Application of Cassava-Peels and Palm-Oil-Sludge Digestate on Bean Crop for Sustainable Growth

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Abstract:
This study investigates the potential of using digestate, a byproduct of anaerobic digestion, as organic manure in sustainable agriculture. The digestate, derived from cassava peels and palm oil sludge, was processed using a constructed screw press, separating it into liquid and solid components, with the liquid stored at room temperature and the solid subjected to a 20-day solar drying process. Four experimental conditions were tested: a control group, soil with chemical fertilizer, soil with solid digestate, and soil with liquid digestate. A fertilization rate of 1 gram per kilogram of soil was used. Over two months, growth patterns emerged, with the liquid digestate group showing the most significant advantages, concluding with 59 leaves compared to 46 leaves in the solid digestate group, 44 in the chemical fertilizer group, and 42 in the control group. However, the p-value (0.9451) indicates that there was no statistically significant difference between treatments, suggesting that the differences in leaf counts could not be totally attributed to the treatments. The liquid digestate group also demonstrated superior stem width and crop yield, achieving a yield of 99 bean seeds. The study highlights the promise of integrating digestate as organic manure in sustainable agriculture. The use of an anaerobic digester and screw press offers a viable solution for waste-to-resource conversion. Despite the encouraging results, further research is recommended to optimize digestate composition and application methods tailored to specific crop needs. This research contributes to eco-friendly agricultural practices and supports the advancement of sustainable waste management and crop cultivation strategies.
Keywords: Anaerobic co-digestion, Cassava peels, Digestate, Palm oil sludge, Sustainable growth.

1. Introduction

In recent times, agricultural waste (AW) has emerged as a significant contributor to pollution [1]. The unregulated burning of agricultural residues such as straw, leaves and cobs in rural agricultural areas has given rise to a variety of environmental problems. The increasing quantity of this waste and its inadequate disposal methods, especially in developing countries, persistently pose environmental risks, jeopardize public health, and also contribute to the global emission of greenhouse gases (GHGs) [2].

AW can be broadly classified into three categories: crop residue, agro-industrial residue, and kitchen waste. Crop residue refers to the non-edible parts of crops that are discarded as waste, including straw, stubble, stalks, leaves, roots, branches, and trimmings [3]. According to current estimates, global crop residue production is projected to reach a staggering 2802 million metric tons per year (Mt/y) [4]. This figure represents the total annual quantity of crop residues generated worldwide. The significant volume of crop residue highlights the critical importance of implementing effective management and utilization strategies to reduce waste and harness the potential value of these agricultural by-products. [4].

Crop residues such as Cassava peels (CP), comprising around 15% of cassava root, present significant environmental threats in Nigeria. The indiscriminate disposal of these peels post-processing leads to foul odours, air pollution, and soil contamination [5], [6]. The production of offensive odours, contamination of surface and ground waters, and unproductive surrounding soil and vegetation are some of the environmental effects [6]. It was noted that 98% of Nigeria's CP production is lost each year due to drying issues and concerns about proper disposal [7].

Palm oil sludge (POS), on the other hand, a by-product of the crude palm oil industry in Nigeria, also poses detrimental effects on the environment. When discharged untreated, POS exhibits significant oxygen-depleting capabilities in aquatic systems, contributing to pollution [8]. The sludge, containing substantial solids from drained liquid, is a source of environmental degradation [8].

In developing countries, waste management solutions such as landfilling, incineration, and composting have demonstrated detrimental effects on the environment. These effects include the generation of ash, greenhouse gases, and groundwater pollution, which have led to various health issues such as cancer, bronchitis, and reduced lung function [9]–[11]. To mitigate these issues and eventually reduce reliance on fossil fuels, scientists have turned to anaerobic digestion (AD) as a viable solution. AD is widely employed to treat diverse types of waste, ranging from municipal solid waste and household wastewater sludge to agricultural residues and industrial sludge wastewater. It is regarded as a promising approach for extracting renewable energy from bio-based waste materials. However, despite the widespread adoption of AD technology, only a small percentage, approximately 1.6-2.2%, of the total energy potential present in the feedstocks is currently harnessed [12].

