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(Research Article)

Agronomic potential of cactus digestate: Effects on the growth and productivity of okra (*Abelmoschus esculentus*)

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Abstract

Senegalese agriculture, essential for food security, faces major challenges, including soil degradation and the excessive use of chemical fertilizers. In the context of an agroecological transition, this study aims to evaluate the effect of cactus digestate, an organic input, on the growth and productivity of okra (*Abelmoschus esculentus*), compared to a fermented solution of *Calotropis procera* and NPK chemical fertilizer. The results show that cactus digestate significantly improves several agronomic parameters of okra: collar diameter, height, vigor, spread, number of leaves, as well as yield. Although chemical fertilizer (T3) produced the best results in terms of productivity, cactus digestate (T2) proved statistically equivalent to the fermented solution of *Calotropis procera* (T1) for several growth parameters. This performance may be explained by its balanced nutrient supply and stimulation of soil microbial activity. These results suggest that cactus digestate is a viable and sustainable alternative to chemical fertilizers, reconciling productivity with environmental preservation in an agroecological perspective.

Keywords: Cactus; Calotropis; Digestate; Agronomic potential; Okra

1. Introduction

Humans have always relied on nature to meet their basic needs, including food. Nowadays, food is increasingly diverse and plays several roles, both nutritional and health-related (Gbohaïda et *al.*, 2016). Food security has become one of the main goals for many tropical countries in order to feed a growing population (Drame, 2003). Agriculture is therefore essential, as it remains the main source of food for the global population (FAO, 2004) and also constitutes a major contributor to Gross Domestic Product (GDP) (OECD/FAO, 2016). It remains a central element of the West African economy, accounting for 30 to 50% of GDP in most countries and representing the largest source of income and livelihood for 70 to 80% of the population (FAO, 2008). In Senegal, the agricultural sector is considered the driving force of the national economy (ANSD, 2014). It is the engine of the primary sector, contributing 9.4% of national GDP and 62.8% of the value added (in nominal terms) of the primary sector (ANSD, 2020).

Within this sector, market gardening plays an important role in food supply (FAO, 2012). It is one of the urban agriculture subsectors that enables the production of fruits and vegetables, which are rich in nutrients and help consumers maintain good health (Tchiegang & Ka, 2004; Atchibri et *al.*, 2012). Among these vegetables, okra holds a prominent place as it is considered an essential condiment in households (FAO, 2012). It is a major crop valued for its

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edible leaves and immature fruits, used in soups and sauces (Khomsug et *al*., 2010). Over the past three years, global okra production has increased from 10,548,942 tonnes in 2020 to about 11,200,000 tonnes in 2022. India remains the leading producer with nearly 6.87 million tonnes, followed by Nigeria and Mali (Helgi Library, 2022). Africa contributes around 33% of global okra production, representing 3,478,555 tonnes (FAOSTAT, 2020). According to ANSD (2021), okra production in Senegal during the 2021 horticultural season was 13,790 tonnes.

However, despite its potential, Senegalese agriculture faces multiple constraints that affect both production and biodiversity conservation. The primary sector recorded a decline of 2.3% in 2022, resulting in a GDP contribution of -0.2% of the primary sector's added value (ANSD, 2022). These challenges are primarily environmental and social in nature, including soil degradation, biodiversity loss due to the massive use of chemical fertilizers which are harmful to both the environment and human health economic inequalities, and food insecurity. To address these issues, the concept of agroecological transition has emerged. It is a process aimed at transforming conventional agricultural practices into more sustainable and environmentally friendly methods based on agroecology principles.

It is in this context that various strategies have been proposed, including the use of cactus digestate as an organic fertilizer. This approach, which constitutes the core of our study, aims to sustainably improve okra productivity in Senegal.

The specific objectives are to

- Evaluate the effect of cactus digestate on the growth and yield of okra.
- Compare the effectiveness of cactus digestate with that of a fermented solution of *Calotropis procera* and NPK chemical fertilizer.

2. Materials and Methods

2.1. Study Area Description

The study was conducted in Senegal, a country located between latitudes 12° and 17° North, and longitudes 11° and 18° West. More specifically, the experiments took place in Bambey, at the Application and Production Center (CAP) of the Institut Supérieur de Formation Agricole et Rurale (ISFAR) (Figure 1).

