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COMPARATIVE ASSESSMENT OF PRE- AND POST-EMERGENCE APPLICATIONS OF CASSAVA MILL EFFLUENT FOR WEED MANAGEMENT

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ABSTRACT

Weed management in smallholder and low-input farming systems is constrained by the cost, environmental risks, and declining efficacy of synthetic herbicides. Cassava mill effluent (CME), a cassava-processing by-product rich in cyanogenic compounds, has potential for weed control, but its application strategy and persistence are poorly understood. This study evaluated the efficacy of CME applied as a pre-emergence soil treatment and as a post-emergence foliar spray for weed control. A screen-house experiment was conducted using a Completely Randomised Design with three replicates. CME was applied at rates equivalent to 6, 12, 18, and 24 g CN ha^{-1}, alongside an untreated control, either before weed emergence or after weed establishment. Weed density, species richness, fresh and dry biomass, and weed control efficiency (WCE) were assessed over two successive weed flushes. Pre-emergence soil application of CME showed no significant effects on weed density, biomass, or species richness across both flushes, indicating limited effectiveness under soil-applied conditions. In contrast, post-emergence foliar application significantly reduced weed density from 1188 to 280 plants m^2, fresh weight from 3927 to 495 g m^2, , and dry weight from 825 to 118 g m^2 during the first weed flush. The highest level of weed control was achieved at 24 g CN ha^{-1} applied post-emergence, with weed control efficiency peaking at 85.9%. No significant weed suppression was observed during the second flush, suggesting limited residual activity of CME. The study concludes that CME functions as a short-lived bioherbicide when applied post-emergence, with effectiveness dependent on direct contact with weed foliage. Its low persistence implies minimal risk to subsequent crops, supporting its suitability for sustainable and integrated weed management systems. Therefore, repeated post-emergence applications of CME at 24 g CN ha^{-1}, or its integration with other weed control methods, are recommended to enhance long-term weed management effectiveness.

Keywords: Bio-herbicide; cyanogenic compounds; Cassava processing waste; Weed control efficiency.

INTRODUCTION

Weeds remain one of the most persistent biological constraints to crop productivity, reducing yields through competition for water, nutrients, and light, while also serving as alternate hosts for insect pests and plant pathogens. Globally, chemical herbicides have become the dominant weed control strategy because of their rapid action and

labour-saving advantages. However, continued reliance on synthetic herbicides has raised concerns related to herbicide resistance, environmental contamination, non-target effects, and increasingly stringent regulatory restrictions (Duke, 2012; Délye *et al*., 2013; Heap, 2014). These challenges have stimulated growing interest in alternative and complementary weed management approaches, including bioherbicides and natural-product-based weed control agents.
A central principle governing herbicide performance is the mode of action, defined as the specific biochemical or physiological process disrupted within the plant. Mode of action not only determines herbicide selectivity and spectrum but also dictates optimal timing and method of application (Dayan *et al*., 2009). Herbicides that interfere with photosynthesis, lipid synthesis, or amino acid biosynthesis typically exhibit greater efficacy when applied post-emergence, as they require direct contact with metabolically active foliage (Devine *et al*., 1993; Duke, 2012). In contrast, pre-emergence herbicides generally act on germinating seeds or young seedlings by disrupting cell division, membrane integrity, or early metabolic processes, and are therefore applied to or incorporated into the soil to target the weed seedbank (Soomro *et al*., 2024). These principles are equally relevant when evaluating non-synthetic herbicidal agents whose bioactivity is influenced by plant developmental stage, exposure pathway, and persistence in the soil environment.

Cassava (*Manihot esculenta* Crantz) processing generates large volumes of cassava mill effluent (CME), an agro-industrial waste rich in linamarin, a cyanogenic glucoside that enzymatically hydrolyses to release hydrogen cyanide (HCN). Cyanide is a potent respiratory inhibitor that suppresses mitochondrial electron transport by binding to cytochrome C oxidase, leading to rapid energy deprivation, metabolic disruption, and eventual plant death or severe physiological stress (Zuhra and Szabo, 2022; Xu *et al*., 2023). In addition to its direct phytotoxicity, repeated discharge of CME into soils has been reported to modify soil chemical and biological properties, including reductions in soil pH, accumulation of cyanide residues, and alterations in microbial activity (Osunbitan *et al*., 2012; Patrick *et al*., 2011; Lawal *et al*., 2019). The extent to which these effects persist is influenced by soil buffering capacity, organic matter content, and microbial degradation processes, all of which regulate cyanide retention, volatilization, and bioavailability (Refsgaard *et al*., 2010; Ubalua, 2010)). Consequently, the weed-suppressive effects of CME are inherently time-dependent and may vary markedly between pre-emergence exposure of germinating seeds and post-emergence contact with established seedlings (Ogundola and Liasu, 2007; Ganyam *et al*., 2022).

