Impact of Glyphosate Herbicide on Growth and Rhizome Production in Arrowroot (*Maranta arundinacea L.*)

Renato Teles Neves [1], Josimara Nolasco Rondon [2*], Marney Pascoli Cereda [3], Francilina Araujo Costa [4]

Abstract

Background: Arrowroot (Maranta arundinacea L.) is a starchy, herbaceous plant with significant agricultural and industrial value, particularly in the production of starch. While herbicides like glyphosate are commonly used in agriculture, their effects on arrowroot cultivation, especially concerning growth and rhizome production, remain underexplored. This study investigates the impact of glyphosate on arrowroot growth, rhizome yield, and soil properties. Methods: The study was conducted at Fazenda Escola, UCDB, in Campo Grande-MS, Brazil, using the Common cultivar of arrowroot. Two soil analyses were performed: one before planting millet (Pennisetum glaucum) to assess soil structure, and another after its incorporation to evaluate physical and chemical improvements. The plants were subjected to two weed control treatments: glyphosate application and manual weeding. Growth parameters, chlorophyll content, and rhizome yield were assessed at different stages of development. Results: Soil analysis revealed significant improvements in soil structure and nutrient content after millet incorporation. Glyphosate-treated plants showed delayed growth in height and a decrease in leaf number compared to manually weeded plants. Chlorophyll content was lower in glyphosate-treated plants but not significantly detrimental to plant health. Glyphosate application led to a reduction in rhizome count (2,513 units vs. 4,953 units in control), though the size and weight of individual rhizomes were minimally affected. Rhizomes from glyphosate-treated plants were slightly larger in diameter but lighter than those from the control group. Conclusion: Glyphosate application negatively affected arrowroot's early growth and rhizome production, leading to fewer rhizomes and reduced leaf number. However, it did not substantially alter rhizome size. The results suggest that glyphosate application may impair the overall yield of arrowroot rhizomes, which is critical for starch production. Therefore, glyphosate is not recommended for weed control in arrowroot cultivation, as it adversely impacts rhizome yield and could hinder the plant's starch production potential.

Keywords: Glyphosate, arrowroot, rhizome production, plant growth, herbicide effects

Significance | This study evaluates glyphosate's effect on arrowroot growth, highlighting its impact on rhizome production and plant health.

*Correspondence. Josimara Nolasco Rondon, Ceteagro-Catholic University of Dom Bosco, Campo Grande, MS, Brazil.
Email: rondon.josimara@yahoo.com.br

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Introduction

Arrowroot (*Maranta arundinacea* L.) is an herbaceous plant of significant agricultural and industrial value, primarily cultivated for its starchy rhizomes. In Brazil, three main cultivars are recognized: Common, Creoula, and Banana. Among these, the Common and Creoula cultivars are the most prominent, with the Common cultivar being commercially dominant. The Common cultivar is

Author Affiliation.
[1] Agronomy, Catholic University of Dom Bosco, Brazil. Email: telesneves@gmail.com
[2] Ceteagro-Catholic University of Dom Bosco, Campo Grande, MS, Brazil.
[3] Ceteagro, Catholic University of Dom Bosco, Campo Grande, MS, Brazil. cereda@ucdb.br
[4] Department of Agronomy, Catholic University of Dom Bosco, Campo Grande, MS, Brazil.

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characterized by its superior starch quality, compact size (approximately 60 cm in height), and clear, conical rhizomes that reach lengths of 10–25 cm, depending on soil quality. The Creoula cultivar, native to the Antilles, is a taller variety (over 1 meter) and produces surface-level rhizomes in clumps, which must be carefully washed to prevent the formation of low-quality, black starch. Creoula also exhibits abundant flowering under tropical conditions but does not produce fruit or seeds (Leonel & Cereda, 2002; Monteiro & Peressin, 2002).

Industrial arrowroot is typically a plant with a height of 1.20 meters, possessing fusiform rhizomes that are scaly and produced in tufts. Harvesting occurs between 9 to 12 months after planting, with the plant's leaves wilting and changing color from brown to straw-yellow. Fresh rhizomes can contain over 20% starch, depending on the plant's age (Monteiro & Peressin, 2002; Pereira et al., 1999). Zárate and Vieira (2005) recommend using rhizome pieces from the middle or tips, with at least six buds for propagation. Ideal planting conditions include shallow pits with a spacing of 0.30 to 0.40 meters between plants and 0.70 to 0.80 meters between rows. The total required seed rhizome mass for planting is 2–3 tons per hectare (Laura et al., 2000; Monteiro & Peressin, 2002).

