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Evaluating the effects of different anaerobic digestate rates on the growth, yield, and chlorophyll content of finger millet (Eleusine coracana) grown in biochar treated soil under semi-arid ecosystems of Zimbabwe

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Evaluating the effects of different anaerobic digestate rates on the growth, yield, and chlorophyll content of finger millet (*Eleusine coracana*) grown in biochar treated soil under semi-arid ecosystems of Zimbabwe.

ABSTRACT

Finger millet (*Eleusine coracana*) is a drought-tolerant and nutritious crop that remains underutilized in smallholder farming in semi-arid regions of Zimbabwe. Its productivity is low because fertilizers used in maize production may not supply nutrients, particularly micronutrients, required for quality grain and yield. This study evaluated the effects of anaerobic digestate application rates on the growth, chlorophyll content, and grain yield of finger millet grown in biochar-treated soil. Research was conducted at the Gwanda State University Agriculture-Innovation Park using a randomized complete block design with four treatments replicated four times. Treatments comprised a control without digestate and digestate rates of 1000, 2000, and 4000 ml per plot, while plots received 2 kg of biochar per plot (5 t/ha). Digestate was produced from cow dung, goat manure, chicken droppings, vegetable waste, and wood ash using a 200 L biodigester, while biochar was produced from digestate slurry and maize stalks. Emergence, stem height, chlorophyll content, and grain yield were measured. Data were analyzed using one-way ANOVA and Fisher's LSD. The 4000 ml rate produced the highest stem height, SPAD value (45.44), and grain yield (2368.75 kg/ha). Combining biochar with digestate, at 4000 ml per plot, enhanced finger millet productivity under semi-arid conditions.

Keywords

Finger millet; Anaerobic digestate; Biochar; Chlorophyll content; Semi-arid ecosystems.

Introduction

Finger millet (*Eleusine coracana*) known as rapoko in Zimbabwe was domesticated 5,000 years ago in the higher elevations of East Africa. It was first introduced in Zimbabwe's semi-arid Midlands and Matabeleland districts such as Filabusi and Gwanda during the twentieth century. It is essential to farmers because of its ability to withstand drought, produce grain under low rainfall conditions, and remain viable during long term storage has made it an important crop for enhancing household food

security in semi-arid areas. (Sood *et al*., 2016). Traditionally, it was a staple crop in Africa and now it is commonly used in porridges and traditional alcoholic beverages. It has a deep rooting system which makes it drought tolerant and grows well in poor soils with minimal amounts of water compared to maize. It also contains important minerals such as calcium, iron and proteins which is crucial for food security among small holder farmers (Musidzaramba *et al*., 2025).

Despite these benefits finger millet remains underutilized because there are no fertilizers manufactured specifically with recommendation for the crop. Consequently, many farmers apply generic fertilizers formulated for maize production that are not compatible with finger millet cultivation as they lack micronutrients to complement macro nutrients. Continuous application of these fertilizers may harm the crop by increasing salinity levels and reduce soil nutrients (Thilakarathna *et al*., 2015).

This study examined the effectiveness of digestate produced from biodigesters applied to biochar treated soil (organic amendment available locally) as an environmentally friendly fertilizer for finger millet cultivation. Digestate-biochar blends have the potential impact to improve soil fertility, reducing emissions, enhancing yield of finger millet, and minimizing adverse environmental impacts (Hewage *et al.,* 2016).

Sustainable soil fertility management has therefore become increasingly important for improving finger millet production, particularly under the semi-arid conditions of Zimbabwe where soils are generally low in organic matter and are prone to moisture stress. Organic soil amendments such as digestate and biochar have attracted considerable attention because they improve soil fertility while promoting environmentally sustainable crop production. Digestate is enriched in macronutrients (N, P, K) and micronutrient (zinc, calcium, iron) which are essential and required by plants for growth according to Akbar *et al*, (2021). Biochar is produced through burning biomass in low oxygen environment, and it improves soil crumby structure, water retention, and reducing nutrients leaching (Hewage *et al.*, 2016; Blanco-Canqui, 2021a). Although numerous studies have demonstrated the benefits of digestate and

biochar in crops such as maize and wheat, limited information is available regarding their combined use in finger millet production under Zimbabwean semi-arid conditions. This knowledge gap limits the development of evidence-based fertilizer recommendations for finger millet. According to Murtaza *et al*, (2023), when biochar is combined with digestate, it increases nutrient availability, soil microbial activities, and prevents nitrate leaching. Besides, it aids in managing drought and salt stress conditions (Kul, 2022). Hence, digestate rich in nutrients can be useful in providing crops with nutrients especially for indigenous small grains such as finger millet.

