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Optimization of Healthy Lettuce Production Through The Tofu Waste Poc Application

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Abstract
The tofu industry generates large amounts of liquid waste that can pollute the environment if not properly managed. However, this waste contains nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which can be utilized to produce liquid organic fertilizer. This study evaluates the effectiveness of tofu waste-based fertilizer (POC LIMBAT) for sustainable lettuce (Lactuca sativa L.) cultivation. POC LIMBAT is produced through fermentation with molasses, coconut water, EM4, spices, and sprouts. Laboratory tests show that it contains macro- and micronutrients that meet national quality standards (SNI). The experiment used a randomized block design (RBD) with four fertilizer concentrations: 0% (P1), 15% (P2), 30% (P3), and 45% (P4), each repeated six times. Data were analyzed using ANOVA and Duncan's Multiple Range Test (DMRT) at a 5% significance level. Results indicated that the 30% concentration (P3) produced the best plant growth and yield, including height, leaf number, leaf area, fresh weight, root weight, total plant weight, and harvest index. Therefore, POC LIMBAT is an effective, eco-friendly, and applicable liquid organic fertilizer to enhance lettuce productivity.

INTRODUCTION

The tofu industry is one of the food sectors that generates a significant amount of waste, particularly in the form of liquid waste. This tofu liquid waste is a by-product of the production process which, if not properly treated, can lead to serious environmental pollution due to its high organic content and biochemical oxygen demand (BOD). However, this waste also contains beneficial nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are essential for plant growth and can be utilized as raw materials for producing liquid organic fertilizer (POC). By applying a controlled fermentation process involving beneficial microorganisms, the complex organic compounds in tofu liquid waste can be decomposed into simpler, plant-available forms. The addition of molasses, coconut water, EM4, and natural ingredients such as spices and sprouts enhances microbial activity and nutrient enrichment during fermentation. The resulting fertilizer is not only eco-friendly but also contributes to improving soil fertility and plant productivity. Utilizing tofu liquid waste as POC aligns with sustainable agricultural practices by reducing waste pollution, promoting nutrient recycling, and supporting organic farming systems. This approach represents an innovative and practical

solution for managing agro-industrial waste while fostering environmental conservation and sustainable food production.

Lettuce cultivation (*Lactuca sativa L.*) is one of the farming options that is in great demand by farmers because it has a relatively short harvest cycle and is able to adapt to various planting media, both open land and hydroponic systems Jagur *et al*., (2021). Despite this, lettuce cultivation still faces challenges such as the need for intensive care and susceptibility to pest and disease attacks, so the selection of the right type of fertilizer is a determining factor for the success of production by Hapsoh *et al*., (2024). As an innovative effort to increase productivity and efficiency, several farmer groups in Jogoroto District have begun to utilize liquid organic fertilizer (POC) made from tofu waste in the cultivation of Sari and Wibowo lettuce, (2023).

Various studies have been conducted related to the use of tofu liquid waste as liquid organic fertilizer. Marian and Tuhuteru (2019) showed that the administration of POC of tofu waste on chicory plants can increase growth parameters, with optimal concentrations of 10% to 30%. Farhana and Yayi (2021) also proved that the application of POC of tofu waste in chili and tomato plants can significantly accelerate the rate of growth and development in the vegetative phase. Meanwhile, Putra *et al*. (2022) and Anggara *et al*. (2023) emphasizes the benefits of tofu waste POC in environmental and social aspects, namely reducing pollution due to industrial waste and increasing public awareness in managing waste productively.

Liquid organic fertilizer applied through leaves is known to contain essential macro and micro nutrients such as N, P, K, Ca, Mg, Fe, and other microelements, which are important for supporting the process of photosynthesis, vegetative growth, and yield formation. In addition, additives in the fermentation process such as molasses, coconut water, EM4, spices (turmeric and lemongrass), and sprouts, also play an important role in accelerating the decomposition of organic matter and improving the quality of fertilizers. Molasses as a source of carbohydrates supports the growth of fermented microorganisms, while EM4 contains effective microbes that help fertilize the soil and reduce dependence on chemical fertilizers Fitria and Sari, (2023). The fermentation process with the addition of molasses and EM4 bioactivators has been proven to increase the nutrient content in liquid organic fertilizers and accelerate the decomposition process of organic matter Jalaluddin *et al.,* (2020) Spices and sprouts also add bioactive value and accelerate fermentation through the contribution of local microorganisms that increase fermentation activity Arifin *et al.,* (2022).

