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Chemical Characteristics of Ultisols and Purple Eggplant Yields due to the Application of Composted Paper Sludge and NPK Fertilizer

Rika Yayu Agustini[1]*, Liska Mutiara Septiana[2], Aliya Azkia Zahra[3]

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ABSTRACT

Paper sludge is waste that has the potential to be used as a soil ameliorant to improve soils with low fertility levels, such as Ultisols. This study aimed to evaluate the impact of applying composted paper sludge and NPK fertilizer on selected chemical properties of Ultisols, including pH, total nitrogen, total phosphorus, and total potassium, as well as on the yield of purple eggplant. The study used seven treatments consisting of sludge doses of 10, 20, and 30 tons/ha in combination with NPK fertilizer doses of 150 and 300 kg/ha. The results showed that the application of composted paper sludge and NPK fertilizer improved the chemical properties of Ultisols, with total-N (0.47%), total-P (0.16%), and total-K (0.03%) increasing, as well as producing the best results in terms of number of fruits (6), fruit length (31.00 cm), and fruit weight (268.20 g). The best combination for improving soil chemical properties was obtained from the treatment of 30 tons/ha of composted paper sludge with 300 kg/ha of NPK fertilizer, while the best combination for increasing purple eggplant yields was obtained from the treatment of 30 tons/ha of composted paper sludge with 150 kg/ha of NPK fertilizer. The application of composted paper sludge as a soil ameliorant promoted fertility in Ultisols. In addition, the more composted paper sludge applied, the more positive the effect on soil fertility and purple eggplant yield was.

Keywords: fertilizer, paper sludge, purple eggplant, ultisols, waste

INTRODUCTION

The pulp and paper sector significantly contributes to Indonesia's economy. Over the past decade, the industry has experienced strong growth in the global market. Indonesia's pulp industry ranked eighth in the world in 2020, with a production capacity of approximately 11.83 million tons per year. Meanwhile, the paper industry has a production capacity of approximately 17.94 tons per year, ranking sixth worldwide. During the manufacturing process, paper mills generate sludge waste that may pose environmental risks if not properly managed. According to the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number P.18/MENLHK/SETJEN/KUM.1/8/2020, 2020 on the Utilization of Hazardous and Toxic Waste, sludge generated from the pulp and paper industry may be utilized as an alternative raw material for organic soil ameliorants, provided that it satisfies the minimum technical standards, including passing the Toxicity Characteristic Leaching Procedure (TCLP) test.

Paper sludge has the potential to be used as a soil ameliorant. confirmed that the heavy metal Pb content in the roots, leaves, and planting media treated with paper sludge was at a level that is safe for humans and had a low translocation factor (TF<1). In addition, referring to the results of research by, paper sludge waste has an organic-C of approximately 17.70% with a pH of 7.34 and a total-N of 1.08%, P_2O_5 1.31 mg/kg, and K_2O of 0.37 mg/100 g. Furthermore, Kusumarini *et al.* (2022), reported that sludge contains both macronutrients, such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), and micronutrients, including copper (Cu), manganese (Mn), zinc (Zn), and iron (Fe). These nutrients can be utilized by plants after the sludge undergoes fermentation and is combined with other materials to produce the compost. The findings further suggest that paper sludge waste has potential as a soil amendment and could serve as an alternative approach to enhance the quality of marginal soils in Indonesia, particularly in Ultisols.

Ultisols are soils with acidic pH levels, low organic carbon content, and low nutrient levels, occupying approximately 25% of Indonesia's land area (Napoleon *et al.* 2025). This area has the potential to be utilized as part of a program to expand agricultural land to increase agricultural production. Endriani *et al.* (2025), state that nutrient deficiencies in Ultisols can be

[1] Agrotechnology Study Program, Faculty of Agriculture, University of Singaperbangsa Karawang, Karawang 41361, Indonesia
[2] Soil Science Program, Faculty of Agriculture, Lampung University, Lampung 35141, Indonesia
[3] Pharmacy Study Program, Faculty of Health Sciences, University of Singaperbangsa Karawang, Karawang 41361, Indonesia
* Corresponding Author:
Email: rika.agustini@faperta.unsika.ac.id

overcome by adding organic matter that can improve aeration, facilitate root penetration, increase soil pH and nutrients, and improve soil structure, thereby increasing the cation exchange capacity of the soil.

