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Research article

Ameliorating Soil Nutrient Dynamics and Morphological Characteristics of Soybean (*Glycine max* L. Merr.) through Banana Stem Extract as Bioinput

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Abstract

The growing demand for soybeans in the food and feed sectors in the Philippines faces significant challenges due to reliance on imports, leading to persistently low domestic production, making marketing the produce a problem for farmers. Compounding this issue is the increasing accumulation of agricultural waste, particularly from the banana industry, which contributes to global warming. Addressing these challenges presents an opportunity to utilize this waste as an alternative nutrient source for sustainable agricultural practices. Our field study addresses these pressing issues by transforming banana pseudostems, a significant waste product, into effective foliar fertilizer. The study evaluated the influence of varying levels of banana stem extract (BSE) on the agronomic, yield performance, and the soil chemical properties when applied to soybean cultivation. There were five treatments (T_0 (0% BSE), T_1 (3% BSE), T_2 (6% BSE), T_3 (9% BSE), and T_4 (12% BSE)) arranged in a randomized complete block design (RCBD). The results revealed that banana stem extract significantly affected soybean's plant height during its 60^{th} and 75^{th} days after sowing, whereas number of pods and number of filled pods were influenced by the T_2 (6% BSE), T_3 (9% BSE), and T_4 (12% BSE) with a significantly comparable result. The yield (t ha^{-1}) components also revealed a significant difference among treatments, with the application of T_3 (9% BSE). Future research should focus on the phytochemical properties of BSE, evaluating its effects on not only soybean but also other crops and exploring its potential as a natural biopesticide and fertilizer. Controlled laboratory evaluations and field trials will provide essential insights into maximizing BSE's benefits and promoting sustainable agricultural practices.

Keywords: soybean; banana stem extract (BSE); soil chemical properties; foliar fertilizer; sustainable agriculture

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1. Introduction

Over the years, most soybean imports to the Philippines for use in food and feed, amounting to 99.9%, were obtained from the United States, with local production contributing only 1% to the total supply (Soyagrains Alliance, 2020). Soybean (*Glycine max L.* Merr.), an annual legume of the pea family Fabaceae, is a necessary ingredient for the food and feed sectors in the Philippines and is noted for its high protein content (Galang, 2020) and for its potential to generate renewable energy (Neupane, 2022). However, because of the country's continued status as a significant net importer of the particular commodity, it is not widely produced throughout the nation (Balanay & Laureta, 2021). Beyond its role as a food source, soybeans have the ability to "fix" nitrogen (Sun et al., 2018). This multifaceted utility has earned soybeans recognition as a "world's wonder crop" (Layson, 2013).

Other than the low production of soybeans in the Philippines, another problem is the substantial biomass waste generated by the other plants, which poses a potential environmental challenge as it contributes to elevated greenhouse gas emissions. According to Acevedo et al. (2021), global production of banana biomass is 153 million tons annually, with only 30-40% of this being edible, leaving the remaining 60% as biomass waste. This equates to approximately 114.08 million metric tons of banana waste-loss worldwide, contributing to environmental issues such as excessive greenhouse gas emissions of various gases including methane, a gas which is ten times more harmful than carbon dioxide (Acevedo et al., 2021). Finding a balance between optimizing soybean yields and mitigating the environmental consequences of agricultural practices is crucial for sustainable and responsible cultivation.

Saba *(Musa acuminata x balbisiana),* the second most cultivated banana in the Philippines, absorbs significant amount of water per land unit, primarily taking up potassium (K) and nitrogen (N) (Ohagan et al., 2023). Moreover, the banana pseudostem has been recognized as a potential source of liquid organic fertilizer (Suprihatin, 2011). The banana plant, particularly its pseudostem, contains a high proportion of fluid, typically around 80-85% (Islam et al., 2023), making it a valuable source of organic fertilizer (Cao et al., 2018). Studies have shown that banana pseudostem harbors elevate levels of various nutrients such as NO_3/ NH_4, K, P, Ca, Mg, Zn, and Fe (Suprihatin, 2011). In addition, researchers have identified several phytochemicals, including amino acids, 3-amino-2-naphthoic acid, cyclopentene-1-acetic acid, and aminobenzoic acid, within the banana pseudostem, which play crucial roles in plant growth, metabolism, and possess anti-pathogenic properties (Islam et al., 2022).

Consequently, this study examined the influence of different concentrations of banana stem extract on soil chemical properties and soybean productivity, revealing intricate interactions between organic input and crop performance. Mitigating production challenges while utilizing farm waste represents a critical step toward a sustainable agricultural future. The findings offer valuable insights into sustainable agricultural practices, explaining potential benefits and challenges of applying these organic amendments

2. Materials and Methods

The research was conducted at a highland location (8° 37’ 27” N, 124° 55’ 1” E) at 654.5 m above mean sea level. The study’s duration was selected to cover key phases of the

soybean growth cycle and observed the impact of varying levels of banana stem extracts on soil chemical properties and soybean productivity.