The efficiency of the AD process is influenced by several factors, including ammonium accumulation, incomplete biomass conversion, and prolonged lag phases. Addressing these limiting factors is crucial in enhancing the efficiency of the AD process and unlocking its full energy-generating potential [12]. Currently, most of the anaerobic digestion (AD) plants rely on mono-digestion systems, meaning they process a single feedstock. Mono-digestion has significant drawbacks, including digester instability, limited availability of certain feedstocks throughout the year, presence of heavy metals, and low biogas/methane yield. Anaerobic co-digestion presents an opportunity to address these drawbacks by simultaneously digesting two or more feedstocks. Its advantages include enhanced system stability and increased methane yield. This is achieved through the synergistic effects of promoting a more diverse microbial community within the AD process [13].
To effectively manage biodegradable waste at a low cost, the byproducts of AD namely biogas and digestate can be utilized in the management process. The digestate can be used as a soil amendment or manure, and the biogas that is produced through AD as either a replacement for fossil fuels or processed into bio-methane for use in applications such as the fuelling of automobiles or the natural gas system [14], [15].

Despite the known benefits of organic fertilizers, there is limited research on the direct application of cassava peels and palm oil sludge to improve crop growth. This study seeks to investigate the potential of digestate derived from cassava peels and palm oil sludge as organic fertilizers. Specifically, the study examines the effects of the digestate on the growth and yield of beans, a commonly cultivated crop in Nigeria. By repurposing these agricultural wastes, the study aims to contribute to sustainable waste management practices and improved agricultural productivity.

1.1 Oil palm Fruit

The oil palm, scientifically known as *Elaeis guineensis*, thrives in hot and humid tropical regions, making it a highly profitable commodity. Its year-round production makes it a significant crop in these areas. Palm oil, the product derived from the oil palm, is one of the most widely produced and consumed oils worldwide due to its affordability, production efficiency, and excellent stability. It finds extensive use in various cuisines, cosmetics, hygiene products, and is occasionally utilized as a biofuel source [16]. Originally from West Africa, the cultivation of oil palm rapidly expanded to Southeast Asian countries, including Malaysia, Indonesia, and Thailand. Agricultural goods derived from crude palm oil are relatively interchangeable with those from other plants, and oil palm plays a crucial role in the economies of Southeast Asian nations, particularly those classified as third world countries [17], [18]. A notable point to contemplate is that palm oil accounts for merely 10% of the dry matter found in an oil palm, with the remaining 90% consisting of waste oil palm biomass [19].

1.2 Cassava

Cassava (*Manihot esculenta Crantz, Euphorbiaceae*) holds the position of the sixth most important food crop globally, both in terms of annual production and its significance as a staple food for approximately 800 million people. This perennial root crop is grown in the tropics, including sub-Saharan Africa, Asia, the Pacific Islands, and Central and South America, and is cultivated in over 100 countries worldwide [20]. Farmers in the north and northeast of Brazil heavily rely on cassava as a vital socioeconomic staple crop, while Nigeria and other tropical African countries consider it a major source of carbohydrate, often referred to as the 'bread of the tropics,' 'food of the poor,' or 'poverty fighter.' Cassava cultivation provides subsistence farmers with limited resources the flexibility of harvesting schedules, thanks to its resilience to drought and its ability to thrive in various types of soil, including marginal soils [28]. However, the processing of cassava generates solid, liquid, and air emissions waste, with cassava wastewater being a significant concern due to its high nutrient content and the common practice of direct soil disposal, leading to soil poisoning and water contamination/eutrophication [21]–[23]

1.2.1 Cassava Peels

Cassava peels (CP), comprising 10 to 12% of the root's total dry weight and measuring 1 to 4 mm thick, are often discarded during cassava processing [24]. In Nigeria, this results in the annual generation of around 9 million tonnes of peels, contributing to environmental issues [24]. However, these peels present untapped potential as they contain residual starch and valuable nutrients, making them suitable for livestock feed and various industries [24]. CP are abundant in sugars and polysaccharides like starch and hemicelluloses. The peels also encompass around 5% crude protein and a substantial array of minerals making it a cost-effective solution for enhancing feed quality [25]

1.3 Fertilizer

The term "fertilizer" refers to a category of substances that are made up of organic and inorganic chemical compounds that contain necessary elements of nutrient composition. These compounds can either be found naturally or manufactured artificially in a facility that specializes in the production of chemicals [26]

1.3.1 Chemical Fertilizer

The use of chemical or inorganic fertilizers in agriculture poses significant dangers to both the environment and human health [27]. Despite their role in increasing plant nutrients, the negative consequences associated with their widespread and intensive use cannot be overlooked [27].

