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Comparative Effects of Plant and Animal Liquid Organic Fertilizers on Soil Fertility, Nutrient Uptake, and Shallot Yield in Ultisols

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Abstract. Ultisols are characterized by strong acidity, low cation exchange capacity, and high phosphate fixation, which limit nutrient availability and crop productivity. Sustainable fertilization strategies are needed to improve soil quality and reduce dependence on inorganic inputs. A pot experiment was conducted from January to August 2025 using a randomized complete block design with nine treatments and three replications (270 plants). Treatments included combinations of 50% NPK fertilizer with liquid organic fertilizers (LOFs) derived from goat urine, rabbit urine, banana peels, and pineapple peels. Data were analyzed using analysis of variance (ANOVA), followed by orthogonal comparison tests. The combined application of LOFs with 50% NPK significantly increased biomass, bulb yield, soil CEC, organic C, total N, available K, and plant N and K uptake ($p < 0.01$) compared to 100% NPK. Yield increased by 27.7%, while N and K uptake rose by 63.0% and 65.0%, respectively. Rabbit urine LOF showed the highest effectiveness, improving yield by up to 36.0% compared to goat urine. Plant-based LOFs enhanced soil organic C, CEC, and K availability, whereas animal-based LOFs were more effective in increasing soil N. The integration of LOFs with reduced NPK improves soil fertility and shallot productivity under controlled conditions. Rabbit urine LOF at 300 mL L^{-1} is the most effective treatment. However, field validation is required before large-scale application.

Keywords: banana peel; nutrient uptake; rabbit urine; shallot yield; ultisol

1. Introduction

Ultisols are widely distributed in humid tropical regions and are characterized by strong acidity, low cation exchange capacity, and high phosphate fixation, which severely limit the availability of essential nutrients such as N, P, and K (Shalihah et al., 2024; Sumini & Wartono, 2025). These constraints contribute directly to low crop productivity, including shallots (*Allium cepa* L.). Although inorganic fertilizers such as NPK are commonly used to overcome nutrient deficiencies, their long-term application can reduce soil organic carbon, degrade soil structure, and decrease nutrient-use efficiency (Li et al., 2021; Nur et al., 2025). This indicates that reliance on mineral fertilizers alone is insufficient to sustain soil fertility and productivity in Ultisol systems. In response, liquid organic fertilizers (LOFs) have emerged as a promising alternative due to their ability to supply nutrients while improving soil quality. Previous studies consistently show that integrating organic and inorganic fertilizers enhances soil fertility, microbial activity, and nutrient dynamics compared to sole chemical fertilization (Denoncourt et al., 2025; Mandasari et al., 2025). However, most studies focus on solid organic amendments, while research on LOFs remains limited, particularly in comparative contexts. Importantly, the effectiveness of LOFs depends on their source materials. Animal-based LOFs tend to provide readily available nitrogen, whereas plant-based LOFs are generally richer in potassium and organic compounds that stimulate microbial activity Wang et al. (2024).

Another important gap is the limited

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evidence on whether LOFs can partially substitute inorganic fertilizers without reducing crop yield, especially in nutrient-poor Ultisols. Although integrated fertilization strategies have shown positive effects on soil properties and crop performance. These findings are in line with the long-term research results by Bo et al. (2024), which reported that the combination of organic and inorganic fertilizers has a greater impact on soil quality than chemical fertilization alone. They found that combining the two types of fertilizers can improve soil quality indices, strengthen microbial activity, and support increased crop yields. These findings confirm that organic inputs not only serve as a source of nutrients, but also as a key trigger for soil biochemical processes that play a role in mobilizing nutrients. Organic amendments have also been shown to contribute significantly to increases in soil organic carbon, aggregate stability, and cation exchange capacity. Yi et al. (2022) emphasized that organic matter can significantly improve the physical and chemical characteristics of soil, especially in degraded soils such as Ultisols. By increasing the active organic fraction in the soil, this amendment can improve soil structure and increase nutrient availability for plants.

The same point is emphasized by Singh et al. (2024), who report that organic fertilizers and biofertilizers can increase soil enzyme activity while improving the uptake of N, P, and K by plants. The impact is directly seen in the strengthening of plant physiological processes, including biomass formation and vegetative growth. However, most of these studies focus more on solid organic fertilizers or compost, while studies on liquid organic fertilizers are still relatively limited. This condition shows that research on the effectiveness of LOF as an alternative to sustainable fertilization is still very relevant to be further developed. Studies on the use of liquid organic fertilizers (LOF) from various sources of materials are actually continuing to develop, but research that places plant-based and animal-based LOF in a comprehensive comparative framework is still very rare. In fact, these two groups of materials have different chemical properties and are very likely to have different effects on soil and plants. LOF from animal materials such as goat urine and rabbit urine usually contains nitrogen in the form of ammonium and a number of soluble minerals that can quickly enrich the soil, as noted by Mmbaga et al. (2024). Meanwhile, LOF from banana or pineapple peels is generally richer in potassium, simple sugars, and plant metabolite compounds that can activate microorganisms around the roots—a mechanism described by Khanyile et al. (2024) and Mandasari et al. (2025). With such significant differences in chemical characteristics, it is only natural that the responses observed in the soil and plants should also differ. However, in reality, there has been no research that directly tests these two types of LOF in shallot cultivation systems on Ultisol soil.

