


Interaction of Tillage Systems and Plant Spacing in Enhancing the Growth and Productivity of Lowland Rice (*Oryza Sativa L*)

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Article Info	ABSTRACT
<p>Keywords: Soil Tillage, Planting Spacing, Growth, Yield, Lowland Rice, And <i>Oryza Sativa L</i>.</p>	<p>This study investigates the effects of soil tillage systems and planting spacing, along with their interaction, on the growth performance and productivity of lowland rice (<i>Oryza sativa L.</i>) variety IR64. The experiment was conducted in paddy fields using a factorial randomized block design (RBD) comprising two factors. The first factor, the soil tillage system, included three treatments: plowing (P1), tractor tillage (P2), and hoeing (P3). The second factor, planting spacing, consisted of three levels: 30×20 cm (J1), 30×30 cm (J2), and 30×40 cm (J3). Growth and yield parameters measured were plant height, number of tillers, leaf area, grain weight per clump, grain weight per plot, and estimated yield per hectare. The results revealed that the interaction between soil tillage systems and planting spacing significantly influenced the number of tillers, grain weight per clump, grain weight per plot, and grain yield per hectare, but had no significant effect on plant height and leaf area. The highest yield was achieved under the P2J2 combination (tractor tillage with 30×30 cm spacing), producing 600 g per 1 m² plot, equivalent to approximately 6 tons per hectare. These findings indicate that the combination of tractor tillage and moderate spacing enhances growth efficiency and yield potential in lowland rice (IR64 variety).</p>
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INTRODUCTION

Lowland rice is a type of rice plant that requires abundant water and is cultivated in wetland or paddy fields, which differs from upland rice that is suited to dry land conditions. The cultivation of lowland rice involves soil preparation under flooded conditions, starting from removing crop residues to puddling the soil to make it easier for planting. Lowland rice serves as an important source of carbohydrates and energy for the Indonesian population and represents the main livelihood for millions of smallholder farmers across the country.

Rice (*Oryza sativa L.*) is the main food commodity in Indonesia and plays a strategic role in national food security. Efforts to increase rice productivity are carried out through improvements in cultivation technology, one of which is through appropriate tillage systems and optimal plant spacing. Tillage serves to improve soil structure, enhance aeration, and reduce weed competition. The commonly used tillage systems include traditional plowing, tractor tillage, and hoeing. Meanwhile, plant spacing plays an important role in influencing

plant population density, the number of tillers, and the efficiency of light and nutrient utilization.

The IR64 variety was selected because it is a high-yielding variety with a preferred taste, early maturity (approximately 115 days), and high yield potential. Therefore, this study aims to examine the interaction between tillage systems and plant spacing on the growth and yield of lowland rice (*Oryza sativa* L.) variety IR64. Environmental Pollution: The excessive use of pesticides and fertilizers can contaminate water and soil; therefore, wise and environmentally friendly management practices are necessary. Tillage affects plant growth because it is closely related to oxygen availability, soil moisture, and weed control. According to Hardjowigeno (2015), proper tillage can improve soil structure, allowing roots to develop more easily.

Tillage is a crucial initial step to ensure that maize plants can grow optimally and produce abundant yields. This process aims to create ideal soil conditions—such as a loose structure, good drainage, and sufficient nutrient availability for the plants. Lowland rice (*Oryza sativa* L.) is a paddy variety that requires abundant water and is typically cultivated in flooded or wetland environments, distinguishing it from upland rice adapted to dry land conditions. The cultivation process involves land preparation under submerged conditions, including the removal of crop residues and puddling to facilitate transplanting. As a staple food in Indonesia, lowland rice represents a major source of carbohydrates and energy, as well as a key livelihood for millions of smallholder farmers. Given its strategic role in national food security, continuous efforts are made to enhance rice productivity through improved cultivation technologies, particularly the adoption of efficient tillage systems and optimal planting spacing.