2.1 Materials

The materials used in the study were as follows: draft animal, native plow for harrowing and plowing, lime, soybean seeds (Manchuria variety), seed inoculant, insecticide, farm tools (bolo, digging bar, etc.), net bags, zip-locks, knapsack sprayer, improvised mortar and pestle, fine mesh cloth, strainer, funnel, narrow transparent container, galloon, bamboo sticks, twine/strings, marker, ribbon, laminated labels, tape measure, ruler, roll meter, weighing scale, pen, data record sheets, phone camera, and laptop.

2.2 Experimental design and treatment

The study used the simple randomized complete block design (RCBD) with five treatments, replicated three times. The experimental treatments and their respective ratios of banana stem extract (BSE) used in the study are outlined in Table 1.

Table 1. Experimental treatments of the study

Code	Treatments	% BSE
T_0	Control	0%
T_1	50.01 L BSE + 1,616.99 L water / ha (Fernando & Karunarathna, 2020)	3%
T_2	100.02 L BSE + 1,566.98 L water / ha	6%
T_3	150.03 L BSE + 1,516.97 L water / ha	9%
T_4	200.04 L BSE + 1,466.96 L water / ha	12%

This recommended application rate was implemented alongside a standardized planting distance to ensure uniformity across all treatment plots. Specifically, soybean seeds were sown following a spacing of 50 cm between furrows and 30 cm between hills, with one healthy plant maintained per planting hole. This spacing arrangement was chosen to optimize plant growth, facilitate ease of management, and allow for uniform application of treatments.

The banana stem extract (BSE) was applied as a foliar spray at five critical growth stages of the soybean crop—on the 14th, 28th, 42nd, 56th, and 70th days after sowing (DAS). These intervals were selected to align with key phenological stages of soybean development, ensuring that the plants could benefit from the nutrients and bioactive compounds present in the BSE throughout their growth cycle.

The experimental treatments consisted of varying concentrations of BSE, where T_0 served as the control group with 0% BSE, T_1 received 3% BSE, T_2 was applied with 6% BSE, T_3 with 9% BSE, and T_4 with the highest concentration of 12% BSE. In all treated plots, each plant consistently received 25 mL of the appropriately diluted BSE solution per application. This dosage was based on the recommendations of Fernando and Karunarathna (2020) to ensure effective delivery of nutrients without risking phytotoxicity.

The careful timing, consistent application volume, and standardized spacing were all designed to provide reliable and comparable results across treatments while maintaining agronomic relevance.

To maintain consistency and minimize variability, all foliar applications were conducted manually using calibrated knapsack sprayers under uniform environmental conditions. This ensured that each plant within the treatment groups received an equal and accurate amount of the diluted BSE, thereby enhancing the reliability of the results.

2.3 Soil sampling methodology

To ensure consistency and accuracy in evaluating soil chemical properties, a rigorous soil sampling protocol was followed throughout the study. Initial soil sampling was conducted by collecting multiple subsamples from different random points within the 275 m² experimental plot at a uniform depth of 0-15 cm using a soil auger. These subsamples were thoroughly mixed to create a representative composite sample, which was submitted for baseline analysis prior to planting.

Similarly, at harvest, composite soil samples for each treatment plot were collected using the same methodology to minimize sampling variability. Each sample was air-dried, sieved to remove debris, and analyzed under standardized laboratory conditions at the Department of Agriculture Region X Soil Laboratory. The careful adherence to uniform sampling depth, composite sample preparation, and proper storage helped ensure that the observed changes in soil organic matter (OM) and other chemical parameters were reliably captured.

It is also important to note that the experimental site, characterized by sandy loam soil under tropical highland conditions, was prone to faster organic matter mineralization due to high microbial activity and environmental factors such as rainfall and temperature fluctuations. The observed decline in soil OM over the 75-day period aligned with this dynamic, as well as the nutrient demands of the soybean crop, which is known for its intensive nitrogen uptake and soil nutrient use efficiency.

2.4 Banana stem extract production

In extracting banana pseudostem sap, it began with selecting a healthy, mature, and unproductive saba banana plant. To expose the fresh pseudostem, the dry outer sheath was removed and then cut into thin slices for easier extraction. The slices were smashed using an improvised mortar and pestle, and the resulting material was squeezed with a fine mesh cloth to separate the sap from the pulp. The sap was then strained through a fine cloth, placed in a long container, and left to settle overnight. The extract was carefully transferred into a safe container using a funnel and strainer, ready for dilution and application (Fernando & Karunarathna, 2020).