Based on this background, this study aims to evaluate the effect of applying liquid organic fertilizer derived from tofu liquid waste (POC LIMBAT) on the growth and yield of lettuce plants *(Lactuca sativa L.*) to determine the optimal concentration for plant productivity. POC LIMBAT is produced through a fermentation process that utilizes tofu liquid waste combined with molasses, coconut water, EM4, and natural ingredients such as spices and sprouts, which function to enhance microbial activity and nutrient availability. The application of this fertilizer is expected to improve soil fertility, stimulate plant growth, and increase lettuce yield through the supply of essential macro and micronutrients. In addition, this research emphasizes the importance of utilizing agro-industrial waste as an alternative organic fertilizer to reduce dependence on chemical fertilizers that can harm the environment. The study also serves as an effort to promote circular economy principles by converting waste into valuable agricultural inputs. Through this approach, it is hoped that the findings can support the development of environmentally friendly agricultural innovations and sustainable cultivation practices that not only enhance crop productivity but also minimize the negative environmental impacts of food industry waste

RESEARCH METHODOLOGY

This research was conducted in Jarak Kulon Village, Jogoroto District, Jombang Regency, from April to May 2025. The study aimed to evaluate the effectiveness of tofu waste-based liquid organic fertilizer (POC LIMBAT) in improving the growth and yield of lettuce (Lactuca sativa L.). The research used an experimental method with a randomized block design (RBD) consisting of four levels of POC LIMBAT concentration treatments: 0% (P1), 15% (P2), 30% (P3), and 45% (P4). Each treatment was repeated six times, bringing the total number of experimental units to 24.

The fertilizer was produced through a fermentation process using tofu liquid waste mixed with molasses, coconut water, EM4, spices, and sprouts to enhance microbial activity and nutrient availability. Observations were made on various growth parameters, including plant height, number of leaves, leaf area, root length, and biomass weight. Yield components such as fresh weight and harvest index were also measured to determine the most effective concentration. Data were analyzed using analysis of variance (ANOVA) and continued with Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results were expected to identify the optimal POC concentration that promotes healthy, sustainable, and environmentally friendly lettuce cultivation.

The manufacture of POC LIMBAT is carried out through a fermentation process for 14 to 21 days. The main ingredients used consisted of 80 liters of tofu liquid waste, 2 kg of lemongrass, 1 kg of turmeric, 1 kg of sprouts, 3 liters of molasses, 200 mL of EM4, and 10 liters of coconut water. The equipment used includes buckets, stirrers, scales, and measuring cups. Lemongrass is finely chopped, while turmeric and sprouts are mashed using a blender or mash tool. The three ingredients are mixed in one container and a little coconut water is added to make it easier to mix. The spice mixture is then put into a barrel that has been filled with tofu liquid waste, followed by the addition of molasses and EM4 slowly while stirring evenly to ensure optimal distribution of microorganisms. Once all ingredients are homogeneously mixed, the fermentation container is tightly sealed to make it airtight and stored in a stable room temperature shade. Once fermentation is complete, the solution is filtered using a fine cloth, then packaged in a clean container like a jerrycan. The finished POC LIMBAT is applied by dissolving 2–4 measuring cups (200 mL each) in 15 liters of water, then watered into the planting medium according to the treatment.

The parameters observed in this study include plant height, number of leaves, leaf area, fresh weight of plants, root weight, plant weight per plot, and harvest index value. Observations are carried out periodically until the plants are 35 days old after planting. The data obtained was analyzed using variance analysis (ANOVA), and if there was a significant difference between treatments, further tests were carried out using *Duncan's Multiple Range Test* (DMRT) at a significance level of 5%.

RESULTS AND DISCUSSION

Chemical Characteristics of POC LIMBAT

To determine the quality of the nutrient content in the liquid organic fertilizer produced, laboratory analysis was carried out on POC LIMBAT. The parameters tested included C-organic levels as well as the content of the main macronutrients, namely nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O). The results of laboratory tests are presented in Table 1 below.