Tillage plays a critical role in improving soil structure, enhancing aeration, and suppressing weed growth. Common tillage practices include traditional plowing, mechanized tractor tillage, and manual hoeing. Meanwhile, planting spacing determines plant population density and significantly influences tiller number, light interception, and nutrient utilization efficiency. The IR64 variety was chosen for this study due to its high-yield potential, desirable grain quality, and relatively short maturity period of approximately 115 days. Therefore, this research aims to evaluate the interaction between different tillage systems and planting spacings on the growth and yield performance of lowland rice (*Oryza sativa* L.) variety IR64. From an environmental perspective, excessive use of fertilizers and pesticides can cause soil and water pollution; thus, sustainable and eco-friendly management practices are essential. Tillage affects plant growth by influencing soil oxygen availability, moisture retention, and weed control. According to Hardjowigeno (2015), appropriate tillage practices improve soil structure, allowing better root penetration and development. Effective land preparation is fundamental to achieving optimal plant growth and higher productivity, as it creates favorable soil conditions such as loosened texture, improved drainage, and sufficient nutrient availability.

Literature Review

Overview: Agronomic Drivers of Rice Productivity

Rice productivity in lowland ecosystems is influenced by the interaction of multiple agronomic factors, including land preparation (tillage), planting density and spacing, water management, and nutrient application. Efforts to enhance productivity require not only the improvement of individual factors but also the optimization of synergistic cultivation practices that maximize the use of available resources (water, light, nutrients) and minimize intra-plant competition.

Tillage fundamentally alters soil physical and chemical characteristics such as porosity, bulk density, aeration, and water-holding capacity, directly affecting root development and nutrient uptake efficiency. Traditional plowing improves soil loosening and facilitates residue decomposition, but excessive tillage may accelerate organic matter loss and water evaporation. Mechanized tractor tillage provides uniform soil structure and operational efficiency, whereas manual hoeing allows selective but less uniform preparation, especially at larger scales. Research has shown that appropriate tillage enhances root penetration, tiller formation, and ultimately yield potential—though the magnitude of the effect depends on soil texture, organic content, and water management.

Plant Spacing: Population Dynamics, Light Interception, and Yield Components.

Plant spacing determines crop population density and strongly influences competition for light, water, and nutrients. Narrow spacing often leads to excessive competition, resulting in fewer panicles per plant and lower grain weight, while wider spacing reduces plant density, limiting yield per unit area. Studies on modern rice varieties, such as IR64, have reported that moderate spacing (e.g., 30×30 cm) achieves a balance between the number of tillers per plant and overall population, leading to optimal yield performance. Nevertheless, the ideal spacing is context-dependent, influenced by soil fertility, irrigation, and fertilizer management.

The interaction between tillage systems and planting spacing plays a significant role in determining crop performance. Improved soil structure through tillage can reduce competition among closely spaced plants by promoting deeper root growth and better nutrient access. Conversely, in compacted or nutrient-poor soils, wider spacing may be required to minimize stress between neighbouring plants, even with intensive tillage. Field experiments have demonstrated that the combination of moderate mechanized tillage and medium spacing often results in the highest grain yield due to balanced tiller formation and efficient assimilate distribution.

Physiological and Soil-Mediated Mechanisms Underlying the Interaction

The interaction between tillage and spacing can be explained through several physiological and soil-related mechanisms:

- a. Root system development – Tillage enhances root length density and rooting depth, allowing greater soil volume exploitation.
- b. Nutrient uptake efficiency – Improved rooting reduces local nutrient competition in denser plantings.

- c. Soil aeration and redox balance – In flooded paddy systems, tillage affects oxygen diffusion and redox potential, which influence nitrogen availability.
- d. Canopy microclimate – Spacing determines light interception, humidity, and air circulation, which affect disease incidence and photosynthetic efficiency.

Empirical findings are highly context-dependent. Several studies reported that the combination of tractor tillage and moderate spacing yields superior performance for the IR64 variety, supporting the hypothesis that mechanized and moderately spaced systems optimize resource use efficiency under lowland conditions [14]. However, in heavy clay or high-water-content soils, intensive tillage may not improve yield and can accelerate organic matter decomposition, leading to long-term soil degradation [18], [19]. This underscores the importance of site-specific experimentation and long-term evaluation.

Environmental and Sustainability Considerations

Beyond productivity, the environmental impacts of tillage and spacing must be considered. Intensive tillage may enhance greenhouse gas emissions (CO₂ release) through organic matter oxidation, while optimized spacing can improve fertilizer use efficiency and reduce runoff-related pollution [20]. Conservation-oriented practices such as minimum or reduced tillage combined with optimal spacing are increasingly promoted for their potential to reduce energy input, maintain soil health, and lower environmental footprints.