In addition to this gap, there has been no research assessing the extent to which LOF can replace NPK fertilizer by up to half the dose without sacrificing crop productivity. In fact, a number of studies show that a combination of organic and inorganic fertilizers can produce much better results than the use of chemical fertilizers alone. Wu et al. (2024) even emphasized that the integration of these two types of fertilizers can improve soil quality, strengthen microbial activity, and have a positive impact on crop yields. Similarly, Xu et al. (2025) reported that the addition of organic matter can improve soil structure, increase organic carbon content, and raise cation exchange capacity—an important benefit for degraded tropical soils such as Ultisols. However, most of these studies still focus on solid organic fertilizers or compost, so the contribution of LOF as a modern fertilization technology has not been studied in depth. Based on this, this study proposes a strong new contribution. This study aims to analyze the effects of plant-based and animal-based liquid fertilizers on the fertility of Ultisol soil,

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compare the effectiveness of both fertilizer types in improving plant growth and yield, evaluate the interaction between fertilizer type and soil conditions on plant performance, and determine the most optimal liquid fertilizer for enhancing productivity in Ultisol soil.

2. Materials and Methods

Time and Place

This research was conducted at the Experimental Garden of the Faculty of Agricultural Technology, Satu Nusa Lampung University, while all laboratory analyses related to soil chemistry and plant tissue were carried out at the Integrated Laboratory of Lampung University from January to August 2025.

Materials and Tools

The materials used included Bima Curut Brebes variety shallot seeds, a planting medium consisting of a mixture of Ultisol topsoil and burnt husks, 30 × 30 cm polybags, 16–16–16 NPK fertilizer, as well as materials for making liquid organic fertilizer (LOF) consisting of goat urine, rabbit urine, banana peel, pineapple peel, brown sugar solution, and EM4 as a fermentation microbe inoculum. Research equipment included a soil sieve, digital scale, measuring cup, tape measure, caliper, documentation tools, and laboratory instruments such as a pH meter, UV-Vis spectrophotometer, AAS/ICP-OES, and Kjeldahl titrator.

Experimental Design

The study was designed using a one-factor randomized block design (RBD) with nine treatments and three replicates, resulting in 27 experimental units. Randomization the experimental area was divided into three blocks based on microclimatic variation. Nine treatments were randomly assigned within each block, ensuring that each treatment appeared once per block. The positions of polybags within each experimental unit were also randomized to minimize positional effects. When necessary, periodic rotation of polybags was conducted. This procedure ensures that each treatment has an equal opportunity to experience environmental conditions.

Each experimental unit consisted of five polybags, each planted with two seedlings, resulting in a total of 270 plants. The use of polybags has several limitations compared to field conditions: (1) restricted soil volume limits root development, (2) water and nutrient dynamics do not fully represent natural processes such as percolation and runoff, (3) environmental variability is lower, (4) there is a higher potential for temperature fluctuations in the growing media, and (5) results are experimental in nature and require field validation. Nevertheless, polybag experiments remain valuable for preliminary studies, as they allow better control of variables and clearer analysis of cause–and–effect relationships.

The treatments were combinations of 50% NPK inorganic fertilizer and LOF from animal and plant sources at two different concentrations, as well as a 100% NPK control. The nine treatments were: K0 = 100% NPK dose (10 g polybag^{-1}); D1 = 50% NPK dose (5 g polybag^{-1}) + 100 ml L^{-1} goat urine LOF; D2 = 50% NPK dose (5 g polybag^{-1}) + 300 ml L^{-1} goat urine LOF; C1 = 50% NPK dose (5 g polybag^{-1}) + 100 ml L^{-1} rabbit urine LOF; C2 = 50% NPK dose (5 g polybag^{-1}) + 300 ml L^{-1} rabbit urine LOF; P1 = 50% NPK (5 g polybag^{-1}) + 100 ml L^{-1} banana peel LOF; P2 = 50% NPK (5 g polybag^{-1}) + 300 ml L^{-1} banana peel LOF; N1 = 50% NPK dose (5 g polybag^{-1}) + 100 ml L^{-1} pineapple peel LOF; and N2 = 50% NPK dose (5 g polybag^{-1}) + 300 ml L^{-1} pineapple peel LOF. This design was chosen because it minimizes variability due to differences in microclimate and planting medium heterogeneity, as recommended in controlled horticultural research (Zhao et al., 2024).

Research Procedure

Preparation of Materials

LOF production is carried out through a controlled anaerobic fermentation process for 21 days using EM4 as a microbial inoculant

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containing Lactobacillus spp., Saccharomyces spp., and photosynthetic bacteria. The fermentation of goat and rabbit urine is carried out by mixing 20 L of urine, 400 mL of EM4, and 400 mL of brown sugar solution (1:1 w/v), then storing it in an airtight container with a gas release valve. Plant material fermentation was carried out by mixing 20 kg of banana or pineapple peel with 20 L of water and EM4-brown sugar solution with the same composition. The fermentation process was considered successful when the ammonia odor decreased and the pH stabilized in the range of 4–5 (Merlo et al., 2025).

The Ultisol soil was sieved for homogenization, then mixed with burnt husks at a ratio of 3:1 to improve aeration, porosity, and nutrient retention capacity. Shallot bulbs were selected based on size uniformity, cut one-third of the tip to stimulate sprout growth, then planted at a depth of 2–3 cm. NPK fertilizer was applied once at two weeks after planting, while LOF was applied weekly for ten times during the study. LOF was diluted to a total volume of 1 L and then applied at 250 mL per polybag. The application technique followed a simple fertigation method so that the LOF solution was optimally absorbed by the root zone (Wu et al., 2024).

Observation and Sampling

The variables observed included soil chemical properties (organic carbon, total nitrogen, available phosphorus, total phosphorus, available potassium, pH, and soil cation exchange capacity), N, P, and K nutrient uptake, as well as plant growth and yield parameters. Soil sampling was conducted after harvest using the composite sampling technique, which involved mixing three sample points per polybag to obtain a representative sample, in accordance with the FAO soil sampling protocol. The soil was dried, sieved to 2 mm, and then analyzed for its chemical properties. Soil pH was measured with a pH meter using a soil: water ratio of 1:2.5. Organic C was analyzed using the Walkley–Black method, total N using the Kjeldahl method, available P using the Bray I method for acidic soils, available K using 1N ammonium acetate extraction, and CEC was analyzed using the ammonium acetate leaching–adsorption method, following standard procedures commonly used in tropical pedology (Merlo et al., 2025).