Finger millet production in semi-arid areas in Zimbabwe is affected by factors that reduce food security and affect production efficiency. Small-scale farmers often use generic chemical fertilizers suitable for maize and other cereal crops. Such fertilizers do not supply the nutrient balance required by finger millet to produce maximum yields. In addition, chemical fertilizers cause soil degradation by increasing salinity and pH, which result in reduced finger millet production.

On the other hand, some small holder farmers grow finger millet with raw organic manure which is problematic due to its slow and inconsistent nutrient release process. The type of organic matter, storage conditions, and degree of decomposition determine the nutrient content of organic manure. Some smallholder farmers also grow finger millet without fertilizers because the crop resembles *Eleusine indica*, a grass which grows naturally in the region, they therefore assume that finger millet can grow well without external inputs, which results in poor production and low yielding. These limitations associated with fertility management methods exacerbate the stress caused by increasing soil salinity, droughts, and irregular rainfall in Zimbabwe. Therefore, this study investigates whether digestate applied on the soil treated with biochar from anaerobic digestates can improve soil fertility and finger millet productivity under semi-arid conditions.

Methodology

Study Site Description

The research was carried out at Gwanda State University Agro-Innovation Park situated in Filabusi, Insiza District, Matabeleland South Province, Zimbabwe (20°26'11.37"S, 29°16'8.64"E). The research site is located at 1,120 m above sea level in Natural Region IV. It is semi-arid in nature with average annual rainfall of 450-650 mm focused in one rainy season. That is, November-March (Sibanda *et al.*, 2020). Annual average temperature is between 14-25°C with October being the hottest month with an average maximum temperature of 32°C and July the coldest month with an average minimum temperature of 8°C. Evapotranspiration is much higher than rainfall, that is, 1,800-2,000 mm annually.

The soil samples were analysed in the laboratory of the International Crops Research Institute for the Semi-Arid Tropics had the following parameters before the cultivation process: soil was acidic with pH = 6.1 and EC = 334 µS/cm. Soil was rich in calcium with 2.45 meq/100 g, magnesium with 2.06 meq/100 g, and potassium with 0.36 meq/100 g. Sodium level was rather low (0.12 meq/100 g), while cation exchange capacity (CEC) was rather high (8.59 meq/100 g).

Soil organic matter was 4.63% or moderate. Total nitrogen was 0.32%, and available phosphorus was 13.46 µg/g. The content of micronutrients was as follows: zinc, 1.2 µg/g; manganese, 50 µg/g; copper, 7 µg/g; and iron, 84 µg/g. Analysis of the soil texture revealed that the soil sample was 45% sand, 53% silt, and 2% clay. Therefore, the sample is classified as silt loam the soil samples were analyzed using standard laboratory procedures, including ammonium acetate extraction for exchangeable cations, Bray P1 method for phosphorus determination, Walkley–Black method for organic matter analysis, and the hydrometer method for soil texture determination.

The site experiences moderate salinity risk, with borehole irrigation water exhibiting electrical conductivity of 0.85 dS/m and sodium adsorption ratio of 3.2, requiring

careful management to avoid salt accumulation in the root zone (Munns *et al*., 2015). Common crops in surrounding smallholder farms include drought-tolerant maize varieties, sorghum, pearl millet, finger millet, groundnuts, and cowpeas, reflecting adaptation to the challenging agroecological conditions (Ncube *et al.*, 2022).

The selection of the Gwanda State University Agro-Innovation Park was appropriate because the area represents the semi-arid agroecological conditions under which finger millet is commonly cultivated in Zimbabwe. The site's low and erratic rainfall, relatively high temperatures, and silt loam soils provided suitable conditions for evaluating the effectiveness of digestate as a soil amendment under water-limited environments. Therefore, the findings generated from this study are relevant to smallholder farming systems within similar agroecological regions.