Table 1. POC LIMBAT Laboratory Test Results

Parameter	Unit	Quality Standards	Hasil Little Tongue
C-Organic	% (w/f)	Minimum 10	15,21
Hara macro: • N • P2O5 • K2O	% (w/f)	2-6	N 1,92 P2O5 1,96 K2O 2,01

The results of laboratory analysis showed that the C-organic content in POC LIMBAT reached 15.21%, exceeding the minimum standard of 10%, which indicates its ability to increase microbial activity and improve soil structure. The content of macronutrients, namely nitrogen (1.92%), phosphorus (1.96%), and potassium (2.01%) indicates that potassium levels have met the quality standards of liquid organic fertilizers (2–6%), while nitrogen and phosphorus are slightly below the minimum limit. However, the content of the three is still considered sufficient to support plant growth, making POC LIMBAT have high potential as an efficient and environmentally friendly alternative organic fertilizer.

Lettuce Plant Response to POC LIMBAT Application

Research shows that treatment with a concentration of 30% (P3) produces the best growth in all growth parameters and yield of lettuce plants compared to other treatments as evidenced by several results of each parameter as follows:

1. Plant Height

Table 2. Lettuce Plant Height Based on Treatment Percentage of POC LIMBAT Use

Treatment	Lettuce Plant Height (cm)				
	7HST	14HST	21HST	28HST	35HST
P1 (0%)	1,56 ±1,50 a	3,70 ±2,09 a	6,73 ±4,84 a	10.43 ±6.74 A	20.70 ±6.54 A
P2 15% (150ml/liter)	2,13 ±1,63 b	4,76 ±2,33 b	7,36 ±3,66 b	11.00 ±8.67 A	21.76 ±4.08 B
P3 30% (300ml/liter)	3,13 ±3,01 c	6,66 ±5,31 c	9,90 ±2,09 c	17,80 ±7,48 c	24,96 ±5,57 c
P4 45% (450ml/liter)	2,16 ±1,50 b	4,76 ±4,80 b	7,73 ±3,26 b	15.20 ±6.32 B	22.26 ±3.26 B

Information:
Numbers followed by the same letter in the same column show no real difference

The results of the observation showed that the application of liquid organic fertilizer based on tofu waste had a significant effect on the high growth of lettuce plants. The P3 treatment with a concentration of 30% (300ml/liter) gave the best response with a plant height of 24.96cm at 35 HST, followed by P4 (45%) at 22.26cm, P2 (15%) at 21.76cm, and control (P1) at 20.70cm.

The optimal concentration of liquid organic fertilizer is at 30%, where an increase in concentration of up to 45% actually decreases the height of the plant. This is in line with research by Kurniawati and Islami (2020) who reported that certain concentrations provide an optimal response to lettuce growth. Decreased growth at high concentrations indicates a toxicity effect that inhibits plant growth Aisyah *et al.,* (2022).

2. Number of Leaves

Table 3. Number of Lettuce Leaves Based on Treatment Percentage of POC LIMBAT Use

Treatment	Number of Lettuce Leaves (strands)				
	7HST	14HST	21HST	28HST	35HST
P1 (0%)	1,40 ±2,52 a	2,23 ±1,50 a	6,70 ±2,09 a	10.87 ±2.42 a	18.07 ±2.42 a
P2 15% (150ml/liter)	1,53 ±2,73 a	2,46 ±2,42 a	7,06 ±3,01 a	11.53 ±4.13 a	18.93 ±3.01 b
P3 30% (300ml/liter)	1,90 ±2,09 b	4,86 ±2,42 c	9,80 ±6,19 c	18,00 ±6,81 c	23,80 ±4,73 c
P4 45% (450ml/liter)	1,56 ±1,50 a	3,20 ±2,82 b	8,76 ±4,08 b	16.00 ±10.80 b	19.27 ±3.93 b

Information:
Numbers followed by the same letter in the same column show no real difference

The increase in the number of leaves was also highest in P3 (23.80 leaves) compared to the control (18.07 leaves), with an exponential growth pattern of up to 21 HST, then decreased in the generative phase. These findings are consistent with the study of Setyaputri *et al*. (2020) which shows the significant role of organic fertilizers on the leaf growth of horticultural plants.