In addition to the land expansion program, the Indonesian government, through the Director General of Agricultural Infrastructure and Facilities Decision No. 17.3/KPTS/SR.030/B/01/2022, 2022 the Ministry of Agriculture implements agricultural land development through agricultural cultivation activities with food crops, plantations, and horticulture, based on the potential and existing conditions of agricultural land. This is done through the development of intensification and extensification of land on a large scale (food estate). This can be applied to eggplant crops. Efforts to increase eggplant production, in addition to improving Ultisol using composted paper sludge, can also include the addition of NPK fertilizer as a source of plant growth nutrients. The use of composted paper sludge combined with NPK fertilizer can be used to obtain the best dosage combination for purple eggplant production. Given the above discussion, this study aimed to examine how paper sludge waste influences soil characteristics (pH, organic-C, total-N, total-P, and total-K) and the productivity of purple eggplant in Ultisols.

METHODS

Sludge Preparation

Before being applied to the soil, paper sludge was first treated by composting. Before composting, the paper sludge was dried to a moisture content of approximately 20%. The sludge was then chopped using a chopper and sieved using a 5 mm sieve. After sieving, the paper sludge was stirred with cow manure and dolomite in a ratio of 5.5:3.5:1 (by weight), and water was added until the moisture content reaches approximately 40-50%. Subsequently, the paper sludge was left for 30 days and stirred every 7 days. If the mixture is dry during stirring, water is added back to the sludge. The paper sludge that is ready for use is blackish in color, odorless, and has a moisture content of approximately 60-70% (Figure 1).

Figure 1 Paper sludge waste.

Experimental Design

The experiment was conducted using a pot-based approach in Mulyamekar Village, Babakancikao District, Purwakarta Regency, West Java, from March to May 2025. A single-factor randomized block design was applied, comprising seven treatments with four replicates, resulting in a total of 28 experimental units. When the analysis of variance indicated a significant effect, the Duncan Multiple Range Test (DMRT) was conducted to identify the treatment that yielded the best results. The treatment combinations used in this study are listed in Table 1.

Treatment and planting

The growing medium used was Ultisol soil material from Karawang Regency. Soil was collected from a depth of 30 cm, then air dried. The soil was refined and sieved using a 20 mesh sieve. After sieving, the soil was homogenized and placed in pots measuring 60 × 60 cm.

After the growing medium was prepared, the soil was incubated with composted paper sludge waste for 14 days. After the incubation period, 30-day-old purple eggplant seedlings were planted. The next treatment was the application of NPK fertilizer, which was applied three times at 14, 24, and 34 days after planting according to the treatment dosage (Table 1 Treatment Combinations of Composted Paper Sludge and NPK Fertilizer).

Observation Variables

The observed variables related to soil chemical properties included pH H_2O (1:5), total nitrogen (determined using the Kjeldahl method), total phosphorus (analyzed through HNO_3 + $HClO_4$ extraction and measured with a spectrometer), and total potassium (extracted using HNO_3 + $HClO_4$ and measured by Atomic Absorption Spectrophotometry/AAS) (Soil and Fertilizer Instrument Standard Testing Center 2023). The parameters used to assess the purple eggplant yield included the number of fruits, fruit length, and fruit weight. Yield measurements were taken 49 days after planting, corresponding to the harvest stage of the crop.

RESULTS AND DISCUSSION

Soil Characteristics

The initial soil fertility analysis (Table 2 Soil Characteristics) showed that Karawang Ultisols have an active acidity (pH H_2O) that is classified as acidic, namely 5.82, with a low soil organic-C (1.27%). Organic-C is an indicator of soil fertility, and this organic carbon can be used by microorganisms to carry out activities in the soil.

Table 2 also shows that the N-Total content is in the low category (0.13%). From the organic-C and total-N results, a C/N ratio of 9.63 was obtained, which is in the low category. In addition, the initial soil measurement results also showed that the total-P content was in the medium category (63.91 mg/100 g) and total-K was in the medium category (33.52 mg/100 g) with a CEC value of 19.70 cmol (+)/kg, which is in the low category. stated that the low nutrient content in Ultisols soil was due to the loss of bases as a result of intensive leaching, while the low organic matter content was due to rapid decomposition and erosion. Additionally, acidic pH causes low nutrient availability for plants and has the potential to increase the availability of toxic elements, resulting in nutrient deficiency in plants.