Within the framework of sustainable agriculture and circular economy principles, the valorization of cassava mill effluent for weed management presents a dual opportunity to address both environmental and agronomic challenges (Geissdoerfer *et al*., 2017; Velenturf and Purnell, 2021). Cassava processing generates substantial quantities of liquid waste that, if indiscriminately discharged, contributes to soil and water pollution. Redirecting this waste stream for controlled agricultural use aligns with circular economy concepts by converting an environmental liability into a functional input within crop production systems. When judiciously applied, CME has the potential to reduce dependence on synthetic herbicides, lower production costs for smallholder farmers, and promote more resource-efficient weed management strategies, particularly in cassava-based and mixed cropping systems prevalent in the tropics.

Despite growing interest in CME as a low-cost bioherbicidal resource, existing studies have largely focused on its general phytotoxic effects or environmental implications, with limited emphasis on how application timing influences weed control outcomes. To our knowledge, no study has rigorously compared the relative weed-suppressive efficacy of cassava mill effluent applied at pre - and post-emergence stages under controlled experimental conditions. This knowledge gap limits the development of evidence-based guidelines for optimising CME use and constrains its rational integration into weed management systems.

This study comparatively evaluated the weed-suppressive efficacy of cassava mill effluent applied at pre- and post-emergence stages. It is hypothesised that application timing significantly influences CME bio-efficacy due to differences in exposure pathways, physiological sensitivity, and soil-mediated interactions. The findings are expected to contribute to a better mechanistic understanding of CME action and to support the development of practical recommendations for incorporating CME as a complementary tool within integrated weed management programmes, particularly in cassava-producing regions where effluent disposal poses both environmental challenges and agronomic opportunities.

MATERIALS AND METHODS

The study was conducted in a naturally ventilated screenhouse located at the Institute of Agricultural Research and Training (IAR&T), Ibadan, Nigeria (7°31'N, 3°45'E), within the rainforest–savanna transition agro-ecological zone. During the experimental period, screenhouse temperatures ranged from 24 to 33 °C, while relative humidity varied between 52 and 79%. These conditions were considered suitable for evaluating the weed suppressive potential of cassava mill effluent (CME) while minimising environmental variability associated with open-field trials.

Topsoil (0–15 cm) was collected from an arable field within IAR&T, air-dried, sieved through a 2-mm mesh, and thoroughly homogenised prior to use. The soil was classified as clay loam and exhibited low fertility, with soil organic carbon of 1.62%, total nitrogen of 0.12%, available phosphorus of 11.33 ppm, exchangeable potassium of 0.74 cmol kg^{-1}, calcium of 1.70 cmol kg^{-1}, magnesium of 2.33 cmol kg^{-1}, and sodium of 1.50 cmol kg^{-1}. Micronutrient contents were 7.95 ppm Mn, 1.97 ppm Cu, 120.67 ppm Fe, and 0.81 ppm Zn, with a slightly acidic pH (H_2O) of 6.75. Five kilograms of the processed soil were weighed into each plastic pot. No fertiliser was applied throughout the experiment to avoid confounding the effects of CME on weed emergence and growth.

Fresh cassava mill effluent was obtained from the International Institute of Tropical Agriculture (IITA), Ibadan. The effluent was analysed for cyanide concentration using the ninhydrin-based spectrophotometric method described by Surleva *et al.* (2013). The quantified cyanide content was used to determine application rates expressed as g CN ha^{-1}, which were subsequently converted to pot-equivalent doses based on soil surface area and applied volume per pot.

Two independent experiments were conducted to assess pre-emergence and post-emergence applications of CME. Each experiment was laid out in a Completely Randomised Design (CRD) and analysed separately, as the two application timings target different weed growth stages and modes of action. Five treatments were evaluated in each experiment, comprising four CME rates equivalent to 6, 12, 18, and 24 g CN ha^{-1}, alongside an untreated control. Each treatment was replicated three times, resulting in 15 pots per experiment and a total of 30 pots.

