



Physiological Indicator for Egg Plant Growth in Red Yellow Podzol Soil with Beneficial Reuse of Pollutant Materials

Hasan Basri JUMIN¹, Mardaleni¹, Ernita¹, Sulhaswardi¹, Selvia Sutiana¹

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ABSTRACT

Background: Red-yellow Podzol soil is generally regarded as infertile and covers approximately 45.7 million hectares in Indonesia, accounting for about 29.7% of the national land area. Despite these limitations, this soil type can be utilized for agricultural production through the application of appropriate soil amendments and alternative nutrient sources.

Methods: A two-factor experiment was conducted at the experimental station of the Faculty of Agriculture, Islamic University of Riau, Indonesia. The first factor examined the effect of Pekanbaru city wastewater on eggplant (*Solanum melongena* L.), while the second factor was the application rate of palm kernel shell ash. Observed parameters included net assimilation rate (NAR), mean relative growth rate (MRGR), dry matter weight and total plant biomass.

Result: Net assimilation rate and mean relative growth rate served as physiological indicators of dry matter accumulation. The combined application of city wastewater and palm kernel shell ash showed a significant interactive effect on eggplant growth. Increases in NAR were consistently followed by increases in MRGR, resulting in a significant enhancement of dry matter production. The application of palm kernel shell ash contributed to the amelioration of excessive iron and aluminum availability in red-yellow Podzol soil, thereby improving nutrient uptake efficiency. Overall, the integrated use of city wastewater and palm kernel shell ash significantly increased eggplant dry matter yield on red-yellow Podzol soil.

Key words: City wastewater, Eggplant growth, Net-assimilation-rate, Palm-kernel-shell-ash, Red-yellow-podzol soil, Sustainable-soil-management.

INTRODUCTION

Red-yellow Podzol soils are widely utilized for rice cultivation, plantations, rubber gardens, coffee and oil palm production. In Indonesia, these soils are extensively distributed across West Java, Sumatra, Kalimantan, Sulawesi, Nusa Tenggara and Papua. They cover approximately 45.7 million hectares, accounting for about 29.7% of the country's total land area (Badan Pusat Statistik Indonesia, 2023).

Red-yellow Podzol soils are characterized by strong acidity, low organic matter content and poor availability of macro nutrients, particularly phosphorus, which typically ranges from 2 to 10 mg kg⁻¹. The low availability of phosphorus is mainly caused by its fixation through binding with Al³⁺ and Fe³⁺ ions. These soils generally have a cation exchange capacity of less than 16 cmol kg⁻¹, base saturation below 35%, low organic carbon content and high concentrations of aluminum and iron, resulting in a high phosphorus fixation capacity. Soil pH commonly ranges from 3.10 to 5.00, classifying these soils as strongly to very strongly acidic. Such acidity is primarily attributed to intensive leaching of essential base cations, which reduces soil fertility and limits agricultural productivity (Prasetyo and Suriadikarta, 2006; Sulaiman *et al.* 2018; Adlim *et al.* 2020).

Pekanbaru is a rapidly developing city on the island of Sumatra, where population growth is largely driven by economic expansion. The rapid establishment of new industries and increased local transmigration have

¹Faculty of Agriculture, Islamic University of Riau, Indonesia.

Corresponding Author: Hasan Basri JUMIN, Faculty of Agriculture, Islamic University of Riau, Indonesia.

Email: hbjumin@agr.uir.ac.id

ORCID: 0000-0002-5996-3421

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contributed significantly to urban development. However, liquid waste generated from traditional markets in Pekanbaru is poorly managed and poses a serious threat to environmental quality. This wastewater produces unpleasant odors, degrades urban aesthetics and contaminates ground water as well as surface water bodies such as rivers and lakes, which are widely used for drinking water, domestic activities and other essential purposes.

Waste derived from oil palm fruit processing, particularly palm oil shells (endocarps), may negatively affect agricultural land if not properly managed. Because palm oil shells decompose slowly, farmers commonly burn them to produce charcoal or ash. Previous studies have reported that palm oil shell ash contains essential nutrients, including calcium, magnesium and other minerals (Jumin *et al.*, 2021; 2024). In addition, ash

application can enhance the availability of key soil nutrients such as nitrogen, phosphorus, calcium and magnesium. The presence of calcium and magnesium is particularly important, as these elements can reduce the toxic effects of excessive aluminum and iron in acidic soils (de Oliveira *et al.*, 2013).