One of the primary concerns is the adverse impact of chemical fertilizer application on the environment. Imbalanced application of these fertilizers can lead to environmental contamination, as they often contain heavy metals and radioactive compounds [28]. Over time, the accumulation of these contaminants in the soil can reach toxic levels, posing risks to ecosystems and the overall health of the environment [28]. Additionally, the extensive use of inorganic fertilizers globally has been linked to the accumulation of contaminants such as arsenic (As), cadmium, and other toxic elements. These contaminants can persist in the soil for extended periods, potentially contaminating water bodies through leaching and adversely affecting water quality [28].

Furthermore, chemical fertilizers can disrupt soil health and fertility. Excessive use of nitrogenous fertilizers, for example, can result in nutrient losses through leaching and volatilization [29]. This not only reduces nutrient use efficiency but also contributes to environmental threats, such as the contamination of water bodies with nitrates. Phosphorus fertilizers, on the other hand, have low-use efficiency, with only a small portion being utilized by the crop plant, while the rest remains in the soil or finds its way into water bodies [29]. This accumulation of phosphorus in the soil can lead to environmental problems and impact water quality [29].
The dangers of chemical fertilizers extend beyond environmental concerns to human health. The accumulation of heavy metals, such as cadmium and lead, in crops can pose risks to human consumers. Consumption of crops grown in soil contaminated with these heavy metals can lead to health issues, including kidney and lung disorders. Uranium, another element found in phosphate fertilizers, can accumulate in the body, particularly in the kidney and bones, potentially causing nephritis and disrupting calcium levels [28].

1.3.2 Organic Fertilizer

Organic fertilizers are derived from naturally existing materials sourced from plants or animals. Examples include compost, household waste, crop residues, and livestock manure. These organic fertilizers serve a dual role by directly supplying plant nutrients and indirectly influencing the physical, chemical, and biological properties of the soil. There are several reasons why organic fertilizers are gaining popularity. These include the increasing costs of mineral fertilizers and the implementation of strict regulations regarding environmental protection [26], [30], [31].

2. Materials & Methods

2.1 Digestate

The digestate was gotten from a constructed digester within Covenant University. It was made up of Cassava peels, palm oil sludge, cow dung, crushed eggshells, and water with 15kg, 15kg, 30kg, 1.33kg and 80kg respectively. The waste was digested for a hydraulic retention time of 30 days after which biogas was generated.

Figure 1: **Image of Designed Anaerobic Digester**

2.2 Screw press

The screw press is composed of a 25-liter container designed to accommodate waste, serving as a reservoir. The upper section of the apparatus includes a threaded shaft, screw, and compression plate, collaborating to compress the waste and facilitate the effective separation of solids and liquids. The sieve and outlet play a crucial role in efficiently collecting the liquid portion after the successful separation process..

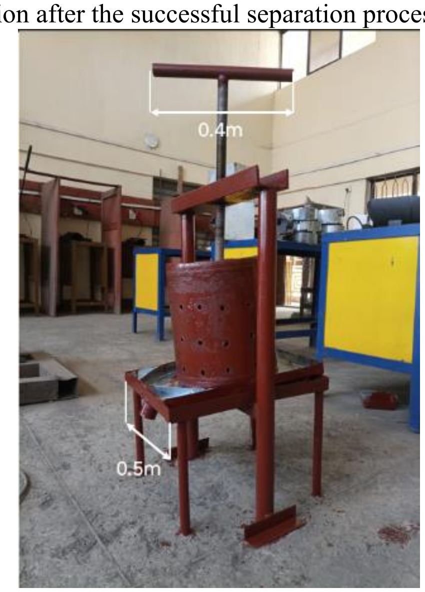

Figure 2: **Side view of constructed screw press.**

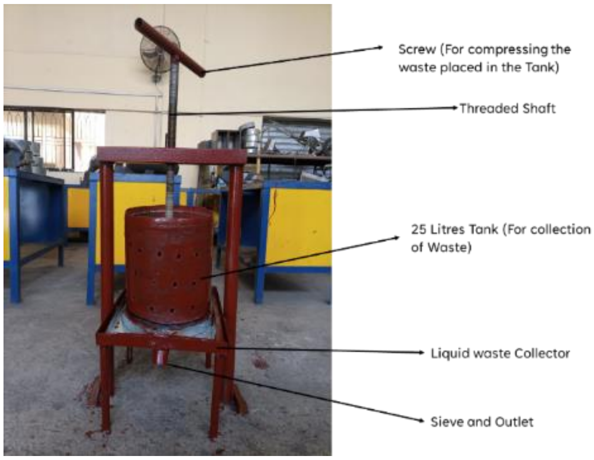

Figure 3: **Image of constructed screw press showing labelling.**

a) 2.3 Chemical Fertilizer

The chemical fertilizer utilized comprised the subsequent percentages of essential plant nutrients: Nitrogen (15%), Phosphorus (15%), Potassium (15%), and Sulphur (10.2%).