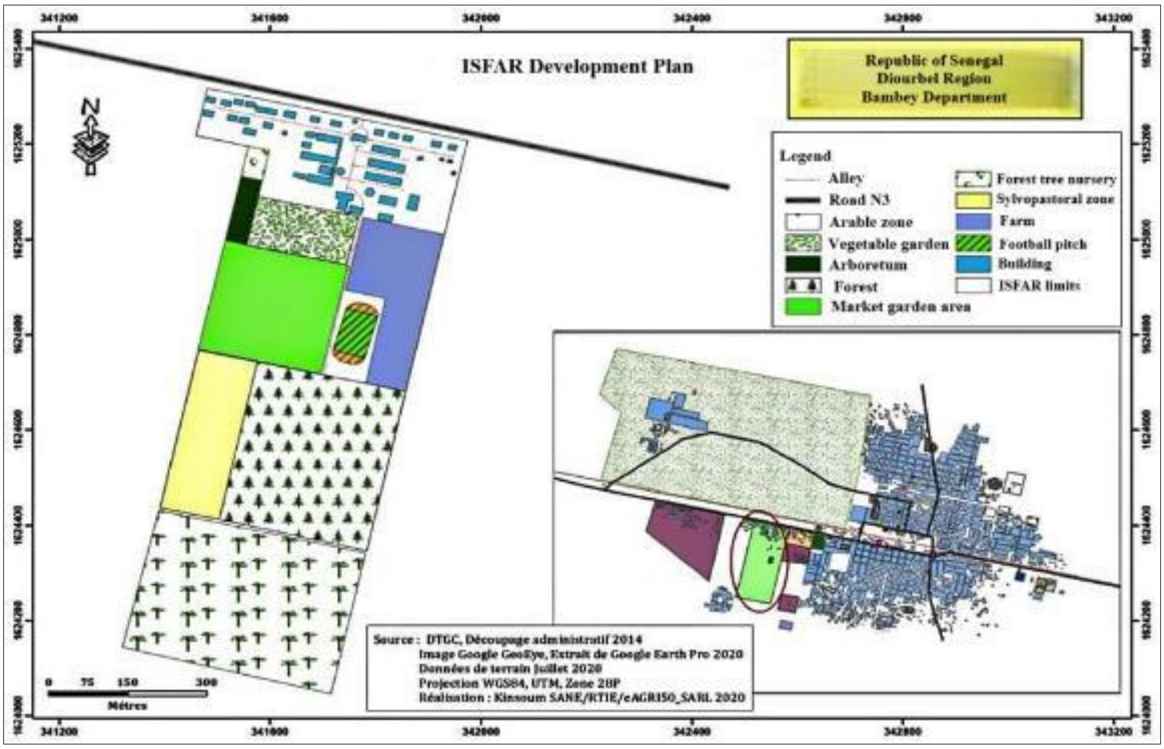

Figure 1 Location of the experimental zone (Sané, 2020)

The geographic coordinates of the site are 14°57’56’’ N and 16°40’82’’ W. This site, situated in the north-central part of the country in the Diourbel region, lies at an altitude of 17 meters above sea level. Bambey is characterized by a tropical climate with a dry tendency, marked by two distinct seasons: a dry season from November to May, and a rainy season from June to October.

In terms of relative humidity, September is the most humid month with an average of 96.87%, while June records the lowest humidity with 34.17%. Minimum humidity values range from 34.17% to 67.35%, and maximum values from 89.43% to 96.87% (Meteorological Station of the CNRA in Bambey, 2024).

The soil at the experimental site has the following physical and chemical characteristics: sandy texture composed of 86% sand, 6% silt, and 8% clay. The pH is slightly acidic (6.7), with an organic matter content of 5.9 $g{\cdot}kg^{-1}$ and a cation exchange capacity (CEC) of 5.3 $cmolc{\cdot}kg^{-1}$ (Trail et *al*., 2016).

3. Materials

3.1. Plant Material

The plant material used in this study is okra (*Abelmoschus esculentus*), a species belonging to the Malvaceae family. The variety used is Indiana, an okra well adapted to the cool dry season. This variety was selected for its ease of use, resistance to YVMV (Yellow Vein Mosaic Virus), and its suitability for export.

The plant is well-branched and compact, allowing for high planting density. It produces long, slender, and straight fruits; medium to dark green in color; with pentagonal cross-sections and slightly ribbed surfaces. Depending on the climatic conditions and the growing region, it reaches maturity 45 to 55 days after sowing, with a total growth cycle of 110 to 120 days.

Figure 2 Okra plant (Indiana variety)

3.2. Technical Equipment

The equipment used in the field included a measuring tape, which was used to demarcate the plots. Stakes with labels were used to mark the different experimental blocks. To identify the plots corresponding to each treatment, labels were attached using stakes. A notebook was used for manual data collection. An electronic scale was used to weigh the harvests. Finally, a mask and gloves were used to comply with health and safety measures during the application of phytosanitary treatments.

3.3. Inputs Used

The experiment required the use of different fertilizers. The applied fertilizers were

- Cactus digestate, whose chemical composition is presented in Table 1,
- NPK 10-10-20 chemical fertilizer,
- Fermented solution of *Calotropis procera*, with its chemical composition shown in Table 2.