Sludge Paper Waste Characteristics

This study shows that the chemical content analysis of paper sludge waste indicates that the pH level of the sludge is 8.1, which, based on the national standard for organic fertilizer quality set by the Ministry of Agriculture's National Standard for Solid Organic Fertilizer Quality No. 261/KPTS/SR.310/M/4/2019 meets the criteria. Furthermore, the results of the organic C analysis of the sludge showed a value of 21.69%, which meets the criteria with a minimum organic C limit of 15%.

Table 3 shows that paper sludge waste contains 1.01% total N and 1.21% total P, which falls under the criteria of insufficient, as sludge used as a soil conditioner is required to contain a minimum of 2% total N and P. Furthermore, the analysis results for total K in paper sludge fell within the criteria of sufficiency, with a value of 3.22%. These results indicate the potential of utilizing paper sludge waste as a soil ameliorant in Ultisols.

Soil pH

The statistical analysis results showed a significant effect of paper sludge waste and NPK fertilizer application on the pH of the Ultisols. The results of the analysis are presented in Table 4.

The results of the DMRT test at the 5% level showed that the S3N2 treatment had the best effect on increasing the pH of Ultisols, which was significantly different from that of the other treatments. The initial soil pH was 5.82, which increased to 6.64 after the addition of paper sludge waste. The soil pH with the

Table 1 Treatment combinations of composted paper sludge and NPK fertilizer

Code	Treatment	
	Composted paper sludge (tons/ha)	NPK (kg/ha)
S0N0	-	300
S1N1	10	150
S2N1	15	150
S3N1	20	150
S1N2	10	300
S2N2	15	300
S3N2	20	300

Note: S0N0 = Without Composted Paper Sludge and NPK 300 kg/ha; S1N1 = Composted Paper Sludge 10 ton/ha and NPK 150 kg/ha; S2N1 = Composted Paper Sludge 15 ton/ha and NPK 150 kg/ha; S3N1 = Composted Paper Sludge 20 ton/ha and NPK 150 kg/ha; S1N2 = Composted Paper Sludge 10 ton/ha and NPK 300 kg/ha; S2N2 = Composted Paper Sludge 15 ton/ha and NPK 300 kg/ha; S3N2 = Composted Paper Sludge 20 ton/ha and NPK 300 kg/ha.

Table 2 Soil characteristics

Parameter	Unit	Test Results
pH (H_2O)	-	5.82
Organic-C	%	1.27
Total-N	%	0.13
Total-P	mg/100g	63.91
Total-K	mg/100g	33.52
CEC	cmol(+)/kg	19.70

Table 3 Composted paper sludge characteristics

Parameter	Unit	Test Results	Criteria*
pH (H_2O)	-	8.1	4
Organik-C	%	21.69	Min. 15
Total-N	%	1.01	Min. 2
Total-P	%	1.21	Min. 2
Total-K	%	3.22	Min. 2
Zn	mg/kg	171.44	Maks. 5000

Note: *Based on theMinistry of Agriculture's National Standard for Solid Organic Fertilizer Quality No. 261/KPTS/SR.310/M/4/2019 2019.

NPK treatment without sludge waste decreased from 5.82 to 5.48., stated that the decrease in soil pH due to the application of NPK fertilizer was likely caused by the dissolution of nitrogen content during the nitrification process, which produced hydrogen ions (H^+) that could lower the soil pH.

This study found that the application of paper sludge waste increased the pH of Ultisols. Paper sludge waste is an ameliorant derived from organic materials. In acidic soil conditions, such as Ultisols, toxic elements can dissolve, and phosphorus tends to be less available because it can be bound by Al and Fe into a form that is unavailable to plants. The application of organic materials as soil ameliorants can play a role in chelating metal elements such as Al and Fe in the soil and forming organo-complex compounds that are difficult to dissolve in water. With a reduction in Al concentration, the hydrogen ions that cause soil acidity are reduced, and the soil pH increases.

Total N, P, and K Content

The statistical analysis results indicate that the application of paper sludge waste in combination with NPK fertilizer significantly affected the total N, P, and K levels in Ultisols. The outcomes of the F-test at the 5% significance level are shown in Table 5.

The DMRT analysis at the 5% significance level (Table 5) indicated that the S2N1 treatment produced the highest total nitrogen content in Ultisols, reaching 0.47%, and was significantly different from the other treatments. For total phosphorus, the application of paper sludge at 30 tons/ha combined with 300 kg/ha of NPK fertilizer (S3N2) resulted in the greatest increase, with a value of 0.16%. However, this result was not significantly different from that of S2N2 (0.16%) and S2N1 (0.14%). Similarly, the analysis of total potassium showed that S3N2 provided the highest value (0.03%) in Ultisols. Nevertheless, this outcome was statistically comparable to that of S2N2, S1N2, S3N1, and S2N1, all of which recorded total K values of 0.02%.

