



Agronomic value of biodigester digestate for market garden crop production in Sèmè-Podji, Benin: case of lettuce (*Lactuca sativa* L.) And cucumber (*Cucumis sativus* L.)

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1 ABSTRACT

Mineral fertilizers remain the primary input in market gardening across sub-Saharan Africa, yet their long-term use degrades soil organic matter and poses environmental risks. Biodigester digestate, a by-product of anaerobic digestion, represents a promising organic amendment that could reduce dependence on synthetic inputs while closing nutrient cycles. This study evaluated the agronomic performance of liquid digestate produced by the Biogaz Benin biodigester on two widely consumed vegetable crops namely lettuce (*Lactuca sativa* L.) and cucumber (*Cucumis sativus* L.) under field conditions in Sèmè-Podji, southern Benin. A Completely Randomized Block design with three treatments and three replications was implemented: digestate treatment (TD, 1 L/m²), conventional treatment (TC, NPK mineral fertilizer combined with poultry manure), and an unfertilized control (TT). For lettuce, digestate produced the highest values across all measured growth and yield parameters: leaf number (6.57 ± 2.41), stem diameter (8.18 ± 3.88 cm), plant height (142.27 ± 3.84 mm), canopy diameter (100.94 ± 12.01 mm), and fresh weight yield (26.67 ± 2.31 t/ha). For cucumber, digestate also yielded the best results for leaf number (3.31 ± 3.37), seed emergence rate ($97.78 \pm 3.85\%$), stem diameter (4.55 ± 4.04 cm), and stem length (352.65 ± 554.77 mm), although the highest mean fruit number (1.22 ± 0.69) was recorded under conventional treatment. Statistical analysis showed that TD and TC were not significantly different for most parameters, yet both consistently outperformed the unfertilized control. These findings demonstrate that biodigester digestate can effectively substitute mineral fertilizers for lettuce and cucumber production, supporting its promotion as a sustainable organic amendment in the context of West African urban and peri-urban agriculture.



2 INTRODUCTION

Agriculture remains the backbone of food security and economic development in Benin, employing a significant share of the active population and contributing substantially to national GDP (Assouma *et al.*, 2020). Within this sector, market gardening, encompassing the production of leafy vegetables, fruit vegetables, and root crops plays an increasingly critical role in meeting urban dietary needs and generating income for peri-urban smallholders. In Benin alone, horticultural production employs an estimated 60,000 people, representing approximately 4% of the active workforce (Yolou *et al.*, 2015). Lettuce (*Lactuca sativa* L.) and cucumber (*Cucumis sativus* L.) rank among the most economically significant vegetables in urban and peri-urban markets along the Beninese coast. Lettuce is prized for its rapid growth cycle and year-round demand, while cucumber is increasingly incorporated into local diets and catering. Both crops are highly responsive to soil fertility management, making fertilization a central determinant of yield performance. Conventional market gardening systems in southern Benin rely heavily on mineral fertilizers, particularly NPK and urea, often combined with poultry manure to meet crop nutrient requirements. While these inputs deliver short-term yield gains, their exclusive or excessive use leads to well-documented adverse effects: progressive depletion of soil organic matter, soil acidification, aluminium toxicity, and contamination of water bodies through nitrate leaching (Garba *et al.*, 2022; Biaou *et al.*, 2017).