Palm oil shell ash has long been used by farmers in Sumatra and preliminary observations indicate that its application can improve vegetative growth and yield of oil palm plants. These observations highlight the potential of palm oil shell ash as an alternative organic soil amendment. Moreover, palm oil shell ash may help alleviate aluminum and iron toxicity in swampy or strongly acidic soils, thereby improving soil chemical properties and crop performance (Costa *et al.* 2004). In Red-yellow Podzol soils, the effectiveness of Rhizobium is often limited due to low calcium and magnesium availability (Adlim *et al.*, 2020). Reduced nutrient availability and soil acidity can suppress photosynthetic activity, which is reflected in lower mean relative growth rate (MRGR) and net assimilation rate (NAR). Net assimilation rate, which represents the rate of dry matter accumulation, is strongly influenced by leaf area, as leaves capture solar radiation and facilitate the absorption of carbon dioxide (CO₂) and water for photosynthesis. The availability of CO₂, water and oxygen is closely associated with light interception by the plant canopy.

Therefore, this study aims to evaluate the interaction between urban wastewater and palm oil shell ash on the mean relative growth rate and net assimilation rate of eggplant (*Solanum melongena* L.) grown in Red-yellow Podzol soil.

MATERIALS AND METHODS

Experimental design and plant material

The study was conducted from August 2023 to July 2025 at Agricultural Laboratory and the Experiment Station of the Islamic University of Riau, Indonesia using eggplant (*Solanum melongena* L.) as the experimental crop. The experiment employed a two-factor factorial design arranged in a completely randomized design (CRD). The first factor was city wastewater, applied at four levels: 0.0 mL L⁻¹, 500 mL L⁻¹, 750 mL L⁻¹ and 1000 mL L⁻¹. The second factor was the dose of palm kernel shell ash (Fig 1), consisting of four levels: 0.0 g plant⁻¹, 250 g plant⁻¹, 500 g plant⁻¹ and 750 g plant⁻¹. Plants were grown under natural light conditions with a photoperiod typical of the local environment.

Mean relative growth rate (MRGR)

Dry weight (W) data of eggplant biomass were collected over four sampling periods at 7-day intervals, starting from 7 days after planting (DAP). The mean relative growth rate (MRGR) was calculated using the equation proposed by South (1995).

$$\text{MRGR} = \frac{\ln W_2 - \ln W_1}{t_2 - t_1} \text{ g/day} \quad \dots(1)$$

Where,

W1 and W2= Plant dry weights at times t1 and t2, respectively.

Net assimilation rate (NAR)

Net assimilation rate (NAR) was calculated based on total dry weight per unit leaf area. Sampling was carried out four times at 7-day intervals, beginning at 7 DAP. Data were analyzed using the equations proposed by Briggs and Whittinghamf (1952) and Vernon and Willson (1963), as follows:

$$\text{NAR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log W_2 - \log W_1}{A_2 - A_1} \text{ mg/cm}^2/\text{day} \quad \dots(2)$$

Where,

W1 and W2= Total plant dry weights. A1 and A2= Leaf areas at times t1 and t2, respectively.

Leaf area and growth analysis

Leaf area was measured from subsamples using a leaf area meter and image analysis software following the method of Briggs and Whittinghamf (1952). Leaf area (L) was recorded four times during the observation period. The mean values of dry weight (W) and leaf area (L) were then used to calculate the efficiency of dry matter production (EM), representing the mean assimilation efficiency for each time interval (t2-t1), as proposed by Vernon and Allison (1963).

$$\text{EM} = \frac{1}{L} \frac{dW}{dt} \quad \dots(3)$$

Net assimilation rate (NAR) represents the increase in total plant dry weight per unit leaf area over a given period of time.

Wastewater analysis

The chemical composition of the city wastewater was analyzed using standard laboratory procedures at the Laboratory of Agricultural Technology. Parameters analyzed included nitrogen, phosphorus, calcium, pH, metals, heavy metals and other potential pollutants. The characteristics of city wastewater in Pekanbaru, as in many urban areas of Indonesia, are influenced by population density, domestic activities and industrial inputs. Although wastewater characteristics may vary depending on sampling location and time, both physical properties (color, temperature and odor) and chemical properties were determined using appropriate standard analytical methods.

Dry weight measurement

Plant dry weight was measured four times during the growth cycle. Samples were collected at 7, 14, 21 and 28 days after planting (DAP). Dry weight was used as a key parameter for evaluating MRGR and NAR, following the method described by Jumin *et al.* (2019).

