, Phil 97-3501

Rating 4 (Highly Sensitive): None

Rating of 5 (Severely Sensitive): None

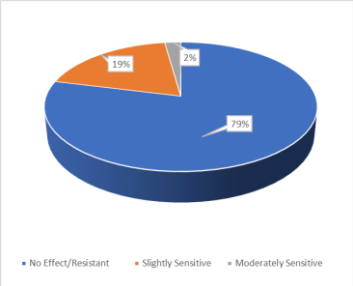

Figure 6: Responses of sugarcane varieties to 2,4-D application at germination stage

Sensitivity screening for Diuron at tillering stage

Data on sugarcane varieties' susceptibility to Diuron herbicide during the tillering stage show a wide range of varied responses. Remarkably, 34% of the tested types showed no effect at all or proved to be resistant to Diuron, suggesting that a significant level of tolerance exists in this subset of sugarcane cultivars (**Figure 7**). Comparably, 34% showed a small degree of sensitivity, indicating a mild reaction to the application of Diuron. On the other hand, 11% of the varieties exhibited a moderate sensitivity, signifying a more pronounced reaction to the herbicide. Furthermore, 12% of the varieties were susceptible, and 9% were severely affected by Diuron application. The range of sensitivities among sugarcane varieties must be understood in order to optimize herbicide use and improve weed management strategy during the tillering stage. Below are the list of varieties along with their respective responses to Diuron application.

Rating 1 (No Effect/resistance): Phil 2012-1263, Phil 2011-1121, Phil 08-0909, Phil 06-2289, Phil 06-1899, Phil 05-1763, Phil 05-1197, Phil 02-0359, Phil 01-0295, Phil 00-2417, Phil 00-2155, Phil 00-1893, Phil 00-1419, Phil 97-3501, Phil 97-1123, Phil 97-0693, Phil 97-1215, Phil 93-2349, Phil 93-1601, Phil 92-0751, Phil 90-1237, Phil 89-43, Phil 88-39, Phil 88-35, Phil 84-77, Phil 83-61, Phil 80-13, Phil 65-53, PSR 00-034, VMC 86-550

Rating 2 (Slightly Sensitive): Phil 2012-0537, Phil 2012-0475, Phil 2009-1969, Phil 07-243, Phil 05-0645, Phil 05-0483, Phil 05-0055, Phil 04-0827, Phil 04-0081, Phil 03-1389, Phil 03-0021, Phil 02-0421, Phil 00-2569, Phil 00-0881, Phil 00-0791, Phil 99-1427, Phil 98-0255, Phil 97-3933, Phil 94-0913, Phil 93-3727, Phil 92-0577, Phil 88-29, Phil 87-27, Phil 87-15, Phil 85-83, Phil 80-93, Phil 78-1440, Phil 67-23, PSR 00-343, VMC 84-524

Rating 3 (Moderately Sensitive): 2010-G6, Phil 99-1793, Phil 92-0051, Phil 91-1091, Phil 77-79, Phil 72-70, Phil 53-33, Phil 50-01, PSR 00-161, VMC 87-559

Rating 4 (Highly Sensitive): Phil 2011-1683, Phil 2011-0449, 2011-J47, Phil 2010-01107, Phil 2009-1867, Phil 00-1491, Phil 93-3849, Phil 75-44, Phil 74-64, Phil 62-120, VMC 71-39

Rating of 5 (Severely Sensitive): Phil 07-221, Phil 04-1011, Phil 03-1727, Phil 99-0925, Phil 93-3155, Phil 89-43, Phil 72-28, Phil 66-07

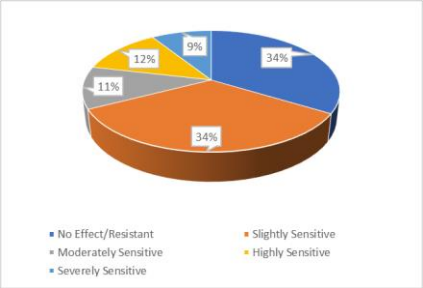

Figure 7: Responses of sugarcane varieties to 2,4-D application at germination stage

Sensitivity screening for Glyphosate at tillering stage

The data pertaining to the glyphosate herbicide sensitivity of sugarcane varieties during the tillering stage reveals a significant pattern marked by minimal variability. Interestingly, none of the examined varieties demonstrated glyphosate resistance; similarly, none were categorized as slightly sensitive. Most of the varieties, constituting a substantial proportion, exhibited sensitivity levels ranging from moderate to severe (**Figure 8**). Specifically, only 1% of the varieties exhibited a moderate sensitivity, suggesting a relatively subdued response to glyphosate. In contrast, 19% of the varieties showed high sensitivity to the herbicide. The most notable finding was that glyphosate application had a substantial negative impact on a large number of the varieties. This consistent and pronounced impact emphasizes the need for careful consideration and tailored approaches when using glyphosate on sugarcane at the tillering stage, taking into account the prevalent high sensitivity observed across the majority of the varieties in this study. The list of varieties and how each one reacts to the application of Glyphosate is as follows.