Table 1 Chemical Composition of Cactus Digestate (SenAgriTech, 2022

Chemical Elements	Concentration in g/l
Azote (N)	159
Phosphore (P)	204
Potassium (K)	503

Table 2 Chemical Constituents Isolated from the Leaves of Calotropis procera (Niang, 2022)

Plant Parts	Groups of Compounds	Isolated Substances	References
Leaves	Cardenolides	Calotropin (0.165%), Calorigenic (0.087%)	Hesse & Reicheneder (1936)
		Uscharin, Uscharidin, Calotropin, Calotoxin, Uzarigenin, Acide-19-calotropin	Brüschweiler (1969)
		Proceroside	Qudrat-I-KHuda & Amir (1969)
	Polysaccharide	D-glucose + D-arabinose + D-glucosamin + L-rhamnose	

4. Methods

4.1. Experimental Design

The experimental design used was a Randomized Complete Block Design (RCBD), also known as Fisher's blocks. The principle involved randomly assigning treatments to experimental units block by block through a full random draw without replacement. The trial considered the input type as the factor under study, with three (3) replications, each constituting a block. Each block contained four (4) treatments: T0 (control), T1 (fermented solution of *Calotropis procera*), T2 (cactus digestate), and T3 (NPK), corresponding to different types of fertilization. The experiment was conducted on an area of 86.25 m^2 (10.5 m × 6.5 m), consisting of 3 rows of 10.5 m in length per block. The blocks were spaced 1 meter apart and each contained four (4) elementary plots measuring 1.8 m in length and 1.5 m in width, making a total of twelve (12) elementary plots (Figure 3).

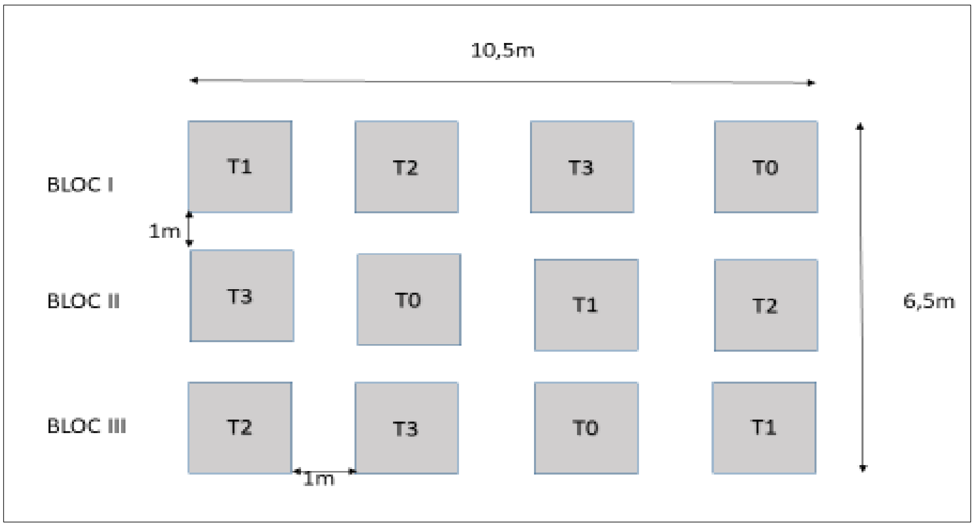

Figure 3 Experimental design

In these elementary plots, spaced 1 meter apart, okra seeds were sown in four (4) rows. The spacing between rows was 0.5 meters, and between planting holes (hill pockets) was 0.6 meters. Four (4) okra plants were randomly selected in each elementary plot to serve as the useful sample plot.