The study implemented a comprehensive set of cultural management practices for soybean cultivation, beginning with intensive land preparation involving repeated plowing and harrowing to ensure optimal soil condition. Field layout was carefully measured and marked based on treatment designs, and seed inoculation was performed using commercial inoculant under shaded conditions to promote nitrogen fixation. Soybean seeds were planted following a strategic spacing (50 cm between furrow; 30 cm between hill), with thinning carried out a week after the emergence to maintain one healthy plant per hill. Fertilization was achieved through scheduled foliar application of banana stem extract, while irrigation relied mainly on rain fall, supplemented by manual watering as needed.

Regular monitoring for pest and diseases was conducted, with pesticide and manual weeding applied for control. Harvesting was timed at physiological maturity, followed by manual threshing and solar drying to preserve seed quality and collect reliable postharvest data.

For data analysis, the study employed statistical tools to evaluate the effects of treatments on soybean productivity. Specifically, analysis of variance (ANOVA) was used to determine whether significant differences existed among the treatment means. In cases where significant differences were detected, Tukey's honest significant difference (HSD) test at a 5% significance level was conducted to identify which specific treatments differed from each other. These statistical methods provided a robust framework for validating the experimental results and drawing meaningful conclusions from the observed outcomes.

3. Results and Discussion

3.1 Soil chemical properties

3.1.1 Initial soil analysis

Table 2 presents the result of the initial soil analysis. A single composite soil was sent to the Department of Agriculture Region X Soil's laboratory to represent the entire experimental area.

Based on the initial analysis, it was stipulated that the amount of organic matter present in the 275 m^2 experimental area was 7.0% before the experimental commodity was planted, which was much higher than the expected level of a typical land of 3-6% (Magdoff & Van Es, 2021). According to Fenton et al. (2008), high organic matter offers benefits in terms of soil physical, chemical, and biological components that contribute to the yield of the field (Magdoff & Van Es, 2021). The amount of available phosphorus as measured by the Olsen method was 137 ppm, and the exchangeable potassium of 358 ppm, as measured by the Ammonium Acetate @pH 7.0 Method-AA 6300, indicating a high level of both macronutrients present in the field.

High soil pH can coexist with high organic matter levels due to complex interactions between soil chemistry and microbial processes (Anderson et al., 2018). Soil pH is a key factor in priming effects on soil organic matter decomposition, with the highest priming effects occurring at pH between 5.5 and 7.5 (Wang & Kuzyakov, 2024). Based on the analysis, a 7% organic matter content, which was considered high likely contributed to improved soil structure, fertility, and water retention. Gartley et al. (2024) noted that soils with high organic matter often have a lower target pH, as organic matter can moderate soil acidity. Wherein, 5.6 soil pH result indicates a moderately acidic soil (Zhou et al., 2019).

The results of the baseline soil analysis (Table 2) indicate that no additional phosphorus or potassium fertilization was required at the start of the experiment, which were sufficient for soybean growth (Tang et al., 2024). The Department of Agriculture Regional Soil Laboratory suggested balancing the acidity with 1.2 tons of lime per hectare for the reason that soybean performs well in soil with 6.0-7.0 soil pH (Anderson, 2018). This baseline soil condition provided the reference point for assessing how different concentrations of banana stem extract influenced soil chemical properties throughout the study.

Table 2. Result of the initial soil analysis

Parameters	Result	Description	Reference
Organic Matter, %	7.0	High	Department of Agriculture, 2003
Total Nitrogen, %	0.35	Adequate	Wibowo & Kasno, 2021
Available Phosphorus, ppm	137	High Adequate	Sotomayor-Ramírez et al., 2004
Exchangeable Potassium, ppm	358	High	Rezk & Amer, 1969
pH	5.60	Moderately acidic	USDA Natural Resources Conservation Service, 2022

3.1.2 Soil analysis at harvest

Five composite soil samples were sent to the Department of Agriculture Region X Soil's laboratory to represent the respective five treatments used in the study.

The result from this analysis (Table 3) showed changes in the soil chemical properties of the experimental area after harvest, with a noticeable difference among treatments as influenced by the varying levels of banana stem extract. These changes were expected because both the application of agricultural lime and the nutrient uptake of the soybean crop during growth and harvest naturally alter soil chemical status, particularly in terms of available phosphorus, exchangeable potassium, organic matter, total nitrogen, and soil pH (Fageria et al., 2014).