3 MATERIALS AND METHODS

3.1 Study area: The experiment was conducted in the municipality of Sèmè-Podji, located in the Ouémé Department of south-eastern Benin, between latitudes 6°22'–6°28' N and longitudes 2°28'–2°43' E, along the Atlantic coast. Covering an area of 250 km², the municipality borders Porto-Novo to the north,

Cotonou to the west, and the Federal Republic of Nigeria to the east. The climate is subequatorial with two rainy seasons, favouring year-round horticultural production. The study site was selected for its representativeness of peri-urban market gardening conditions in the region. The financial burden of synthetic inputs further constrains smallholder profitability, particularly in the context of volatile import prices. In this context, the valorisation of organic by-products from biogas installations constitutes a promising pathway toward sustainable soil fertility management. Biodigester digestate, the liquid and semi-solid effluent remaining after anaerobic digestion of organic waste is rich in readily available nitrogen, phosphorus, potassium, and micronutrients in mineralized forms (Koszel and Lorencowicz, 2015; Kouřimská *et al.*, 2012). Unlike raw manures or composts, digestate delivers nutrients in forms that are rapidly accessible to crops, potentially matching or exceeding the efficacy of mineral fertilizers for certain growth parameters (Lee *et al.*, 2021). Previous work conducted at EPAC/UAC by Chidikofan and *al*, 2022 demonstrated that digestate application significantly increased leaf number in amaranth (*Amaranthus hybridus* L.), while noting the need for comparative trials against conventional inputs on other crops (Assouma, 2020). Building on this foundation, the present study was designed to rigorously evaluate the agronomic value of liquid digestate from the Biogaz Bénin biodigester on lettuce and cucumber, comparing its performance against a combined NPK/poultry manure treatment and an unfertilized control. The dual-crop approach enables broader conclusions relevant to the diverse vegetable production systems of southern Benin.

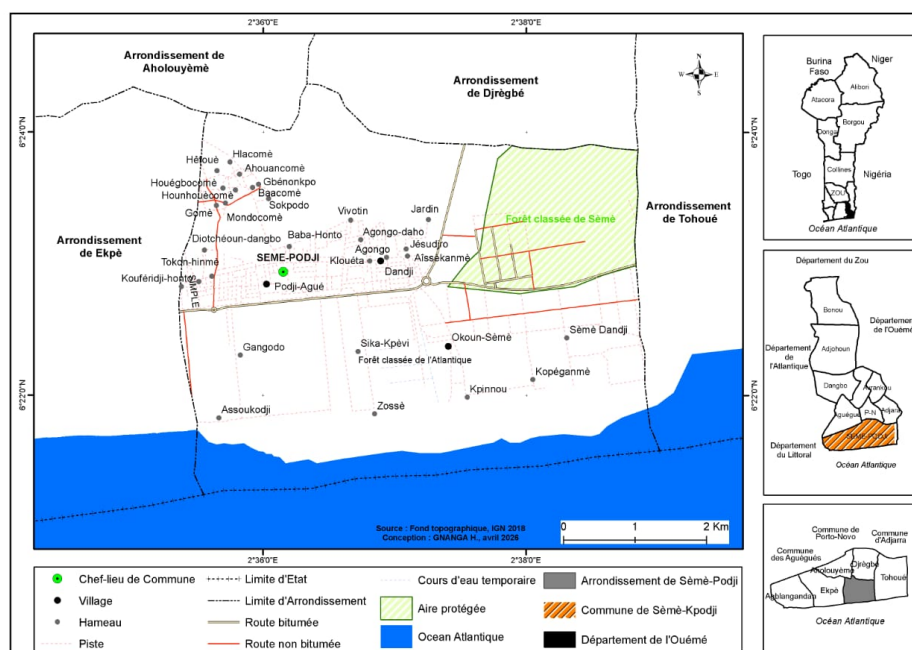


Figure 1. Geographic location of Sèmè-Podji municipality, Ouémé Department, Benin. Source: IGN topographic base, updated 2024.

3.2 Plant material: Two market garden crops were selected based on their agronomic importance and short production cycles: lettuce (*Lactuca sativa* L., common variety) and cucumber (*Cucumis sativus* L., hybrid variety Nandin 732 F1). Lettuce seedlings were raised in a nursery prior to transplanting, while cucumber seeds were sown directly in the experimental plots. Both crops are widely cultivated and consumed in the Sèmè-Podji area, and their short cycles allowed multiple measurement intervals within a single season.