RESULTS AND DISCUSSION

Characteristics of domestic wastewater in pekanbaru

Domestic wastewater in Pekanbaru City, Riau Province, Republic of Indonesia, originates mainly from household

activities such as toilets, kitchens and laundry. Wastewater samples were collected from four different areas of Pekanbaru City, namely the southern, northern, eastern and western zones. Additional contributions to wastewater originate from commercial activities, including restaurants, traditional markets and small workshops, as well as minor industrial discharges such as food processing units and car-washing facilities. In several drainage systems, stormwater run off mixes with domestic sewage (Fig 1), further influencing wastewater characteristics.

The analysis of wastewater quality indicated high levels of organic pollution. Biological Oxygen Demand (BOD) values were high, reflecting a substantial organic load, while Chemical Oxygen Demand (COD) values were typically two to three times higher than BOD, confirming the dominance of biodegradable organic matter. Dissolved oxygen (DO) concentrations were very low, indicating intensive microbial decomposition of organic substances (Tabel 1). The pH of

the wastewater ranged from slightly acidic to near neutral, which is typical for urban domestic wastewater.

Effect of treatments on plant growth

Vegetative growth of eggplant continued into the juvenile stage, during which physiological growth parameters, namely net assimilation rate (NAR) and mean relative growth rate (MRGR), were evaluated. The responses of eggplant to the combined application of city wastewater and palm kernel shell ash are presented in Fig 2 and 3. The observed variations in NAR and MRGR indicate that plant growth dynamics were strongly influenced by nutrient availability and environmental conditions during the vegetative phase. These parameters provide a sensitive measure of the efficiency of photosynthesis and biomass accumulation under different treatment combinations.

Main Sources in Pekanbaru Domestic wastewater (toilets, kitchens, laundry) as contributor at the Pekanbaru city Riau province, Republik of Indonesia. Wastewater collected from wastewater Pekanbaru city in four place; south, north, east and west. Commercial activities (restaurants, markets, small workshops). Minor industrial discharge (food processing, car washing). Storm water runoff mixing with sewage in some drainage systems. Biological Oxygen Demant (BOD), Indicates high organic load, Typically $2-3 \times$ BOD value and chemical Oxygen Demant (COD Very low due to organic pollution, Dissolved Oxygen (DO) Very low due to organic pollution and pH slightly neurtal to acid.

The vegetative growth continued into the juvenile stage, during which NAR and MRGR were analyzed. The results of the treatments are presented in (Fig 2 and 3). The combined application of palm kernel shell ash and city wastewater significantly enhanced the net assimilation rate (NAR) and mean relative growth rate (MRGR) of eggplant. A strong positive linear relationship was observed between palm kernel shell ash and city wastewater with respect to NAR ($y = 0.9004x + 11.073$; $R^2 = 0.8515$) (Fig 2), indicating a substantial improvement in photosynthetic efficiency associated with increased nutrient availability.

Table 1: The chemical composition of waster water at pekanbaru 2024.

Parameter	Composition mg/l			
	West	East	South	North
BOD ₅ day 20°C	6.4	1049	980	870
COD by K ₂ Cr ₂ O	68.	5765	5693	4980
Nitrogen total	216	163	336	336
Phosphorus	9.2	3,4	109	4.681
Potassium (K)	8.1	<0,019	0.4	4.7
Magnesium (Mg)	458	4681	29	30
Calcium (Ca)	4.6	60	0.02	0.01
Lead (Pb)	<0.01	<0,0017	<0,001	<0.01
Sodium (Na)	84.	1265	3634	33
Copper (Cu)	<0.01	<0,01	<0.01	<0.01
pH	6.4	4.5	3.4	3.0

Biological COD, Indicates high organic load, Typically $2-3 \times$ BOD value and COD Very low due to organic pollution, Dissolved Oxygen (DO) Very low due to organic pollution and pH slightly neurtal to acid.



Fig 1: Experiment materials.

Under control conditions, the relationship between NAR and MRGR remained positive but was comparatively weaker ($y = 0.6221x + 2.6887$; $R^2 = 0.5435$) (Fig 3), suggesting limited physiological response in the absence of external nutrient inputs. In contrast, egg plants treated with 1000 mL L^{-1} city wastewater combined with 750 g plant^{-1} palm kernel shell ash at 60 days after planting exhibited a very strong linear relationship between NAR and MRGR ($y = 0.979x + 0.7562$; $R^2 = 0.9692$) (Fig 4). This indicates highly efficient biomass accumulation driven by enhanced photosynthetic activity.