Figure 4: Image of Chemical fertilizer

b) 2.4 Preparation of Digestates

The digestate utilized in this study was obtained from a 225-liter digester situated at Covenant University. It consisted of specific quantities of Cassava peels (15kg), palm oil sludge (15kg), cow dung (30kg), crushed eggshells (1.33kg), and water (80kg). The processing of these digestates was carried out using the constructed screw-press, as illustrated in Figure 5 below. Subsequently, the liquid fraction of the digestates was preserved in a 10-liter jerry can at ambient temperature, while the solid component underwent a drying process in a greenhouse for a duration of 20 days before being stored under room temperature.

Figure 5: **Image showing extracted liquid digestate**

Figure 6: Image of extracted liquid digestate stored in a can.

Figure 7: Image of Solid-digestate

2.5 The Planting process

The buckets were filled with approximately 5 kg of loamy soil. Each bucket was labelled according to the crop planted and the type of fertilizer added to the soil. The fertilizer was introduced one week after the initial planting was done. Subsequently, fertilizers were applied at intervals of three weeks, starting from planting until the onset of pod formation. This schedule was designed to coincide with the critical vegetative growth stages of the beans, particularly during leaf and root development, which typically occurs in the first 6–9 weeks of growth. Ensuring nutrient availability during these key stages promotes optimal leaf production, which is essential for photosynthesis and subsequent yield. Each treatment was applied to 2 replicates, with 8 samples in total across all treatment groups.

Figure 8: Planting of seeds

The experimental variables included in the investigation were as follows:

i. 1 – Soil – only treatment (Control)
ii. 2 – Soil + Artificial fertilizer
iii. 3 – Soil + Solid fertilizer
iv. 4 – Soil + Liquid fertilizer

Each fertilizer was administered at a rate of 1 grams per kilogram of soil [32]. The samples were fertilized during the first two months at intervals of three weeks.

2.6 Data Collection

The following data were collected during the plant growth process.

2.6.1 Temperature

The temperature of the greenhouse, atmosphere and soil were measured throughout the period of planting. The process is as follows:

i. The thermometer was placed outside the greenhouse to measure the atmospheric temperature and the value recorded.
ii. The thermometer was placed within the greenhouse to measure the greenhouse temperature and the value recorded.
iii. The thermometer was placed in 2 soil samples and the temperature recorded.

2.6.2 Number of Leaves

The number of leaves grown on each plant was noted over a two-month period. This was carried out as fertilizer was applied one week after the initial planting was done. The process is outlined as follows:

i. The leaves for each plant were counted.

2.6.3 Width of Stem

The stem's width of each crop was assessed over a two-month period following the application of fertilizer. The methodology is outlined as follows:

i. The vernier calliper is positioned approximately 2 to 3 centimetres above the soil surface along the plant's stem.

The measurement is subsequently recorded based on the reading displayed on the vernier calliper

Figure 9: Width of Stem measured using a Vernier calliper.

3. Results & Discussions

3.1 Physio-chemical Characterization of Soil and Digestate

The laboratory test results shown in Figure 10 was obtained at a temperature of 25°C and a humidity of 51%. They provide an insight into the contents of the sludge before and after the AD process.

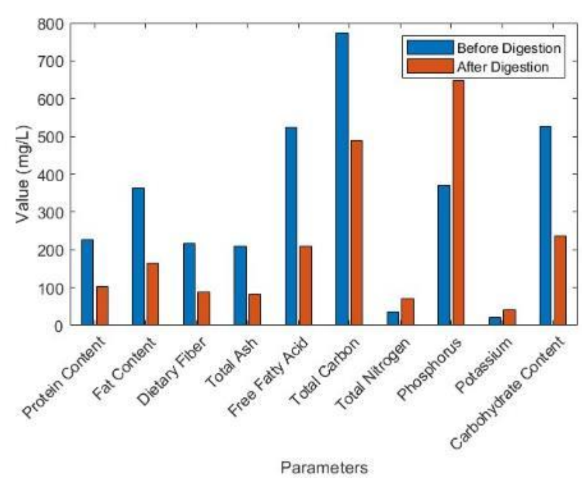

Figure 10: Comparison of nutrients before and after anaerobic digestion of cassava peels and palm oil sludge.