Experimental Design/ Treatments

The experiment was laid out randomized complete block design (RCBD) was used with four treatments replicated four times. The slope gradient in the field was used as a blocking factor in the RCBD. There were four plots (each measuring 2 m × 2 m = 4 m^2) per block, amounting to 16 plots in total. Each plot was spaced 0.5 m apart from other plots, and there was 1 m space between blocks, which helped in the performance of management practices and reduced edge effects using guard rows. Weeding in the paths was done manually.

Four treatments were used in this experimental design, including the negative control without fertilizer and digestate rates (1000 ml, 2000 ml, 4000 ml), with each applied to a biochar treatment rate of 5 tons/ha (2 kg/plot). A Randomized Complete Block Design was selected because it minimizes the influence of field variability by grouping experimental units with similar characteristics into blocks before randomly assigning treatments. This design improves the precision of treatment comparisons and reduces experimental error arising from soil heterogeneity

Treatment table

Table 1: Digestate application rate used in the study

Treatment	Dosage rate	Treatment description
T1 (Control)	0 ml/12L	No fertilizer applied
T2	1000 ml/12L	Low digestate liquid
T3	2000 ml/12L	Medium digestate liquid
T4	4000 ml/12L	High digestate liquid

Table 1 shows that selected digestate application rates intended to represent increasing nutrient supply levels in order to determine the optimum rate for enhancing finger millet growth and grain yield. Including an untreated control provided a baseline against which the effects of digestate application could be objectively evaluated.

Experimental Management

Treatment preparation

Digestate preparation

Digestate was produced using a 200 L batch-type anaerobic biodigester, which was made from a high-density cement tank, operated at Gwanda State University's Agro industrial park. Materials used were selected based on locally available organic resources in smallholder farming systems, comprising of:

Cow dung: 15kg (wet weight) obtained from indigenous cows which graze freely in their natural rangeland.

Goat dropping: 15kg produced by penned goats consuming crop residues and browsing.

Chicken dropping: 10kg obtained from broiler chicken.

Vegetable waste: 5kg consisting of residue cabbage and tomatoes grown in the farm.

Food waste: 5kg collected from the university dining hall.

Wood ash: 2 kg from indigenous tree species. (Colophospermum mopane)

Feedstock materials were sliced into smaller particles and mixed thoroughly with water to increase surface area for microbial colonization before anaerobic digestion (Möller *et al.,* 2012). Wood ash was used to create favorable conditions for methanogenic bacteria and buffering against acid accumulation during early digestion phases

(Alburquerque *et al.*, 2012).

The digester was closed, connected with a gas collection system, and kept at mesophilic temperatures (28-35°C) for 60 days retention time. Temperature was monitored daily and weekly pH measurements were done to check process stability. Biogas production, observed through water displacement, started after 7-10 days and peaked at 25-30 days, which matches typical batch digestion patterns (Möller *et al.,* 2015).

After digestion was complete, digestate was discharged, mixed well, and passed through a 2 mm mesh sieve to remove coarse, undigested materials. Total digestate volume recovered was 45 L, with solids content of 8.5% and pH 7.2. Representative subsamples were taken for nutrient analysis at the National University of Science and Technology research lab.

Table 2: Macro and micronutrient composition of digestate

Nutrient	Typical Range
Macronutrients	
Nitrogen(N)	5.20%
Phosphorus (P)	2.40%
Potassium(k)	4.10%
Calcium (Ca)	3.80%
Magnesium (Mg)	1.20%
Sulphur (S)	ND
Micronutrients	
Sodium (Na)	ND
Iron (Fe)	1850mg/kg
Manganese (Mn)	320mg/kg
Zinc (Zn)	210mg/kg
Copper (Cu)	85mg/kg

Biochar Preparation

Table 2 shows that Biochar produced through burning harvested digestate slurry and dried maize stalks under low oxygen environment. Firstly, they were air-dried to below

15% moisture content under covered conditions for 14 days, then cut down to 2-5 cm pieces to help with uniform pyrolysis.

Pyrolysis was done using a 200 L steel drum with holes made inside the inner chamber and insulated outer jacket, following established designs for smallholder biochar production (Lehmann *et al*, 2015). The drum was loaded with 35 kg of dried digestate slurry and maize stalks, lit from the top, and allowed to burn under limited oxygen conditions for 4-6 hours until smoke stopped coming out, indicating the pyrolysis was complete.

