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Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) of Green Beans (*Vigna radiata* L.) with Combination of Organic Fertilizers in Ultisol Soil

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Abstract

This study aimed to investigate the impact of the interaction between organic fertilizer on the Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) of mung beans grown in Ultisol soil. The research was conducted in Pangkalan Kuras District, Pelalawan Regency, from July to October 2024. The experimental design was a factorial, completely randomized design (CRD) with two factors. The first factor consisted of different doses of bamboo leaf compost fertilizer (0, 50, 100, and 150 g/plant), while the second factor included various concentrations of tofu liquid waste LOF(0, 25%, 50%, and 75%). Statistical analysis was performed using variance analysis followed by the Honest Real Difference Test (BNJ) at a significance level of 5%. The results indicated that the interaction between bamboo leaf compost fertilizer and tofu liquid waste LOFsignificantly influenced the plants' relative growth rate and net assimilation rate. The most effective treatment was observed with 150 g/plant of bamboo leaf compost fertilizer combined with 75% concentration of tofu liquid waste. Furthermore, the main effect of bamboo leaf compost fertilizer was significant on RGR and NAR, with the optimal treatment being 150 g/plant. Similarly, the main effect of tofu liquid waste was significant on RGR and NAR, with the best treatment observed at a 75% concentration.

Keywords: Bamboo Leaves, Combination, Mung Bean, LOF, Tofu Liquid Waste, Ultisol

1. Introduction

Mung beans (*Vigna radiata* L.) are a crucial food crop in Indonesia, providing a valuable source of vegetable protein for the population. Rich in protein, fiber, vitamins, and minerals, mung beans are commonly used in processed food products like porridge and flour (Wu et al., 2019). Beyond their nutritional value, mung beans also enhance soil fertility by forming a symbiotic relationship with nitrogen-fixing bacteria (Rhizobium spp.), naturally enriching the soil with nitrogen and reducing the need for synthetic fertilizers (Diatta et al., 2020).

Ultisol soil, prevalent in tropical regions like Indonesia's Sumatra and Kalimantan, faces challenges due to its low pH (<4.5) and high aluminum and iron levels, which can harm plants. Effective management strategies, such as adding organic matter, are crucial to enhance soil quality and plant growth. Research by Iskandar et al. (2020) demonstrates that a blend of organic fertilizer and dolomite lime boosts legume crop yields, like green beans, in acidic soils. Moreover, utilizing biochar from agricultural waste can enhance cation exchange capacity (CEC), balance pH, and improve water retention in Ultisol soil. By implementing these methods, the productivity of Ultisol soil can be optimized to support sustainable agriculture in tropical regions.

Utilizing organic waste for composting addresses waste management issues and sustainably enhances soil quality. The tofu industry, present in urban and rural areas, generates solid and liquid waste during production. Solid waste is a byproduct of filtering and coagulation, while liquid waste results from washing, boiling, pressing, and tofu production, leading to significant liquid waste output. Improper disposal of this waste, common due to the large number of tofu industries, can have adverse environmental impacts (Levina, 2016).

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Bamboo leaves, rich in essential macronutrients like phosphorus (P) and potassium (K), have been identified as a valuable organic material for composting. Research by Baroroh (2015) demonstrates that bamboo leaves can yield high-quality compost, enhancing soil's physical and chemical properties. With an optimal C/N ratio of 17–36%, bamboo leaves decompose quickly compared to other organic materials (Fitriana et al., 2021).

Moreover, tofu industry waste, particularly the dregs, is a valuable nitrogen source crucial for promoting plant growth (Yulianti et al., 2021). Combining bamboo leaf compost with tofu waste can create nutrient-rich organic fertilizer, effectively boosting agricultural yields on Ultisol soil.