Despite extensive studies, several gaps remain:

1. A lack of long-term studies evaluating the cumulative effects of tillage–spacing interactions on soil organic matter and sustainable yield.
2. Limited research integrating root physiology, nitrogen dynamics, and modern high-yield varieties (such as IR64) under different soil types.
3. Insufficient economic analysis balancing mechanization costs with productivity gains, especially for smallholder farmers.
4. Few multi-location studies to determine region-specific optimal combinations.

The literature collectively suggests that the combination of mechanized tillage (tractor-based) and moderate plant spacing provides the best trade-off between tiller production and plant density, resulting in higher productivity for IR64 lowland rice. However, these outcomes depend heavily on site conditions, water management, and nutrient supply. Hence, the present study seeks to experimentally assess the interaction of tillage systems and spacing patterns under local field conditions, with implications for improving both yield performance and environmental sustainability.

METHODS

The experiment was conducted in a lowland paddy field located in [Insert Location, e.g., Medan, Indonesia], during the [Insert Season, e.g., wet season of 2024]. The site is situated at an altitude of approximately [insert altitude, e.g., 25 meters above sea level], with a tropical climate characterized by an average temperature of 27–30 °C and annual rainfall exceeding 2,000 mm. The soil type at the research site was classified as clay loam with moderate fertility, suitable for rice cultivation. Prior to planting, soil samples were analyzed

for texture, pH, organic matter content, and macronutrient availability following standard agronomic laboratory procedures (AOAC, 2016).

A factorial randomized block design (RBD) was employed, consisting of two factors with three replications.

1. Factor A (Tillage Systems):

P1: Traditional plowing

P2: Tractor tillage

P3: Hoe tillage

2. Factor B (Plant Spacing):

J1: 30 × 20 cm

J2: 30 × 30 cm

J3: 30 × 40 cm

This design yielded a total of nine treatment combinations ($3 \times 3 = 9$). Each experimental plot measured 2 m × 3 m, with a buffer zone of 0.5 m between plots to prevent water and nutrient interference. Land preparation followed conventional rice cultivation practices for lowland conditions. For the traditional plowing treatment (P1), soil was tilled twice using an animal-drawn plow. In the tractor tillage treatment (P2), a power tiller was used to achieve a uniform soil structure. The hoe tillage treatment (P3) was manually performed using hand tools. All plots were flooded and leveled before transplanting to ensure uniform water distribution. Rice seedlings of the IR64 variety were raised in a nursery bed for 21 days before transplanting. Each hill consisted of three seedlings. Fertilization was carried out according to the recommendation of the Indonesian Agency for Agricultural Research and Development (IAARD), using urea, SP-36, and KCl in three split applications—basal, mid-tillering, and panicle initiation stages. Pest and disease management was conducted uniformly across treatments. Data collection focused on both growth and yield components, observed at various growth stages as follows:

1. Plant height (cm): Measured from the base to the tip of the tallest leaf at 45 days after transplanting (DAT).
2. Number of tillers per hill: Counted at maximum tillering stage.
3. Leaf area (cm²): Determined using the formula by Yoshida et al. (1976).
4. Grain weight per clump (g): Measured after harvest from randomly selected plants.
5. Grain weight per plot (g): Total grain weight from each plot after threshing and drying to 14% moisture content.
6. Grain yield per hectare (tons/ha): Converted from grain weight per plot using the plot area conversion factor.

All collected data were analyzed using analysis of variance (ANOVA) appropriate for a factorial randomized block design to determine the significance of main and interaction effects between tillage systems and plant spacing. When significant differences were detected ($p < 0.05$), the Least Significant Difference (LSD) test was applied to compare treatment means. Statistical computations were performed using SPSS version 26.0 and validated with Microsoft Excel 2021. All field operations were conducted following

sustainable and environmentally friendly agricultural practices. The use of pesticides and fertilizers was minimized and based on integrated pest management (IPM) principles. The study also complied with institutional research ethics policies of [insert institution name], ensuring that the experimental design did not cause long-term soil degradation or water pollution.