After cooling, the biochar was weighed (yield 20 kg, about 25% of the slurry and maize dry weight), crushed to less than 5 mm particle size using a hammer mill, and mixed well before application.

Agronomic Practices

Land Preparation

Land was cleared of previous vegetation and manually ploughed using hand hoes to dig the ground to a depth of 20cm. It was then harrowed to produce a fine seedbed. This was done to create good seed-soil contact, reduce soil compaction, and help retain moisture for germination (Oluoch *et al.*, 2018). Seed bed preparation was carried out before planting to avoid moisture loss through surface evaporation.

Planting Material

Finger millet seeds of the last season were collected from local smallholder farmers in Insiza district. This is a drought-resistant cultivar with maturity of 110-120 days, possessing moderate tolerance to blast (Magnaporthe grisea) diseases, and having yields of 1.8-2.5 t/ha. Germination tests were done before planting showed a germination percentage of 88% through the sprouting technique. (Rocha *et al.*, 2023).

Planting and Fertilizer Application

Seeds were planted on 27 November 2024 after effective rainfall (over 20 mm) to ensure adequate moisture content for germination. Seeds were broadcasted in the plots and then covered with fine soil to ensure soil to seed contact (Mushonga *et al*., 2020). Two weeks after germination, thinning was conducted to reduce competition within

plots resulting in 16 plants in each plot.

Biochar was incorporated before planting; hand hoes were used to spread and mix it into the top 10 cm of the soil. (Lehmann *et al*., 2015). Digestate treatments were applied during planting (right after sowing, before covering the seeds) and as top-dressing at the 4-6 leaf stage (about 28 days after germination). Digestate solutions were prepared fresh for each application by diluting raw digestate with borehole water, then applied evenly using a 16 L knapsack sprayer calibrated to deliver the required volume per plot (Kuhn, 2016). Control plots received the same amount of borehole water without digestate to isolate treatment effects.

Crop Management

Seeds were irrigated immediately after planting using borehole water (EC 0.85 dS/m) and it was done on extended dry periods (more than 10 days) using perforated buckets to ensure that water did not seal up the soils or lead to soil compaction. Weeding was done manually three, six, and nine weeks after planting using hand hoes. In regards to pest management, the fields were scouted weekly to look out for stem borers (Busseola fusca, Chilo partellus), aphids, and birds. Grain filling bird damage was prevented through deployment of personnel to shoo off birds from the plot during the early morning and evening when birds are most active.

Data Collection

The following parameters were measured:

Percentage emergence

Percentage emergence was obtained by planting 36 seeds per treatment. The trial was run until no further seedlings emerged. Emergence was recorded when seedlings became visibly established above the soil surface, and only healthy, normal seedlings were counted. Once the final number of emerged seedlings was obtained, percentage emergence was calculated using the standard formula:

$$\text{Percentage Emergence (\%)} = \left(\frac{\text{Number of seedlings emerged}}{\text{Total number of seeds planted}} \right) \times 100$$

This value reflected the proportion of seeds that successfully established as seedlings under the given conditions.

Stem length

Stem length was measured at 2-week interval after the seed emergence using a graduated 30 cm ruler. It was selected because it is a reliable indicator of vegetative growth and reflects the crop's response to nutrient availability during early development.

Chlorophyll content

A SPAD-502Plus chlorophyll meter was used to assess chlorophyll content in the leaves of finger millet. This was done at a 2-week interval and three fully expanded upper leaves per plant were measured at top, middle, and bottom canopy positions, and averaged to obtain mean SPAD values (Tibugari *et al.*, 2022). Chlorophyll measurements provided a rapid and non-destructive estimate of plant nitrogen status, enabling assessment of treatment effects on crop physiological performance.

Data on yield

Yield was determined during harvesting to determine the yield potential of finger millet when subjected to various digestate rates on the soil treated with biochar amendments. In each plot, there were sixteen finger millet and the combined yield was obtained in kilograms for each plot. For the ease of comparison between the treatment levels and blocks, the yield was standardized by converting to yield per hectare (kg/ha). Grain yield was considered the principal response variable because it directly reflects the agronomic effectiveness of the digestate treatments and determines the practical value of the technology for farmers.