3.3 Digestate characterization: The liquid digestate used in this study was collected from the anaerobic digestion unit operated by Biogaz Bénin Sarl (Houéyiho, Cotonou). The substrate processed by the unit consists primarily of household organic waste and market waste. The digestate was applied at a rate of 1 L/m² as both a basal amendment and a top-dress fertilizer. Nutrient content analysis of the digestate was not performed in the present study and constitutes a recommended focus for future

work, as quantitative nutrient characterisation would strengthen interpretation of observed agronomic effects.

3.4 Experimental design: The experiment followed a Completely Randomized Block (CRB) design with three treatments and three replications, for a total of nine plots. Each plot measured 6 m² (6 m × 1 m), with 0.15 m inter-plot spacing. The three treatments were:

- Digestate treatment (TD): liquid biogas digester digestate applied at 1 L/m² as basal and foliar amendment;
- Conventional treatment (TC): mineral NPK fertilizer combined with poultry droppings, applied according to local recommended doses;
- Unfertilized control (IT): no fertilizer application.

Basal amendments were incorporated into the soil seven days prior to planting. For lettuce, transplanting was carried out 21 days after nursery sowing. For cucumber, direct seeding was performed at a depth of 2 cm.

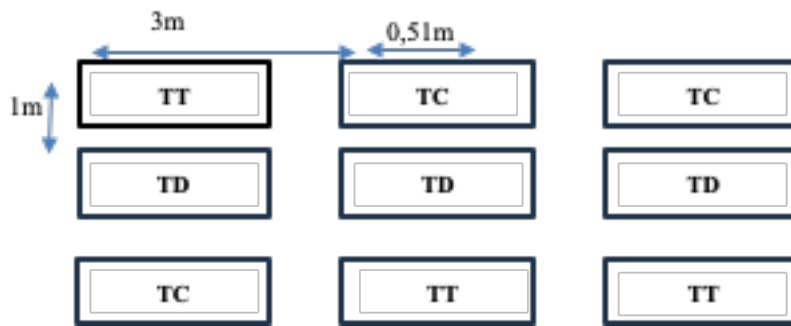


Figure 2. Schematic layout of the experimental design. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Each block contains one replicate of each treatment (6 m² plots, 0.15 m inter-plot spacing).

3.5 Measured parameters: Growth and yield parameters were measured at weekly intervals throughout the crop cycle. For lettuce, measured variables included: (i) number of leaves per plant, (ii) stem diameter (cm), (iii) plant height (mm), (iv) canopy diameter (mm), and (v) fresh weight yield (t/ha). For cucumber, measured variables included: (i) number of leaves per plant, (ii) seed emergence rate (%), (iii) stem diameter (cm), (iv) stem length (mm), and (v) fruit number yield. A minimum of five plants per plot were measured at each observation date.

4 RESULTS

4.1 Effects of treatments on lettuce (*Lactuca sativa* L.)

4.1.1 Leaf number: Mean leaf number per plant ranged from 3.94 to 6.57 across treatments (Figure 3). Digestate-amended plants (TD) produced the highest mean leaf count (6.57 ± 2.41), followed by the conventional treatment

3.6 Statistical analysis: Data were entered in Microsoft Excel and analysed using R statistical software (version 4.x). One-way Analysis of Variance (ANOVA) was performed to assess treatment effects on each parameter. Where ANOVA assumptions of normality and homoscedasticity were not met, the non-parametric Kruskal-Wallis test was applied as an alternative. When significant differences were detected ($p < 0.05$), means were separated using the Student-Newman-Keuls (SNK) post-hoc test. Results are expressed as mean \pm standard error (SE).

(TC: 5.87 ± 1.86) and the unfertilized control (TT: 3.94 ± 0.61). Despite this trend, ANOVA revealed no statistically significant difference among treatments ($p = 0.079 > 0.05$), suggesting that both fertilized treatments exerted comparable positive effects on leaf development relative to the control.