Based on the results of the initial soil analysis, the application of paper sludge waste and NPK fertilizer increased the total N content in the soil from 0.13% to 0.47%, total P from 0.06% to 0.16%, and total K from 0.02% to 0.03%. The increase in N, P, and K content is thought to be due to a reaction between the paper sludge waste as an organic material and NPK fertilizer applied to the soil. When NPK was applied without paper sludge, the increase in N content was not as high as when NPK was applied with paper sludge waste. Referring to the results of research by, organic matter can provide additional nutrients to the soil from the decomposition process, thereby stimulating the increase of nitrogen in the soil. The results of the study showed that when NPK fertilizer is applied without a balancing agent such as organic matter in the soil, the nutrients from the NPK fertilizer can only be utilized by plants, and leaching can occur, which does not help increase soil fertility. Mentioned that the application of organic matter can increase the activity of decomposer microorganisms in the soil. These microorganisms can help in the process of mineralizing organic nitrogen into a form that is available to the soil and plants.

The combination of composted paper sludge and NPK fertilizer also increased the P and K content in the soil, which is likely related to the increased activity of

Table 4 Effect of composted paper sludge and NPK fertilizer application on Ultisols pH

Treatment	Average pH
S0N0 (No Sludge + NPK 300 kg/ha)	5.48^{d}
S1N1 (Sludge 10 tons/ha + NPK 150 kg/ha)	6.15^{b}
S2N1 (Sludge 20 tons/ha + NPK 150 kg/ha)	6.11^{b}
S3N1 (Sludge 30 tons/ha + NPK 150 kg/ha)	6.17^{b}
S1N2 (Sludge 10 tons/ha + NPK 300 kg/ha)	5.74^{c}
S2N2 (Sludge 20 tons/ha + NPK 300 kg/ha)	6.07^{b}
S3N2 (Sludge 30 tons/ha + NPK 300 kg/ha)	6.64^{a}
Coefficient of Variation (%)	2.36

Note: Numbers marked with the same letter are not significantly different according to Duncan's multiple range test at the 0.05% significance level.

Table 5 Effect of composted paper sludge and NPK fertilizer application on total N, P, and K content in Ultisols

Treatment	Total-N	Total-P	Total-K
		%	
S0N0 (Without Sludge + NPK 300 kg/ha)	0.36^{b}	0.06^{cd}	0.01^{b}
S1N1 (Sludge 10 tons/ha + NPK 150 kg/ha)	0.37^{b}	0.04^{d}	0.01^{b}
S2N1 (Sludge 20 tons/ha + NPK 150 kg/ha)	0.47^{a}	0.12^{b}	0.02^{ab}
S3N1 (Sludge 30 tons/ha + NPK 150 kg/ha)	0.36^{b}	0.09^{c}	0.02^{ab}
S1N2 (Sludge 10 tons/ha + NPK 300 kg/ha)	0.39^{b}	0.14^{ab}	0.02^{ab}
S2N2 (Sludge 20 tons/ha + NPK 300 kg/ha)	0.32^{b}	0.16^{a}	0.02^{ab}
S3N2 (Sludge 30 tons/ha + NPK 300 kg/ha)	0.37^{b}	0.16^{a}	0.03^{a}
Coefficient of Variation (%)	11.44	13.51	39.27

Note: Numbers marked with the same letter are not significantly different according to Duncan's multiple range test at the 0.05% significance level.

soil microorganisms that can dissolve P and K into available forms. The analysis of sludge waste showed that the K content was above the minimum technical requirement for organic fertilizer, which is 3.22%, where this element can dissolve in the soil and provide nutrients for plants. In addition, the increase in P in the soil is also suspected to be due to an increase in the pH of Ultisols. Makatita *et al.* (2025), mentioned that an increase in soil pH will increase the available P because the amount of Al-dd is reduced.

Purple Eggplant Yield

The application of composted paper sludge and NPK fertilizer had a significant effect on the number of purple eggplant fruits. Table 6 shows the average number of fruits per plant for each treatment.