Plant tissue analysis was performed on leaves and tubers dried at 80 °C to constant weight. The samples were finely ground and analyzed for N content using the Kjeldahl method, while P and K were analyzed by UV-Vis spectrophotometry and AAS/ICP-OES. Nutrient uptake was calculated by multiplying the nutrient concentration in the tissue by the dry weight of the plant (Dhobhal, 2023). Growth observations included plant height, number of leaves, tuber diameter, number of tubers per clump, wet plant weight, dry plant weight, and shallot tuber yield. Harvesting was carried out at 80 days after planting when the leaves turned yellow and weakened, and the tubers appeared on the soil surface, following the physical indicators commonly used for shallot plants.

Statistical Analysis

All instruments used in this study were calibrated before data collection to ensure accurate and reliable measurements. Weighing scales were calibrated using standard reference weights, while measuring tools such as rulers and analytical balances were checked against known standards following laboratory procedures. Before analyzing variance (ANOVA), the data were tested for normality and homogeneity of variance. Normality was assessed using the Shapiro–Wilk test, homogeneity using the Bartlett test, and additivity using the Tukey test. When needed, data were transformed (e.g., using logarithmic or square-root transformation) to meet ANOVA assumptions. However, if the data already met these assumptions, no transformation was applied. Possible sources of experimental bias, such as environmental

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variation, differences in handling, and measurement errors, were minimized through proper randomization, uniform crop management, and consistent measurement procedures across all experimental units. ANOVA was then performed at the 5% and 1% significance levels. When significant differences were found, orthogonal comparison tests were used as a follow-up to identify specific differences among treatments more clearly. To improve the interpretation of results, effect sizes (such as mean differences and percentage differences) were reported together with p-values. In addition, 95% confidence intervals were included to show the precision and reliability of the treatment effects.

3. Results and Discussion

Observation Results

The results of the analysis of variance (ANOVA) showed that the treatment had a significant effect on several parameters of soil chemical properties, nutrient uptake, growth, and red onion yield. The analysis of variance showed that the treatment had a very significant effect ($p<0.01$) on the parameters of wet weight and dry weight of plants, red onion yield, soil CEC, organic C content, total N, and potassium, as well as N and K uptake by red onion plants, but had no significant effect ($p \geq 0.05$) on plant height, number of leaves, number and diameter of tubers, soil pH, available P and total P content, and P uptake in Table 1.

Table 1. Summary of the analysis of variance of treatment effects

Variable Observation	F-count	Variable Observation	F-count
Growth and Yield of Shallots:		**Chemical Properties of Soil in Root System (continued):**	
a. Plant Height (cm)	1.05 ^{ns}	d. N-total (%)	28.23**
b. Number of Leaves (pieces)	0.31 ^{ns}	e. Available P (P2O5 ppm)	1.68^{ns}
c. Number of tubers per clump (fruit)	0.29 ^{ns}	f. Potential P (mg P2O5 100 g)	1.49^{ns}
d. Tuber Diameter (mm)	0.71 ^{ns}	g. Kalium (mg K_2O/100 g)	49.11**
e. Wet Plant Weight (g)	8.30 **		
f. Dry Plant Weight (g)	17.48**	**N, P, and K Nutrient Uptake:**	
g. Red Onion Tuber Yield (g plant^{-1})	9.7 **	a. N Uptake (g plant^{-1})	24.83**
Chemical Properties of Soil in Root System:			
a. pH-H_2O	0.02^{ns}	b. P Uptake (mg plant^{-1})	2.05^{ns}
b. KTK (Cmol/kg)	82.64**	c. K Uptake (g plant^{-1})	15.68**
c. C-Organic (%)	39.9**		

Note: ns = not significant; **= $p < 0.01$; T-table (0.05 = 2.59), F-table (0.01) = 3.89

Growth and Yield of Shallots

The results of the orthogonal comparison test (Table 2) show that the application of 50% NPK + LOF fertilizer produced a higher wet weight of plants (68.98 g) compared to 100% NPK fertilizer (57.10 g), with a difference of 11.88 g plant^{-1} (20.8%). The application of goat urine LOF and rabbit urine LOF resulted in heavier wet plant weight (75.55 g) compared to banana peel LOF and pineapple peel LOF (62.41 g), with a difference of 13.14 g plant^{-1} (21.1%). The application of rabbit urine LOF had a very significant effect, resulting in a heavier wet weight of plants (84.04 g) compared to goat urine LOF (67.07 g), with a difference of 16.97 g plant^{-1} (25.3%). The results of the orthogonal comparison test for the dry plant weight parameter (Table 3) showed the same pattern as the wet plant weight parameter, with the effect of rabbit

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urine LOF dose being significantly different ($p<0.05$). Several comparisons showed non-significant differences ($p > 0.05$), indicating that the treatments produced relatively similar effects on plant dry weight. This lack of significance is likely due to the small differences in mean values between treatments, such as those observed in the comparisons of P vs N, D1 vs D2, P1 vs P2, and N1 vs N2, where the differences were minimal. In addition, the presence of variability among replicates may have increased the experimental error, thereby reducing the ability of the statistical test to detect significant differences. The limited number of replications (three replicates) may also have contributed to the lower statistical power, making it more difficult to distinguish subtle treatment effects. Furthermore, the similarity in nutrient composition and mode of action among certain treatments could have resulted in comparable plant responses, leading to statistically non-significant outcomes.