Among the five treatments, from the initial result (Table 2) to the final analysis of organic matter (Table 3), T_0 (0% BSE) dropped the lowest, decreasing from 7.0% to 4.0%. This was followed by T_1 (3% BSE), which decreased to 4.1% OM and T_4 (12% BSE), which decreased to 4.4% organic matter. At the same time, T_3 (9% BSE) dropped from 7.0% to 4.6% OM, and T_4 (12% BSE), with the least reduction (4.8% OM from the initial result of 7.0% organic matter). In terms of total nitrogen, T_0 (0% BSE) also recorded the lowest percentage (reducing from 0.35 to 0.20%). This was followed by T_1 (3% BSE) with 0.21% and T_4 (12% BSE) with 0.22%. Meanwhile, T_3 (9% BSE) showed a slightly higher nitrogen level at 0.23%, and T_2 (6% BSE) showed the highest total nitrogen at 0.24%.

Table 3. Soil chemical properties at harvest

	Soil Analysis at Harvest				
Treatments	Organic matter (%)	Total Nitrogen (%)	Available Phosphorus (ppm)	Exchangeable Potassium (ppm)	pH
T_0 (0% BSE)	4.0	0.20	148	362	6.19
T_1 (3% BSE)	4.1	0.21	196	448	6.02
T_2 (6% BSE)	4.8	0.24	198	374	6.23
T_3 (9% BSE)	4.6	0.23	158	484	6.18
T_4 (12% BSE)	4.4	0.22	139	492	5.86

Leguminous crops possess the unique ability to fix atmospheric nitrogen through a process known as symbiotic nitrogen fixation (Goyal et al., 2021), allowing them to largely meet their nitrogen requirements without the great reliance for a huge amount of synthetic fertilizer (Castañeda et al., 2018). Due to their high nitrogen demand and nutrient-absorbing capabilities, these crops also utilize a significant portion of the existing nitrogen in the soil. This intensive uptake can contribute to the gradual decline of soil organic matter, as organic matter is a key reservoir of nitrogen (Fenton et al., 2008). Given the strong positive correlation between soil organic matter and total nitrogen (Wibowo & Kasno, 2021), the depletion of organic matter directly affects the overall nitrogen availability in the field.

For the available phosphorus (P), the initial result in the entire area was 137 ppm (Table2). After harvest, T_2 (6% BSE) recorded the highest P level (198 ppm), followed by T_1 (196 ppm), T_3 (158 ppm), T_0 (148 ppm), and T_4 (138 ppm). Moreover, exchangeable potassium (K) increased across all treatments relative to the baseline of 358 ppm. The greatest increase occurred in T_4 (12% BSE) with 492 ppm, followed by T_3 (484 ppm), T_1 (448 ppm), and T_2 (374 ppm), while the control (T_0) increased slightly to 362 ppm. This trend is consistent with previous reports showing that banana pseudostem contains considerable amounts of mineral nutrients, particularly potassium as well as P, Ca, Mg, and trace elements (Mohapatra et al., 2010; Cao et al., 2018). Therefore, the observed increases in exchangeable K among the BSE-treated plots provide an indication that the applied banana stem extract contributed to the variation in soil nutrient levels among treatments.

The comparison of the initial and final soil analyses showed an overall increase in soil pH across the treatments. Most of the plots shifted from the baseline pH of 5.60, which is considered moderately acidic, to slightly higher values after harvest. Specifically, T_2 (6% BSE) increased to 6.23, which can be interpreted as slightly acidic, followed by T_0 (0% BSE) with 6.19, T_3 (9% BSE) with 6.18, and T_1 (3% BSE) with 6.02. Meanwhile, T_4 (12% BSE) increased from 5.60 to 5.86, which remains in the moderately acidic range (Zhou et al., 2019).

The highest increase in soil pH in T_2 (6% BSE) could be due to a balanced interaction between the banana stem extract (BSE) and the soil's pH buffering system. At this concentration, BSE likely provided an optimal level of organic acids and nutrients that stimulated microbial activity without overwhelming the soil (Lubis & Pakpahan, 2026). This promoted better soil structure and enhanced the lime's effect in raising pH and nutrient availability. Thus, the higher concentrations of BSE in T_3 (9%) and T_4 (12%) may have introduced excess acids (Li et al., 2024a,b), which could have counteracted the pH-raising effect of the lime. Therefore, the 6% BSE concentration struck the ideal balance for boosting soil pH. Although numerical differences in soil pH were observed among treatments, these variations were not statistically significant and therefore did not translate into meaningful differences in agronomic interpretation within the scope of this study.

3.2 Agronomic parameters

3.2.1 Plant height (cm)

The application of varying concentrations of banana stem extract did not produce a statistically significant effect on the plant height of soybean at 15, 30, 45, 60, and 75 days after sowing (DAS). As presented in Table 4, all treatment groups exhibited comparable mean heights across the observation periods, suggesting that the banana stem extract,

irrespective of concentration, had no discernible impact on vertical vegetative growth. This lack of response implies that the bioactive compounds present in the extract may not directly influence cell elongation or division associated with stem growth under the given experimental conditions. It is also possible that environmental factors or the physiological growth stage of the soybean limited the responsiveness to exogenous biostimulants during the observation period. Further studies exploring longer-term effects, different application methods, or interactions with other growth parameters may provide more insight into the role of banana stem extract in soybean development.