The results of this study indicate that the S3N2 treatment had the best effect on the number of purple eggplants, with no significant difference from the S3N1 treatment, but a significant difference from the other treatments. The application of 30 tons/ha of paper sludge waste with 300 kg/ha of NPK resulted in the highest number of fruits, with an average of six fruits per plant, while the application of 30 tons/ha of paper sludge waste with 150 kg/ha of NPK resulted in an average of 5.50 fruits. The number of fruits is influenced by the availability of photosynthates from photosynthesis. Nitrogen, a component of nucleic acids and proteins, plays a role in hormone formation during flower and fruit formation. Phosphorus increases the number of flowers and fruits, whereas potassium plays a role in carbohydrate formation, enzyme activation, and the conversion of amino acids into proteins (Farhan *et al.* 2024). According to Choirunnisa *et al.* (2025), NPK nutrients can improve plant physiology during the generative phase, such as fruit formation, number, and size, thereby increasing production.

Paper sludge waste not only contains macro nutrients NPK but also micro nutrients Zn at 171.44 mg/kg, which plays a role in fruit formation. The Zn content in the organic granular fertilizer from paper sludge waste still met the national quality standards for solid organic fertilizers (Table 3). According to Salem *et al.* (2019), Zn acts as a catalyst that stimulates carbohydrate metabolism during photosynthesis, thereby increasing the availability of carbohydrates for fruit formation. In addition, it plays an important role in auxin formation during the development and differentiation of meristem cells, fruit formation, and prevention of flower and fruit drop. The application of composted paper sludge and NPK fertilizer had a significant effect on purple eggplant fruit length. The average fruit length per treatment is presented in Table 7.

Based on the results of the DMRT at the 5% level, the best fruit length was obtained in the S3N1 treatment with a fruit length of 31.00 cm, which was not significantly different from the S3N2 treatment with a fruit length of 27.75 cm, but was significantly different from the other treatments. The highest dose of NPK fertilizer did not produce better fruit length; therefore, the right dose is needed to provide nutrients that have a good effect on crop production. Based on the description of the fruit length of the purple eggplant

Table 6 Effect of composted paper sludge and NPK fertilizer application on the number of purple eggplants

Treatment	Average number of fruits (fruits)
S0N0 (No Sludge + NPK 300 kg/ha)	2.00^{c}
S1N1 (Sludge 10 tons/ha + NPK 150 kg/ha)	3.25b^{c}
S2N1 (Sludge 20 tons/ha + NPK 150 kg/ha)	3.75^{b}
S3N1 (Sludge 30 tons/ha + NPK 150 kg/ha)	5.50^{a}
S1N2 (Sludge 10 tons/ha + NPK 300 kg/ha)	3.25b^{c}
S2N2 (Sludge 20 tons/ha + NPK 300 kg/ha)	4.00^{b}
S3N2 (Sludge 30 tons/ha + NPK 300 kg/ha)	6.00^{a}
Coefficient of Variation (%)	23.1

Note: Numbers marked with the same letter are not significantly different according to Duncan's multiple range test at the 0.05% significance level.

Table 7 Effect of composted paper sludge and NPK fertilizer application on the length of purple eggplant fruit

Treatment	Average fruit length (cm)
S0N0 (No Sludge + NPK 300 kg/ha)	20.00
S1N1 (Sludge 10 tons/ha + NPK 150 kg/ha)	20.50
S2N1 (Sludge 20 tons/ha + NPK 150 kg/ha)	23.50^{bc}
S3N1 (Sludge 30 tons/ha + NPK 150 kg/ha)	31.00^{a}
S1N2 (Sludge 10 tons/ha + NPK 300 kg/ha)	22.00^{bc}
S2N2 (Sludge 20 tons/ha + NPK 300 kg/ha)	24.25^{bc}
S3N2 (Sludge 30 tons/ha + NPK 300 kg/ha)	27.75^{a}
Coefficient of Variation (%)	15.20

Note: Numbers marked with the same letter are not significantly different according to Duncan's multiple range test at the 0.05% significance level.

variety Mustang F1, the average fruit length was 20 cm. The combination of paper sludge waste and NPK fertilizer is thought to provide the nutrients N, P, and K needed for the formation of eggplant fruit. This is proven by the fact that the fruit length of the experimental plants with a paper sludge waste dose of 20 tons/ha showed the highest average fruit length. The roles of nitrogen, phosphorus, and potassium nutrients is very important in the formation of eggplant fruits. Nitrogen plays a role in producing photosynthates as food reserves that are translocated throughout the plant, including in the fruit and seeds. Potassium plays a role in optimizing fruit formation, such as fruit quality and length, whereas phosphorus plays a role in cell and cell membrane formation and in optimizing the use of nitrogen in fruit formation (Syarifah *et al.* 2025).