Table 2. Results of the orthogonal comparison test for wet plant weight data

Comparison	Average wet weight of plants		Difference		Significance
	Left	Right	G	%	
K0 vs D,C,P,N	57.10	68.98	-11.88	20.8	**
D,C vs P,N	75.55	62.41	13.14	21.1	**
D vs C	67.07	84.04	-16.97	25.3	**
P vs N	64.77	60.06	4.71	7.8	ns
D1 vs D2	68.08	66.06	2.02	3.1	ns
C1 vs C2	82.84	85.23	-2.39	2.9	ns
P1 vs P2	63.34	66.19	-2.84	4.5	ns
N1 vs N2	62.07	58.04	4.02	6.9	ns

Note: K0= NPK dose 100%; D1= NPK dose 50%+ goat urine LOF 100 ml L-1; D2= NPK 50%+ goat urine LOF 300 ml L-1; C1 = 50% NPK + 100 ml L-1 rabbit urine LOF; C2 = 50% NPK + 300 ml L-1 rabbit urine LOF; P1 = 50% NPK + 100 ml L-1 banana peel LOF; P2 = NPK 50% + LOF banana peel 300 ml L-1; N1 = NPK 50% + LOF pineapple peel 100 ml L-1; and N2 = NPK 50% + LOF pineapple peel 300 ml L-1; ns = not significant; ** = $p < 0.01$.

Table 3. Results of orthogonal comparison tests of plant dry weight data

Comparison	Average dry weight of plants		Difference		Significance
	Left	Right	G	%	
K0 vs D,C,P,N	8.67	12.90	-4.23	48.8	**
D,C vs P,N	15.77	10.03	5.73	57.1	**
D vs C	11.30	20.23	-8.93	79.1	**
P vs N	9.50	10.57	-1.07	11.2	ns
D1 vs D2	11.10	11.50	-0.40	3.6	ns
C1 vs C2	18.47	22.00	-3.53	19.1	*
P1 vs P2	9.00	10.00	-1.00	11.1	ns
N1 vs N2	10.47	10.67	-0.20	1.9	ns

Note: ns = not significant; * = $p < 0.05$; ** = $p < 0.01$

Observations of shallot bulb yields (Table 4) show that the application of 50% NPK + LOF fertilizer had a very significant effect ($p < 0.01$), producing heavier shallot bulbs compared to 100% NPK fertilizer, with a difference of 12.24 g plant^{-1} (27.7%).

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The application of goat urine LOF and rabbit urine LOF had a very significant effect on producing heavier shallot bulbs compared to banana peel LOF and pineapple peel LOF, with a difference of 13.66 g plant^{-1} (27.5%). The application of rabbit urine LOF had a very significant effect on producing heavier red onion bulbs compared to goat urine LOF, with a difference of 19.31 g (36.0%).

Several orthogonal comparisons non-significant differences ($p > 0.05$), indicating that certain treatments had relatively similar effects on red onion bulb yield. For example, the comparisons of P vs N, D1 vs D2, C1 vs C2, P1 vs P2, and N1 vs N2 resulted in small differences in yield, ranging from only 0.88 to 6.10 g per plant (1.9–8.7%). These relatively minor variations suggest that the treatments within each group produced comparable responses, making it difficult to detect statistically significant differences. In addition, variability among replicates may have contributed to higher experimental error, thereby reducing the sensitivity of the statistical test. The limited number of replications (three replicates) may have further lowered the statistical power, preventing the detection of subtle differences. Moreover, the similarity in nutrient composition and effectiveness among the compared treatments likely led to uniform plant growth and bulb development, resulting in non-significant outcomes.

Table 4. Results of the orthogonal comparison test of red onion bulb yield data

Comparison	Average yield of shallots		Difference		Significance
	Left	Right	g plant^{-1}	%	
K0 vs D,C,P,N	44.26	56.51	-12.24	27.7	**
D,C vs P,N	63.34	49.68	13.66	27.5	**
D vs C	53.68	72.99	-19.31	36.0	**
P vs N	51.30	48.05	3.25	6.8	ns
D1 vs D2	55.23	52.13	3.10	5.9	ns
C1 vs C2	69.94	76.04	-6.10	8.7	ns
P1 vs P2	50.01	52.59	-2.58	5.2	ns
N1 vs N2	48.50	47.61	0.88	1.9	ns

Note: ns = not significant; ** = $p < 0.01$

Observations of onion growth and yield variables indicate that a combination of inorganic fertilizer and LOF can modify onion growth response in Ultisol soil. In general, the 50% NPK treatment combined with LOF (D1, D2, C1, C2, P1, P2, N1, N2) produced plant height, number of leaves, number and diameter of bulbs that were equivalent (not significantly different; $p \geq 0.05$) or even higher in terms of plant wet weight, plant dry weight, and onion yield compared to the 100% NPK control treatment (K0). This pattern indicates that reducing the NPK fertilizer dose to 50% can still optimize vegetative growth when balanced with the supply of organic nutrients and bioactive compounds from LOF.

Discussion This study shows that the integration of liquid organic fertilizer (LOF) with inorganic NPK fertilizer can significantly modify the growth dynamics and productivity of shallots cultivated on Ultisol soil. Ultisol soil is generally characterized by low fertility, limited cation exchange capacity, and minimal organic matter content. Therefore, plant response to fertilization interventions is often highly determined by the efficiency of improving the growing environment in the root zone. The results of this study are in line with findings

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in various international literature which confirm that the use of organic fertilizers together with inorganic fertilizers can create a more stable nutritional balance, improve soil chemical properties, and increase nutrient availability in a sustainable manner (Wang et al., 2025; Yetunde et al., 2022).