In Riau Province, the inadequate management of tofu industrial waste leads to environmental pollution. When discharged into water bodies, the high organic content in liquid tofu waste can cause eutrophication. To address this issue, compost-based waste processing technology is essential. Research by Harahap et al. (2021) shows that converting tofu waste into organic liquid fertilizer is eco-friendly and boosts plant growth by up to 30% on suboptimal land like Ultisol. Integrating agricultural systems with local organic materials, including tofu waste, offers a sustainable solution for modern agriculture in Indonesia. This study aims to assess the impact of organic material interactions on the Relative Growth Rate (RGR) and Net Assimilation Rate (NAR) of green beans grown in Ultisol soil.

2. Material and Methods

The study occurred in Pangkalan Kuras District, Pelalawan Regency, specifically at the geographical coordinates 0.14078, 102.07575. This study was conducted over four months, commencing in July and concluding in October 2024. The components utilized in this investigation included Vima 1 mung bean seeds (*Vigna radiata* L.), ultisols soil, water, polybags with dimensions of 35 cm x 40 cm, Dhitane M-45, Curacron, bamboo leaf compost fertilizer, and tofu liquid waste. The equipment utilized for this investigation included hoes, tarpaulins, sieves, meters, rulers, parents, calipers, watering cans, analytical scales, ovens, cameras, books, and stationery.

The research method employed in this study was a factorial, Completely Randomized Design (CRD) with two factors. The initial variable being studied is the application of bamboo leaf compost fertilizer, comprised of four distinct treatment levels. The second variable being examined is the strength of the tofu wastewater, which encompasses four distinct levels of treatment. Sixteen different treatment combinations were obtained by combining the two specified treatments. There were a total of 48 experimental units, with each treatment combination being repeated three times. Each experimental unit comprised 9 plants, resulting in a total of 432 plants being sampled for the experiment.

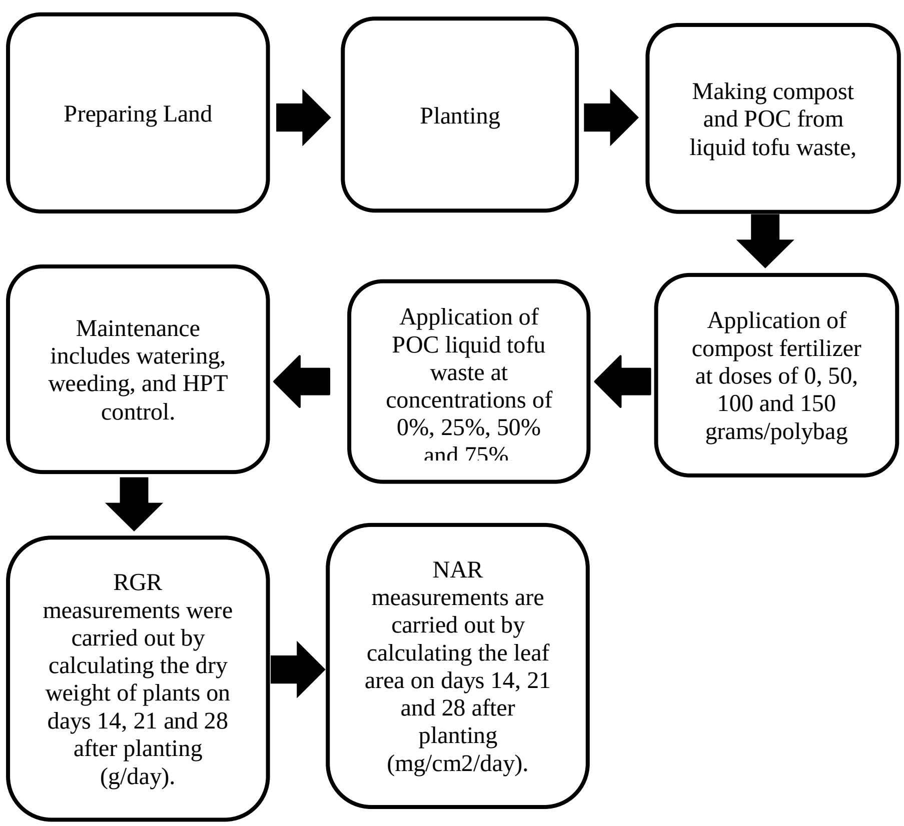

Figure 1. Research flow diagram

RGR measurements were carried out by dismantling the sample plants, cleaning and drying them in an oven at 700C for 48 hours, and weighing them using an analytical balance. Observations were made 3 times, namely when the plants were 14, 21, and 28 HST. The results obtained were analyzed statistically and presented in tabular form. The relative growth rate is calculated using the following formula:

$$\mathbf{RGR} = \frac{Ln\,W_2 - Ln\,W_1}{T_2 - T_1}$$

Notes:
RGR = Relative growth rate
W2 = Dry weight observation 2 (g)
W1 = Dry weight observation 1 (g)
T2 = Age of plant observed 2 (days)
T1 = Age of plant observed 1 (day)
Ln = 1/log

Observations were made by dismantling the sample plants, cleaning and drying them using an oven at 700 C for 48 hours, and weighing them using an analytical scale. Observations were made 3 times, namely when the plants were 14, 21, and 28 HST. The results obtained were then analyzed statistically and presented in tabular form. The net assimilation rate can be calculated using the following formula:

$$\mathbf{NAR} = \frac{(W_2 - W_1)}{(T_2 - T_1)} \times \frac{(LnLD_2 - LnLD_1)}{(LD_2 - LD_1)}$$

Notes:
NAR = Net Assimilation Rate
D2 = Leaf area observation 2
D1 = Leaf area observation 1
T2 = Age of plants observed 2nd (days)
T1 = Age of plant observed 1 (days)
Ln = 1/log

The observation data from each treatment were analyzed statistically using the R Studio program version 4.4.1. If the calculated F is greater than the F table, it is continued with the BNJ further test at the 5% level.

3. Results and Discussion

3.1. Relative Growth Rate (g/day)

The results of observations of the relative growth rate of green bean plants at the age of 14-21, 21-28, and 28-35 days after planting after analysis of variance showed that the interaction and main treatment of bamboo leaf compost fertilizer and tofu liquid waste had a significant effect on the relative growth rate of green bean plants. The average relative growth rate of green bean plants after further testing for Honestly Significant Differences (HSD) at the 5% level can be seen in Table 1.

Table 1. Average relative growth rate of green bean plants (g/day) with bamboo leaf compost and tofu liquid waste treatment

Plant Age (HST)	Bamboo Leaf Compost (g/plant)	Tofu Liquid Waste (% v/v)				Mean
		0 (T0)	25 (T1)	50 (T2)	75 (T3)	
14-21	0 (B0)	0,0338 ±0,003 j	0,0387±0,004 ij	0,0374 ±0,007 ij	0,0437 ±0,003 ghi	0,0384 ±0,02 d
	50 (B1)	0,0399 ±0,008 hij	0,0510±0,001 ef	0,0460 ±0,001 fgh	0,0564 ±0,001 de	0,0483 ±0,003 c
	100 (B2)	0,0498 ±0,005 fg	0,0520 ±0,003 ef	0,0618 ±0,004 cd	0,0667 ±0,001 bc	0,0576 ±0,002 b
	150 (B3)	0,0612±0,002 cd	0,0677 ±0,002 bc	0,0715 ±0,001 b	0,0790 ±0,007 a	0,0698 ±0,002 a
	Average	0,0462±0,003 c	0,0523 ±0,001 b	0,0542 ±0,002 b	0,0614 ±0,004 a	
		KK = 4,00%	**BNJ B&T = 0,0024**	**BNJ BT = 0,0065**		
21-28	0 (B0)	0,0833 ±0,003 g	0,0867 ±0,005 fg	0,0880 ±0,003 fg	0,1016±0,007 ef	0,0899 ±0,002 c
	50 (B1)	0,0850 ±0,008 fg	0,0927 ±0,003 ef	0,0933 ±0,009 ef	0,1130 ±0,003 cd	0,0960 ±0,004 c
	100 (B2)	0,1070 ±0,007 de	0,1150 ±0,008 cd	0,1133 ±0,003 cd	0,1217 ±0,004 bc	0,1143 ±0,004 b
	150 (B3)	0,1075 ±0,002 de	0,1384 ±0,003 ab	0,1413 ±0,006 ab	0,1437 ±0,006 a	0,1327 ±0,007 a
	Average	0,0957 ±0,007 c	0,1082 ±0,002 b	0,1090 ±0,003 b	0,1200 ±0,002 a	
		KK = 5,14%	**BNJ B&T = 0,0062**	**BNJ BT = 0,0169**		
28-35	0 (B0)	0,1557 ±0,006 g	0,1607 ±0,001 efg	0,1673 ±0,001 d-g	0,1737 ±0,002 d-g	0,1643 ±0,007 c
	50 (B1)	0,1597 ±0,02 fg	0,1827 ±0,001 c-g	0,1883 ±0,02 b-g	0,1990 ±0,001 bcd	0,1824 ±0,004 b
	100 (B2)	0,1833 ±0,014 b-g	0,1600 ±0,006 fg	0,1943±0,007 b-f	0,2217 ±0,019 ab	0,1898 ±0,001 b
	150 (B3)	0,1970 ±0,006 b-e	0,2027 ±0,006 a-d	0,2133 ±0,006 abc	0,2380 ±0,019 a	0,2128 ±0,006 a
	Average	0,1739 ±0,008 c	0,1765 ±0,004 c	0,1908 ±0,007 b	0,2081 ±0,009 a	
		KK = 6,41%	**BNJ B&T = 0,0133**	**BNJ BT = 0,0364**		

