

Influence of soil organic carbon on rice biomass allocation in agroecosystem area, Tuban, East Java.

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Abstract. Rice (*Oryza sativa* L.) serves as Indonesia's primary staple crop, with its productivity closely linked to soil fertility parameters, particularly organic carbon content. This study investigates the correlation between soil organic carbon levels and biomass distribution (aboveground and belowground) in rice plants across three agroecosystem areas in Tuban Regency: Jenu, Palang, and Plumpang. Biomass measurements included aboveground and belowground components, along with root-to-shoot ratios. Jenu, with the highest organic carbon content (4.538%), exhibited the greatest total biomass (134.13 g), comprising 95.06 g shoots and 39.07 g roots, and an R:S ratio of 1:2.4. Palang, with low organic carbon (0.434%), yielded 80.23 g biomass (62.16 g shoots, 18.07 g roots) and an R:S ratio of 1:3.4. Plumpang, with moderate organic carbon (1.328%), produced 57.73 g biomass (48.73 g shoots, 9 g roots) and an R:S ratio of 1:5.4. The relatively balanced biomass allocation in Jenu suggests that elevated soil organic carbon enhances both shoot and root development. Correlation analysis confirmed significant positive relationships between organic carbon and shoot biomass ($r = 0.797$; $p = 0.010$), root biomass ($r = 0.853$; $p = 0.003$), and R:S ratio ($r = 0.763$; $p = 0.017$). These findings underscore the critical role of organic carbon in optimizing biomass partitioning and improving rice productivity, highlighting the need for soil management strategies that prioritize organic matter enrichment.

1 Introduction

Rice (*Oryza sativa* L.) is one of the main staple food commodities in Indonesian. As the population continues to grow, the demand for food crops such as rice is also increasing [1]. Rice productivity is not only determined by seed quality but is also strongly influenced by soil fertility, one of its key indicators being soil organic carbon (SOC) [2, 3]. SOC plays a crucial role in improving soil structure, enhancing water-holding capacity, and supporting microbial activity that contributes to the availability of macro- and micronutrients [3].

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Beyond its role in soil fertility, soil organic carbon (SOC) plays a strategic function in the global carbon cycle. SOC not only enhances the bioavailability of soil nutrients but also affects soil fertility through various mechanisms and is essential for maintaining the global carbon balance, which significantly influences CO₂ concentrations in the atmosphere. SOC stores a larger carbon reserve than the atmosphere, therefore, its preservation is critical for global carbon stability [4, 5].

Rice fields possess great potential for carbon sequestration through CO₂ uptake during photosynthesis, as well as the accumulation of soil organic carbon (SOC) from roots and other belowground components [6]. Productive rice fields can contribute substantially to carbon sequestration by storing approximately 14% of total SOC reserves, both in the soil and plant biomass [3, 6]. Recent studies have shown that plant biomass dynamics, particularly root biomass play a decisive role in determining the amount of carbon that can be stored or released from the soil [3, 4]. Song et al. [3] emphasized that an increase in rice root biomass under future climate conditions could compensate for SOC losses. Enhancing the amount of carbon stored in soil and plant biomass through organic farming practices may contribute to reducing atmospheric CO₂ concentrations [6]. Thus, the interaction between soil organic carbon and rice growth not only affects productivity but also contributes to climate change mitigation.

The accumulation of plant biomass, both aboveground and belowground, reflects the plant's capacity to absorb and store carbon through photosynthesis [7]. The root-to-shoot ratio (R:S) serves as a physiological indicator of biomass allocation balance, which is influenced by environmental factors such as nutrient availability and soil quality [8]. However, studies that specifically examine the relationship between natural variations in SOC content and the distribution of rice shoot and root biomass under field conditions remain limited. Therefore, this study aims to determine how variations in soil organic carbon (SOC) content influence rice growth and biomass distribution across three locations in Tuban Regency, East Java, characterized by different levels of SOC. The findings are expected to provide a deeper understanding of the role of SOC in supporting rice productivity and its contribution to the carbon cycle, thereby offering a scientific basis for sustainable soil management practices that enhance food security and support climate change mitigation.

2 Material and methods

2.1 Study site

This study was conducted on rice fields in three subdistricts in Tuban Regency, East Java, namely Jenu (6°52'02.95"S 112°01'26.22"E), Palang (6°54'10.7"S 112°06'50.0"E), and Plumpang (7°02'01.22"S 112°06'19.26"E). The research was conducted from December 2024 to June 2025 and was limited to one planting cycle or one growing season.

2.2 Soil and Plant Sampling

Soil sampling was conducted using a diagonal sampling method at five representative points in each location—four at the corners and one at the center of each plot. The rice variety used was the local HMS 700 cultivar, sampled at harvest maturity (96 days after planting). At each sampling point, plants were harvested entirely and separated into aboveground (grain and straw) and belowground (roots) components. Each site was replicated three times to ensure data reliability.

2.3 Rice Biomass Measurement

Plant samples were separated into aboveground and belowground components. All plant parts were oven-dried at 70°C for 48 hours until a constant weight was achieved, after which dry weight was measured. The total biomass and root-to-shoot (R:S) ratios were then calculated for each sampling location.

2.4 Laboratory Analysis

SOC was analyzed using the Walkley–Black method. Additional soil chemical properties, including pH, total nitrogen (N), phosphorus (P), and potassium (K), were measured following the standard protocols established by the Soil and Fertilizer Instrument Testing Center of the Indonesian Ministry of Agriculture [9]. These analyses provided an overview of the soil fertility characteristics at each site.

2.5 Data Analysis

Data on biomass and SOC were analyzed both descriptively and inferentially. The relationships between SOC content and rice biomass (aboveground, belowground, and R:S ratio) were tested using Pearson’s correlation analysis. Linear regression analysis was performed to determine the influence of SOC on biomass accumulation. All statistical analyses were carried out using SPSS version 25.