One of the most striking results of this study was the increase in biomass—both wet and dry weight—in the treatment combining 50% NPK with LOF. This finding shows that reducing the dose of inorganic fertilizer does not automatically decrease plant productivity, as long as there is a supply of organic matter capable of maintaining the availability of essential nutrients. This phenomenon reflects the principle of integrated nutrient management, where fertilization efficiency can be improved through the cooperation between organic compounds derived from LOF and mineral nutrients from inorganic fertilizers. In tropical agricultural systems, the strategy of reducing NPK doses has long been envisioned to reduce production costs while avoiding soil degradation due to long-term use of synthetic fertilizers. Multi-location research by Sogani et al. (2023) shows that a combination of organic and inorganic fertilizers can maintain productivity at the same level as full inorganic fertilization, while significantly improving soil organic carbon.

Furthermore, the results of this study clearly show the difference in performance between animal-based and plant-based LOF. LOF derived from goat and rabbit urine provides a much stronger growth response than LOF made from banana and pineapple peels. Animal urine contains higher concentrations of nitrogen and potassium, especially nitrogen in the form of urea, which is easily decomposed by soil microorganisms and thus quickly available to plants. These findings are consistent with reports on urine-based liquid organic fertilizers, which show that animal-based nutrients tend to produce faster nitrogen mineralization, thereby supporting optimal protein synthesis, photosynthetic activity, and plant biomass formation (Yetunde et al., 2022). Meanwhile, banana peels and pineapple peels, although rich in potassium and antioxidant compounds, generally have lower nitrogen content and slower mineralization rates. This is reinforced by (Mandasari et al., 2025), who reported that the fermentation of pineapple peels with EM4 produced LOF with N, P, and K contents that were still below the SNI quality standards for liquid organic fertilizers, despite an increase in organic C content and microbial activity during the fermentation process.

The most interesting finding is that among animal LOF sources, rabbit urine consistently provided the highest results in almost all growth and yield parameters. The average wet weight, dry weight, and shallot bulb yield in the rabbit urine treatment far exceeded the goat urine treatment. The superiority of rabbit urine has been reported in several previous studies. Mbonayo et al. (2025) showed that rabbit urine has a higher total nitrogen content than ruminant urine and contains a number of dissolved organic compounds that help improve the efficiency of N and K absorption by plants. Yetunde et al. (2022) also noted that the application of rabbit urine to Amaranthus plants resulted in greater biomass increases compared to urea fertilizer, indicating the complex role of bioactive components in rabbit urine, not just its nutrients. The same pattern also appeared in this study, where the response of shallot plants to rabbit urine LOF showed an increase in bulb weight of more than 35% compared to goat urine.

The changes in soil chemical properties in this study indicate that the application of LOF—both from plant materials such as banana and pineapple peels and animal materials such as goat and rabbit urine—combined with 50% NPK contributes significantly to improving the fertility of Ultisol soil. In general, the NPK 50% + LOF treatment produced higher values of organic C, total N, available K, and CEC than the NPK 100% treatment without LOF. This condition indicates that LOF functions not

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only as an additional nutrient source but also as an organic colloid-forming agent that enriches the cation exchange complex in the root zone.

The increase in CEC in (Table 5) the plant-based LOF treatment was clearly evident from the orthogonal test results, which showed that banana peel and pineapple peel had higher average CEC than animal-based LOF. This finding is in line with the report by Khanyile et al. (2024), which states that banana peel-based biofertilizer can significantly increase available K, organic C, and cation exchange capacity because banana peel is rich in potassium and easily decomposable carbon (Table 6). Similarly, Mandasari et al. (2025) showed that fermenting pineapple peel with EM4 produces LOF rich in soluble organic compounds and soluble K, which has the potential to improve soil colloid properties even though its N content is not as high as animal-based materials. This explanation is consistent with the results of this study, which found that plant-based LOF provides higher organic carbon, available potassium, and CEC values than animal-based LOF. Conversely, for the total nitrogen parameter, animal-based LOF showed a much greater increase than plant-based LOF. This can be explained by the composition of goat and rabbit urine, which has a much higher soluble nitrogen content—especially urea—than fruit peel waste. Mmbaga et al. (2024) confirmed that rabbit urine contains high total nitrogen and is highly mineralizable, thereby rapidly increasing soil total N after application. Global research conducted by Li et al. (2021) also found that organic inputs from animal sources increase soil nitrogen stocks and accelerate the accumulation of labile nitrogen fractions that are highly available to plants. This explains why treatments based on rabbit and goat urine show the greatest increase in total N.

Chemical Properties of Soil Around Root Systems

When comparing animal sources, rabbit urine again showed a stronger effect than goat urine on soil total N parameters. This finding is consistent with the report by Yetunde et al. (2022), which states that rabbit urine provides greater plant growth than urea fertilizer because its nitrogen and active organic compound content is more concentrated and easily utilized by plants. The differences between doses also showed interesting dynamics. In animal LOF, an increase in dose from 100 mL L^{-1} to 300 mL L^{-1} had a more pronounced effect, especially in the rabbit urine treatment, which showed a significant increase in soil N-total (Table 7). This pattern is in line with the findings of Mbonayo et al. (2025), who demonstrated that increasing the dose of a combination of rabbit urine and cow manure fertilizer can proportionally increase total N and plant nutrient uptake.