Rating 1 (No Effect/resistance): None

Rating 2 (Slightly Sensitive): None

Rating 3 (Moderately Sensitive): Phil 2009-1867

Rating 4 (Highly Sensitive): Phil 2009-1969, Phil 05-1197, Phil 05-0483, Phil 04-1011, Phil 03-1727, Phil 00-2417, Phil 99-1427, Phil 92-0577, Phil 87-27, Phil 85-83, Phil 74-64, Phil 67-23, Phil 50-01, PSR 00-034, PSR 00-343

Rating of 5 (Severely Sensitive): Phil 08-0909, Phil 07-243, Phil 07-221, Phil 06-2289, Phil 06-1899, Phil 05-1763, Phil 05-0645, Phil 05-0055, Phil 04-0827, Phil 04-0081, Phil 03-1389, Phil 03-0021, Phil 02-0421, Phil 02-0359, Phil 01-0295, Phil 00-2569, Phil 00-2155, Phil 00-1893, Phil 00-1491, Phil 00-1419, Phil 00-0881, Phil 00-0791, Phil 99-2541, Phil 99-1793, Phil 99-0925, Phil 98-0255, Phil 97-3933, Phil 97-3501, Phil 97-1123, Phil 97-0693, Phil 97-1215, Phil 94-0913, Phil 93-3849, Phil 93-3727, Phil 93-3155, Phil 93-2349, Phil 93-1601, Phil 92-0751, Phil 92-0051, Phil 91-1091, Phil 90-1237, Phil 89-43, Phil 88-39, Phil 88-35, Phil 88-29, Phil 87-15, Phil 84-77, Phil 83-61, Phil 80-93, Phil 80-13, Phil 78-1440, Phil 77-79, Phil 75-44, Phil 72-70, Phil 72-28, Phil 66-07, Phil 65-53, Phil 62-120, Phil 53-33, PSR 00-161, VMC 87-559, VMC 84-524, VMC 71-39, VMC 86-55.

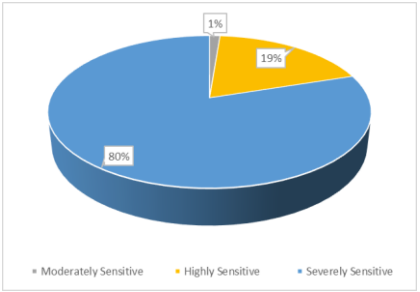

Figure 8: Responses of sugarcane varieties to Glyphosate application at germination stage

Sugarcane Mechanism to Herbicides

The observed diversity in herbicide tolerance and resistance across distinct plant varieties can be attributed to a range of factors such as genetic variation, herbicidal metabolism and morpho-physiological differences (**Figure 9 & 10**), with genetic variation standing out as a key determinant (Sen et al., 2023).

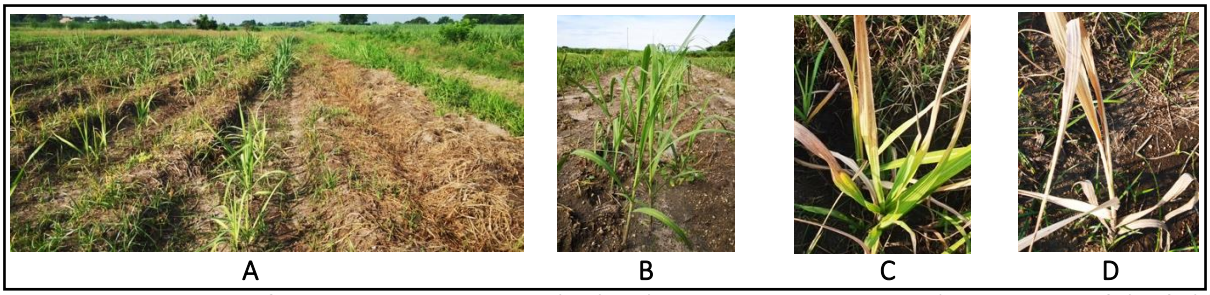

Figure 9. Responses of suagarcane varieties to herbicides at germination stage (A. overview of the field experiment with different morphological responses of sugarcane plant and affected weeds; B. Resistant; C Moderate; D. Susceptible plant)