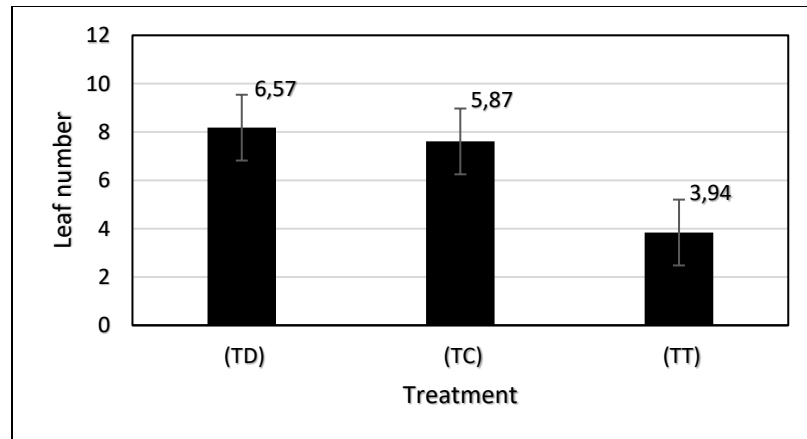


Figure 3. Mean number of leaves per lettuce plant (*Lactuca sativa* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Error bars represent standard error. Different letters indicate significant differences (SNK test, $p < 0.05$).

4.1.2 Stem diameter: Stem diameter varied significantly among treatments (ANOVA: $p = 0.045 < 0.05$), ranging from 3.84 cm in the control to 8.18 cm under digestate amendment (Figure 4; Table 1). TD produced the widest mean stem diameter (8.18 ± 3.88 cm), marginally

exceeding TC (7.61 ± 3.04 cm), while TT yielded significantly narrower stems (3.84 ± 1.26 cm). The SNK test confirmed that TD and TC were statistically equivalent and both differed significantly from TT.

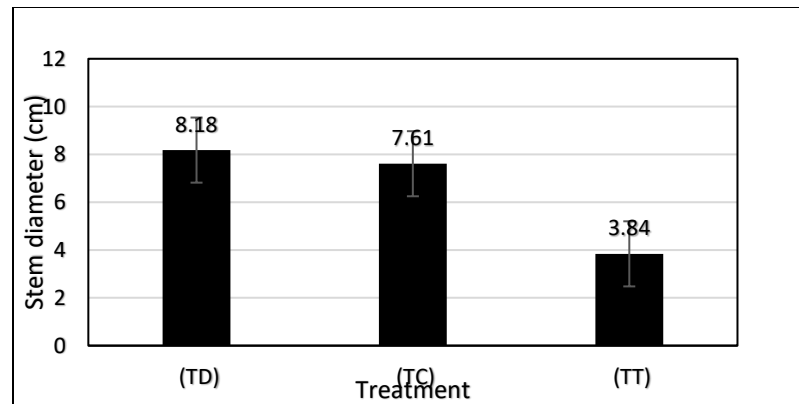


Figure 4. Mean stem diameter (cm) of lettuce plants (*Lactuca sativa* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Error bars represent standard error.

Table 1. Effect of treatments on mean stem diameter of lettuce (*Lactuca sativa* L.)

Treatment	Mean \pm SE (cm)	SNK grouping
Digestate (TD)	8.18 ± 3.88	a
Conventional (TC)	7.61 ± 3.04	a
Control (TT)	3.84 ± 1.26	b

Means sharing the same letter are not significantly different at the 5% level (SNK test). SE: standard error.

4.1.3 Plant height: Digestate treatment produced the tallest lettuce plants (142.27 ± 3.84 mm), significantly exceeding both TC (shown in Figure 5) and TT. ANOVA detected a

significant treatment effect on plant height, and SNK post-hoc separation confirmed that TD was statistically distinct from the control, while the difference between TD and TC was also

significant for this parameter — a notable result suggesting that digestate provides a more readily

available nitrogen supply supporting vertical growth.