For the pre-emergence experiment, CME was applied to weed-free soil immediately after pot filling and before weed emergence. The required volume of effluent for each treatment was measured using a graduated cylinder and applied evenly to the soil surface with a handheld sprayer to ensure uniform distribution across each pot. Following application, pots were lightly watered to facilitate effluent–soil interaction without causing leaching. In the post-emergence experiment, CME was applied when naturally emerging weeds were well established at the 2–4 leaf growth stage. Application was carried out as a foliar spray using a handheld sprayer calibrated to deliver a uniform spray volume per pot. Spraying was done at close range to ensure complete leaf wetting while avoiding runoff. Untreated control pots were maintained for both experiments.

Weed assessments were conducted through destructive sampling. Weed density and biomass (fresh and dry weights) were determined at 4 weeks after treatment (WAT) in the pre-emergence experiment and at 3 WAT in the post-emergence experiment, corresponding to periods of peak weed establishment. Weed regrowth was further assessed at 8 WAT to evaluate the residual or suppressive effects of CME treatments. Harvested weed samples were oven-dried at 65 °C to constant weight before dry biomass determination. Weed Control Efficiency (WCE) was calculated using the expression:

$$WCE\ (\%) = \left(\frac{(Weed\ biomass\ in\ control\ -\ Weed\ biomass\ in\ treatment)}{Weed\ biomass\ in\ control}\right) \times 100$$

Data obtained from the pre-emergence and post-emergence experiments were analysed separately using analysis of variance (ANOVA) appropriate for a Completely Randomised Design. Where treatment effects were significant, means were separated using Duncan's Multiple Range Test (DMRT) at the 5% level of probability. All statistical analyses were performed using SPSS Statistics version 23 (George and Mallery, 2016).

RESULTS

Effect of Pre-emergence Soil Application of Cassava-Milled Effluent on Weed Density, Species Richness and Biomass

Pre-emergence application of CME did not result in significant differences in weed density, species count, or biomass for either weed flush (Table 1). During the first flush, weed density ranged from 489 to 559 plants m^{-2} across all treatments and the control. Similarly, the number of weed species ranged narrowly between 3.0 and 4.0. Weed fresh weights varied slightly between 684.8 and 775.6 g m^{-2}, while dry weights ranged from 182 to 231 g m^{-2}. These minimal variations were statistically non-significant, suggesting uniform weed emergence and biomass accumulation irrespective of CME dosage when applied pre-emergence.

During the second flush, no significant differences were also observed. Weed densities remained consistent across treatments, ranging from 517 to 587 plants m^{-2}. The number of species was relatively stable, between 3 and 4. Fresh and dry weights fluctuated within narrow margins (748–832 g m^{-2} and 168 –210 g m^{-2}, respectively), showing no statistical variation (Table 1).

Weed Control Efficiency of Pre-emergence Soil Application of Cassava-Milled Effluent

Weed control efficiencies of pre-emergence treatments were low and inconsistent (Table 2). In the first flush, values ranged from −6.3% (12 g CN ha^{-1}) to 16.4% (18 g CN ha^{-1}), with no significant difference among treatments. Similarly, second flush efficiencies ranged from −5.3% (12 g CN ha^{-1}) to 15.8% (18 g CN ha^{-1}). Several treatments recorded negative values, suggesting that the pre-emergence application of CME either lacked phytotoxicity to suppress emerging weeds or provided favourable conditions for weed growth in some cases. The observed lack of a consistent dose-response pattern further reinforces the absence of a suppressive effect through this application method (Table 2).

Effect of Post-emergence Foliar Application of Cassava-Milled Effluent on Weed Density, Species Richness and Biomass

The post-emergence foliar application of Cassava Milled Effluent (CME) significantly reduced weed density, number of species, and biomass in the first weed flush (Table 3). The control treatment recorded the highest weed density (1188 plants m^{-2}), significantly greater than all other treatments. Post-emergence application of CME at 24 g CN ha^{-1} produced the lowest weed density (280 plants m^{-2}), reflecting substantial suppression of established weeds. Treatments at 6, 12, and 18 g CN ha^{-1} recorded intermediate weed densities (720, 860, and 839 plants m^{-2}, respectively), with no significant difference between 12 and 18 g CN ha^{-1}, but significantly lower than the control.

Number of weed species per pot followed a similar pattern. The control and 6 g CN ha^{-1} treatments recorded 4.3 species, while 24 g CN ha^{-1} had the lowest count (3.0 species), significantly different from the 12 g CN ha^{-1} treatment (6.0 species), which had the highest richness. This outcome suggests a tendency toward species-specific sensitivity at higher CME concentrations.