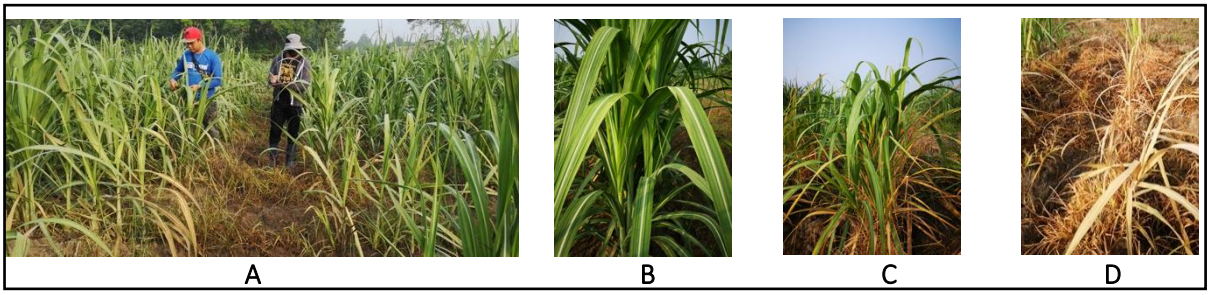

Figure 10. Responses of suagarcane varieties to herbicides at Tillering stage stage (A. overview of the field experiment with different morphological responses of sugarcane plant and affected weeds; B. Resistant; C. Moderate; D. Susceptible)

Genetic variation

Each plant variety inherently obtained unique genetic makeup, contributing to its distinct response to herbicides. This genetic diversity manifests in the presence or absence of specific genes that confer resistance or tolerance to herbicides (Greenwood, 2014). Some plant varieties may carry genetic traits that provide a natural safeguard against the herbicidal effects, enabling them to withstand or tolerate herbicide applications. Conversely, other varieties may lack these protective genetic traits, rendering them more susceptible to the herbicidal impact. Understanding this genetic aspect is crucial for developing targeted and effective herbicide management strategies in sugarcane farming.

Herbicide Metabolism

The capacity of plants to metabolize or detoxify herbicides varies across different varieties, contributing to distinctions in their tolerance levels (Lushchak et al., 2018; Plant and Soil Sciences eLibrary:Print Lesson, n.d.). Some plant varieties exhibit more efficient mechanisms for breaking down or neutralizing herbicide compounds within their physiological processes. These efficient metabolic pathways enable certain varieties to effectively detoxify herbicides, minimizing their adverse effects (Wang et al., 2022). On the other hand, other varieties may have less effective or slower herbicide metabolism, leading to increased susceptibility to the toxic impact of herbicide applications.

Morpho-physiological Differences

The observed diversity in herbicide tolerance and resistance among different plant varieties can be ascribed to various factors, one of which is physiological differences. Varied physiological characteristics, including leaf structure, root development, and overall plant health, distinguish one variety from another. These inherent differences significantly impact how plants interact with herbicides, affecting processes such as absorption, translocation, and response to these chemical

compounds (Nakashita, 2021). For instance, differences in leaf structure may influence the rate at which herbicides are absorbed, while variations in root development can affect the extent to which the herbicide reaches different parts of the plant. Additionally, the overall health of the plant plays a crucial role in determining its ability to withstand or succumb to the herbicidal effects.

SUMMARY, RECOMMENDATION, AND CONCLUSION

The results of the study revealed a wide array of responses among sugarcane varieties to herbicide applications during both the germination and tillering stages. During germination, sugarcane varieties exhibit varying sensitivity to 2,4-D and Diuron herbicide application. A majority, 62%, show resistance or no noticeable effect. However, 27% show mild sensitivity, 10% showed moderate sensitivity, and a minimal percentage show high sensitivity. None are severely sensitive, indicating a generally favorable tolerance for 2,4-D. In Diuron application, 19% showed high tolerance, 42% showed mild sensitivity, 31% moderately sensitive, and 8% highly sensitive. None were considered severely sensitive to Diuron. On the other hand, Glyphosate application demonstrated an absence of tolerance or a weak reaction (resistant to slightly sensitive) in all varieties. However, 5% were moderately sensitive, while the majority (57%) were highly sensitive, and (38%) were severely sensitive. These findings emphasize the importance of carefully considering glyphosate when sugarcanes are still in the germination stage.