As depicted in Figure 10, the concentrations of nitrogen (N), phosphorus (P), and potassium (K) experienced notable increases of 95%, 75%, and 93.8%, respectively. This suggests that the addition of crushed eggshells and the regulation of temperature in a greenhouse created a favorable environment for slow metabolic reactions.

The digestate obtained after 30 days of anaerobic digestion of cassava peels, palm-oil sludge, and cow dung shows a noteworthy increase in organic matter content. Specifically, the NPK percentages for the digestate are measured at 0.702%, 6.475%, and 0.41%, respectively. This represents a substantial elevation compared to their initial concentrations within the mixed substrate. Significantly, these values exceed those reported in a study conducted by Li et al., in 2021, highlighting the enrichment of the obtained digestate with nutrients [33]. As a result, the digestate demonstrates its worth as a valuable, high-quality organic manure that fosters sustainable crop growth.

3.2 Soil Characterization

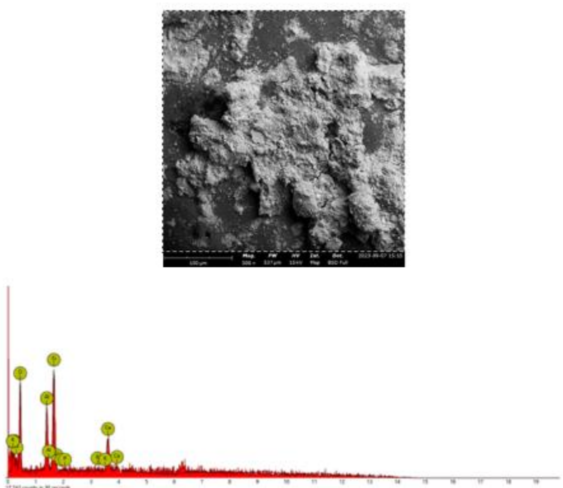

Figure 11: SEM (Scanning Electron Microscopy) and EDX (Energy Dispersive X-ray Spectroscopy) characterization of soil samples used to facilitate bean growth.

The elemental composition of the soil was scrutinized through EDX analysis, yielding insightful information. Oxygen, accounting for 68.37%, emerged as the predominant element, as anticipated due to its presence in both water and organic matter. Silicon ranked as the second most abundant element at 9.88%, followed by nitrogen at 9.35%. Aluminium and calcium were identified at 7.44% and 4.55%, respectively. Potassium was present at a lower concentration of 0.41%, and phosphorus was reported as 0%, indicating a negligible concentration.

3.3 Growth of Bean Crop

Two months following the first fertilizer treatment, the following data were gathered from the different bean crops. Before being transferred to the open environment, the bean crop samples were first grown in a greenhouse for 91 days.