These results clearly demonstrate a synergistic interaction between city wastewater and palm kernel shell ash. The combined application likely improved nutrient uptake, metabolic activity and carbon assimilation, thereby promoting vegetative growth and overall plant performance. The observed linear interaction pattern indicates that an increase in one factor was followed by a proportional increase in the effect of the other. In this study, simultaneous increases in palm kernel shell ash dosage and city wastewater concentration consistently enhanced MRGR.

The relationship between NAR and MRGR under the influence of palm kernel shell ash and city wastewater was predominantly linear, indicating that an increase in NAR was consistently accompanied by an increase in MRGR. Although NAR and MRGR represent distinct physiological parameters, they are closely linked through their shared dependence on photosynthetic efficiency and biomass allocation processes (Poorter and Nagel, 2000).

Based on the present findings, appropriate increases in the concentration of city wastewater and palm kernel shell ash positively affected both NAR and MRGR (However, excessively high application rates of palm kernel shell ash may pose potential risks to agricultural land, particularly in red yellow podzol soil or poorly drained soils, due to possible nutrient imbalance or alkalinity stress).

The results further indicate that plants became more tolerant of Red-Yellow Podzol soil conditions following treatment with city wastewater and palm kernel shell ash. This response is expected, as Red-Yellow Podzol soils are characterized by low pH and deficiencies in calcium and magnesium (Table 1). Palm oil shell ash is known to

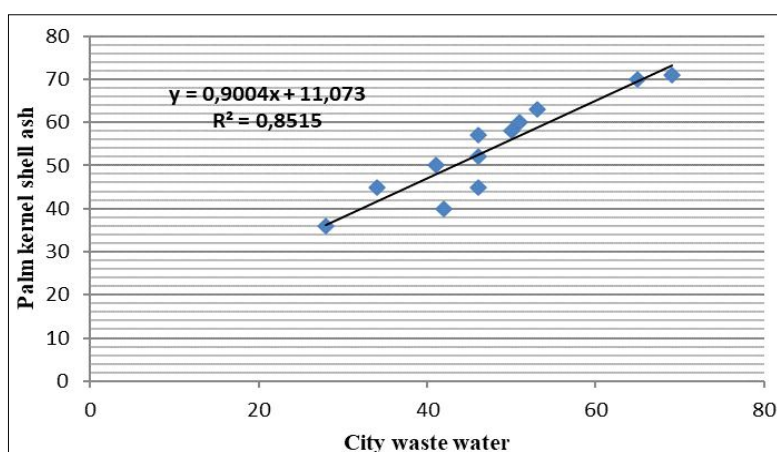


Fig 2: Relationship between net assimilation rate $\times (\text{mg. cm}^{-2} \text{ day}^{-1})$ and mean relative growth rate $\times (0.01 \text{ g. day}^{-1})$ under the influence of palm kernel shell ash and city wastewater in the egg plant.

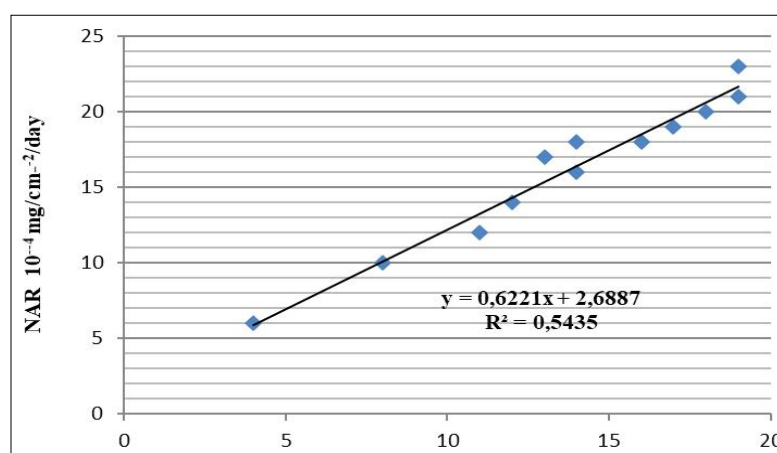


Fig 3: Net assimilation rate $\times (0.001 \text{ mg. cm}^{-2} \text{ day}^{-1})$ of egg plant under control of palm kernel shell ash and city waste water.

contain calcium, potassium and magnesium compounds (Hutahaen, 2007; Herman and Rolly, 2018). Calcium and magnesium are essential macronutrients; however, their availability in Red-Yellow Podzol soils is often restricted due to high iron and aluminum concentrations. Nutrient inputs from city wastewater significantly improved soil fertility and plant growth, consistent with previous findings (Kouadio, 2018; Al-Shamary *et al.* 2025).