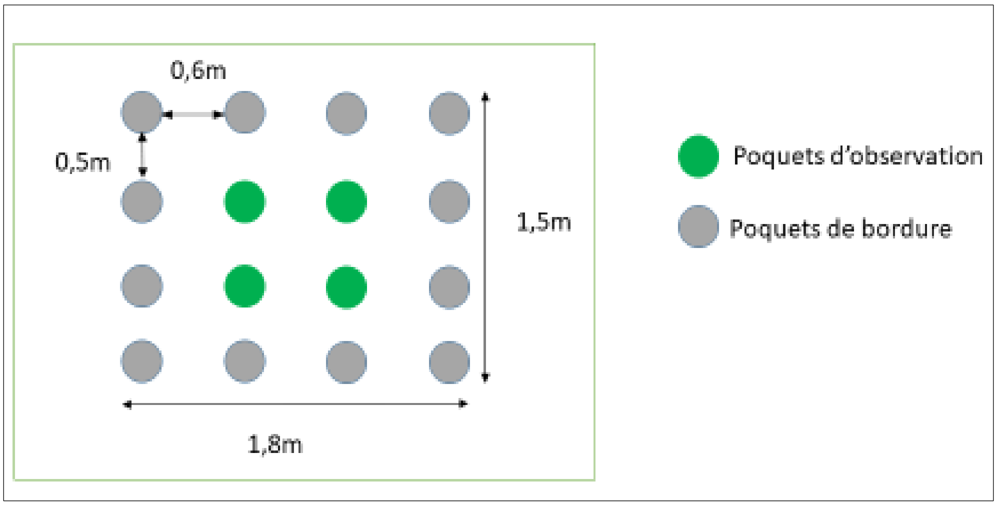

Figure 4 Experimental Unit

4.2. Trial Management

The trial began with superficial tillage (15–20 cm deep) using a traditional "*sine*" hoe, followed by leveling with a rake and soil treatment using the fungicide Ivo Plus 80 WP (Mancozeb 800g/kg) to protect against pests. The plots were demarcated using the 3-4-5 method. Direct sowing was carried out on August 14, 2024, with three seeds per hill. Irrigation was done manually with a watering can, according to the crop's water needs. Thinning to one plant per hill was done on the 15th day after sowing (DAS), followed by four manual weedings using a hoe. Four treatments were applied as shown in Table 3:

T0: Control

- T1: Fermented solution of *Calotropis procera* (20 ml per hill before sowing and then weekly)
- T2: Cactus digestate (same application method as T1)
- T3: NPK 10-10-20 chemical fertilizer (4 g per hill before sowing and 10 g per hill weekly)

Plant protection included several targeted applications

- Mancozeb (10 days before sowing, and on the 38th and 50th day after sowing)
- Neem oil (18th day after sowing)
- Abamectin (28th day after sowing)
- PASCHA 25 EC (47th day after sowing)
- Copper (53rd day after sowing)

These treatments were aimed at controlling insect pests (aphids, whiteflies, caterpillars, termites) and fungal diseases.

Table 3 Number of applications, quantity per application, and application dates

Treatment	Type of Fertilizer	Basal Fertilization	Top Dressing	Application Dose
T0	No fertilizer applied	0	0	0
T1	Fermented solution of *Calotropis procera*	Once	Three times	300 L/ha
T2	Cactus digestate	Once	Three times	300 L/ha
T3	NPK 10-10-20	Once	Three times	300 Kg/ha

4.3. Agronomic Observations and Measurements

In each elementary plot, a sample of sixteen (16) plants was selected, of which four (4) were used for observation, while the remaining twelve (12) were retained to account for edge effects. The growth parameters evaluated included plant height (measured from the cotyledons to the apex on the 30th and 45th Days After Sowing DAS), collar diameter (measured using a caliper), vigor (measured using a GreenSeeker), number of leaves (manually counted below the first inflorescence), and canopy spread (distance between the furthest leaves). Yield (in grams) was assessed by weighing the harvested fruits per treatment using an electronic scale.

The collected data were entered into Excel, which was also used for certain calculations and for generating graphs. Statistical analysis was performed using XLSTAT 2023. An analysis of variance (ANOVA) was applied to the quantitative data following a normal distribution. In cases of significant treatment effects, a multiple comparison test (HSD or Newman-Keuls) was conducted to identify differences between means.

5. Results

5.1. Effect of Treatments on Plant Growth and Development

5.1.1. Collar Diameter

Figure 5 illustrates the evolution of the collar diameter of okra plants under different fertilization treatments on the 30th and 45th Days After Sowing (DAS). The analysis of variance reveals a highly significant difference between treatments at all observation dates ($p < 0.0001$). At 30 DAS, a notable increase in collar diameter was observed with the cactus digestate treatment (T2), reaching an average of 0.429 mm. Although this value is lower than that of the chemical fertilizer treatment T3 (0.533 mm), it is well above that of the control T0 (0.275 mm) and close to the performance of the fermented *Calotropis procera* solution (T1: 0.431 mm). The LSD test grouped the treatments into three distinct classes on this date: Class A for T3, Class B for T1 and T2, and Class C for T0. At 45 DAS, the cactus digestate treatment continued to show good collar development, with an average diameter of 0.892 mm, higher than that of T1 (0.883 mm) and significantly greater than the control T0 (0.558 mm). However, T3 maintained the highest value with 1.017 mm. On this date, the classification of means revealed four groups: T3 in Class A, T2 in Class AB, T1 in Class B, and T0 in Class C.