Climatically, arrowroot thrives in humid, mesothermic conditions (Cfa), preferring well-drained, porous, organic-rich soils like sandy alluvium or Podzólico Red-Amarelo orto soils. However, the cultivation process involves complex decision-making, including the selective application of herbicides such as Roundup® (glyphosate), which has proven efficacy in controlling weeds in many crops. Glyphosate is absorbed by plants and inhibits the synthesis of essential amino acids, affecting the growth of unwanted vegetation (Jiraungkoorskul et al., 2002; Amarante Jr. et al., 2002; Galli & Montezuma, 2005).

Starch extraction is a multi-billion-dollar global industry, with corn, cassava, potatoes, rice, and maize being the primary sources. In Brazil, cassava and corn are the two main starch-producing crops, with industrial capacities reaching up to 800 tons of raw material per day (Da Silva, Assumption & Vegro, 2000). Although starch production from arrowroot is commercially successful in China, it remains underexploited in Brazil. Despite the attention given to other starchy crops like manioc (*Manihot esculenta*), potato (*Arracacia xanthorrhiza*), and sweet potato (*Ipomoea batatas*), arrowroot holds significant potential for expanding Brazil's starch industry (Bermudez, 1997; Kibuuka & Mazzari, 1981; Leonel & Zein, 1985; Zein, 1998).

Historically, arrowroot was cultivated alongside maize, but as maize production systems advanced, arrowroot cultivation declined. This study aims to revive arrowroot farming, improving its production and investigating the impact of herbicides on large-scale cultivation. By optimizing cultivation practices and herbicide use, arrowroot can become a valuable addition to Brazil's starch production, contributing to both local agriculture and industrial sectors.

2. Material and methods

The *Common* variety of arrowroot (*Maranta arundinacea* L.) rhizomes used in this study were sourced from the existing plantation at Fazenda Escola - UCDB, São Vicente Institute, located in Campo Grande-MS, Brazil. The planting area was determined based on the availability of rhizomes, resulting in a 1000 m² plot.

2.1 Soil Analysis and Preparation

Two soil analyses were conducted: the first prior to planting millet to assess the physical and chemical characteristics of the soil, and the second after incorporating millet into the soil. The soil preparation process began with the use of a subsoiler to break up any compacted layers. This was followed by light tilling to further prepare the soil. Subsequently, 1.5 kg of millet (*Pennisetum glaucum*) seeds were sown over the 1000 m² area to improve soil structure.

2.2 Planting and Layout

To demarcate the planting rows, a cultivator equipped with four stems was adapted to achieve a row spacing of 0.90 m × 0.50 m × 0.90 m × 0.50 m, facilitating semi-mechanized planting and harvesting. The rhizomes were cut into sections containing approximately six buds each, which were then planted in rows with a 0.25 m spacing, covering the total planting area of 1000 m² (20 m × 50 m).

2.3 Weed Control

Weed management was carried out using both chemical and manual methods. Glyphosate, a non-selective herbicide, was applied to the central section of the planting area at 110 days after planting (DAP). The remaining area was manually weeded. The effectiveness of these treatments was evaluated by calculating the survival index (number of plants and percentage of plant loss) at 121 DAP, comparing the glyphosate-treated area with the manually weeded section.

2.4 Growth and Chlorophyll Analysis

At 233 DAP, growth measurements were taken, including plant height and chlorophyll content. For these analyses, twenty plants were randomly selected: ten from the glyphosate-treated area and ten from the manually weeded section. Plant height was measured from ground level to the inflection point of the highest leaf using a graduated ruler. Chlorophyll content was assessed using a SPAD-102 chlorophyll meter, providing an indication of the plant's health and nutritional status.

2.5 Harvesting and Production Evaluation

The rhizomes were harvested using an Ikeda implement to ensure uniform soil disturbance and facilitate the ripening of the rhizomes. The harvested rhizomes were evaluated for production by counting, measuring their length and diameter, and weighing the collected

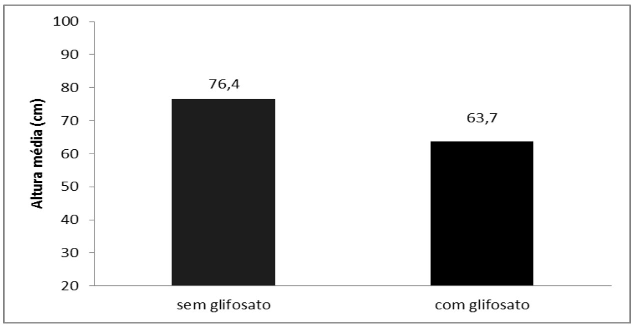

Figure 1. Average height of plants arrowroot after glyphosate application and clear off weed.