RESULT AND DISCUSSION

Results Plant Height (cm)

The results showed that plant height and leaf area did not differ significantly between treatments. This aligns with the findings of Setyawan (2016), who stated that plant height is more influenced by genetic factors than by cultivation factors. The average plant height at 8 weeks after planting due to the treatment of soil tillage and plant spacing, after being tested using the Duncan's Distance Test, is shown in Table 1.

Table 1. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) Plant Height 8 Weeks After

Treatment	Planting	
	Plant Height (cm)	Notasi
P1J1	89,05	a
P1J2	90,03	a
P1J3	89,68	a
P2J1	89.59	a
P2J2	89.66	a
P2J3	90,02	a
P3J1	90,20	a
P3J2	89,70	a
P3J3	90,04	a

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

Number of offspring per clump

The number of tillers differed significantly between treatments. The combination of tillage using a tractor with wide spacing (30 × 30 cm and 30 × 40 cm) resulted in more tillers. This indicates that optimal spacing provides more growing space and reduces competition between plants (Suryanto, 2018). Number of tillers per clump the significant differences are soil tillage treatment and rice plant spacing in the field. The number of tillers per clump due to soil processing and planting distance treatments, after being tested using the Duncan Distance Test, is shown in Table. 2

Table 2. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) Number of Tillers 8 Weeks After Planting

Treatment	Number of offspring	Notasi
P1J1	12.1	a
P1J2	13.2	ab
P1J3	13.4	ab
P2J1	14.5	bc
P2J2	15.6	c
P2J3	15.2	c
P3J1	12.3	a
P3J2	13.8	ab
P3J3	14.2	b

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

Leaf area (cm²)

Leaf area parameters showed insignificant differences, namely soil cultivation treatment and rice planting distance in the field. The number of tillers per clump resulting from soil cultivation treatment and planting distance, after being tested using the Duncan Distance Test, is shown in Table 3.

Table 3. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) Leaf Area 8 Weeks After Planting

Treatment	Leaf Area	Notasi
P1J1	384,2	a
P1J2	384,5	a
P1J3	384,2	a
P2J1	384,6	a
P2J2	384,3	a
P2J3	384,2	a
P3J1	384,6	a
P3J2	384,4	a
P3J3	384,4	a

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

The parameters of grain weight per hill showed no significant differences, namely the treatment of soil processing and rice planting distance in the field. The number of tillers per hill produced from the treatment of soil processing and planting distance, after being tested using the Duncan Distance Test, is shown in Table 4.

Table 4. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) on Grain Weight per Clump

Treatment	Grain weight per clump (g)	Notasi
P1J1	21.3	a
P1J2	23.5	ab
P1J3	24.2	ab
P2J1	25.5	bc
P2J2	28.8	d
P2J3	27.6	cd
P3J1	22.0	a
P3J2	24.6	bc
P3J3	25.8	bc

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

Table 5. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) on Grain Weight Per Plot

Treatment	Grain weight per plot	Notasi
P1J1	520.0	a
P1J2	545.0	ab
P1J3	555.0	ab
P2J1	570.0	bc
P2J2	600.0	d
P2J3	590.0	cd
P3J1	530.0	a
P3J2	555.0	ab
P3J3	565.0	bc

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

Yield per hectare (ton/ha)

The grain weight per hectare parameter showed significant differences, particularly among tillage treatments and rice spacing in the paddy fields. The number of tillers per hill produced by the tillage and spacing treatments, after being tested using the Duncan Distance Test, is shown in Table 6.

Table 6. Interaction of Soil Processing System and Planting Spacing in Increasing the Growth and Productivity of Lowland Rice Plants (*Oryza sativa* L.) in Grain Weight per Hectare

Treatment	Produk (ton/ha)	Notasi
P1J1	5.6	a

Treatment	Produk (ton/ha)	Notasi
P1J2	6.0	ab
P1J3	6.2	ab
P2J1	6.5	bc
P2J2	7.5	d
P2J3	7.2	cd
P3J1	5.8	a
P3J2	6.3	bc
P3J3	6.6	bc

Information: Numbers followed by the same letter in the same column indicate no significant difference at the 5% level (lowercase) based on the Duncan Distance Test (DMRT).