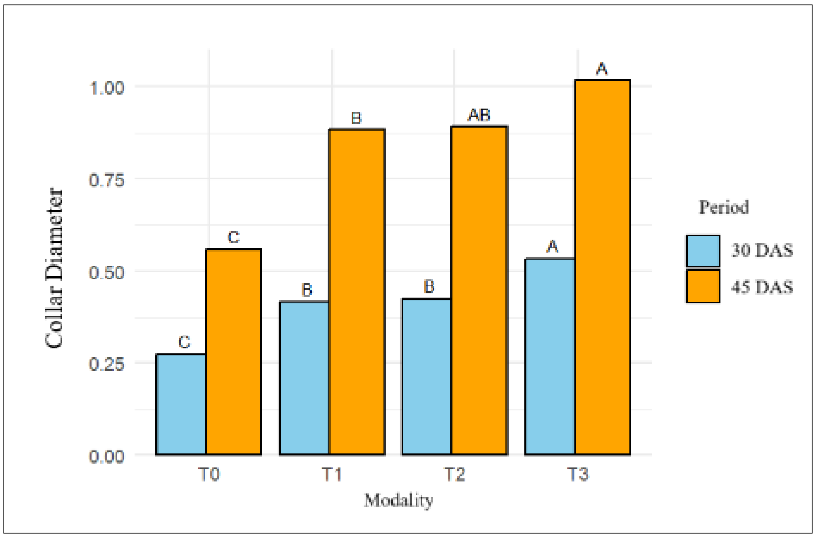

Figure 5 Effect of treatments on plant collar diameter

5.1.2. Plant Height

Figure 6 illustrates the effect of the different treatments chemical fertilizer, cactus digestate, and fermented *Calotropis procera* solution on okra plant height over time. The cactus digestate treatment (T2) proved particularly effective. At 30 days after sowing (DAS), the plants treated with cactus digestate reached an average height of 17.750 cm, falling within the same statistical group (A) as those treated with the fermented *Calotropis procera* solution (T1: 18.583 cm) and the mineral fertilizer 10-10-20 (T3: 19.250 cm). In comparison, the unfertilized control (T0) recorded the lowest height at 12.000 cm, belonging to statistical group B. At 45 DAS, the cactus digestate treatment maintained its effectiveness, with an average height of 43.833 cm, still within the same statistical group (A) as T1 (45.417 cm) and T3 (47.500 cm). The control (T0) continued to lag behind with an average height of 36.083 cm, remaining in group B. The analysis of variance showed a highly significant difference between treatments at each measurement date ($P < 0.001$).

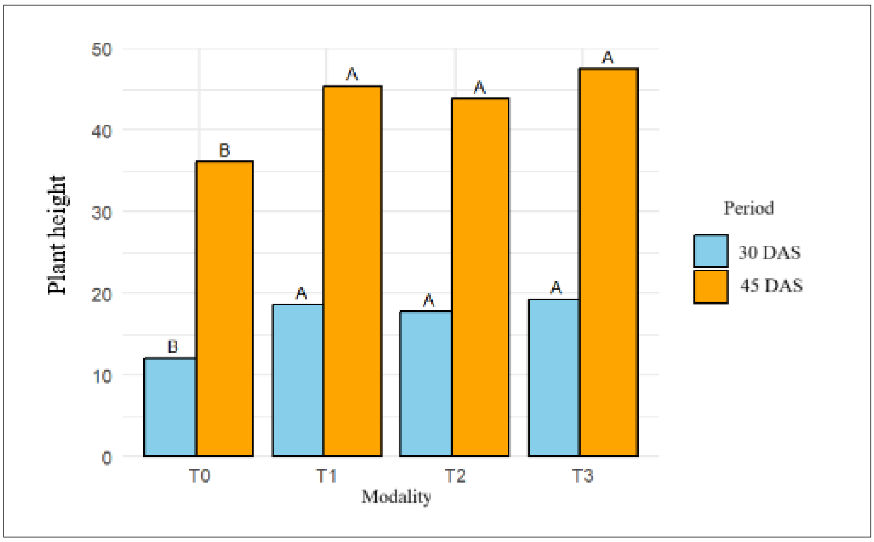

Figure 6 Effect of treatments on plant height

5.1.3. Plant Vigor

The analysis of variance for okra plant vigor under different fertilizer treatments, presented in Figure 7, highlights the notable performance of cactus digestate (T2). At 30 days after sowing (DAS), treatment T2 recorded an average vigor of 0.626, very close to that of the fermented *Calotropis procera* solution (T1: 0.628) and just behind the chemical fertilizer (T3: 0.678). According to the Newman-Keuls test, all three treatments (T1, T2, T3) were grouped into the same homogeneous group A. The absolute control (T0), with no fertilizer input, showed the lowest vigor value at 0.357, belonging to group B. At 45 DAS, cactus digestate maintained an average vigor of 0.738, identical to T1 (0.738) and slightly lower than mineral fertilizer T3 (0.753). The control T0 remained significantly less vigorous with a value of 0.674. The analysis of variance revealed a highly significant difference between treatments at each date ($p < 0.0001$).