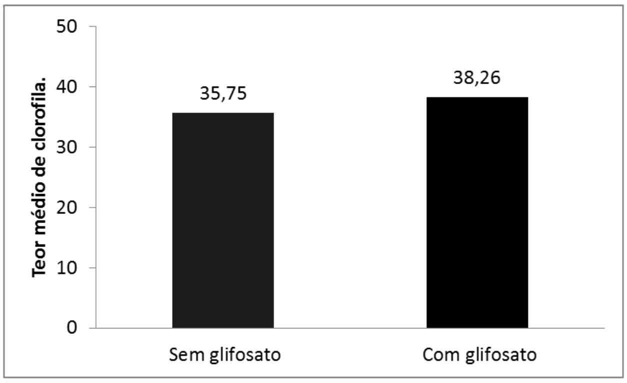

Figure 2. Average total chlorophyll content (mg / g FW of leaf) of arrowroot plants after application of glyphosate herbicide and no herbicide (clear off weed).

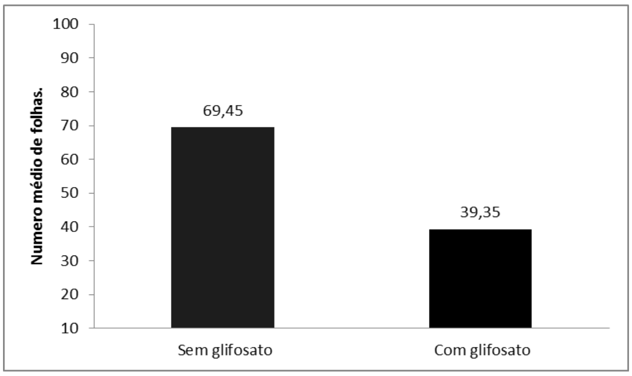

Figure 3. Average number of leaves of plants treated with glyphosate and no glyphosate.

Table 1. Chemical analysis of soil for evaluation of soil characteristics.

Identification	pH		MO	P	K	Ca	Mg	Al	H +Al	T	V
	H_2O	$CaCl_2$	g/kg	Mg/dm^3	$Cmolc/dm^3$						%
0,0 a 0,2	6,25	5,26	27	2,4	0,24	4,0	1,1	0,2	5,1	10,5	51,1

P (phosphorus) and K (potassium): Mehlich; pH 12.5; MO: Colorimetric; Ca (calcium), Mg (magnesium) and Al (aluminum): KCL 1N; H (hydrogen) + Al (aluminum): Calcium Acetate pH 7.0.

Table 2. Chemical analysis of soil for evaluation of residual capacity of millet corn.

Identification	pH		MO	P	K	Ca	Mg	Al	H +Al	T	V
	H_2O	$CaCl_2$	g/kg	Mg/dm^3	$Cmolc/dm^3$						%
0,0 a 0,2	7,14	6,58	29	4,5	0,32	4,0	2,5	0,0	9,8	15,7	43,3

P (phosphorus) and K (potassium): Mehlich; pH 12.5; MO: Colorimetric; Ca (calcium), Mg (magnesium) and Al (aluminum): KCL 1N; H (hydrogen) + Al (aluminum): Calcium Acetate pH 7.0.

rhizomes from both the glyphosate-treated and manually weeded areas.

3. Results

The comparison of soil analyses before and after the planting of millet revealed a significant improvement in both the physical and chemical properties of the soil. The incorporation of millet notably enhanced soil structure, with improved aeration and porosity, while chemical parameters, such as nutrient content and pH, also showed positive changes (see Tables 1 and 2).

In terms of plant development, arrowroot plants treated with glyphosate herbicide exhibited a delay in height growth compared to those subjected to manual weeding (Figure 1). This suggests that glyphosate application may temporarily inhibit vertical growth, potentially due to its impact on overall plant metabolism.

Furthermore, chlorophyll content was notably lower in plants treated with glyphosate compared to those that underwent manual weeding. Despite this, the decrease in chlorophyll was not sufficiently severe to be considered harmful to the plants. The difference in chlorophyll levels suggests that while glyphosate may slightly impact plant health, it does not significantly affect chlorophyll production in arrowroot plants (Figure 2).