According to Amami *et al.* (2025), there are other factors in the elongation of eggplant fruit size, including temperature, humidity, and soil pH. If the supporting factors are favorable, the plants will grow optimally. In this experiment, the average air temperature of 29.6°C was the optimal temperature for growing purple eggplant, while the average air humidity of 71.71% was still in line with the growing requirements of eggplant plants. The pH of Ultisols after being treated with paper sludge waste increased to 6.64, which was in line with the growing requirements of eggplant plants, encouraging plant growth, especially in terms of fruit length.

The application of composted paper sludge and NPK fertilizer had a significant effect on the weight of purple eggplant fruit. The average fruit weight per treatment is presented in Table 8. Based on the observation results, the best fruit weight was obtained in the S3N1 treatment with an average fruit weight of 268 g, which was not significantly different from the S3N2 treatment with an average fruit weight of 208.00 g, but was significantly different from the other treatments. The average fruit weight per harvest showed good results compared to the treatment without paper sludge waste treatment. Fruit weight and size are influenced by the availability of the main nutrients, namely, nitrogen, phosphorus, and potassium. According to Maghfoer *et al.* (2014), the role of nitrogen in starch/food formation is inseparable from the role of potassium in supporting plant immunity and the role of phosphorus in promoting flower and fruit formation.

Nitrogen is essential for the synthesis of carbohydrates (food reserves), whereas phosphorus contributes to cell development and supports faster flowering and fruiting processes. In contrast, potassium is involved in the translocation of carbohydrates and plays a role in cell division, thereby influencing fruit formation (Liu *et al.* 2024). This statement explains that the role of NPK greatly influences fruit formation and weight in eggplant plants. An increase in the number of fruits generally leads to smaller fruit sizes, whereas fewer fruits tend to result in larger individual fruits. This condition is related to the allocation of assimilates during fruit development. (Bangun *et al.* 2023) reported that the application of 20 tons/ha of organic sludge fertilizer combined with 150 kg/ha of NPK fertilizer supplied sufficient nutrients for soybean plants (*Glycine max* L.) and produced the highest average seed weight per plant. Similarly, Arta *et al.* (2023) found that the combination of 20 tons/ha of organic sludge fertilizer and 300 kg/ha of NPK fertilizer resulted in the highest average cob weight in sweet corn (*Zea mays saccharata*).

Eggplant plants can be harvested 15 times during a single growing season. If the average yield per harvest is approximately 268.20 g, then the potential yield per hectare with a population of 50,000 plants is approximately 201.15 tons. Based on the yield potential of the seeds used, purple eggplant can produce approximately 100 tons/ha, assuming that paper sludge waste and NPK fertilizer can be used as one of the recommendations for increasing purple eggplant yields.

CONCLUSION

The findings indicate that the combined application of composted paper sludge and NPK fertilizer can significantly enhance several chemical properties of Ultisols while also increasing the yield of purple eggplants. The most effective treatment for improving soil chemical characteristics was the application of 30 tons/ha of paper sludge combined with 300 kg/ha NPK

Table 8 Effect of composted paper sludge and NPK fertilizer application on purple eggplant fruit weight

Treatment	Average fruit weight (g)
S0N0 (No Sludge + NPK 300 kg/ha)	100.02 d
S1N1 (Sludge 10 tons/ha + NPK 150 kg/ha)	100.30 d
S2N1 (Sludge 20 tons/ha + NPK 150 kg/ha)	193.43 bc
S3N1 (Sludge 30 tons/ha + NPK 150 kg/ha)	268.20 a
S1N2 (Sludge 10 tons/ha + NPK 300 kg/ha)	121.70 cd
S2N2 (Sludge 20 tons/ha + NPK 300 kg/ha)	174.88 bc
S3N2 (Sludge 30 tons/ha + NPK 300 kg/ha)	208.00 ab
Coefficient of Variation (%)	29.70

Note: Numbers marked with the same letter are not significantly different according to Duncan's multiple range test at the 0.05% significance level.

fertilizer. In contrast, the highest eggplant yield was achieved with 30 tons/ha of paper sludge and a lower NPK dose of 150 kg/ha. The use of composted paper sludge as a soil ameliorant contributed to improved soil fertility in ultisols. Furthermore, the optimal fertilizer rate for maximizing crop yield was identified at 150 kg/ha of NPK, indicating that higher applications of sludge waste tend to have more beneficial effects on both soil fertility and eggplant production.

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