At 15th DAS, the highest plant height was obtained by the T_4 (12% BSE), having 15.16 cm, with T_0 (0% BSE) having slight difference at 15.08 cm. On the other hand, $T_{2\,a}$ (6% BSE) had the shortest plant height, while T_1 (3% BSE) had 14.72 cm and T_3 (9% BSE) had 14.83 cm plant height, and no significant differences were observed based on the result. At 30 DAS, the highest plant height treatment was observed in T_3 (9% BSE), having 30.84 cm, with T_0 (0% BSE) having slight difference, with 30.45 cm, followed by T_1 with 29.41 cm and T_4 (12% BSE) having the shortest plant height. T_2 (6% BSE) followed with 29.76 cm, and was followed by T_1 (3% BSE) with 29.41 cm, making T_4 (12% BSE) the shortest among the other treatments with 29.34 cm in plant height.

Table 4. Plant height (cm) of soybean with varying levels of banana stem extract

Treatments	Plant Height (cm)				
	15 DAS	30 DAS	45 DAS	60 DAS	75 DAS
T_0%BSE(control)	15.08	30.45	64.31	85.57^{b}	87.09^{c}
T_{1-}3% BSE	14.72	29.41	65.14	89.33^{ab}	94.30^{b}
T_{2-}6% BSE	14.69	29.76	67.64	95.68^{ab}	98.04^{ab}
T_{3-}9% BSE	14.83	30.84	69.90	98.33^{a}	102.91^{a}
T_{4-}12% BSE	15.16	29.34	68.07	100.23^{a}	103.91^{a}
F-test	ns	ns	ns	*	*
CV (%)	4.1	4.94	5.06	4.53	2.5

BSE – Banana Stem Extract; DAS=Days after sowing
ns not significant ($p \geq 0.05$)
* Significant at a level of 5% of probability ($p \leq 0.05$)

The initial absorption of nutrients from a foliar-applied organic fertilizer, such as banana stem extract, begins within minutes after application (Fernando & Karunarathna, 2020). However, the visible physiological responses in plants—such as enhanced greening, increased growth rate, and improved overall performance—typically emerge over a longer period, generally within or more than 1 to 4 weeks from the time of application (Iqbal et al., 2019). This explains why, during the early stages of observation (15-45 DAS), the plant heights among treatments did not differ significantly. The nutrients absorbed were still being metabolized and utilized by the plant as part of a gradual internal process that supported long-term development. Therefore, the lack of significant differences and the day-to-day variation in plant height can be attributed to the ongoing physiological adjustments and the establishment of a stronger growth foundation triggered by the applied banana stem extract. Changes in soybean plant height between treatments occurred until the end of the vegetative phase.

The plant height of soybeans at 60 to 75 DAS showed significant differences among all treatments. At 60 DAS, the application of T_4 (12% BSE) achieved the highest plant heights, measuring 100.23 cm, which was comparable to T_3 (9% BSE) with a plant height of 98.33 cm. These treatments were significantly higher than T_0 (0% BSE), which recorded the lowest mean plant height of 85.57 cm. In contrast, T_1 (3% BSE) and T_2 (6% BSE) had plant heights of 89.33 cm and 95.68 cm. At 75 DAS, the analysis showed a highly significant result, further confirming that BSE application considerably affected plant height. T_4 (12% BSE) showed the tallest plant height of 103.19 cm, which was comparable to T_3 (9% BSE) with a plant height of 102.91 cm. However, the application of T_2 (6% BSE) measured 98.04 cm, and T_1 having 94.13 cm; these were all significantly higher than T_0 (control), which was the shortest at 87.09 cm.

The findings suggest that higher levels of BSE application positively affected the plant height of soybean, with 9% and 12% BSE resulting in the tallest plant height. A study by Abro et al. (2023) reported similar findings, showing that fresh banana pseudostem sap significantly improved growth parameters of onion seedlings, including an increase in plant height relative to the untreated control. Another study by Islam et al. (2022) showed that fresh banana stem extract not only contained micro and macronutrients but also had beneficial plant compounds such as 1-amino-1-carboxycyclopropane, 4-aminobenzoic acid, glutamic acid, 1,4-benzoquinone, proline betaine, butanoic acid, hydroxycitric acid, 2,4-dihydroxybenzoic acid and aluminum acetate, which positively influenced the growth of the crop used in the study. A similar study confirmed that many beneficial metabolites and mineral nutrients in aqueous banana pseudostem sap, particularly in lower concentrations (5%-15%), significantly influenced seedling growth over control. The plant height of tall soybean varieties generally ranges from approximately 91 to 152 cm at maturity (Stowe & Vann, 2022). In the present study, the recorded plant heights fall within this typical range, indicating that the growth responses observed under the different banana stem extract concentrations were consistent with normal soybean development.