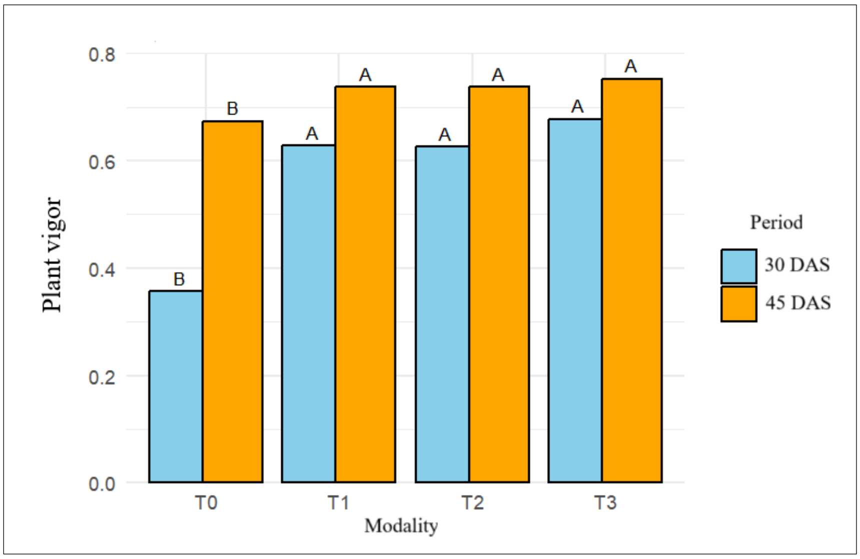

Figure 7 Effect of treatments on plant vigor

5.1.4. Plant Spread

Figure 8 illustrates the evolution of plant spread in okra at 30 and 45 days after sowing (DAS) under different fertilizer treatments. A highly significant effect was observed at all dates ($p < 0.0001$). At 30 DAS, the cactus digestate (T2) resulted in an average spread of 43.250 cm, slightly lower than the fermented *Calotropis procera* solution (T1: 45.333

cm) and close to the chemical fertilizer (T3: 43.333 cm). At 45 DAS, cactus digestate maintained strong performance with an average spread of 70.667 cm, placing it in statistical group A alongside T1 (72.750 cm) and T3 (67.333 cm). The absolute control (T0) showed the lowest values, with 32.5 cm at 30 DAS and 53.333 cm at 45 DAS, forming group B.

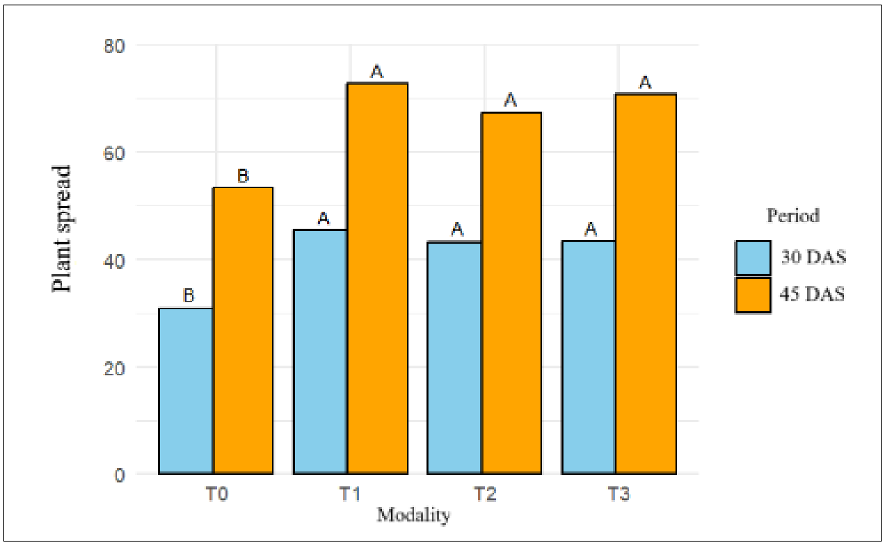

Figure 8 Effect of treatments on plant spread

5.1.5. Number of Leaves per Plant

Figure 9 illustrates the evolution of the number of leaves on okra plants at 30 and 45 days after sowing (DAS) according to the fertilizer treatments. Analysis of variance reveals a highly significant difference between treatments at each date ($p < 0.0001$). At 30 DAS, the cactus digestate (T2) resulted in an average of 6.917 leaves per plant, close to that of the fermented *Calotropis procera* solution (T1: 7.250) and slightly lower than the mineral fertilizer (T3: 7.833). The absolute control (T0) showed the lowest value with 4.417 leaves. At 45 DAS, the average number of leaves for the cactus digestate (T2) was 10.417, very close to T1 (10.333) and still lower than T3 (11.333). The control (T0) lagged behind with 7.167 leaves. The mean comparison test grouped the treatments into two homogeneous groups: group A composed of T1, T2, and T3, and group B consisting solely of the control T0.