Plants grown in soils with varying mineral compositions, including calcium, magnesium and other essential and non-essential elements, tend to adjust their

NAR and MRGR to optimize growth and adapt to specific ecological conditions (Beyer and Onken, 2004). This adaptive response was clearly reflected in the improved physiological performance observed in this study.

The influence of wastewater application growth is presented in Fig 5. Although palm oil shell ash is generally regarded as an agricultural waste product (Su *et al.*, 2018), in this study it functioned effectively as a nutrient source due to its beneficial mineral composition. Wastewater-derived nutrients enhanced soil productivity and egg plant growth by increasing soil pH and reducing the toxic effects

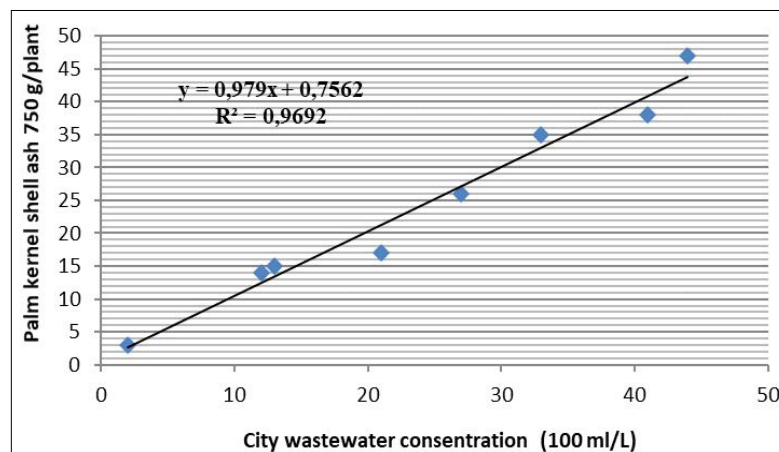


Fig 4: Relationship between net assimilation rate and mean relative growth rate of eggplants (g/plant) after treated with city waster water and eggshell ash of palm oil at 60 days age.

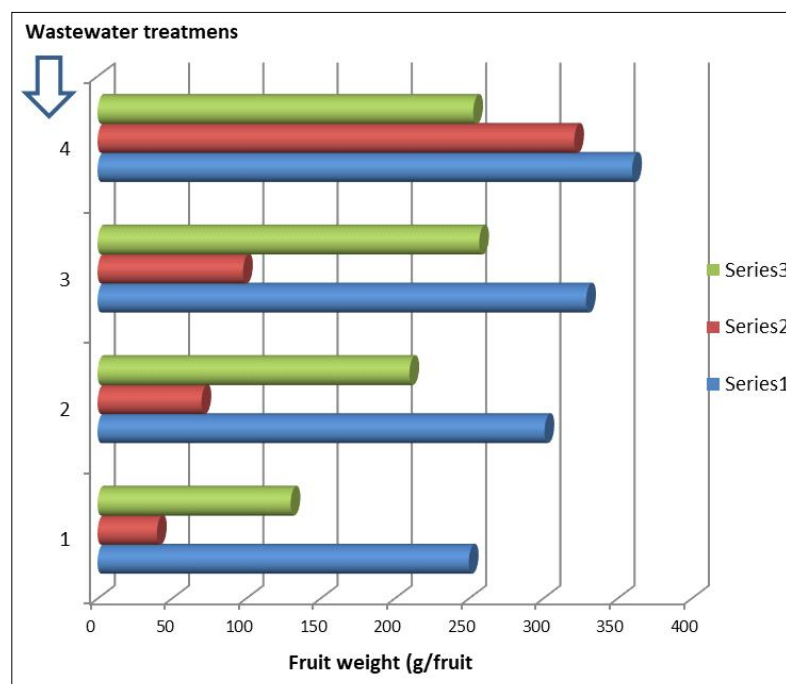


Fig 5: Relationship between seed dray weight, net assimilation rate and mean relative growth of egg plants after treated with city waster water and palm kernel shell ash (series 1 fruit weight (g/fruit), series 2 is MRGR × (0.01 mg/day), series 3 is NAR × (0.003 mg/cm²/day).

Table 2.1: Chemical characteristic pekanbaru city wastewater 2024.