3.2.2 Number of pods

The result revealed that there was a significant difference among the treatments due to the varying levels of banana stem extract applied through foliar spraying on soybean production. T_4 (12% BSE), having the highest concentration of BSE, produced the greatest number of pods among the treatments. It had 972 pods from 10 sample plants and was comparable to T_1 (3% BSE), T_2 (6% BSE) and T_3 (9% BSE), which had 915, 959, and 965 pods, as listed. Meanwhile, T_0 (0% BSE) obtained the lowest number of pods with 564 pods, clearly showing a difference between treatments applied with BSE at varying levels (Figure 1).

An article from Ohio State University Extension (2022) suggested that the more pods a soybean plant can have, the more it correlates with the increase in yield, as it indicates more growing seeds. While soybean is a nitrogen fixer plant (Sun et al., 2018) and that the soil had a very high amount of organic matter based on the soil analysis result stipulated in Table 1, which was 7.0% OM, were likely responsible for the soybean to generate many pods since nitrogen were already present in the soil at the reproductive stage of the soybean growth cycle (Li et al., 2024a,b). In addition, the high level of potassium in the BSE, likely supported the significant effect on the soybean pod number (Khanam et al., 2016). Potassium helps nutrient transfer from the soil to the plant (Ernest, 2014) and supports yield enhancement during the reproductive stage (Kvail, 2020).

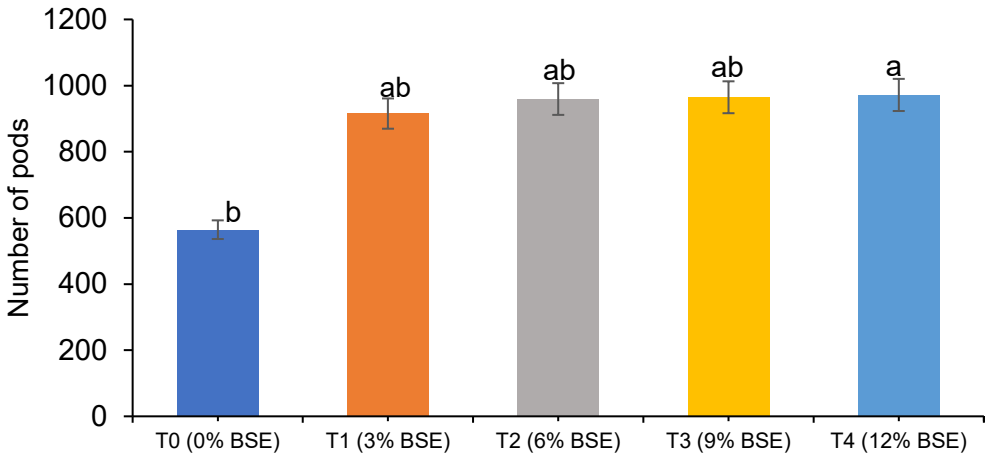


Figure 1. Number of pods of soybean with varying levels of banana stem extract

3.2.3 Number of filled pods

Figure 2 shows the number of filled pods applied with varying levels of banana stem extract. The results revealed a significant effect across treatments. It was observed that T_4 (12% BSE) had the highest number of filled pods with a value of 936 and it was comparable to T_3 (9% BSE) and T_2 (6% BSE) with values of 958 and 955, respectively, and T_1 (3% BSE) having 910 number of filled pods. On the other hand, T_0 (0% BSE) produced the least number of filled pods with 559, which was significant different among all treatments applied with banana stem extract.

A study by Shahkoomahally and Shahkoomahally (2017) showed that there was a direct relationship between the number of filled pods and the yield of a soybean crop. In comparison, macronutrients such as nitrogen, phosphorus, and potassium play a significant role in producing a pod with an economic value (Timotiwu et al., 2020). The experimental commodity in the present study received these nutrients by relying on the BSE treatment and the present nutrient in the soil. In addition, a study by Fernando and Karunarathna (2020) on cowpea showed a significant effect on the same parameter which was the number of filled pods.

3.2.4 Weight per pod (g)

Table 6 presented the weight per pod of soybean applied with different levels of banana stem extract. It was observed that T_2 (6% BSE) exhibited the heaviest dried pod weight at 0.101 g, closely followed by T_0 (0% BSE) with 0.100 g. The other treatments, T_1 (3% BSE), T_3 (9% BSE), and T_4 (12% BSE), recorded comparable values of 0.096 g, 0.098 g, and 0.098 g, respectively. Statistical analysis revealed no significant differences among treatments, indicating that banana stem extract (BSE) application had minimal influence on the weight of empty soybean pods.