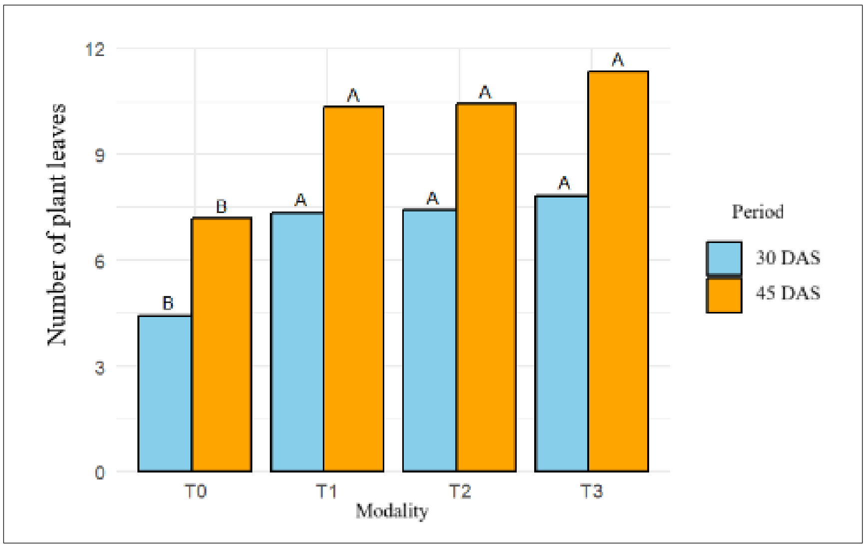

Figure 9 Effect of treatments on the number of plant leaves

5.1.6. Plant Production

Figure 10 presents the effect of different fertilizer treatments on the production of Indiana okra over five harvests (H1 to H5). Analysis of variance reveals a highly significant effect of treatments on production at each harvest ($p < 0.0001$).

At the first harvest (H1), the cactus digestate (T2) yielded an average production of 534 g, placing it in an intermediate class behind the mineral fertilizer (T3: 1,015 g) but ahead of the absolute control (T0: 210 g). The fermented *Calotropis procera* solution (T1) showed a similar production of 614 g. Over the subsequent harvests, production under the cactus digestate progressed as follows: 713 g (H2), 688 g (H3), 725 g (H4), and 992 g (H5). These values are very close to those obtained with T1 (740 g, 740 g, 707 g, 967 g) and clearly higher than those of the control T0 (294 g, 311 g, 332 g, 353 g). The mineral fertilizer treatment (T3) maintained significantly higher yields, reaching up to 1,787 g at the fifth harvest. The Newman and Keuls test classified the treatments into three distinct groups: class A for T3, class B grouping T1 and T2, and class C for the control T0.