Table 5. Results of orthogonal comparison tests of soil cation exchange capacity (CEC) data

Comparison	Average soil KTK		Difference		Significance
	Left	Right	Cmol kg^{-1}	%	
K0 vs D,C,P,N	9.42	10.16	-0.74	7.9	**
D,C vs P,N	9.67	10.66	-0.99	10.2	**
D vs C	9.59	9.74	-0.15	1.6	*
P vs N	10.61	10.71	-0.10	0.9	ns
D1 vs D2	9.75	9.43	0.32	3.4	**
C1 vs C2	9.42	10.06	-0.64	6.8	**
P1 vs P2	10.43	10.79	-0.35	3.4	**
N1 vs N2	10.66	10.75	-0.09	0.9	ns

Note: ns = not significant; * = $p < 0.05$; ** = $p < 0.01$

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Table 6. Results of orthogonal comparison tests of soil organic carbon content data

Comparison	Average soil C-organic		Difference		Significance
	Left	Right	(%)	%	
K0 vs D,C,P,N	1.13	1.33	-0.20	17.5	**
D,C vs P,N	1.15	1.51	-0.36	31.0	**
D vs C	1.14	1.16	-0.02	1.7	Ns
P vs N	1.54	1.48	0.06	4.2	**
D1 vs D2	1.14	1.14	0.00	0.0	Ns
C1 vs C2	1.19	1.13	0.06	5.3	*
P1 vs P2	1.52	1.56	-0.04	2.4	ns
N1 vs N2	1.47	1.49	-0.03	1.8	ns

Note: ns = not significant; * = $p < 0.05$; ** = $p < 0.01$

Table 7. Results of orthogonal comparison tests of soil total N content data

Comparison	Average N-total		Difference		Significance
	Left	Right	(%)	%	
K0 vs D,C,P,N	0.12	0.17	-0.06	47.9	*
D,C vs P,N	0.22	0.13	0.10	76.0	**
D vs C	0.19	0.25	-0.06	29.6	*
P vs N	0.13	0.13	0.00	0.0	ns
D1 vs D2	0.18	0.21	-0.03	17.0	ns
C1 vs C2	0.23	0.27	-0.04	15.9	*
P1 vs P2	0.12	0.13	0.00	2.7	ns
N1 vs N2	0.12	0.13	0.00	2.7	ns

Note: ns = not significant; * = $p < 0.05$; ** = $p < 0.01$

Table 8. Results of orthogonal comparison tests of soil potassium content data

Comparison	Average K_2O		Difference		Significance
	Left	Right	(mg $100g^{-1}$)	%	
K0 vs D,C,P,N	64.82	72.00	-7.19	11.1	*
D,C vs P,N	68.81	75.19	-6.38	9.3	*
D vs C	74.23	63.39	10.84	17.1	**
P vs N	72.97	77.41	-4.44	6.1	ns
D1 vs D2	79.42	69.04	10.38	15.0	*
C1 vs C2	53.47	73.31	-19.84	37.1	**
P1 vs P2	72.33	73.61	-1.28	1.8	ns
N1 vs N2	75.40	79.42	-4.02	5.3	ns

Note: ns = not significant; * = $p < 0.05$; ** = $p < 0.01$

In contrast to these parameters, soil chemical properties such as pH, available P, and total P did not show significant changes even when LOF was applied. The insensitivity of these parameters is mainly related to the characteristics of Ultisols, which are rich in Fe and Al oxides and naturally have a very high phosphate fixation capacity. Nur et al. (2025) explained that acidic soils tend to retain P

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in a bound form, so that the increase in available P through the addition of organic matter is slow and often insignificant in short-term cropping cycles. Overall, the results (Table 8) of this study indicate that the improvement of Ultisol soil chemical fertility by LOF is highly dependent on the composition of the raw material. Plant-based LOF is superior in increasing available K, organic C, and CEC, while animal-based LOF is more effective in increasing total soil N. Among animal LOF, rabbit urine had the strongest effect, with performance increasing at a dose of 300 mL L^{-1}. The combination of these different characteristics confirms that the selection of LOF source materials and dose adjustment are key factors in optimizing soil fertility management, especially in nutrient-poor Ultisols with low adsorption capacity.

Absorption of N, P, and K

Nutrient uptake in plant tissues reflects the availability of nutrients in the rhizosphere and the ability of the root system to access and transport these elements to the canopy. In this study, the patterns of nitrogen (N) and potassium (K) uptake were closely related to changes in soil chemical properties resulting from the application of liquid organic fertilizer (LOF). Treatments that resulted in increases in organic carbon, total nitrogen, available potassium, and cation exchange capacity (CEC) tended to produce higher N and K uptake. This pattern is consistent with the fundamental concept of the relationship between soil quality and plant physiology: when soil colloids become richer in negative charges and microbial activity increases, mineralization and nutrient retention processes occur more efficiently, making it easier for plants to absorb these nutrients.

Table 9. Results of orthogonal comparison tests of N nutrient uptake data

Comparison	Average N uptake		Difference		Significance
	Left	Right	g $plant^{-1}$	%	
K0 vs D,C,P,N	15.57	25.38	-9.81	63.0	**
D,C vs P,N	32.54	18.21	14.33	78.7	**
D vs C	22.86	42.23	-19.37	84.7	**
P vs N	17.40	19.02	-1.62	9.3	ns
D1 vs D2	22.38	23.34	-0.96	4.3	ns
C1 vs C2	37.51	46.94	-9.43	25.1	**
P1 vs P2	16.51	18.30	-1.79	10.9	ns
N1 vs N2	18.75	19.29	-0.54	2.9	ns

Note: ns = not significant; ** = $p < 0.01$

Table 10. Results of orthogonal comparison tests of K nutrient uptake data

Comparison	Average K Uptake		Difference		Significance
	Left	Right	g $plant^{-1}$	%	
K0 vs D,C,P,N	13.03	21.50	-8.47	65.0	**
D,C vs P,N	24.57	18.44	6.13	33.3	**
D vs C	17.91	31.23	-13.32	74.4	**
P vs N	18.44	18.43	0.01	0.1	ns
D1 vs D2	16.97	18.85	-1.88	11.1	ns
C1 vs C2	27.20	35.25	-8.05	29.6	**
P1 vs P2	17.34	19.54	-2.20	12.7	ns
N1 vs N2	17.97	18.89	-0.93	5.2	ns