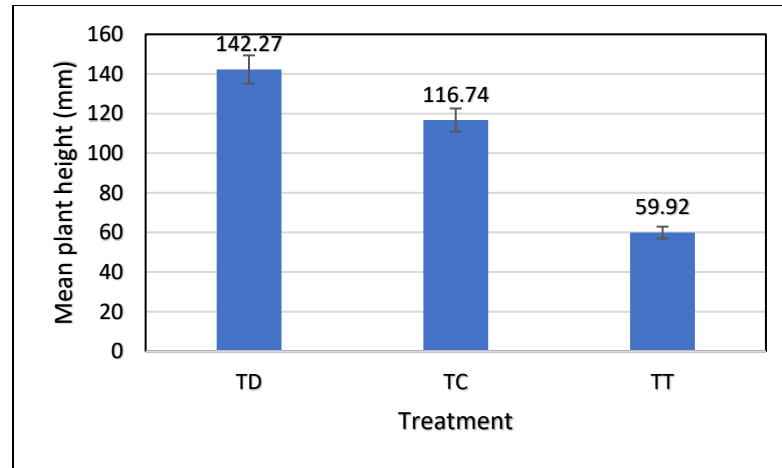


Figure 5. Mean plant height (mm) of lettuce (*Lactuca sativa* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Error bars represent standard error.

4.1.4 Canopy diameter: Canopy diameter ranged from 59.92 mm (TT) to 107.34 mm (TC), with TD producing an intermediate value of 100.94 ± 12.01 mm (Figure 6). Notably, the conventional treatment yielded a marginally wider canopy than digestate, though the

difference was not statistically significant. This result may reflect a differential allocation of nutrients: digestate-amended plants invested more in stem elongation and leaf biomass, whereas the NPK/poultry manure combination may have favoured lateral canopy expansion.

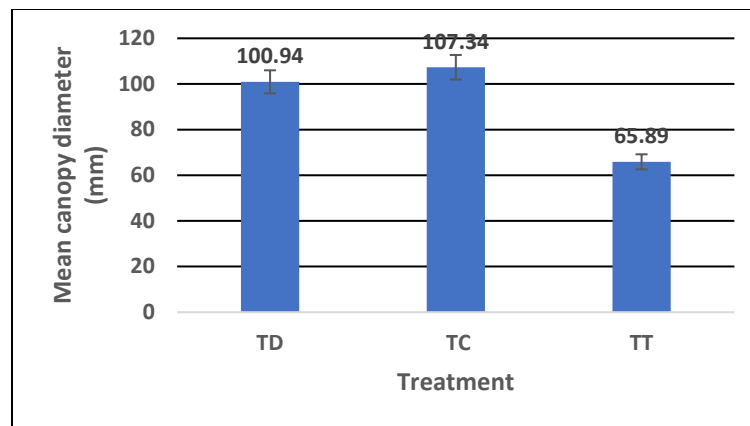


Figure 6. Mean canopy diameter (mm) of lettuce (*Lactuca sativa* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Error bars represent standard error.

4.1.5 Fresh weight yield: Digestate-treated lettuce achieved the highest fresh weight yield of 26.67 ± 2.31 t/ha, outperforming both TC and TT. This represents the most agronomically relevant output metric and confirms the overall superiority of digestate as a fertilization strategy

for lettuce production under the conditions tested.

4.2 Effects of treatments on cucumber (*Cucumis sativus* L.)

4.2.1 Seed emergence rate: Digestate treatment produced the highest seed emergence rate ($97.78 \pm 3.85\%$), exceeding both the

unfertilized control and the conventional treatment (Figure 7). This finding is consistent with observations by Gbaguidi (2008) on lettuce, who reported that organic amendments achieved higher germination rates than mineral fertilizer treatments. The stimulatory effect of digestate on seed germination may be attributable to its content of humic substances and plant growth-promoting compounds released during the digestion process.