3 Result and discussions

3.1 SOC Status

The analysis results showed that the soil organic carbon content in Jenu District ($4.54 \pm 0.60\%$) was highest than in Plumpang ($1.33 \pm 0.16\%$) and Palang ($0.43 \pm 0.10\%$) (Table 1). Based on soil fertility classification, the organic C value in Jenu is in the high category, Plumpang is in the medium category, while Palang is in the very low category [9]. This difference has implications for soil quality and its capacity to support plant growth. Soil with higher organic C content is able to improve soil aggregation, because organic C plays a role in the physical, chemical, and biological characteristics of soil [3, 5]. In addition to organic C, measurements of N, P, and K content were also carried out at each location.

Table 1. Soil chemical properties in three sub-districts of Tuban Regency

Location	C-Organic (%)	N-Total (%)	P-Total (mg/100g P ₂ O ₅)	K-Total (mg/100 g K ₂ O)
Jenu	4.54 ± 0.60	0.416 ± 0.087	53.8 ± 6.94	137.4 ± 16.01
Plumpang	1.33 ± 0.16	0.444 ± 0.042	31.4 ± 8.85	105.4 ± 16.36
Palang	0.43 ± 0.10	0.206 ± 0.023	68.0 ± 6.89	109.8 ± 18.89

Soil quality can be determined by the nutrients it contains. The main macronutrients for rice are nitrogen (N), phosphorus (P), and potassium (K), all of which affect rice growth and development through different physiological and metabolic processes [10, 11]. These results indicate that Jenu has the best soil fertility status because it is the most stable, supported by higher organic C and K content, which are important for nutrient availability and soil structure improvement. Conversely, Plumpang and Palang show limitations in one or more

nutrients, especially low organic C in Palang, which can affect plant growth and biomass accumulation.

3.2 Rice Biomass Accumulation

Rice biomass accumulation differed significantly among locations (Table 2). Jenu exhibited the highest total biomass (134.13 g), consisting of 95.06 g aboveground and 39.07 g belowground biomass. Palang produced 80.23 g total biomass (62.16 g shoots, 18.07 g roots), while Plumpang recorded the lowest biomass (57.73 g total, 48.73 g shoots, 9 g roots).

Table 2. Biomass components in three sub-districts of Tuban Regency.

Location	Aboveground Biomass		Belowground Biomass	Total Biomass	R:S
	Grain (g)	Straw(g)	Root(g)		
Jenu	43.2 ± 9.44	51.87 ± 7.73	39.07 ± 5.30	134.13	1:2.4
Plumpang	21.73 ± 5.00	27.00 ± 4.36	9.00 ± 2.00	57.73	1:5.4
Palang	23.53 ± 2.61	38.63 ± 4.17	18.07 ± 1.76	80.23	1:3.4

The Jenu location with high organic C content produced more balanced roots and crowns (R 1:2.4), while Palang and Plumpang tended to have more dominant crowns (R 1:3.4 and 1:5.4). This is in line with the research by Feng et al. [8], that soil organic carbon or SOC levels affect biomass allocation by regulating the balance between root and canopy growth through its influence on soil water and nitrogen availability. In dry areas, high SOC promotes allocation to roots (increasing the R:S ratio), while in humid areas, high SOC promotes allocation to the canopy and increases total plant biomass. The highest saturated total biomass yield also indicates that positive SOC has direct and indirect effects on increasing total biomass and rice yield through improved soil nutrient availability [2].

3.3 Relationship Between SOC and Biomass

The correlation between soil organic carbon content (SOC) and biomass shows a positive relationship: the higher the organic carbon content, the greater the accumulation of plant biomass. As seen in Jenu, with an organic carbon content of 4.54%, it was able to produce a total biomass of 134.13 g, while Palang, with only 0.43% organic carbon, produced a lower biomass (80.23 g). The results of the correlation analysis reinforce these findings, where there is a significant positive relationship between organic C and crown biomass ($r = 0.797$; $p = 0.010$), root biomass ($r = 0.853$; $p = 0.003$), and the root to crown ratio or R:S ratio ($r = 0.763$; $p = 0.017$). In its correlation with the canopy, SOC can increase plant vegetative growth (total biomass), which in turn increases grain yield [2]. Although in humid areas, SOC encourages allocation to the shoot and increases total plant biomass, the higher the organic C content, the greater the incentive for plants to allocate their photosynthetic products not only to the upper part (shoot) but also to the underground part (root), as indicated by the relatively balanced biomass allocation results in Jenu [2,8].

This is in line with Liu et al. [12], who reported that 17% of the carbon from rice photosynthesis is allocated to the roots and 10% to the soil through rhizodeposition. This proportion of carbon allocation shows that roots and plant residues are important sources of carbon input to the soil. In addition, increased root biomass also strengthens carbon input into the soil and stabilizes SOC through the formation of mineral-associated organic carbon (MAOC) [3]. Thus, high organic C content not only supports plant biomass growth, but there is also a feedback loop between SOC and roots, whereby roots with high biomass will also increase carbon input into the soil through rhizodeposition and residue decomposition.

4 Conclusion

Based on the results of this study, it can be concluded that there is a strong positive relationship between soil organic carbon (SOC) and rice biomass accumulation. Fields with higher SOC exhibited greater total biomass and a more balanced distribution between shoots and roots. These results highlight rice paddies' dual function as productive agricultural systems and effective carbon sinks. Therefore, land management practices that prioritize SOC enhancement such as organic amendments, crop residue incorporation, and minimal tillage are essential for improving rice productivity while contributing to sustainable, low-carbon agriculture.

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