Note: ns = not significant; ** = $p < 0.01$

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Orthogonal comparison results show a very sharp increase in N uptake in the 50% NPK + LOF treatment compared to the 100% NPK (K0) treatment. Average N uptake increased by about 63%, while K uptake jumped by 65%. This increase indicates that LOF not only adds nutrients to the soil but also accelerates the flow of N and K through biological mechanisms, such as increased decomposing microorganism activity and high mobility of dissolved organic N. These findings are in line with the results of a study by Gautam et al. (2022), which found that the addition of animal-based organic matter enriches the labile N fraction of the soil so that plants are able to absorb larger amounts of N than in conditions where only mineral fertilizers are applied.

When LOF is grouped based on its raw material source, a very clear difference can be seen. Animal-based LOF (goat urine and rabbit urine) resulted in 78.7% higher N uptake compared to plant-based LOF (banana and pineapple peels). The same pattern occurred in K uptake. The effectiveness of animal-based LOF is directly related to its chemical characteristics. Animal urine, especially rabbit urine, contains nitrogen in the form of urea, which is highly susceptible to mineralization and thus quickly available to plants. Mmbaga et al. (2024) reported that rabbit urine has a higher N content than ruminant urine and can significantly increase plant growth and biomass accumulation in a relatively short time. The high N content in rabbit urine accelerates the formation of amino acids, chlorophyll, and structural proteins in the vegetative phase of shallots, which is then reflected in the simultaneous increase in N and K uptake.

The superiority of rabbit urine over goat urine is consistent across all nutrient uptake parameters. In the rabbit urine LOF treatment, N uptake was recorded to be almost twice as high as in the goat urine LOF treatment, with a difference of 19.37 g or 84.7% greater. The same occurred in K uptake, where rabbit urine LOF showed an increase of up to 13.32 g or more than 70%. Physiologically, shallots are very responsive to increased N supply at the beginning of growth, as this element plays an important role in the formation of leaves—the main photosynthetic organ. When N availability increases sharply, the rate of photosynthesis also increases, so that carbohydrate formation and translocation of assimilates to the bulbs occur more intensively. This explains why rabbit urine LOF not only has higher nutrient uptake but also produces the highest biomass and tuber yield.

Research by Yetunde et al. (2022) shows that rabbit urine can increase the growth and yield of Amaranthus hybridus beyond inorganic urea fertilizer, as it not only provides N but also dissolved organic compounds that strengthen plant metabolism. Mbonayo et al. (2025) also found that rabbit urine significantly increased plant height, biomass, and nutrient uptake when used as the main nutrient source in food crop cultivation.

The differences between doses of rabbit urine LOF further reinforce these results. Treatment C2 (300 mL L^{-1}) showed higher N and K uptake than C1 (100 mL L^{-1}), with differences of 25.1% for N and 29.6% for K, respectively in (Table 9) and (Table 10). Increasing the dose increased the amount of nutrients released into the soil and enriched labile N in the rhizosphere. On the other hand, rapid mineralization makes nutrients immediately available to plants; thus, increasing the dose does not cause nutrient saturation but instead produces a concentration gradient that is more in line with the physiological needs of shallots. This phenomenon of high-dose superiority was also noted in a study of fish waste-based LOF by Sutriana et al. (2023), which showed that increasing LOF concentration increased N and K uptake up to the physiological optimum threshold before a decrease in response occurred.

In contrast, plant-based LOF from banana peel and pineapple peel showed no significant differences between doses. A characteristic of plant-based sources is their

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lower N content and slower decomposition rate, so that increasing the dose does not necessarily increase N mineralization. Mandasari et al. (2025) reported that fermentation of pineapple peel with EM4 did not result in a significant increase in N and P in the final formulation, and that the LOF was more effective as a potassium supplier and carbon source than as a nitrogen source. This is consistent with the results of this study, where N uptake in the P1 vs. P2 and N1 vs. N2 groups did not differ significantly.

Overall, the pattern of N and K nutrient uptake in this study shows a strong relationship between organic matter quality, nutrient content, and physiological effectiveness. Animal LOF was found to provide a more readily available nutrient supply, while plant LOF worked more slowly and did not provide sufficient N uptake to maximize crop yields. When compared directly, rabbit urine ranked highest in all parameters, both at the soil and plant levels. Therefore, the combination of 50% NPK with 300 mL L^{-1} of rabbit urine LOF emerged as the most efficient fertilization formulation if the main objective was to increase nutrient uptake while improving the chemical conditions of nutrient-poor Ultisols.