The numbers in the columns followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

The elevated growth rate observed in B3T3 can be attributed to its correlation with an increase in dry weight. The rise in dry weight signifies the plant's capacity for accumulating organic material within itself, leading to an increase in overall weight. A plant's dry weight refers to its mass after eliminating all water content from its organs. Determining dry weight is a significant indicator for evaluating plant growth and development, as it represents the overall accumulation of organic compounds synthesized by the plant. This metric provides valuable insight into the plant's physiological processes and productivity. The measurement of plant dry weight also indicates the proportion of water versus solid materials present in plant tissue, which is a controlled factor. According to Kustiawan and colleagues (2024), using rice washing water at a 75% concentration in combination with Organic NPK has a discernible impact on the relative growth rate. This indicates that the amount of dry weight is strongly linked to the presence of nutrients in the growing medium and the ability of the photosynthesis process to continue sustainably.

The process of photosynthesis significantly impacts the relative growth rate of plants, as it directly influences the accumulation of biomass and, consequently, the dry weight of the plant over a certain period. The availability of nutrients and the efficiency of the photosynthesis process significantly impact the relative growth rate of plants in this particular instance. The synthesis of plant biomass, encompassing all organic materials produced through photosynthesis, nutrient uptake, and water absorption, arises from a multifaceted physiological mechanism. Lakitan (2011) defines the relative growth rate as the rise in biomass accumulation that contributes to the development of plant tissues and organs, originating from the products of photosynthesis—Furthermore, studies conducted by Poorter et al. The study conducted in 2012 demonstrates that environmental conditions, including light exposure, humidity, and temperature, play a significant role in influencing the effectiveness of photosynthesis. These factors ultimately impact the quantity of biomass plants can produce.

Maximizing and effective photosynthesis is crucial in enhancing the quantity of assimilation materials generated by plants. These nutrients are subsequently transported throughout the plant's tissues, including its leaves, stems, and roots, to facilitate a range of essential physiological functions, such as growth and the development of crucial plant organs necessary for survival, such as leaves, flowers, and roots. During photosynthesis, plants transform light energy into chemical energy stored as carbohydrates, serving as the primary source for both vegetative and generative growth.

Optimal photosynthetic efficiency will increase the amount of assimilable material and increase the overall biomass production. Some proposed steps to improve photosynthetic efficiency include optimizing light reactions, improving Calvin cycle enzymes, and introducing carbon concentration mechanisms in C3 plants (Li et al., 2023; He et al., 2023). In addition, multi-omics approaches show great potential in designing biomass crops with desired properties, supporting bioenergy and agricultural sustainability. These developments underscore the importance of a deeper understanding of photosynthesis in improving crop yield and quality in various ecosystems.