Weed fresh weight in the first flush ranged from 495 g m^{-2} in the 24 g CN ha^{-1} treatment to 3927 g m^{-2} in the control. All CME treatments significantly reduced weed biomass compared to the control. Weed fresh weight decreased progressively with increasing CME concentration, declining from 2263 g m^{-2} at 6 g CN ha^{-1} to 1557 g m^{-2}, 1006 g m^{-2}, and 495 g m^{-2} at 12, 18, and 24 g CN ha^{-1}, respectively.

Similar trends were observed for dry weight: 825 g m^{-2} in the control, reducing to 524, 468, 398 and 119 g m^{-2} in ascending order of CME concentration. All reductions in fresh and dry weights were statistically significant, with the 24 g CN ha^{-1} treatment resulting in the lowest biomass accumulation.

In contrast, no statistically significant differences were observed among treatments during the second flush. Weed density remained within a narrow range across all CME concentrations and the control (538 to 678 plants m^{-2}). The number of species per pot ranged from 3.3 to 4.7, with no clear pattern of suppression attributable to increasing CME concentration. Weed fresh and dry weights during the second flush showed no significant reduction; values ranged from 755 to 860 g m^{-2} (fresh weight) and from 154 to 210 g m^{-2} (dry weight). Thus, the suppressive effect of post-emergence foliar-applied CME was more evident during the first weed flush and declined subsequently (Table 3).

Weed Control Efficiency of Post-emergence Foliar Application of Cassava-Milled Effluent

Weed Control Efficiency (WCE) of post-emergence CME application showed marked differences among treatments in the first weed flush but not in the second (Table 4). The WCE increased proportionally with CME concentration during the first flush, from 36.6% at 6 g CN ha^{-1} to 85.9% at 24 g CN ha^{-1}. While treatments at 6, 12, and 18 g CN ha^{-1} were statistically similar, the 24 g CN ha^{-1} treatment achieved significantly higher WCE. This consistent dose-dependent increase suggests that higher concentrations of CME were more effective at suppressing early weed growth.

Conversely, all treatments recorded negligible WCE values, ranging from −0.2% to 0.2% during the second flush, with no significant differences. Some treatments even recorded slightly negative values, indicating a possible rebound in weed growth after the initial suppression (Table 4).

Table 1: Effect of Pre-emergence Soil Application of Cassava Mill Effluent on Weed Density, Species Number, and Biomass

CME (g CN ha^{-1})	Weed density (plants m^2)	No. of species	Weed fresh weight (g m^2)	Weed dry weight (g m^2)
		First flush		
6	489.2a	3.7a	719.8a	209.6a
12	489.2a	3.3a	747.7a	230.6a
18	559.0a	3.0a	775.6a	181.7a
24	489.2a	3.7a	684.8a	195.7a
Control	559.0a	4.0a	761.6a	216.6a
		Second flush		
6	586.9a	3.5a	747.7a	188.7a
12	559.0a	4.0a	831.6a	209.6a
18	559.0a	3.4a	768.6a	167.7a
24	517.1a	3.4a	747.7a	202.7a
Control	572.9a	3.4a	810.7a	199.1a

Means within the same flush and column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at P = 0.05.

Table 2: Weed Control Efficiency of Pre-emergence Soil Application of Cassava Mill Effluent Across Successive Weed Flushes

CME (g CN ha^{-1})	Weed control efficiency (%)	
	First flush	Second flush
6	3.4a	5.3a
12	-6.3a	-5.3a
18	16.4a	15.8a
24	11.7a	-1.8a

Means in a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at P = 0.05.

Table 3: Effect of Post-emergence Foliar Application of Cassava Mill Effluent on Weed Density, Species Number, and Biomass

CME (g CN ha^{-1})	Weed density (plants m^{-2})	No. of species	Weed fresh weight (g m^{-2})	Weed dry weight (g m^{-2})
	First flush			
6	719.6b	4.3ab	2263.4b	524.1b
12	859.6ab	6.0a	1557.3c	468.2b
18	838.6ab	4.7ab	1006.3d	398.3b
24	279.5c	3.0b	495.1e	118.8c
Control	1187.9a	4.3ab	3927.3a	824.6a
	Second flush			
6	677.8a	3.3a	768.7a	167.7a
12	628.9a	4.7a	908.4a	188.7a
18	559.0a	3.7a	754.7a	153.7a
24	538.0a	3.7a	803.6a	209.6a
Control	580.0a	3.3a	859.5a	181.7a

Means within the same flush and column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at P = 0.05

Table 4: Weed Control Efficiency of Post-emergence Foliar Application of Cassava Mill Effluent Across Successive Weed Flushes

CME (g CN ha^{-1})	Weed control efficiency (%)	
	First flush	Second flush
6	36.6b	0.1a
12	43.4b	-0.1a
18	51.8b	0.2a
24	85.9a	-0.2a

Means in a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test (DMRT) at P = 0.05.