Regarding rhizome production, the glyphosate-treated plants yielded significantly fewer rhizomes (2,513 units) than the control plants, which produced 4,953 rhizomes. However, the size of the rhizomes was not adversely affected by the herbicide treatment. The average diameter of the glyphosate-treated rhizomes was 29.43 cm, with an average length of 12.01 cm and an average weight of 27.78 grams. In contrast, control plants had slightly smaller rhizomes with an average diameter of 24.15 cm, length of 11.40 cm, and weight of 33.13 grams. These findings indicate that while glyphosate treatment reduced the total number of rhizomes, the size and weight of individual rhizomes were only marginally influenced, with the glyphosate-treated rhizomes being slightly larger but lighter on average.

Finally, a significant reduction in the number of leaves was observed in glyphosate-treated plants compared to those subjected to manual weeding (Figure 3). This suggests that glyphosate may negatively affect leaf production, potentially impacting the plant's overall biomass accumulation.

In summary, while glyphosate application resulted in fewer rhizomes and a reduction in leaf number, it did not substantially affect the size of the rhizomes. The herbicide's impact on plant height and chlorophyll content suggests a mild, temporary disturbance to plant growth and development, without long-term detrimental effects on rhizome size or yield.

4. Discussion

The use of post-emergence glyphosate in agriculture, particularly in genetically modified crops like Roundup Ready (RR) soybean, has raised concerns about its potential impacts on plant growth and productivity. Glyphosate is known to affect nutrient uptake and plant metabolism, influencing the overall health and yield of crops. Albrecht et al. (2010) highlighted that glyphosate application can alter the mineral nutrition of plants, with potential deficiencies in essential nutrients such as manganese (Mn), nitrogen (N), calcium (Ca), magnesium (Mg), iron (Fe), and copper (Cu). These nutrient imbalances can lead to reduced biomass accumulation, stunted growth, and ultimately lower crop productivity.

In this study, glyphosate's effects were first observed in the shoot development of arrowroot (*Maranta arundinacea* L.), followed by noticeable changes in rhizome production. This aligns with findings from other studies, where glyphosate's action is primarily due to its inhibition of the enzyme 5-enolpyruvylshiquimate-3-phosphate synthase (EPSPS), which is involved in the synthesis of tryptophan. Tryptophan is a precursor to auxins, which are vital plant growth hormones responsible for regulating cell elongation and overall plant growth (Amarante Jr. et al., 2002; Galli & Montezuma, 2005). Therefore, the inhibitory effect of glyphosate on auxin production likely explains the observed delays in height growth and the reduction in leaf number in treated arrowroot plants.

Although glyphosate application has been shown to affect plant growth and development, its impact on rhizome size and biomass in arrowroot appears to be less pronounced. As seen in this study, glyphosate-treated plants produced slightly larger rhizomes in terms of diameter and length, but these rhizomes weighed less than those of the control plants. This suggests that while glyphosate may not significantly alter rhizome size, it may influence the allocation of resources, resulting in slightly lighter rhizomes despite their larger size. This phenomenon could be related to the disruption of nutrient uptake and biomass synthesis, a common consequence of glyphosate's impact on the plant's metabolic pathways (Kremer et al., 2005).

Previous studies have reported similar effects of glyphosate on various crops. For instance, research by Kremer et al. (2005) emphasized that glyphosate could negatively affect water use efficiency, photosynthesis, and secondary metabolite production, all of which are crucial for plant health and productivity. In the case of RR soybeans, glyphosate's application has been shown to affect not only nutrient uptake but also physiological processes such as photosynthesis and root development (Correia et al., 2007; Gazziero et al., 2007). While glyphosate's effects on arrowroot rhizomes in this study were somewhat limited, the broader implications for nutrient cycling and plant health in other crops should not be overlooked.

5. Conclusion

In summary, the findings of this study suggest that glyphosate application may delay the growth of arrowroot shoots and reduce leaf production, likely due to its effects on hormone synthesis and nutrient uptake. However, the impact on rhizome size was minimal, with slight increases in diameter and length, though rhizome weight was reduced. These results underscore the importance of considering the broader physiological and metabolic effects of glyphosate when applying it in agricultural systems, especially for crops like arrowroot, where the final yield depends on rhizome production. The implications for glyphosate use in large-scale arrowroot cultivation are thus mixed, with potential benefits for rhizome size but trade-offs in overall plant health and productivity. Further research is needed to better understand the long-term effects of glyphosate on arrowroot and other crops, particularly in terms of nutrient dynamics and crop yield.

Author contributions

R.T.N. contributed to the conceptualization and data collection for the study. J.N.R. supervised the research, guided the methodology, and served as the corresponding author. M.P.C. participated in data analysis and provided critical feedback on the manuscript. F.A.C. contributed to the interpretation of results and assisted in drafting and reviewing the manuscript.

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Competing financial interests

The authors have no conflict of interest.

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