Data analysis

Data were analyzed using one-way Analysis of Variance (ANOVA) to determine whether significant differences existed among digestate application rates. Where significant treatment effects were detected ($P < 0.05$), Fisher's Least Significant Difference (LSD) test was used to separate treatment means. The assumptions of ANOVA, including normality and homogeneity of variance, were assessed before

analysis to ensure the validity of statistical inferences.

The methodology adopted in this study was designed to ensure reliable evaluation of digestate application rates under controlled field conditions. Appropriate experimental design, standardised measurement procedures, and statistical analysis enhanced the accuracy and reproducibility of the findings while reducing potential experimental bias.

RESULTS

Table 3: Effects of Digestate rate on Finger Millet Emergence

(Emergence %)

TREATMENT (ML)	**EMERGENCE (%)**
0 (CONTROL)	88.44a
1000	88.69a
2000	87.36a
4000	87.10a
P VALUE	0.18
LSD	2.184
CV	5.03%

The result of the One-way ANOVA on table 3 shows that there was no significant effect of digestate-biochar amendment on the finger millet emergence percentage in the treatments (P=0.18, P >0.05). Emergence percentage maintained high percentage rate across all digestate application rate on the soil treated with biochar. It ranges between 87.1% and 88.69% showing uniform seed germination at all digestate application rates. Although the 1000ml recorded the highest emergence percentage of 88.69%, closely followed by the control treatment which recorded second (88.44%), the difference in the means was lower than the Least Significant Difference (LSD = 2.184). Considering the coefficient of variation (CV) being equal to 5.03%, there was low variability in the

dataset, implying the presence of precise data analysis. Therefore, with all the treatments in one significance group a it was evident that there was no significant effect of 2kg basal biochar together with different digestate application rates on finger millet germination emergence percentage (Table, 3).

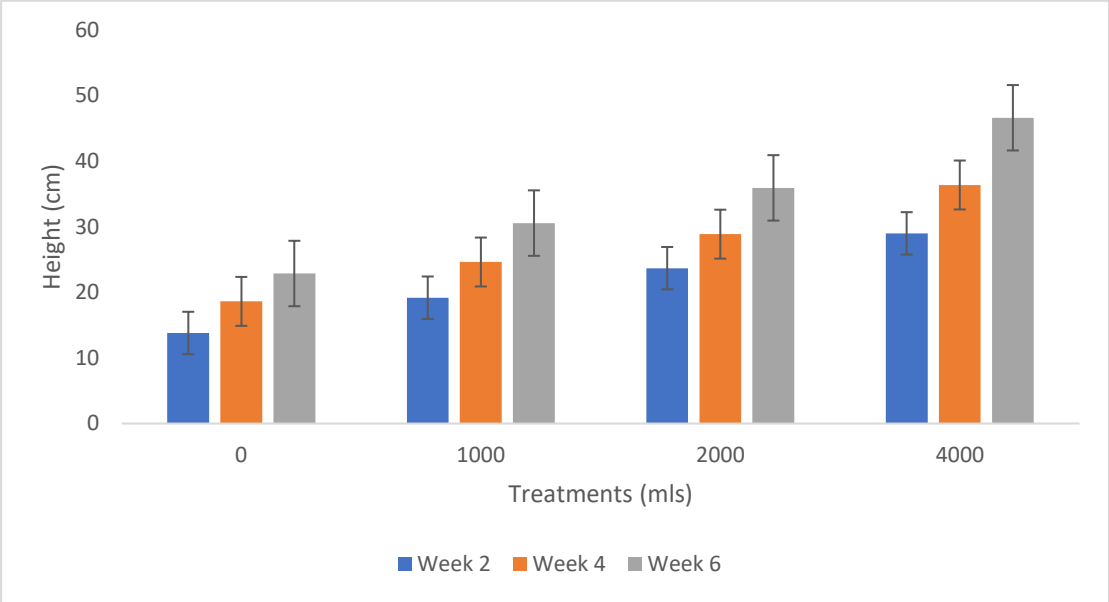


Figure 1: Shows the effects of Digestate Rate on finger millet stem height (cm)