3. Leaf Area

Table 4. Lettuce Leaf Area Based on Treatment Percentage of POC LIMBAT Use

Treatment	Lettuce Leaf Area (cm2)
P1 (0%)	3457.80 ±1381.24 a
P2 15% (150ml/liter)	4758.47 ±1914.29 b
P3 30% (300ml/liter)	6755.87 ±1074.81 d
P4 45% (450ml/liter)	5226.57 ±1584.13 c

Information:
Numbers followed by the same letter in the same column show no real difference

The application of liquid organic fertilizer has a significant effect on the area of lettuce leaves. The P3 treatment (30%) resulted in the highest leaf area of 6755.87cm², a 95% increase compared to the control (3457.80cm²). P4 (45%) and P2 (15%) treatments yielded leaf areas of 5226.57cm² and 4758.47cm².

A concentration of 30% provides an optimal response with low variability (±1074.81), indicating good growth consistency. This is in line with the research of Sondari *et al.,* (2023) that liquid organic fertilizer has a real effect on the area of lettuce leaves. The decrease in leaf area at a concentration of 45% indicates the effect of toxicity that inhibits the development of Baharuddin leaves, (2020).

4. Fresh Weight of Plants

The application of liquid organic fertilizer based on tofu waste showed a significant influence on the fresh weight of lettuce plants. The P3 treatment (30%) resulted in the highest fresh weight of 180.33grams, an increase of 98% compared to the control (91.10 grams). The P4 (45%) and P2 (15%) treatments gave almost the same results, namely 143.17 grams and 140.33 grams.

Table 5. Fresh Weight of Lettuce Based on Treatment Percentage of POC LIMBAT Use

Treatment	Fresh Weight of Lettuce (grams)
P1 (0%)	91.10 ±19.08 a
P2 15% (150ml/liter)	140.33 ±55.85 b
P3 30% (300ml/liter)	180.33 ±20.10 c
P4 45% (450ml/liter)	143.17 ±22.39 b

Information: Numbers followed by the same letter in the same column show no real difference

A concentration of 30% is the optimal dose, where an increase in concentration of up to 45% actually decreases production. This is in accordance with the research of Kurniawati and Islami (2020) which reported the real effect of liquid organic fertilizer on lettuce yields with a certain concentration. Decreased yields at high concentrations indicate disturbances in nutrient balance that can reduce crop production (Sari, 2023). High data variability in P2 (±55.85) showed a non-uniform response at low concentrations, whereas P3 provided the best result consistency with the smallest standard deviation (±20.10).

5. Root Weight

Table 6. Lettuce Root Weight Based on Treatment Percentage of POC LIMBAT Use

Treatment	Lettuce Root Weight (grams)
P1 (0%)	18.93 ±4.67 a
P2 15% (150ml/liter)	29.23 ±10.68 b
P3 30% (300ml/liter)	36.97 ±21.48 c
P4 45% (450ml/liter)	30.50 ±7.12 b

Information:
Numbers followed by the same letter in the same column show no real difference

The application of liquid organic fertilizer has a significant effect on the development of the lettuce root system. The P3 treatment (30%) resulted in the highest root weight of 36.97grams, an increase of 95% compared to controls (18.93grams). The P4 (45%) and P2 (15%) treatments resulted in root weights of 30.50 grams and 29.23 grams.

The concentration of 30% provided an optimal response to root development, despite having the highest data variability (±21,48). This is in line with research that the application of liquid organic fertilizer has a real effect on the growth of Hapsoh lettuce plants, (2023). The increase in root weight indicates the availability of nutrients that support the development of a better root system, where the mixing of liquid organic fertilizers has a positive effect on the growth of lettuce plants. A decrease in root weight at a concentration of 45% indicates a toxicity effect that can inhibit root development Sondari *et al.,* (2023).

6. Plant Weight per Plot

Table 7. Weight of Plant/Lettuce Plots Based on Treatment Percentage of POC LIMBAT Use

Treatment	Plant Weight per Plot (grams)
P1 (0%)	455.50 ±95.44 a
P2 15% (150ml/liter)	701.67 ±276.26 b
P3 30% (300ml/liter)	901,67 ±100,53 c
P4 45% (450ml/liter)	715.83 ±111.96 b

Information:
Numbers followed by the same letter in the same column show no real difference

In the P3 treatment, the total plant weight per plot reached 901.67 g, showing an increase in land efficiency and yield compared to other treatments. These results are in line with the findings of Puspitasari (2021) regarding the efficiency of organic soil improvement in supporting the production of leafy vegetables.

