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**ORIGINAL RESEARCH ARTICLE**

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# Performance of two rice varieties in different numbers of seedlings hill-1 at Khairahani, Chitwan, Nepal

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**ABSTRACT**

A field experiment was conducted from June to October 2022 at Khairahani Municipality, Chitwan, Nepal, to evaluate the effects of the number of seedlings (one, two, three, and four) hill $^{-1}$ and rice varieties (US-305 and Ramdhan) on rice yield. The number of seedlings hill$^{-1}$ is one of the most important factors for determining rice yield. Farmers need to know the appropriate number of seedlings hill$^{-1}$ needed for different rice varieties. Thus, we aimed to evaluate the performance of two rice varieties under different numbers of seedlings hill$^{-1}$, to determine the optimum number of seedlings hill$^{-1}$ or improving rice yield at Khairahani, Chitwan, Nepal. The experiment was conducted in a randomized complete block design with three replications. Seedlings of both varieties were planted at a spacing of 20×20 cm. The study focused on various growth and yields, attributing parameters of rice, including plant height, tiller number, effective tillers, thousand grain weight, grain yield per hectare, and biological yield per hectare. The number of seedlings hill$^{-1}$ was found to have the highest impact on yield attributing characters. The highest plant height (124.72 cm), effective tiller per square meter (342), panicle length (28.65 cm), number of filled grains per panicle (120.43), economic yield, biological yield, and HI were found in two seedlings, hill$^{-1}$. Whereas one seedling hill$^{-1}$ had the highest effective grains per panicle (142.66), test weight (24.23g), and straw yield (10.63 t/ha). Thus, US-305 had better growth and yield attributes, suggesting farmers of Khairahani can combine two seedlings of US 305.

## INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops worldwide and provides a stable food source for nearly half of the global population (Bin Rahman & Zhang, 2023). Rice occupies first place in terms of area coverage, production, and preferences in Nepal, as it covers 48.26% of the total cultivable land in Nepal and contributes 32.7 % to the GDP, with an average productivity of 3.76 mt/ha (MOALD, 2023). Remarkably, Chitwan alone contributes 22.25% of the rice production in Bagmati province, underscoring its importance in the region's agricultural landscape (MOALD, 2023). Rice production significantly contributes to the national food supply, improving livelihoods and enhancing the agricultural economy. However, rice productivity in Nepal falls below the global average of 4.67 tons/ha, highlighting challenges of agronomic practices and varietal perfor-

mance under different field conditions (FAO, 2023). Among various agronomic practices affecting rice yield, the number of seedlings transplanted hill[-1] plays a critical role in determining the rice yield. The farmers in the study area lack information on the optimum seedling density hill[-1] for maximum yield. Additionally, they have been purchasing costly hybrid seeds and planting them at a high density, expecting that this would increase rice production (MOALD, 2021). But transplanting too few seedlings may lead to reduced plant population due to a higher mortality rate, while transplanting too many seedlings can lead to increased competition for resources, reducing productivity (Deng *et al.*, 2022). The density of seedlings had a significant impact on rice growth and grain yield because of the impact of interplant competition on both vegetative and reproductive development (Wu *et al.*, 2025). Higher density might cause mutual shading, susceptibility to lodging, and more vegetative growth than the grains. Whereas a low number of seedlings might produce fewer numbers of tillers, causing the wastage of space and unutilized nutrients, which might result in a poor yield (Zhu *et al.*, 2023). Moreover, if a high number of seedling hill[-1] is planted, then there will be a crowding of seedlings, which is not cost-effective (Dejen, 2018), whereas with fewer seedlings, hill[-1], the expected yield cannot be gained (Gurjar *et al.*, 2018).