3.2. Net Assimilation Rate (NAR) (mg/cm2/day)

The findings of the observations conducted on the net assimilation rate of green bean plants at the ages of 14-21, 21-28, and 28-35 days after planting, after the analysis of variance, demonstrated that the interaction and primary treatment of bamboo leaf compost and tofu liquid waste exerted a significant effect on the net assimilation rate of green bean plants.

Table 2. Average net assimilation rate of mung bean plants (mg/cm2/day) with bamboo leaf compost and tofu liquid waste treatment.

Plant Age (HST)	Bamboo Leaf Compost (g/plant)	Tofu Liquid Waste (% v/v)				Mean
		0 (T0)	25 (T1)	50 (T2)	75 (T3)	
14-21	0 (B0)	0,0262 ±0,001 g	0,0293 ±0,001 fg	0,0317 ±0,001 fg	0,0370 ±0,002 ef	0,0311 ±0,001 c
	50 (B1)	0,0310 ±0,003 fg	0,0380 ±0,001 fg	0,0487 ±0,001 bc	0,0493 ±0,001 bc	0,0418 ±0,001 b
	100 (B2)	0,0463 ±0,002 cde	0,0387±0,001 ef	0,0517 ±0,001 abc	0,0523 ±0,003 abc	0,0473 ±0,001 a
	150 (B3)	0,0483 ±0,001 bcd	0,0513 ±0,009 abc	0,0573 ±0,002 ab	0,0603 ±0,001 a	0,0436 ±0,004 b
Average		0,0380 ±0,001 c	0,0393 ±0,004 bc	0,0474 ±0,001 ab	0,0498 ±0,001 a	
		KK = 7,25%	**BNJ B&T = 0,0035**	**BNJ BT = 0,0096**		
21-28	0 (B0)	0,0493 ±0,001 i	0,0509 ±0,001 hi	0,0587 ±0,001 gh	0,0695 ±0,001 ef	0,0571 ±0,001 c
	50 (B1)	0,0620 ±0,004 fg	0,0590 ±0,002 gh	0,0780 ±0,002 cd	0,0797 ±0,007 cd	0,0697 ±0,003 b
	100 (B2)	0,0710 ±0,023 de	0,0787 ±0,011 cd	0,0817 ±0,001 bc	0,0827 ±0,001 abc	0,0785 ±0,007 a
	150 (B3)	0,0770 ±0,009 cde	0,0810 ±0,006 bcd	0,0890 ±0,002 ab	0,0903 ±0,005 a	0,0724 ±0,003 b
Average		0,0648 ±0,009 b	0,0674 ±0,004 b	0,0768 ±0,003 a	0,0805 ±0,004 a	
		KK = 3,68%	**BNJ B&T = 0,0030**	**BNJ BT = 0,0081**		
28-35	0 (B0)	0,1510 ±0,008 h	0,1595 ±0,005 gh	0,1618 ±0,012 gh	0,1730 ±0,019 d-g	0,1613 ±0,006 d
	50 (B1)	0,1580 ±0,060 gh	0,1727 ±0,005 efg	0,1610 ±0,008 gh	0,1957±0,016 bcd	0,1718 ±0,025 c
	100 (B2)	0,1717 ±0,036 fgh	0,1850 ±0,036 c-f	0,1880 ±0,015 b-f	0,2070 ±0,004 ab	0,1879 ±0,016 a
	150 (B3)	0,1930 ±0,028 b-e	0,2043 ±0,011 abc	0,2157 ±0,011 a	0,2187 ±0,027 a	0,1823 ±0,009 a
Average		0,1684 ±0,022 c	0,1804 ±0,015 b	0,1816 ±0,003 b	0,1986 ±0,009 a	
		KK = 3,84%	**BNJ B&T = 0,0078**	**BNJ BT = 0,0212**		

The numbers in the columns followed by the same lowercase letter are not significantly different according to the BNJ test at the 5% level.