Parameter	Typical concentration	Notes
Ammonia (NH ₃ -N)	10-30 mg/L	From urea and protein breakdown
Total phosphorus (TP)	3-10 mg/L	Mainly from detergents
Oil and grease	10-50 mg/L	From kitchen and food industries
Chloride	50-150 mg/L	From domestic salt and cleaning agents

Table 2.2: Biological characteristics.

Parameter	Typical observation
Coliform bacteria (Total coliform)	10 ⁶ - 10 ⁸ MPN/100 mL
Fecal coliform	10 ⁵ - 10 ⁷ MPN/100 mL
Pathogens	Presence of <i>E. coli</i> , <i>Salmonella</i> , <i>Shigella</i> common

of excessive iron and aluminum, thereby improving calcium and magnesium availability.

Furthermore micro organisms biological process improved the soil micro environment around root hairs, enhancing biological nutrient uptake of the plants and increasing the availability of nutrients essential for peanut growth (Choudhary and Verma, 2024). Palm oil shell ash, which contains nitrogen, magnesium and other minerals, further compensated for nutrient deficiencies commonly found in red yellow podzol soil or acidic soils, making such environments more suitable for horticultural crops (Ohanaka *et al.*, 2025).

The relationship between NAR and MRGR for eggplant (Fig 2) revealed strong interdependence, with increases in NAR consistently followed by increases in MRGR. This positive relationship resulted in greater dry matter accumulation and ultimately higher yields, particularly in peanut plants (Fig 5). Leaf expansion plays a critical role in light interception and photosynthetic efficiency. Reduced leaf expansion limits light absorption, while palm kernel shell ash soil pollutants may induce chlorophyll deficiency, thereby suppressing photosynthetic rates (Kumar *et al.*, 2025; Kumar and Singh, 2022). The application of palm oil shell ash to Red-Yellow Podzol soils increased calcium and magnesium availability while reducing iron and aluminum uptake by plants (Ewelike *et al.* 2021).

Chlorophyll acts as a photosynthetic antenna, capturing light energy for photochemical reactions that convert solar energy into carbohydrates such as glucose (Pezeshki, 2018; Kumar and Singh, 2022); The mean relative growth rate (MRGR) reflects overall plant growth over a given period without directly accounting for leaf-level efficiency (South, 1995), whereas net assimilation rate (NAR) provides a more precise estimate of photosynthetic activity per unit leaf area per day. Thus, MRGR serves as a rapid indicator of whole-plant growth dynamics, while NAR offers insight into physiological efficiency (Vernon and Allison, 1963, Shipley, 2006). Simultaneous evaluation of these parameters is essential for early detection of growth limitations.

Organic matter present in city wastewater can reduce excessive iron and aluminum availability by limiting their

uptake, particularly in acidic and peat soils (Ungureanu *et al.*, 2021; Kouadio *et al.*, 2018; Khamidah and Saputra, 2020). In Red-Yellow Podzol soils, palm oil shell ash further immobilizes iron and aluminum, rendering them less available to plants. Consequently, the interaction between city wastewater and palm kernel shell ash helps regulate metal concentrations and improve soil chemical balance. The calcium, magnesium and supplied by both inputs increase soil pH toward near-neutral conditions, thereby enhancing nutrient availability and plant growth (Al-Shamary *et al.*, 2025).

According to Gage (2004), soil microorganisms play a crucial role in decomposing organic matter and regulating the soil microclimate, which facilitates nitrogen absorption through plant-microbe interaction in the rhizosphere. Microbial activity benefits both partners: bacteria supply nitrogen to plants through biological process (Table 2.1 and Table 2.2), while plants provide carbon substrates to microorganisms. During organic matter decomposition, micro nutrients also become available, further supporting eggplant growth (Brewin, 2010, Boyle, 2020 and Etasami, 2022).

Overall, the patterns of NAR and MRGR were closely aligned, as dry matter accumulation reflects sustained photosynthetic activity. NAR represents the efficiency of chlorophyll in capturing solar energy, while MRGR reflects cumulative biomass production over time. Under healthy growth conditions, leaves efficiently absorb light and synthesize carbohydrates. However, under stress conditions such as disease or pest infestation, photosynthetic efficiency declines and resulting in reduced NAR. In such cases, MRGR may not decrease proportionally, leading to deviations from linearity between these two parameters.

CONCLUSION

The interactive treatment of Pekanbaru city wastewater and palm kernel shell ash produced significant differences in the net assimilation rate and mean relative growth rate of egg plants grown in red-yellow podzol soil.