3.3.1 Effect of Fertilizer on Number of Leaves

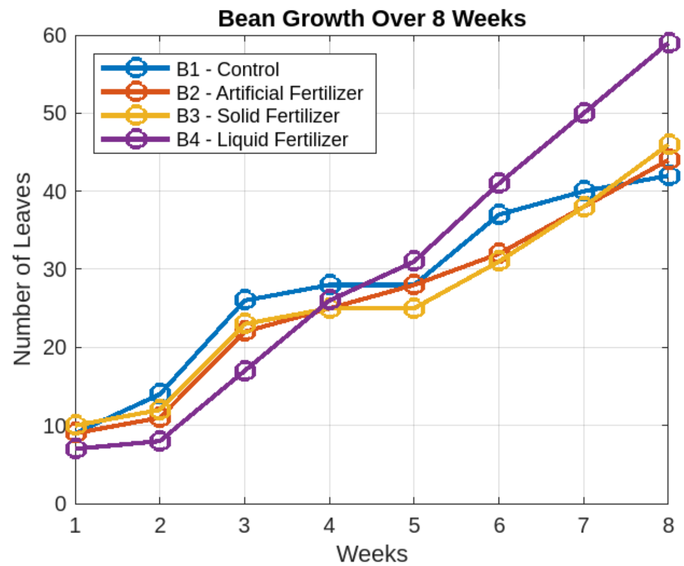

Figure 12: Average number of Leaves grown per Week

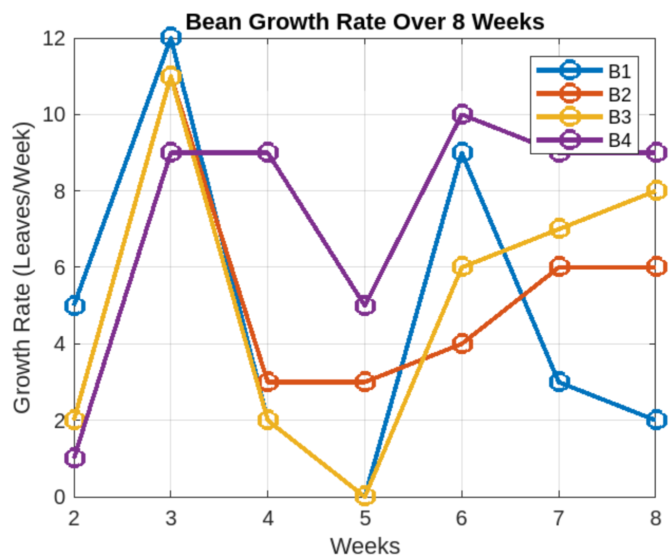

Figure 13: Growth rate of Bean crop (leaf) over the period of 2 months

Different development patterns are apparent among the treatment groups, as illustrated in Figures 12 and 13. The Artificial Fertilizer group (B2) displayed substantial early growth, followed by a gradual decline in growth rate, ultimately resulting in a total of 44 leaves. In contrast, the Control group (B1) exhibited consistent albeit slower growth, accumulating a total of 42 leaves. The Solid Fertilizer group (B3) demonstrated steady and balanced growth throughout the observation period, reaching a total of 46 leaves. On the other hand, the Liquid Fertilizer group (B4) exhibited the most pronounced and rapid development, maintaining a consistently high growth rate and concluding with the highest leaf count of 59 at the end of the two-month period. The p-value (0.9451) indicates that there is no significant difference between the treatments.

The control group's relatively strong performance, reaching a leaf count of 42, prompts careful consideration. Plausible explanations are the presence of residual nutrients in the soil and also the fact that digestates get absorbed gradually into the soil, so the immediate impact on plant growth may be less pronounced and less likely to be fully captured in short term studies.

3.3.2 Effect of Fertilizer on Yield

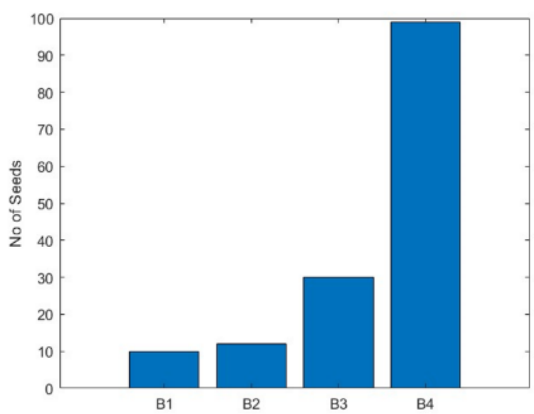

Figure 14: Total bean yield per treatment

The chart depicted in Figure 14 above distinctly illustrates disparities in seed quantities across various bean samples. Noteworthy is Bean Sample B4, subjected to Liquid Fertilizer, which displayed the highest seed count at 99, indicating a potentially favourable impact of this fertilizer on seed development. In contrast, Bean Samples B1 and B2, treated with the Control and Artificial Fertilizer, respectively, exhibited lower seed counts of 10 and 12. Bean Sample B3 yielded a positive outcome, producing 30 seeds. The increased crop yield in B4 informs on a higher percent of nitrogen compared to the other treatments [34]