4.2.2 Vegetative growth parameters: For leaf number, stem diameter, and stem length, digestate treatment produced the highest values among all three treatments: leaf number 3.31 ± 3.37 ; stem diameter 4.55 ± 4.04 cm; stem length 352.65 ± 554.77 mm (Figures 7–9). ANOVA indicated that treatment effects on these parameters were not statistically significant, except for seed emergence rate ($p < 0.05$). These results confirm a consistent positive trend for TD across all vegetative traits.

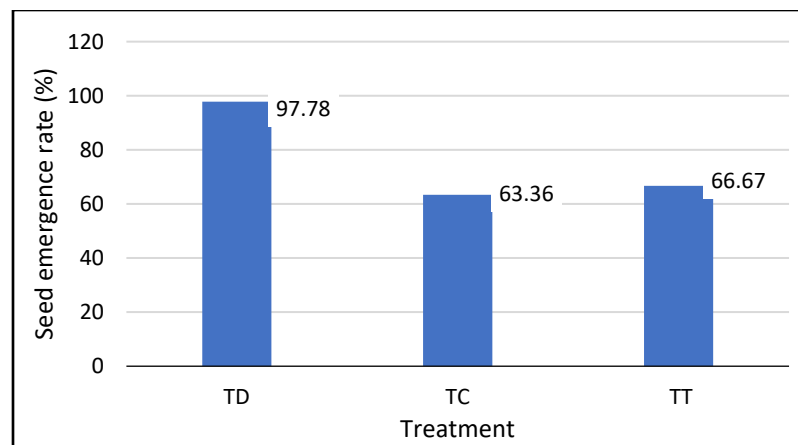


Figure 7. Mean seed emergence rate (%) and leaf number of cucumber (*Cucumis sativus* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control.

4.2.3 Fruit yield: The highest mean fruit number (1.22 ± 0.69) was recorded under conventional treatment (TC), marginally exceeding TD and TT. This was the single parameter for which digestate did not outperform the conventional treatment. The

difference was not statistically significant among treatments, suggesting that fruit set in cucumber may be less sensitive to fertilizer source than vegetative parameters under the conditions tested.

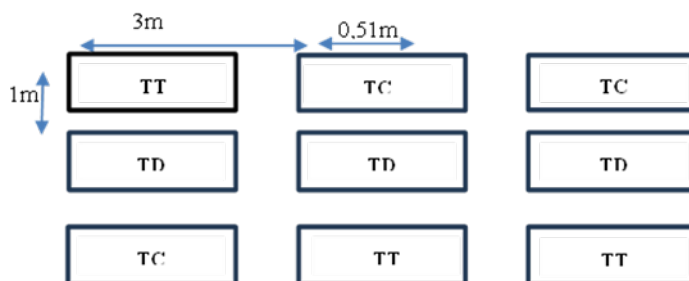


Figure 8. Mean fruit number yield of cucumber (*Cucumis sativus* L.) under three fertilization treatments. TD: Digestate treatment; TC: Conventional treatment; TT: Unfertilized control. Error bars represent standard error.