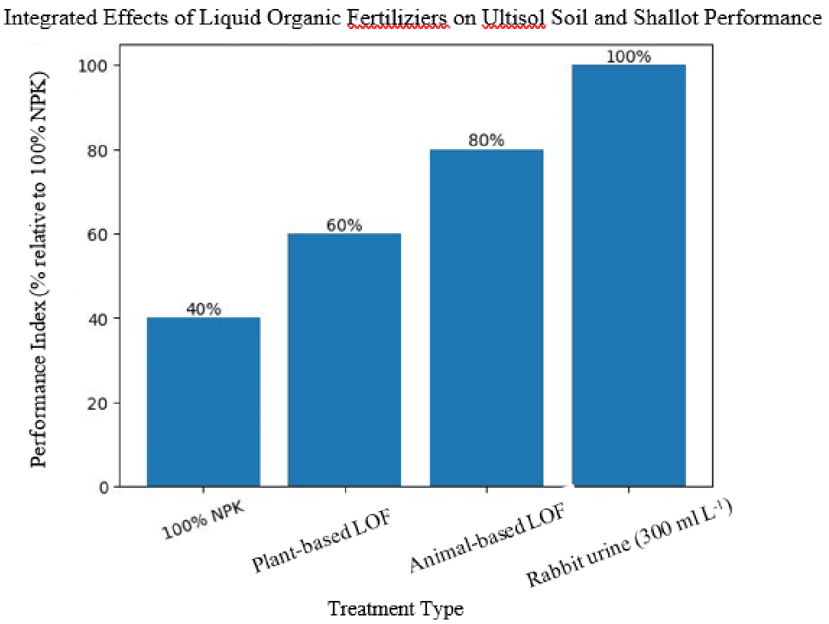

Figure 1. Effectiveness of Liquid Organic Fertilizers in Enhancing Ultisol Fertility and Shallot Yield

Figure 1 illustrates the integrated performance index of different fertilization strategies on Ultisol soil, combining key parameters including soil fertility, nutrient uptake, plant growth, and yield. The results clearly show a progressive increase in performance across treatments. The 100% NPK treatment (control) exhibited the lowest performance (40%), indicating that sole inorganic fertilization is less effective in improving overall soil–plant system productivity in Ultisol conditions. The application of plant-based liquid organic fertilizers (60%) resulted in a moderate improvement, reflecting their role in enhancing soil chemical properties such as organic carbon, cation exchange capacity (CEC), and potassium availability. However, their contribution to nutrient uptake and yield remained limited. In contrast, animal-based liquid organic fertilizers (80%) demonstrated a substantially higher performance. This indicates their stronger effect on nutrient availability, particularly nitrogen, which directly supports plant growth and biomass accumulation. The highest performance was achieved by rabbit urine at 300 mL L^{-1} (100%), confirming its superior

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effectiveness. This treatment maximized nutrient uptake (especially N and K), improved soil fertility, and significantly increased shallot yield. The result highlights the importance of nutrient-rich, rapidly mineralizable organic inputs in improving productivity on low-fertility Ultisol soils.

4. Limitations and Future Directions

This study provides strong evidence that integrating liquid organic fertilizers (LOFs) with reduced NPK rates can improve soil fertility and shallot productivity on Ultisol soils. Nevertheless, several limitations should be acknowledged.

First, this experiment was conducted in polybags under semi-controlled conditions, which may not fully capture the variability of field environments, including runoff, soil heterogeneity, and fluctuating microclimate factors. Second, the study duration covered only one planting period; therefore, long-term impacts—such as nutrient accumulation, changes in soil microbial communities, and potential risks of nitrogen leaching—remain unaddressed. Third, although this research successfully compared plant-based and animal-based LOFs, the biochemical mechanisms underlying nutrient mineralization, microbial interactions, and the stability of organic compounds during fermentation were not evaluated. These mechanistic insights could further clarify why rabbit urine consistently outperformed other LOF sources.

Future research should expand to multi-season and multi-location field trials to improve external validity and evaluate sustainability over time. Studies incorporating soil microbiome profiling, enzymatic activity, and nutrient cycling models are necessary to better understand the biochemical basis of LOF effectiveness. Additionally, future investigations should explore optimizing fermentation techniques, blending plant- and animal-based LOFs, and developing standardized LOF formulations tailored to specific soil constraints. A cost–benefit analysis and environmental impact assessment—including greenhouse gas emissions and nutrient runoff—will also be essential for supporting policy recommendations and large-scale farmer adoption.

5. Conclusion

This study shows that integrating 50% NPK with liquid organic fertilizers (LOFs) improves shallot growth, nutrient uptake, and soil chemical properties in Ultisol soil. Rabbit urine–based LOF was the most effective treatment, significantly enhancing biomass, N and K uptake, and yield. Practically, combining reduced NPK with animal-based LOFs offers a promising strategy to increase nutrient-use efficiency and reduce reliance on synthetic fertilizers, although adoption should consider site-specific conditions. However, the results are limited to short-term, polybag-based conditions and may not fully represent field performance. Therefore, future research should include multi-location field trials, long-term soil fertility evaluation, and investigation of underlying mechanisms such as soil microbial activity and nutrient cycling.

For practical application, farmers are encouraged to adopt integrated fertilization strategies by combining 50% NPK with locally available animal-based liquid organic fertilizers, particularly rabbit urine–based LOF, to improve nutrient-use efficiency and reduce input costs while maintaining soil health. Policymakers should support this approach through extension programs, training, and the development of standards for organic fertilizer production and use. Future research should focus on multi-location field trials under diverse agroecological conditions, long-term assessments of soil fertility and crop productivity, and deeper investigation into the roles of soil microbial activity, nutrient cycling, and environmental impacts to ensure the sustainability and scalability of this fertilization strategy.

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Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the process of compiling this work, the author did not use any AI for any process in this article. The author is also fully responsible for the content of this publication.

Authorship Contribution Statement

[Ansyori, Ansyori]: conceptualization, methodology, investigation, data curation, formal analysis, writing original draft, visualization. [Herfandi Lamdo]: conceptualization, methodology, supervision, writing, review & editing. [Nabillah Anissa]: investigation, data curation, validation, writing, review & editing. [Tika Leoni Putri]: formal analysis, visualization, writing, review & editing. [Soleha Soleha]: investigation, resources, writing, review & editing. [Dian Latifathul Mar'ah]: supervision, project administration, writing, review & editing. [Putri Mariska Fahmi]: supervision, funding acquisition, project administration, writing, review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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