3.3.3 Effect of Fertilizer on Stem width

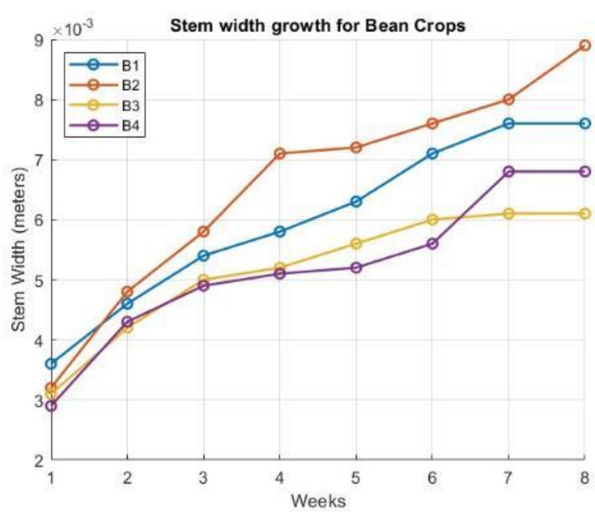

Figure 15: Graph showing Stem width over 2 months.

Figure 15 above illustrates the 8-week stem width growth of bean crops under various fertilizer treatments, providing key insights into the impact of different nutrient applications. It was clearly observed that in the early stages, all treatments exhibited uniform growth, but by week 3, distinct responses emerged. Particularly, the B2 treatment, involving artificial fertilizer, showed a significant surge in stem width, suggesting an early positive response possibly attributed to a well-balanced nitrogen (N), phosphorus (P), and potassium (K) ratio as indicated in a study carried out by Chantal et al., 2019 [35]. However, by week 5, a convergence in growth across treatments indicated a levelling effect, potentially influenced by inherent soil nutrients and initial fertilization. Throughout the 8-week period, B2 maintained a slight growth advantage, highlighting a sustained positive impact with a sustained width of 0.0089m. This aligns with Chantal et al's work carried out in 2019 indicating that the artificial fertilizer has more potassium concentration than the other treatments carried out. The p-value (0.17312) indicates that there is no significant difference between the following treatments [35].

The study found that the application of liquid digestate resulted in the highest leaf count and yield, although statistical analysis showed no significant difference compared to other treatments (p-value = 0.9451). This observation contrasts with some studies in the literature. For example, research by Smith et al. (Year) demonstrated that cassava peel-based compost significantly increased tomato yield compared to traditional fertilizers. Similarly, Jones et al. (Year) reported improved growth metrics in maize when using palm oil sludge as an amendment.

This positive effect of digestate application was also observed in some studies in literature. For example, research by reference [36] applied the solid and liquid fractions of a digestate resulting from the anaerobic digestion of olive waste and citrus pulps on the growth of cucumber which resulted in a high number of leaf production compared to the control. The quality of the cucumber was also seen to be better as there was an increase in its content of phenols and flavonoids. In another work carried out by reference [30], a digestate containing pig, chicken and cow manure was tested on spring wheat, triticale, straw and barley grain. The result was a significant increase in grain yield over the next three years, compared to the synthetic nitrogen fertilizer. These literatures support the result observed here in the high leaf count and yield.

Despite the liquid digestate's positive performance, the p-value of 0.9451 suggested no significant difference, possibly due to a small sample size, variability in conditions such as soil moisture, humidity, pH and a short study duration. The lack of controlled measurements for soil moisture, humidity and pH might have caused variability in plant responses, making it hard to assess their impact on yield and leaf count. This uncontrolled variability could explain why treatments with visual differences in growth did not show statistically significant results.

Future research should use larger sample sizes, improved environmental controls, and longer observation periods for more accurate results.

4. Conclusion

This study looked how the anaerobic digestion (AD) process affects the chemical makeup of digestate. The results showed significant changes in key nutrients like nitrogen, phosphorus, and potassium, with the digestate becoming richer in these nutrients compared to the original material. The digestate's composition, with NPK percentages of 0.702%, 6.475%, and 0.41%, suggests it's a valuable organic fertilizer that could support sustainable crop growth.

When testing the different fertilizers on bean crops, the liquid fertilizer stood out, leading to the highest yield of 99 seeds, compared to the much lower yields from the control, artificial fertilizer, and solid fertilizer treatments. This suggests that the liquid fertilizer is particularly effective in promoting plant growth. However, the study had some limitations. The short two-month duration might not capture the long-term effects of using digestate on crops and soil. The controlled environment of the experiment doesn't fully reflect real farming conditions, where factors like climate and pests could influence the results. Also, since the study focused on just one crop type and used digestate from specific organic waste materials (cassava peels and palm oil sludge), the findings might not apply to other crops or waste materials.

Finally, the lack of significant differences between treatments, despite growth variations, suggests that more research is needed to understand how digestate works as a fertilizer.

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