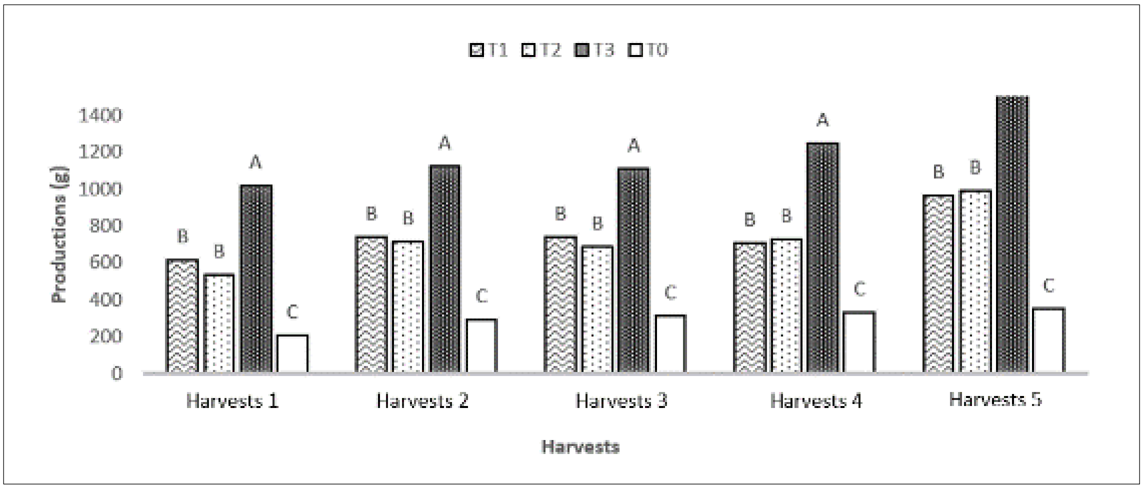

Figure 10 Effect of treatments on plant production

6. Discussion

6.1. Effect of Fertilizers on Plant Growth and Development

The results of the analysis showed that the liquid organic fertilizers, namely cactus digestate and the fermented solution of *Calotropis procera*, had a positive effect on all measured parameters. Regarding collar diameter, a highly significant difference was observed on the 30th and 45th days after sowing (DAS). The treatment with chemical fertilizer 10-10-20 (T3) recorded the largest collar diameters. This performance can be attributed to the composition of chemical fertilizers, which contain essential and readily assimilable nutrients such as nitrogen (N), phosphorus (P), and potassium (K). These elements promote vigorous growth by stimulating the plant's metabolic processes, leading to a more robust development of the collar.

In terms of plant height, vigor, canopy spread, and number of leaves, the plants treated with T3, T1 (fermented *Calotropis procera* solution), and T2 (cactus digestate) showed statistically similar performances. This similarity could be explained by the fact that chemical fertilizer stimulates the assimilation of mineral elements present in the rhizosphere, thus enhancing growth. At the same time, cactus digestate and the *Calotropis procera* solution improve root system development, contributing to better establishment and optimal plant development.

As shown by Pinton et *al*. (1999), the initial content of organic matter (OM) and mineral elements positively influences plant height. Nitrogen (N), in particular, plays a central role in the formation of green plant parts responsible for growth and survival. After application, the fate of the OM contained in digestates depends heavily on the soil and climatic context and the diversity of soil organisms. Literature commonly reports an increase in microbial activity following the application of digestates, which provide an additional source of carbon-based energy, thereby enhancing the production of new microbial cells (Alburquerque et *al*., 2012; Ross et *al*., 1989). These results are consistent with those of Gai (2017), who observed in soybean (*Glycine max*) that a high initial nitrogen supply promoted root activity, leaf photosynthesis, and consequently, grain yield.

However, these findings differ from those reported by Céline et *al*. (2021), where okra plants fertilized with compost had a larger leaf area than those treated with chemical fertilizer. Attigah et al. (2013) also observed the best growth parameters with combined treatments of 175 kg NPK and 4 t/ha of poultry manure compost. Céline et *al*. (2021), working on okra, additionally found longer stems in plants treated with compost.

6.2. Effect of Treatments on Yield Variation

At 50% flowering, plants treated with T3 (10-10-20 fertilizer) were the first to reach this stage, followed respectively by T1 (*Calotropis procera* solution), T2 (cactus digestate), and T0 (control). This earliness could be explained by the fact that mineral fertilizer stimulates the production of growth hormones, particularly auxin (indole-3-acetic acid, IAA), by limiting their enzymatic degradation, which promotes earlier and increased flowering.

In terms of average yield, the highest values were observed with T3, followed by T1, T2, and finally the control T0, which showed the lowest values. The highest yields were recorded on the 64th day after sowing (DAS) with the T3 treatment, followed by T2, T1, and T0. These results align with those of Hellequin et *al*. (2019), who explained that liquid biostimulants used between crops have a delayed effect due to the gradual stimulation of soil microbial communities.

The benefits observed with cactus digestate and the *Calotropis procera* solution can be attributed to phytohormones contained in humic acid, particularly auxins and gibberellins. These hormones are likely responsible for accelerating and enhancing plant development by increasing tissue metabolism in okra. Several studies have shown that the application of digestates favors increased flowering and thus improves crop yield. This is mainly due to the supply of nitrogen and essential nutrients that stimulate plant growth (Möller & Müller, 2012).

7. Conclusion

The experiment demonstrated the agronomic potential of cactus digestate as an effective organic fertilizer for okra cultivation in Senegal. Although it did not outperform chemical fertilizer in terms of total yield, its performance was comparable to that of the fermented *Calotropis procera* solution, with results significantly higher than the untreated control.

The application of cactus digestate promoted good vegetative growth, increased vigor, and regular fruit production, while potentially improving soil fertility. Moreover, its organic origin makes it a suitable input for sustainable agriculture, limiting the harmful effects of chemical fertilizers on human health and the environment.

Thus, the use of cactus digestate fits into a strategy of valorizing local resources and promoting agroecology. It represents a promising avenue for strengthening the resilience of vegetable production systems in the face of current challenges such as climate change and food insecurity.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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