This study suggests that although palm kernel shell ash is commonly regarded as a pollutant that can contaminate soil and water bodies, it also has potential as a valuable source of organic nutrients. In healthy plants—those not affected by disease or pest infestation—the relationship between net assimilation rate and mean relative growth rate typically linear. However, when leaves are infected by bacteria or fungi, the net assimilation rate tends to decline, while the mean relative growth rate may

remain relatively stable. Under such conditions, the relationship between net assimilation rate and mean relative growth rate becomes non-linear.

Conclusion as the combined application of city wastewater and palm kernel shell ash represents a sustainable soil management strategy for improving crop productivity on marginal red-yellow podzol soils, while simultaneously promoting the beneficial reuse of urban and agro-industrial waste.

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Conflict of interest

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REFERENCES

- Adlim, M.K., Hanum, A.R., Nadia, Y. and SyahliDayani, S. (2020). Properties of slow release magnesium and calcium nitrate tablets composed of rice-husk-ash with chitosan coating, within water and in several types of soil. *Journal of Physics: Conference Series*. **1529**: 032085. <https://doi.org/10.1088/1742-6596/1529/3/032085>.
- Al-Shamary, W.F., Asyarif, Y.N.A., Noori, N.E. and Khalel, A.M. (2025). Effect of moisture depletion rate and irrigation water depth on the productivity and water use efficiency of soybean crop (*Glycine max* L.) Merr. under drip irrigation and fixed sprinkler irrigation systems. *Agricultural Science Digest*. **45**(2): 222-27. doi: 10.1885/ag.DF 651.
- Badan Pusat Statistik Indonesia (2023). Berita resmi statistika Indonesia. www.bps.go.id. Jakarta.
- Beyer, L. and Onken, A. (2004). Growth dynamics and assimilation in plant species with different environmental adaptations. *Plant Biology*. **6**(4): 420-426.
- Boyle, J.J. (2020). Chasing unicorns: nodulation origins and the papadox of novelty. *American Journal of Botany*. **103**: 1865-1868. doi: 10.3732/ajb1600260.
- Brewin, N.J. (2010). Root Nodules (Legume-Rhizobium Symbiosis). Wiley. <https://doi.org/10.1002/9780470015902.a0003720.pub2>.
- Briggs, G.E. and Whittingham, C.P. (1952). Factors affecting the rate of photosynthesis of chlorella at low concentrations of carbon dioxide and in high illumination. *New Phytologist*. <https://doi.org/10.1111/j.1469-8137.1952.tb06130.x>.
- Choudhary and Verma, P. (2024). Impact of nutrient management on growth rates of plants: NAR and RGR interactions. *Journal of Plant Nutrition and Soil Science*. **187**(1): 47-58.
- Costa, H.M., Visconte, Y.Y., Nunes, R.C.R. and Futrado, C.R.G. (2004). Rice husk ash filled natural rubber compounds-the use of rheometric data to qualitatively estimate optimum filter loading. *International Journal of Polymeric Materials and Polymeric Biomaterials*. **53**(6): 475-479. <https://doi.org/10.1080/00914030490450100>.
- de Oliveira, A.B., Alencar, N.L.M. and Gomes-Filho, E. (2013). Comparison Between the Water and Salt Stress Effects on Plant Growth and Development. In: Responses of Organisms to Water Stress. [Akinci, S. (Ed.)]. *Intech Open*. <https://doi.org/10.5772/54223>.
- Etasami, H. (2022). Root nodules of legumes: A suitable ecological niche for isolating non-rhizobial bacteria with biotechnological potential in agriculture. *Current Research in Biotechnology*. **4**: 78-86.
- Ewelike, N.C., Orji, J.C., Adieze, I.E., Ogwudire, V.E., Uzoho, B.U. and Ukaoma, A. (2021). Effect of palm oil mill effluent on the growth of maize (*Zea mays*). *Indian Journal of Agricultural Research*. **55**(6): 761-764. doi: 10.18805/IJARE.A-628.
- Gage, D.J. (2004). Infection and invasion of roots by symbiotic, nitrogen-fixing rhizobia during nodulation of temperate legumes. *Microbiology and Molecular Biology Reviews*. **68**(2): 280-300. <https://doi.org/10.1128/MMBR.68.2.280-300.2004>.
- Herman and Rolly I. (2018). The effect of palmshell ash tot the compressive and flexural strength of the brick. *Jurnal Pembangunan Nagari*. **3**(1): 61-74. <https://ejournal.sumbapro.go.id/index.php/jpn/article/view/78/45>. doi: <https://doi.org/10.30559/jpn.v3i1.78>.
- Hutahaen, B. (2007). Pengujian sifat Mekanik beton yang dicampur dengan abu cangkang sawit. Skripsi. Jurusan Fisika FMIPA INIMED. Medan. https://pustaka.uinsu.ac.id/index.php?p=show_detail&id=22240.
- Jumin, H.B., Rahman, A., Ernita, M.N. and Maharani, T. (2024). The optimal production of long-beans in the swamp land by application of *Rhizobium* and rice husk ash. *International Journal of Agricultural and Biosystems Engineering*. **18**(2): 15-18.
- Jumin, H.B., Ikhsan, N. and Maizar. (2021). Rhizobium symbiotic mutualism with rice bean (*Vigna radiata*) root hair on the land polluted by sodium. *Pollution Research*. **40**(4): 1542-1546.
- Jumin, H.B., Rosmawaty, T., Putri, A. and Nur, M. (2019). Slaughterhouse wastewater improve nutrient level in *Apium glaviolens*. *Polution Research*. **38**(1): 9-13.
- Khamidah, N. and Saputr, R.A. (2020). Soil acidity mapping of a swamp land planted with rice in Ampukung village, Kelua district, Tabalong regency. *Tropical Wetland Journal*. **6**(2): 30-59. <https://doi.org/10.20527/twj.v6i2.87>.
- Kouadio, A. (2018). The impact of wastewater on soil fertility and plant growth. *Water, Air and Soil Pollution*. **229**(2): 1-13.
- Kumar, A. and Singh, R.P. (2022). Interplay between net assimilation rate and relative growth rate in crop improvement. *Field Crops Research*. **265**: 108-118.