DISCUSSION

The findings of this study indicate that Cassava Mill Effluent (CME) exhibits both herbicidal and herbistatic properties depending on its concentration and mode of application. Significant reductions in weed density, species richness, and biomass observed during the first weed flush under post-emergence foliar applications, especially at 24 g CN ha^{-1}, point to a strong herbicidal effect. In contrast, lower concentrations and the diminished efficacy observed in the second flush suggest a herbistatic response, wherein weed growth is suppressed without complete mortality. This dual response is consistent with patterns observed in other botanicals for weed control strategies, where phytotoxicity often varies with concentration and exposure (Batish *et al.*, 2004; Khanh *et al.*, 2007).

The superior performance of post-emergence CME application supports the theory that cyanogenic compounds must come into direct contact with plant tissues to inhibit cellular respiration effectively. Hydrogen cyanide (HCN), one of the bioactive constituents of CME, interferes with the mitochondrial electron transport chain by inhibiting cytochrome oxidase, leading to ATP depletion and tissue necrosis (Zuhra and Szabo, 2022; Xu *et al.*, 2023). The physiological impact of HCN is reflected in the marked reduction in weed biomass with increasing CME concentration, particularly at the 24 g CN ha^{-1} treatment level. Similar findings have been reported by Fayinminnu *et al.* (2013) and Ganyam *et al.* (2022), who also observed significant weed suppression following foliar applications of CME under field conditions.

The lack of significant weed suppression under pre-emergence application conditions may be attributed to rapid microbial degradation or volatilization of cyanide compounds in the soil (Jaszczak *et al.*, 2017). The short environmental half-life of cyanogenic substances limits their residual action when applied to soil, thereby reducing their pre-emergent weed control potential. This explanation aligns with the results from this study, where pre-emergence CME application across all concentrations failed to produce significant reductions in weed density or biomass in either weed flush.

Notably, no statistically significant weed suppression was observed during the second weed flush across all treatments. This outcome suggests that CME lacks residual activity, and its weed-suppressive effect is primarily immediate and short-lived. This characteristic, while limiting in terms of long-term weed control, can be advantageous in certain cropping systems. Specifically, the absence of residual phytotoxicity makes CME a suitable candidate for use in crop rotation and relay cropping systems, where residual herbicides may impair germination or early growth of subsequent crops. This outcome aligns with the findings of Aladesanwa (2005), who noted that the short-lived activity of bioherbicides is desirable for integrated cropping systems.

The suitability of bio herbicides for sustainable weed management is reinforced by the work of Dayan *et al.* (2009), who highlighted their biodegradability and minimal environmental footprint as key advantages over synthetic herbicides. According to the same study, the short persistence of bioherbicides reduces the risk of carryover injury and promotes safer application in diverse agroecosystems. Similarly, Wang *et al.* (2021) emphasized that the short half-life and low residual effects of bioherbicides reduce potential harm to non-target organisms and allow for greater flexibility in crop sequencing. These features make CME particularly promising for integrating ecologically based weed management frameworks.

The variability observed in weed species richness under different treatments suggests potential selectivity in CME phytotoxicity. Although not statistically significant in all cases, this may be useful in selectively managing weed populations without completely eliminating vegetative ground cover, which is often important for erosion control or habitat preservation.

This study confirms the efficacy of CME as a post-emergence, contact-type bioherbicide, with its effectiveness largely dependent on application concentration. While limited by its lack of residual activity, this property may benefit systems requiring environmental safety, crop diversity, and rotation flexibility. However, the transient effect also suggests that CME should be integrated with other weed management strategies or applied repeatedly to maintain control over successive weed flushes.

CONCLUSION

This study has established that the method and timing of Cassava Mill Effluent (CME) application critically influence its performance as a weed suppressant. Post-emergence foliar application at 24 g CN ha^{-1} showed significant short-term suppression of weed growth, whereas pre-emergence soil application yielded no appreciable weed-suppressive effect. The results affirm CME's potential as a contact bioherbicide with limited persistence.

CME may best serve as a complementary tool within broader weed management strategies rather than a stand-alone solution. Future investigations should prioritise field-level applications and explore synergies with other cultural or biological methods to improve efficacy and consistency in practical use.

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