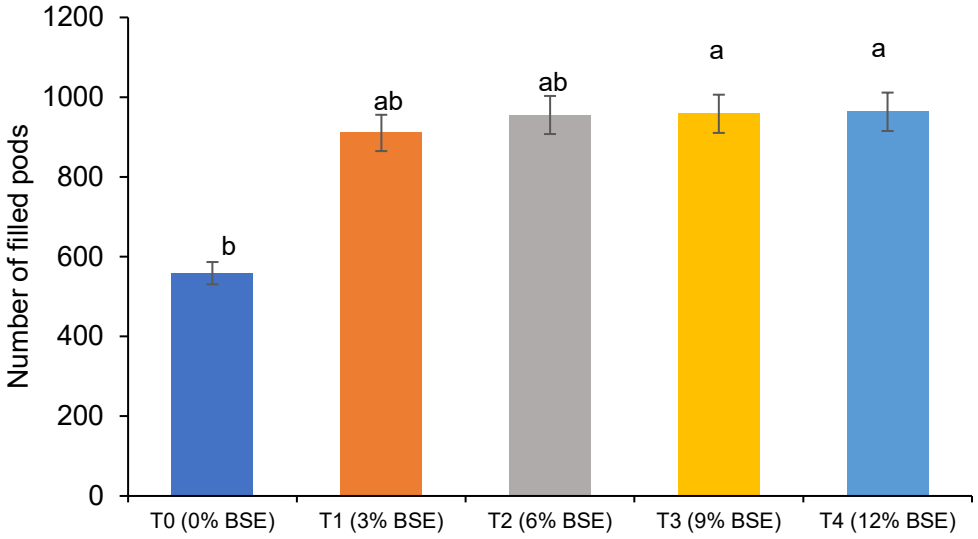


Figure 2. Number of filled pods of soybean applied with varying levels of banana stem extract

Table 6. Weight per pod (g), pod length (cm) and number of seeds per pod of soybean applied with varying levels of banana stem extract

Treatments	Weight Per Pod	Pod Length	Number of Seeds per Pod
T_0 – 0% BSE (control)	0.100	3.98	2.47
T_1 – 3% BSE	0.096	4.04	2.53
T_2 – 6% BSE	0.101	4.05	2.57
T_3 – 9% BSE	0.098	3.99	2.43
T_4 – 12% BSE	0.098	4.02	2.47
F-test	ns	ns	ns
CV (%)	7.87	1.79	2.54

BSE – Banana Stem Extract
ns not significant ($p \geq 0.05$)

Pod weight, particularly after seed removal, is often linked to structural composition rather than direct yield components. Research by Poudel et al. (2024) highlighted that pod dry matter primarily consists of structural carbohydrates, which may not strongly correlate with final seed yield. Furthermore, studies suggest that environmental conditions and genetic traits play a more critical role in determining pod weight than nutrient absorption alone (Killi & BeyciOğlu, 2022). This indicates that while bioinputs like banana stem extract (BSE) may enhance overall plant vigor and reproductive success, their influence on the weight of the pod walls themselves is limited. The partitioning of assimilates during the pod development phase tends to prioritize seed filling over pod structure, which may explain the minimal differences observed across treatments. Additionally, pod wall thickness and composition are often species- or variety-specific traits that are less responsive to external

nutrient application. As a result, pod weight may not serve as a sensitive indicator for evaluating the effectiveness of foliar biofertilizers such as BSE in soybean production.

While potassium—one of the key nutrients in BSE—is known to enhance seed filling and overall yield (Khanam et al., 2016), its direct effect on pod wall weight remains less pronounced. This aligns with the findings of Ortel et al. (2024), who stated that potassium significantly impacts nutrient transfer but does not directly influence pod husk weight. Given these insights, the lack of statistical significance in the present study suggests that while BSE application may contribute to other growth parameters, it does not substantially alter the weight of the dried, empty soybean pods.

3.2.5 Yield (t ha^{-1})

The application of banana stem extract (BSE) significantly influenced the yield per hectare of soybean, as presented in Table 7. Among the treatments, T3 (9% BSE) recorded the highest seed yield at 1.87 t ha^{-1}, which was statistically comparable to T4 (12% BSE) with 1.85 t ha^{-1} and T2 (6% BSE) with 1.82 t ha^{-1}. T1 (3% BSE) also showed an improved yield of 1.71 t ha^{-1} compared to the control. In contrast, the untreated control (T0, 0% BSE) produced the lowest yield at 0.90 t ha^{-1}, which was significantly lower than all BSE-treated plots. These findings suggest that the banana stem extract, particularly at concentrations between 6% and 12%, has a promotive effect on soybean productivity. The improved yield could be attributed to the potential biostimulant properties of BSE, which may enhance nutrient uptake, physiological processes, or stress tolerance, thereby contributing to better reproductive performance. Further investigation into the bioactive compounds present in BSE and their specific modes of action could elucidate the mechanisms driving this yield response.