One-way analysis of variance results from figure 1 indicated that there was statistically significant difference ($P \leq 0.05$) on effect of digestate on finger millet stem heights, suggesting that differences in digestate levels resulted in varying vegetative growth performance due to changes in nutrient concentrations. An increase in digestate level led to an increase in stem height; the treatment receiving 4000 ml of digestate recorded the tallest stems whereas the control treatment had the lowest stem height throughout the study period (figure 1). The statistical significance difference shows that the digestate-biochar treatment combination provided enough nutrients to the plants leading to taller stem heights compared untreated plants. In addition, a statistically significant difference ($P<0.05$) in the stem heights was recorded during the six weeks after planting suggesting that there was increase in growth for the finger millet crops during each week. The highest stem height was recorded in the sixth week after planting indicating the most active nutrient uptake by the plants and faster biomass development. Therefore, the increase in digestate rate and plant age led to vegetative development

and growth performance of the crop.

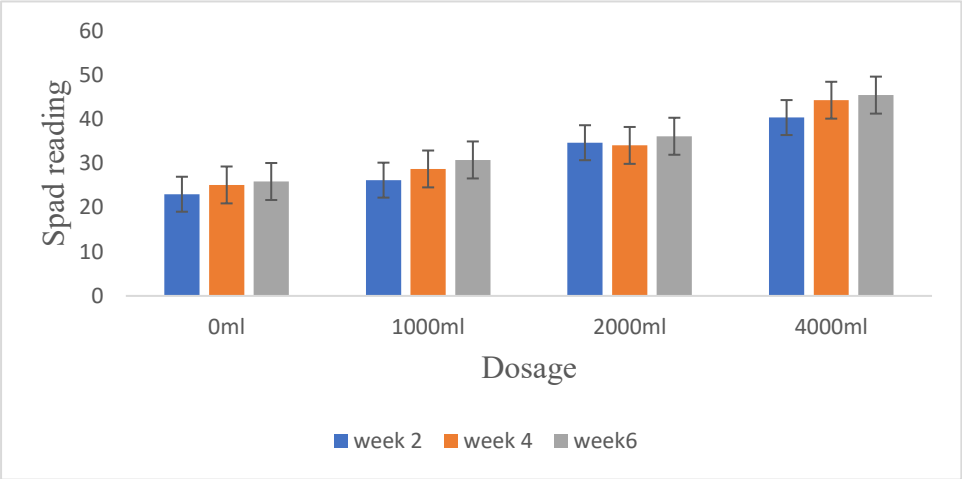


Figure 2: The effects of digestate rates on finger millet chlorophyll content.

Analysis of variance (ANOVA) established that there was a statistical difference ($P \leq 0.05$) between the means of treatments in regard to finger millet chlorophyll content, hence indicating a positive correlation between leaf chlorophyll content and the digestate and biochar application rates as shown in figure 2. Chlorophyll content increases as a result of increased digestate application rate on the soil treated with biochar, with treatment 4000 ml recording the highest chlorophyll content (45.44), treatment 2000 ml recording the second-highest chlorophyll content (36.13), treatment 1000ml recording the third highest chlorophyll content (30.77) and the control had the least chlorophyll content (25.89). The gradual increment in chlorophyll content in relation to the digestate application rates on the soil treated with biochar shows a dose-response relationship. The greatest response was obtained from finger millet treated after 42 days from planting amongst all the treatments. This can be attributed to increased nutrient availability such as nitrogen that helps in chlorophyll formation (Figure 2).

Table 4: Effect of Digestate rate on Grain Yield (kg/ha) of Finger Millet

TREATMENT (ML)	YIELD (KG/HA)
0(CONTROL)	1772.63c
1000	1862.83c
2000	2109.38b
4000	2368.75a
P VALUE	<0.001
LSD	122.40
CV	3.77%

Table 4 indicates that digestate application rate was highly significant ($P<0.001$), meaning there were substantial increases in the grain yield as the digestate rate increased. The analysis interprets that the increase in digestate rate results in an increase in grain yield, where a 4000 ml digestate rate produced the maximum yield value (2368.75 kg/ha), followed by the 2000ml digestate rate with a yield value of 2109.38kg/ha, and the last one is the control rate with a yield value of 1772.63 kg/ha. The LSD of 122.40 helped to differentiate the mean differences to various significant groups, implying that the increases made in digestate rate were significant. However, it was observed that a digestate rate of 1000ml gave slightly higher yield compared to the control treatment. This implies that the two means were within the same significance group ("c"), meaning the difference in yield increase was not significant ($P>0.05$) (Table 4).