The B3T3 treatment of mung bean plants exhibited a notably high net assimilation rate, attributed to the application of 150 g/plant of bamboo leaf compost and 75% of tofu liquid waste. The application of compost and tofu liquid waste has been demonstrated to enhance the nutrient levels in Ultisol soil, serving as an effective medium for plant growth and ensuring the provision of optimal nutrients. According to Nugroho and colleagues, a study conducted in 2019 found that a variety of organic fertilizers has been found to positively impact the growth of plants by increasing their dry weight and leaf area. This effect is attributed not only to the additional nutrients provided by the fertilizers but also to the enhancement of soil physical properties, including aeration and structure. Compost fertilizers with substantial organic matter content have the potential to enhance soil aggregation, leading to improved water infiltration and retention of soil moisture (Wardiyati & Saraswati, 2013).

The decomposition of bamboo leaf compost fertilizer into humus is critical for enhancing the availability of essential macro and micronutrients required for the growth of mung bean plants. Including tofu effluent also enhances plant growth by supplying ample nitrogen, facilitating an improved photosynthetic process. Photosynthesis at its peak efficiency results in higher assimilated production that can be transported to various plant tissues, such as leaves. Hakim et al. stated that... In 2019, the enhancement of photosynthesis not only impacted the leaf area but also the utilization of light, leading to an increase in the net assimilation rate of plants.

Optimal plant metabolism will ensure better biomass formation. The higher the bamboo leaf compost fertilizer dose in this study, the better the Ultisol soil properties. This is supported by Jumin's opinion (2012), which states that a smooth photosynthesis process will ensure optimal vegetative and generative plant growth. In addition, applying tofu liquid waste is known to increase the availability of ammonium nitrogen directly available to plants, thereby accelerating the initial growth of mung bean plants (Syafrudin et al., 2020). The combination of these two organic materials not only increases plant growth but also improves soil fertility sustainably.

The high net assimilation rate in the B3T3 treatment of mung bean plants was produced by administering 150 g/plant of bamboo leaf compost fertilizer and 75% tofu liquid waste. This combination can increase the nutrient content of Ultisol soil, a problematic soil with low nutrient levels. This is supported by Tisdale et al. (2013), who explained that organic materials such as compost play a role in increasing the cation exchange capacity (CEC) of the soil, which supports the provision of essential nutrients for plants. In addition, the provision of organic fertilizers based on waste, such as tofu waste, contributes to balancing the C/N ratio of the soil, so that the decomposition process runs more efficiently (Brady and Weil, 2017).

The decomposition of humus-rich bamboo leaf compost enhances essential macronutrients like nitrogen, phosphorus, and potassium and vital microelements such as magnesium and boron necessary for plant enzymatic activity (Jones et al., 2012). Utilizing tofu liquid waste, rich in nitrogen and ammonium, significantly boosts plant vegetative growth, particularly in leaf expansion and enhanced photosynthesis (Smith et al., 2018).

Organic nitrogen from waste materials has increased plant photosynthesis efficiency by up to 20% on marginal land. The balance of nutrients in the soil plays a crucial role in supporting plant metabolism for both vegetative and generative growth. Lal (2020) suggests that applying organic materials like compost improves soil water retention, which is crucial for dry lands like Ultisols, enabling mung bean plants to maintain efficient photosynthesis even in low water-binding soil conditions. Combining bamboo leaf compost and tofu liquid waste presents a sustainable agronomic approach to enhance plant production and improve soil health.

4. Conclusion

The B3T3 treatment exhibited a significant increase in growth rate, attributed to the synergistic effect of the bamboo leaf compost fertilizer and tofu liquid waste POC. This led to a noticeable augmentation in plant dry weight, reflecting successful biomass accumulation due to enhanced photosynthesis and efficient nutrient absorption from the planting medium. The B3T3 treatment of mung bean plants displayed a high net assimilation rate due to the combined effects of bamboo leaf compost fertilizer, specifically at a dosage of 150 grams per plant, and tofu liquid waste POC at a concentration of 75%.

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