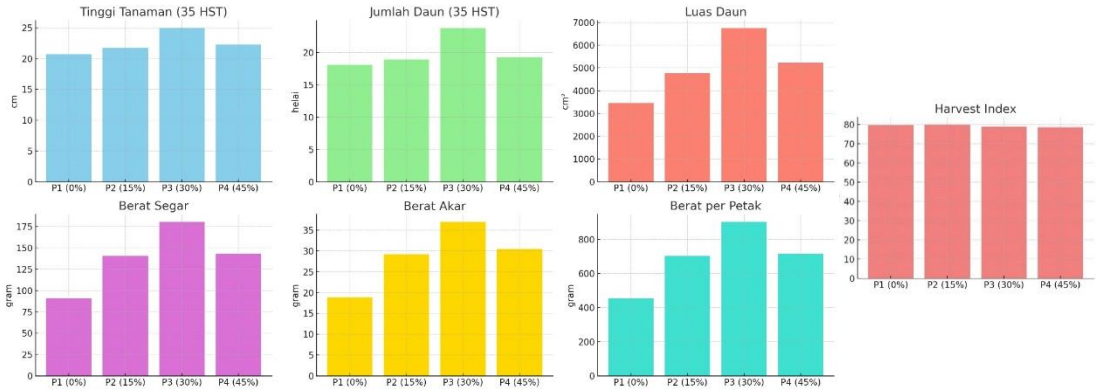
7. *Harvest Index* (HI)

Table 8. *Harvest Index* Lettuce Based on Treatment Percentage of POC LIMBAT Use

Treatment	Average Total Weight (g)	Average Leaf Weight (g)	Average HI (%)
P1 (0%)	94,2	75,0	79,6
P2 15% (150ml/liter)	148,6	118,6	79,8
P3 30% (300ml/liter)	178,8	141,4	78,9
P4 45% (450ml/liter)	143,2	112,8	78,6

The highest harvest index value was recorded at P2 (15%) at 79.8%, followed by P3 (78.9%). Although the HI values between treatments did not differ significantly (range 78–80%), P3 treatment still produced the highest biomass without reducing the efficiency of the harvestable portion of the crop, making it the best combination of growth and productivity.

General Analysis and Research Comparison



Picture 1. Visualization of Lettuce Plant Growth and Yield Data Based on POC LIMBAT Treatment

Based on the results of the research that has been conducted, the POC LIMBAT application shows a real influence on various parameters of lettuce plant growth and yield. Application at four different concentrations, namely 0% (P1), 15% (P2), 30% (P3), and 45% (P4), resulted in varied plant physiological responses. The highest results were generally obtained in the P3 treatment, which shows that the concentration of 30% is the optimal point in the utilization of POC LIMBAT.

The vegetative growth of lettuce plants increased significantly in P3, with the plant height reaching 25 cm, higher than P1 (21 cm) and P2 and P4 which were in the range of 22 cm, respectively. The highest number of leaves was also obtained in P3 with 25 leaves, while other treatments yielded between 18 to 19 leaves. The leaf area produced in P3 reaches 7000 cm², markedly higher than other treatments which only range from 3500–5200 cm². These findings suggest that the nutrients available at a concentration of 30% promote optimal leaf expansion, which contributes directly to the photosynthesis capacity and overall growth of the plant.

In terms of biomass and productivity, the P3 treatment also gave the highest yield, with the fresh weight of the plant reaching 175 grams, almost double that of other treatments ranging from 90 to 145 grams. The root weight at P3 also recorded the highest number, at 37 grams, indicating that the absorption of nutrients from POC LIMBAT not only stimulates the growth of the crown, but also supports the development of the root system. The productivity per crop plot in the P3 treatment reached 900 grams, far exceeding other treatments in the range of 450–750 grams, reinforcing the finding that the 30% concentration had the most optimal effect on crop yields.

Harvest efficiency measured through *the Harvest Index* (HI) value showed stability between treatments, with a value range between 77–79%. This consistency indicates that the increase in biomass produced does not cause an imbalance between the growth of the vegetative and generative parts of the plant. In other words, the increase in productivity that occurs is more efficient, not excessive.