A significant trend in sugarcane varieties' sensitivity to 2,4-D herbicide during the tillering stage was observed. 79% showed no effect or resistance, indicating strong tolerance. 19% showed mild sensitivity, while none showed high or severe sensitivity. While in Diuron application, 34% considered showed no influence or resistant, while 34% showed mild sensitivity. 11% showed moderate sensitivity, while 12% were susceptible. Most notable finding was that glyphosate application had a substantial negative impact on most of the varieties exhibiting moderate to severe sensitivity levels (1% moderately sensitive, 19% highly sensitive and 80% severely affected). This highlights the importance of careful herbicide management during the germination and tillering stage to avoid adverse effects on sugarcane development.

The study shows that the sensitivity of sugarcane varieties to herbicides can vary significantly during this early growth phase. This variability can be attributed primarily to the inherent genetic characteristics of these varieties. Each sugarcane variety possesses unique genetic traits, leading to distinct coping mechanisms for herbicide exposure. The diverse genetic makeup among the varieties contributes to variations in their ability to withstand herbicides at different growth stages. Understanding these inherent genetic differences is crucial for tailoring effective herbicide management strategies, ensuring the successful cultivation of sugarcane while minimizing any potential adverse effects on crop development. Importantly, considering the specific sensitivities of different varieties becomes crucial in optimizing cultural management practices, particularly in weed control.

This knowledge is crucial for plant breeding programs, allowing researchers to develop sugarcane varieties with enhanced resistance to specific herbicides, ultimately contributing to more sustainable and efficient crop management. Furthermore, this results guide farmers in being aware of the characteristics of their sugarcane varieties and selecting appropriate herbicides based on the specific sugarcane varieties they cultivate. This targeted approach can lead to more effective weed management, reducing the risk of crop damage and improving overall yield.

The diverse responses of different sugarcane varieties to various herbicides open further research and exploration possibilities. One potential research avenue could involve investigating the specific impact of herbicide application on sugarcane yield. This could include assessing potential yield losses associated with different herbicides considering factors such as dosage, application timing, and varietal sensitivity. Understanding the complex relationship between herbicide use and sugarcane productivity is essential for developing more precise and efficient weed management strategies. Understanding the intricate relationship between herbicide use and sugarcane productivity is essential for developing more precise and efficient weed management strategies. Additionally, exploring the underlying genetic and physiological factors contributing to herbicide resistance or tolerance in sugarcane varieties could deepen our understanding of plant-herbicide interactions. This knowledge could inform targeted breeding programs to develop sugarcane varieties with inherent resistance to specific herbicides, promoting sustainability in agriculture. These research directions would offer valuable insights to the agricultural community, facilitating more informed decision-making and promoting sustainable crop management practices.

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Appendix Table 1: List of Sugarcane Varieties

Phil 2012-1263	Phil 00-2569	Phil 89-43
Phil 2012-0537	Phil 00-2417	Phil 88-39
Phil 2012-0475	Phil 00-2155	Phil 88-35
Phil 2011-1683	Phil 00-1893	Phil 88-29
Phil 2011-1121	Phil 00-1491	Phil 87-27
Phil 2011-0449	Phil 00-1419	Phil 87-15
2011-J47	Phil 00-0881	Phil 85-83
2010-G6	Phil 00-0791	Phil 84-77
Phil 2010-01107	Phil 99-2541	Phil 83-61
Phil 2009-1867	Phil 99-1793	Phil 80-93
Phil 2009-1969	Phil 99-1427	Phil 80-13
Phil 08-0909	Phil 99-0925	Phil 78-1440
Phil 07-243	Phil 98-0255	Phil 77-79
Phil 07-221	Phil 97-3933	Phil 75-44
Phil 06-2289	Phil 97-3501	Phil 74-64
Phil 06-1899	Phil 97-1123	Phil 72-70
Phil 05-1763	Phil 97-0693	Phil 72-28
Phil 05-1197	Phil 97-1215	Phil 67-23
Phil 05-0645	Phil 94-0913	Phil 66-07
Phil 05-0483	Phil 93-3849	Phil 65-53
Phil 05-0055	Phil 93-3727	Phil 62-120
Phil 04-1011	Phil 93-3155	Phil 53-33
Phil 04-0827	Phil 93-2349	Phil 50-01
Phil 04-0081	Phil 93-1601	PSR 00-034
Phil 03-1727	Phil 92-0751	PSR 00-343
Phil 03-1389	Phil 92-0577	PSR 00-161
Phil 03-0021	Phil 92-0051	VMC 87-559
Phil 02-0421	Phil 91-1091	VMC 84-524
Phil 02-0359	Phil 90-1237	VMC 71-39
Phil 01-0295	Phil 89-43	VMC 86-550