Table 7. Yield (t ha^{-1}) of soybean applied with varying levels of banana stem extract

Treatments	Yield (t ha^{-1})
T_0 – 0% BSE (control)	0.90^{b}
T_1 – 3% BSE	1.71^{ab}
T_2 – 6% BSE	1.82^{a}
T_3 – 9% BSE	1.87^{a}
T_4 – 12% BSE	1.85^{a}
F-test	*
CV (%)	18.48

BSE – Banana Stem Extract
* Significant at a level of 5% of probability ($p \leq 0.05$)

Crop yield is an important metric in agriculture, representing the amount of a particular commodity produced. This is essential to secure food supply (Ritchie et al., 2022), resource efficiency (Mundhe et al., 2023), agricultural productivity, and, importantly, economic viability (Lobell et al., 2009). The yield of a commodity, particularly soybean, is also affected by different factors such as environmental factors (Xu et al., 2020), biological factors (Vogel et al., 2021), and management-related factors (Rinaldi et al., 2023).

The application of banana stem extract also contributes to significant differences in this specific parameter. It was already mentioned in the previous discussion that the same treatment applied to different commodities such as corn (Islam et al., 2023), onion (Abro et al., 2023), and cowpea (Fernando & Karunarathna, 2020) showed a significant effect on the crop growth performance and productivity. Based on the chemical analysis

of the non-enriched banana pseudostem sap in the study by Islam et al. (2023), various nutrients such as P, K, Ca, Mg, Na, Fe, Zn, Cu, Al, and B were determined. Similar findings were found in the banana pseudostem sap analysis performed by Abro et al. (2023). While the study of Fernando and Karunarathna (2020) mentioned that pseudostem sap contained essential macronutrient growth promoting substances like cytokinin and GA_3 (gibberellic acid), and it can be used as an organic nutrient source to increase crop growth and yield.

Several studies have demonstrated that banana pseudostem sap contains beneficial metabolites and essential macro- and micronutrients that can enhance plant growth. In particular, lower concentrations of aqueous pseudostem sap (approximately 5%-15%) have been shown to significantly promote seedling development compared with untreated controls (Islam et al., 2023; Fernando & Karunarathna, 2020). Consistent with these findings, the present study observed that BSE applications—especially in T_2, T_3, and T_4—contributed to improved soybean seed yield.

4. Conclusions

This study explored the use of banana waste, specifically banana stem extract (BSE), as a foliar fertilizer to improve soybean productivity and enhance soil chemical properties within a 275 m^2 field. Utilizing a randomized complete block design (RCBD) and analysis with ANOVA and Turkey's HSD test, the results showed that BSE significantly influenced soybean parameters. The final analysis indicated positive changes in soil characteristics, including organic matter, available phosphorus, exchangeable potassium, and soil pH, highlighting the effectiveness of BSE in correcting nutrient deficiencies in acid soils. While marked improvements were observed in plant height at 60 and 75 days after sowing, along with increases in the number of pods and total seeds, particularly at the concentrations of 6%, 9%, and 12% BSE. The same treatment also resulted in enhanced seed yield, positioning it as a valuable agronomic practice for soybean cultivation. It is suggested that T_2 (6% BSE) showed optimized agronomic performance, while T_4 (12% BSE) led to the highest plant height and pod count. T_3 (9% BSE) yielded the best results for overall seed production per hectare. Future research should investigate BSE's phytochemical properties and the impact of various extraction methods in its effectiveness and potential phytotoxicity. Exploring its role as natural biopesticide and evaluating its antimicrobial properties could advance sustainable agricultural practices. In addition, conducting field trials will provide insights into BSE's applicability across different agricultural settings and promote the use of agricultural waste, thus positioning banana stem extract as a sustainable innovation in farming.

While the present study demonstrated the positive effects of banana stem extract (BSE) on soybean productivity and soil chemical properties, it is important to note that a detailed chemical characterization of the BSE—such as its pH, electrical conductivity (EC), macronutrient, and micronutrient content—was not conducted due to resource limitations. Future research should prioritize the comprehensive analysis of these parameters to better understand the specific mechanisms driving the observed agronomic benefits and to optimize the formulation and application of BSE in sustainable agriculture.

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6. Authors' Contributions

Josefina Shajee Gaguan performed research and wrote the paper; Cyril John C. Nagal coordinated research.

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7. Conflicts of Interest

The authors affirm that there were no conflicts of interest, whether related to the research, writing, or publication of this study.

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