Discussions

The present study showed that the application of digestate on the soil treated with biochar led to increased growth and yield of finger millet based on the varied parameters considered. However, no significant difference was observed in emergence

percentage amongst treatments. The stem height, chlorophyll content, and grain yield of the crop increased when the digestate rate increased.

The absence of significant differences in seed emergence suggests that digestate application did not influence the germination process of finger millet seeds. Seed emergence is primarily controlled by seed viability, soil moisture, temperature, and oxygen availability rather than nutrient supply immediately after sowing. Since digestate nutrients become available mainly after mineralization, their effect is more likely to occur during subsequent stages of crop growth than during germination. However, some research pointed that reduced seed emergence following digestate application is due to high ammonium concentration and increased salinity around seed zone. A study by Robles-Aguilarn *et al.*, 2019) showed that excessive digestate application negatively affected seed germination in maize crops. This is different from the present study because biochar reduces potential toxicity and salinity and this improved germination emergence of finger millet seeds.

These results are in agreement with (Łukowiak *et al.*, 2020) who indicated that at a moderate rate, digestate will not affect the percentage of germination of crops. Nutrients in digestate are absorbed gradually, therefore they do not affect the metabolic processes of the seeds. Grmination of finger millet seeds can be affected by other factors apart from nutrients.

Study by Zhang *et al*, (2022) established that Biochar application stabilized germination emergence across all treatments, enhanced finger millet emergence and improving soil aeration, water-holding capacity, and microbial activity while preventing possible ammonia toxicity caused by digestate application. Moreover, biochar acted as a buffering material that prevents changes in soil acidity, as finger millet grows well under slightly acidic soil conditions. According to (Senevirathne *et al*., 2025), the use of digestate influences vegetative growth and not germination. Consequently, the

results of the present study have provided scientific evidence that supports the safe use of digestate and biochar in finger millet farming.

Despite the uniformity in germination emergence finding of the present research are consistence with those reported by (Alhammad *et al*., 2023) who noticed significant increase in plant height due to digestate application which improve nutrient availability. Stem height increased significantly with increasing digestate application rate, indicating that digestate supplied nutrients required for vegetative development. Nitrogen released from digestate promotes cell division, chlorophyll formation, and leaf expansion, thereby increasing photosynthetic activity and biomass accumulation. The superior performance observed under the 4000 ml treatment suggests that nutrient availability was sufficient to sustain vigorous plant growth throughout the growing period. Similar positive responses have been reported by previous researchers working with digestate and other organic fertilizers in cereal crops. However, the magnitude of response varies among studies due to differences in soil characteristics, climatic conditions, digestate composition, and application rates (Osuna *et al.*, 2015).

Other than the macronutrients, the digestate also contains micronutrients like zinc, iron, magnesium, and manganese, which act as essential elements for various biological activities like the production of chlorophyll, root development, enzyme activation, and nutrient transfer. Hence, an increase in the height of the stem can be attributed to the presence of these macronutrients and micronutrients. Similarly, (Melito *et al.*, 2023) indicated that crops under digestate based fertilization showed greater vegetative growth than unfertilized controls because digestate supplies readily available nitrogen and other nutrients required for plant development.

Increased stem heights indicated a strong plant development during the early growth stages of finger millet. The reason for this is the joint effect of both biochar and digestate. According to (Gebeyehu, 2026), biochar improves nutrient use efficiency and cation exchange capacity, helping retain nutrients in soils as well as supporting

microbial processes. In contrast, some studies have reported no significant increase in plant height particularly in soils with adequate nutrient levels before treatment. Therefore, high stem height in this experiment could be due to the slow release of nutrients by biochar, providing finger millet with nutrients continuously.

There was a positive effect of digestate rates applied on the soil treated with biochar on finger millet chlorophyll content due to increased digestate rates Chlorophyll content was higher in the treatment with 4000 ml compared to the other treatments, while the lowest content of chlorophyll was observed in the control treatment. Therefore, it can be said that higher chlorophyll levels depend on nutrient availability and, in particular, nitrogen. Higher chlorophyll levels depend on nitrogen because this nutrient helps produce chlorophyll, which is made up of nitrogen compounds (Abbas *et al.*, 2021).