- Kumar, C.A., Kumar, D.C., Kishore. K.R., Venkata, C.S. and Reddy, P.R.K. (2025). Effect of feeding deoiled palm kernel cake on nutrient utilization, mineral balance and rumen nitrogen dynamics of murrah buffalo bulls. *Agricultural Science Digest*. **59(11)**: 1882-1887. doi: 10.18805/IJAR.B-4860.
- Ohanaka, A.U.C., Okoro, V.M.O., Etuk, I.F., Unamba-Oparah, I.C. and Okoli, I.C. (2025). Effects of palm kernel shell ash as organic mineral supplement on performance of broiler chick. *Indian Journal of Animal Research*. **52(11)**: 1590-1596. doi: 10.18805/ijar.B-792.
- Prasetyo, B.H. and Suriadikarta, D.A. (2006). Karakteristik, potensi, dan teknologi pengelolaan tanah ultisol untuk pengembangan pertanian lahan kering di Indonesia. *Litbang Pertanian*. **2(25)**.
- Pezeshki, S.R. (2018). Photosynthesis in Wetlands. In: The Wetland Book. [Finlayson, C.M. (Ed.)]. Springer. (pp. 297-306). https://doi.org/10.1007/978-90-481-9659-3_64.
- Poorter, H. and Nagel, O. (2000). The role of biomass allocation in the growth response of plants to different environments. *Ecology*. **81(8)**: 2122-2138.
- Shipley, B. (2006). Net assimilation rate, specific leaf area and leaf mass ratio: Which is most closely correlated with relative growth rate? A meta-analysis. *Functional Ecology*. **20(4)**: 565-574. <https://doi.org/10.1111/j.1365-2435.2006.01135.x>.
- South, D.B. (1995). Relative growth rates: A critique. *South African Forestry Journal*. **173**: 43-48.
- Su, W., Sun, Q., Xia, M., Wen, Z. and Yao, Z. (2018). The resource utilization of water hyacinth [*Eichhornia crassipes* (Mart.) Solms] and its challenges. *Resources*. **7(3)**: 46. <https://doi.org/10.3390/resources7030046>.
- Sulaiman, A.A., Subagyo, K., Alihamsyah, T., Noor, M., Hermanto and Muharam, A. (2018). Membangkitkan Lahan Rawa, Membangun Lumbung Pangan Indonesia. IAARD Press.
- Ungureanu, N., Vladut, V., Biris, S.S. and Milut, M. (2021). The effects of waster water irrigation on agricultural soil. *Annals of the University of Craiova-Agriculture, Montanology, Cadastre Series*. **51(2)**: 566-575.
- Vernon, A.J. and Allison, J.C.S. (1963). A methods of calculating net assimilation rate. *Nature*. **200**: 814. <https://doi.org/10.1038/200814a0>.