The results of this study are in line with previous studies that showed the effectiveness of liquid organic fertilizers in improving the performance of horticultural crops. Research by Sari *et al*. (2019) reported an increase in vegetative growth of leaf plants by up to 40–60% due to POC administration, which is consistent with the increase in plant height (19%) and leaf count (39%) observed in P3 treatment. These findings also support the concept of concentration optimization according to the principle of "Liebig's minimum law", where treatment with higher concentrations (P4) actually shows a decrease in performance, indicating a threshold of nutrients that can be accepted by plants.

In addition to affecting the crown section, the increase in root biomass in the P3 treatment suggests that POC LIMBAT also strengthens the root system. This supports the results of Maharani *et al*. (2021) which states that high-quality liquid organic fertilizers are able to provide a growth stimulus not only in the leaves, but also in the roots. The balanced crown and root ratio, which is approximately 4.7:1 at P3, indicates an efficient biomass allocation that supports the long-term resilience and productivity of the crops.

The consistency of *the Harvest Index* value across all treatments reinforces the suspicion that POC LIMBAT is able to provide nutrients in a balanced manner, different from some synthetic fertilizers that tend to trigger excessive vegetative growth and reduce crop efficiency. Thus, it can be concluded that the concentration of 30% is the optimum point that provides a significant improvement in all growth and yield parameters, without sacrificing the physiological efficiency of the plant.

Overall, the results of this study provide a strong scientific basis in recommending the use of POC LIMBAT as an effective alternative to liquid organic fertilizer for healthy lettuce cultivation. Excellence in growth parameters, productivity, harvest efficiency, and alignment with previous research results make POC LIMBAT an applicable solution for sustainable horticultural agriculture.

Implications of the Findings

The findings of this study provide important implications for the development of healthy lettuce cultivation systems based on the principles of sustainable agriculture. The application of POC LIMBAT with a concentration of 30% has been proven to provide a significant improvement in the growth and yield of lettuce plants, showing that tofu liquid waste can be utilized as an effective source of liquid organic fertilizer. This effectiveness reflects the great potential of tofu industrial waste as an alternative raw material for environmentally friendly agricultural inputs, as well as a local resource-based waste management solution.

The application of POC LIMBAT in lettuce cultivation has direct implications for farmers' production cost efficiency, by reducing dependence on chemical fertilizers and increasing independence in the management of agricultural inputs. The abundant use of tofu waste in tofu-producing areas opens up opportunities for production center villages to develop waste-based integrated agricultural systems that are effective and competitive. In addition, these results also show that the increase in crop yield is not accompanied by excessive vegetative growth, but occurs in a balanced manner, as reflected in the stability of the harvest index value.

The results of this study provide a solid scientific foundation for developing farmer training and extension programs focused on the production and application of tofu waste-based liquid organic fertilizer (POC LIMBAT). Through these initiatives, farmers can gain

knowledge and practical skills in managing tofu liquid waste effectively, transforming it from a potential pollutant into a valuable agricultural input. This approach supports efforts to reduce dependence on chemical fertilizers, enhance soil fertility, and promote environmentally friendly farming practices. Moreover, the use of POC LIMBAT can improve crop growth and yield while minimizing environmental degradation caused by industrial waste disposal. Such innovations strengthen farmers' capacity to apply appropriate and sustainable technologies, contributing to rural economic empowerment. The integration between waste management and food crop cultivation also reflects the principles of circular economy, where waste is reused for productive purposes. Overall, this concept offers a practical model for developing efficient, productive, and sustainable agricultural systems, particularly in supporting lettuce cultivation and broader horticultural production in rural areas of Indonesia.

CONCLUSIONS AND SUGGESTION

POC LIMBAT, formulated from tofu liquid waste, effectively increases lettuce growth and yield, with the best results at a 30% concentration. Although its nitrogen and phosphorus levels are slightly below standards, the nutrient content still supports optimal growth. Practice-based training improves farmers' skills in using waste-based fertilizers. Farmers are encouraged to adopt POC LIMBAT to reduce chemical fertilizer use, supported by Gapoktan, local governments, and the tofu industry through collective production and sustainable waste management.

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