5 DISCUSSION

The results of this study provide clear evidence that liquid digestate from a small-scale biodigester can match or exceed the agronomic performance of the NPK/poultry manure combination conventionally used in market garden production in southern Benin, for both lettuce and cucumber. For lettuce, digestate consistently produced the highest values across all growth and yield parameters, except for canopy diameter where the conventional treatment marginally outperformed TD. The superiority of digestate for plant height was statistically significant, distinguishing it from TC, a result that aligns with the hypothesis that rapid mineralization and release of nitrogen from digestate provides a more immediate growth stimulus than the slower-release nitrogen fractions in poultry manure (Tchaniley *et al.*, 2020). Fresh weight yield of 26.67 t/ha under TD represents a commercially relevant output that compares favorably with published yield benchmarks for lettuce production in West African humid conditions. The near-equivalence of TD and TC for most lettuce parameters corroborates findings by Konate *et al.* (2018, 2022) and Garba *et al.* (2022), who similarly reported that organic amendments, whether digestate or compost-based, can achieve statistically comparable results to mineral fertilizer combinations for vegetable crops. This suggests that the nutrient availability profile of well-matured digestate approximates that of combined NPK and organic inputs, at least over the short growing cycle of lettuce. For cucumber, digestate outperformed conventional treatment for vegetative parameters and seed emergence, but the conventional treatment yielded marginally more fruits. This divergence merits attention: digestate may channel available nitrogen preferentially toward vegetative organ development (leaves, stems) at the expense of reproductive structures (fruits), particularly when applied at a fixed dose of 1 L/m² without adjustment for crop stage. Lee *et al.* (2021) noted similar dynamics in their comparative study of digestate versus NPK for crop production,

underscoring the importance of application dose and timing optimization. The lack of statistical significance across most cucumber parameters suggests that a larger experimental scale, with greater spatial replication, would be necessary to detect treatment differences with adequate statistical power, a recommendation for future work. The notably high seed emergence rate under digestate (97.78%) compared with mineral fertilizer treatment is consistent with Gbaguidi's (2008) observations and may reflect the beneficial role of organic matter and microbial activity associated with digestate in improving seed-to-soil contact and moisture retention during germination. This property could be particularly valuable in the sandy, low-organic-matter soils typical of the Sèmè-Podji coastal zone. A key limitation of the present study is the absence of chemical characterization of the digestate used, including quantification of total nitrogen, ammonium-N, phosphorus, potassium, and potentially inhibitory compounds. Such data would allow direct interpretation of observed agronomic effects in terms of nutrient supply rates and would facilitate comparison with published digestate compositions from similar West African biodigestion systems. Future studies should systematically pair field trials with physicochemical analysis of both digestate and soil, enabling dose-response modelling and optimization of application rates for specific crops and soil types. From a circular economy and sustainability perspective, the valorization of biodigester digestate in peri-urban market gardening represents a locally viable strategy for closing organic nutrient loops, reducing dependence on imported mineral fertilizers, and improving soil organic matter in intensively cultivated peri-urban soils. The integration of small-scale biodigesters into urban horticultural systems — as exemplified by the Biogaz Bénin model — deserves wider promotion within national agricultural and environmental policy frameworks in Benin and across the West African sub-region.



6 CONCLUSION

This study evaluated the agronomic performance of liquid biodigester digestate on lettuce and cucumber under field conditions in Sèmè-Podji, Benin, comparing it with a conventional NPK/poultry manure treatment and an unfertilized control. Results demonstrate that digestate application at 1 L/m² produced the highest values for most growth and yield parameters in both crops, with statistically significant effects on stem diameter and plant height in lettuce, and on seed emergence rate in cucumber. The digestate and conventional treatments were statistically equivalent for the majority of parameters, while both consistently outperformed the unfertilized control. These findings confirm that well-matured biodigester digestate constitutes an effective organic amendment capable of substituting mineral

fertilizers in market garden vegetable production. Its adoption would simultaneously reduce production costs for smallholder farmers, improve soil organic matter content, and valorise organic waste streams through anaerobic digestion — contributing to more sustainable and circular agricultural systems in peri-urban Benin. Future research should focus on: (i) chemical characterization of digestate batches to relate nutrient composition to agronomic outcomes; (ii) dose-response trials to identify optimal application rates for lettuce and cucumber; (iii) multi-season trials to assess residual soil fertility effects; and (iv) economic analysis comparing the cost-effectiveness of digestate versus conventional inputs at farm scale.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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