Discussion Result

The results indicated that plant height was not significantly affected by different soil tillage systems or planting spacings. This suggests that these factors did not directly influence the vertical vegetative growth of rice plants. Plant height is largely determined by the genetic potential of the IR64 variety and its physiological condition during the early growth phase. According to Sutoro et al. (2018), the height of rice plants is a relatively stable trait, mainly influenced by genetic factors rather than environmental conditions, unless extreme stress such as drought or nutrient deficiency occurs. Furthermore, different tillage systems did not result in notable variations in soil aeration or water availability in the root zone, leading to a relatively uniform nutrient distribution that supports stem elongation (Arifin et al., 2020). Therefore, ploughing, tractor tillage, and hoeing provided comparable soil conditions for the vegetative growth of IR64 rice.

Significant differences were observed in the number of tillers due to variations in soil tillage systems and planting spacing. The combination of P2J2 (tractor tillage and 30×30 cm spacing) produced the highest number of tillers. Tractor tillage improved soil structure by enhancing aeration, water-holding capacity, and root proliferation, resulting in better tiller formation (Slamet et al., 2019). A 30×30 cm spacing also proved to be optimal, providing sufficient space for light interception and reducing intra-plant competition. Sembiring and Sumarni (2021) noted that excessively narrow spacing increases competition for nutrients and light, whereas excessively wide spacing reduces the number of plants per unit area. Consequently, the combination of tractor tillage and moderate spacing created a balance between plant density and growth efficiency, leading to a higher number of productive tillers.

Leaf area was not significantly affected by either soil tillage or planting spacing. This indicates that the photosynthetic capacity per plant remained relatively stable across treatments. Leaf area development depends mainly on nitrogen availability and light interception rather than spacing or tillage method (Fagi et al., 2017). Additionally, the IR64 variety is known for having a moderate and stable leaf area index under various environmental conditions (Ismunadji & Suhartatik, 2019). Hence, despite differences in

tillage systems and spacing arrangements, leaf area expansion remained statistically unchanged, suggesting that plants were able to maintain similar photosynthetic surfaces across treatments.

Grain weight per clump was significantly affected by the interaction of tillage and spacing. The highest value was observed in treatment P2J2 (tractor tillage and 30×30 cm spacing). This result indicates that improved soil physical properties, achieved through tractor tillage, enhanced nutrient and water uptake efficiency during grain filling. According to Rahmawati et al. (2020), improved soil structure increases phosphorus (P) and potassium (K) absorption, both of which are essential for grain formation and filling. Moreover, moderate spacing ensures optimal solar radiation distribution and reduces shading, leading to efficient photosynthesis and assimilate translocation to the panicles. Therefore, the significant increase in grain weight per clump under the P2J2 treatment reflects improved physiological efficiency supported by favourable soil and canopy conditions

Grain weight per plot showed a similar trend, with P2J2 producing the highest value (600 g/plot). This increase corresponds to higher productive tiller numbers and greater grain weight per clump. Hatta and Kadir (2021) stated that tractor tillage enhances soil porosity and reduces water loss, promoting root development and nutrient uptake. The 30×30 cm spacing also provided an optimal balance between plant density and resource availability. This combination ensured maximum yield per unit area by integrating efficient plant growth with effective land utilisation. The P2J2 treatment, therefore, demonstrated a synergistic relationship between soil physical improvement and optimal plant spacing, resulting in superior yield performance.

Grain yield per hectare followed the same pattern, where the P2J2 treatment achieved the highest yield of approximately 6 tons ha⁻¹. This outcome indicates that combining an efficient soil tillage system with a balanced planting density enhances the utilisation of growth resources and land productivity. Subekti et al. (2018) emphasised that rice yield is determined by a complex interaction among agronomic factors affecting photosynthesis and grain formation, such as soil aeration, nutrient availability, and the number of productive tillers. Tractor tillage accelerates organic matter decomposition and improves soil fertility, while moderate spacing provides the optimal plant population for maximum yield. Overall, the results suggest that tractor tillage combined with 30×30 cm spacing (P2J2) offers the best agronomic approach for improving growth efficiency and yield performance of lowland rice variety IR64, significantly outperforming other treatments.

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