The current research findings agree with previous studies mentioned by(Maucieri *et al.*, 2023), who indicated that digestate increases chlorophyll content of crops. The increase in chlorophyll content observed with increasing digestate application rates indicates improved nitrogen availability for chlorophyll synthesis. Nitrogen forms an essential component of chlorophyll molecules and therefore directly influences leaf greenness and photosynthetic efficiency. Higher SPAD values recorded under the 4000 ml treatment suggest enhanced physiological performance, which probably contributed to improved biomass production and grain yield. Although previous studies generally report similar responses, variations in chlorophyll content have been associated with differences in digestate composition, environmental conditions, and crop species.

Maximum grain yield was found in treatment with 4000 ml digestate application, which was due to increased digestate application in finger millet, while the minimum grain yield (1772.63 kg/ha) was observed in the control plot. Hence, it may be deduced from the results obtained above that there were increased production levels due to several reasons, such as increased nutrient levels, an increase in vegetative growth, and high levels of chlorophyll. The increased levels of nutrients enabled improved

photosynthesis ability, thus improving grain fill. In agreement with the results presented in this research, increased crop yields from digestate application were due to the process of nutrient mineralization and uptake in the soil, according to (García-López *et al.*, 2023). Contrary to this, the close resemblance between the grain yield obtained from the control and 1000 ml treatments implies that the application rate of digestate has to be rather high in order for yield to be noticeably increased. It was further pointed out by (Tazebew *et al.*, 2024)that biochar improves the fertility of soils by increasing the CEC, nutrient holding capacity, and soil water holding capacity. Besides, biochar increases the efficiency of organic fertilizers through gradual retention and release of nutrients during the season. On the other hand, some conflicting of the studies have indicated that there is no increase in grain yield because of digestate application. According to (Ronga *et al.*, 2020), there is a limit to the yield response if the release of the nutrients does not coincide with the need for crops or if the conditions for uptake are not conducive to nutrient absorption. Grain yield response in this case may happen owing to the synchronized nutrient release from the digestate based on the needs of finger millet and due to biochar benefits. Hence, digestate application together with the addition of biochar led to improved soil fertility, which increased finger millet productivity.

Conclusion

This study evaluated the effects of different anaerobic digestate application rates on the growth, chlorophyll content, and grain yield of finger millet grown in biochar-treated soil under semi-arid conditions. The results demonstrated that digestate application significantly improved stem height, chlorophyll content, and grain yield, while seed emergence was not significantly affected. Among the treatments evaluated, the 4000 ml digestate application rate consistently produced the highest crop performance. These findings indicate that digestate, when applied together with biochar, can serve as an effective and sustainable soil fertility management option for improving finger millet productivity in semi-arid regions of Zimbabwe.

Recommendations

The farmers are advised to incorporate the use of digestate and biochar into the finger millet production system because their combination enhances vegetative growth, chlorophyll concentration, and productivity without any effect on seed germination. In view of the results generated that showed high stem growth, high chlorophyll concentration, and high yield in the plants treated with 4000 ml of digestate treatment, the farmers can apply high amounts of digestate according to agronomic recommendations to achieve maximum yield from finger millet. The Agricultural Extension Services should encourage the combination use of digestate and biochar because they constitute environmentally friendly means of promoting soil fertility compared to synthetic fertilizers. Such promotion can go a long way in improving the fertility status of soils and decreasing production costs by minimizing the use of chemical fertilizer. Farmers should be trained the correct way of using digestate and biochar preparation to increase its efficacy in finger millet cultivation. Governments and agricultural development organizations need to practice digestate-biochar technology as a sustainable fertilizer with many benefits on finger millet growth within their climate smart agriculture initiatives. Future researchers should conduct studies concerning the cost-benefit ratio of using digestate-biochar in finger millet production to establish whether the technology is economically viable and affordable to small scale farmers. Investigations should be made on the efficacy of combining digestate and biochar in growing other cereal crops to expand the scope of application of the new technology. The study established that they must be standard recommendations regarding digestate and biochar application developed by research institutions and agricultural extension services to suit finger millet production.

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