Additionally, different rice varieties respond differently to crop management practices, including seedling density hill[-1]. Most of the hybrid rice varieties are popular for higher yield potential, while improved varieties are known to perform better in specific regions of Nepal. Rice varieties and seedling density are major factors affecting the rice yield, but their interaction has not been well explored to date. Although several studies have investigated the effect of seedling density on rice yield, limited study is done about the combined effect of different seedling number hill[-1] and rice varieties across the ecological conditions of Khairahani, Chitwan, Nepal. Moreover, farmers in the research area follow traditional agricultural methods. They employ 10-12 seedlings hill[-1] with wider spacing between them, older seedlings, irrespective of the varieties they are using. Therefore, this research aims to evaluate the yield and growth performance of two rice varieties (US-305 and Ramdhan) when grown with different numbers of seedlings hill[-1], to identify the optimal number of seedlings hill[-1] that maximizes growth and yield performance in Khairahani, Chitwan, Nepal. This research evaluates the number of seedlings hill[-1] for the different varieties, which is essential for decision-making among farmers.

## MATERIALS AND METHODS

### Experimental site
The experiment was conducted in Khairahani Municipality (Ward No. 5), Eastern Chitwan, Nepal (28°17' N, 81°41' E), during the main rice growing season from 9th June 2022 to 21st October 2022. Geographically, it is situated in a tropical zone at an altitude of 200.7 m above sea level. The experimental site consists of sandy loam soil, the predominant type for local rice production (Table 1). The region's climate is defined by three distinct seasons: a hot spring (March–May), a rainy season (June–October), and a cool winter (November–February). The research was conducted during the rainy season, which is the main season for rice, and weather parameters were collected from the NASA Power database. The rice seeds were collected from Nepal Agricultural Research Council (NARC) and nearby Agrovet, which were the recommended variety for the terai region of Nepal.

### Experimental design and treatment details
The study considered two rice varieties: US-305 (Hybrid) and Ramdhan (Improved). For the improved variety, seeds were pre-sorted and treated with salt and a fungicide (Bavistin), while hybrid seeds were acquired pre-treated from a local agrovet. Seedlings for both varieties were established using a dry-bed nursery method. The field experiment followed a two-factor Randomized Complete Block Design (RCBD) with three replications. Factor A includes Hybrid (US-305) and Improved (Ramdhan) varieties, whereas Factor B was the number of seedlings hill[-1], which included four density levels: one, two, three, and four seedlings hill[-1]. This resulted in eight treatment combinations. Altogether 24 research plots were present, where each plot had a dimension of 3m × 3m in the main field.

### Agronomic management and cultivation practices
The experimental field, previously cropped with foxtail millet (*Setaria italica*), was prepared using a tractor-drawn plow followed by manual weeding and stubble removal. All experimental inputs were sourced from local agrovets in Khairahani, Chitwan. Two weeks before planting, a well-decomposed Farmyard Manure was applied@5 tons ha^{-1} in the field. Synthetic fertilizer was applied at the recommended dose of fertilizers (80:60:40 Kg NPK ha^{-1}). Phosphorus and potash were applied entirely as a basal dose alongside one-third of the total nitrogen. The remaining nitrogen was top-dressed in two equal splits at the active

**Table 1.** Physical and chemical characteristics of soil from the research site.

| S. No. | Particulars | Value |
|---|---|---|
| 1. Physical analysis & particle size distribution | Sand | 44.43% |
| | Silt | 42.12% |
| | Clay | 13.54% |
| 2. Chemical properties | Soil pH | 6.1 |
| | Organic carbon | 2.32% |
| 3. Available macronutrients | Nitrogen | 0.12% |
| | Phosphorus | 110.58 kg/hac |
| | Potassium | 215.91 kg/hac |
| 4. Available micronutrients | Boron | 2.54 ppm |
| | Zinc | 1.31 ppm |

(Source: Digital Map of Nepal)

tillering and panicle initiation stages. Spacing between the plots and replications was 0.5m and 1m, respectively. Where 25-day-old rice seedlings were transplanted at a uniform spacing of 20 cm × 20 cm. Manual weeding was done at an interval of 15 days, to reduce weed and pest infestation. No herbicides or pesticides were used. Manual harvesting and threshing using a sickle were done for the crop from each plot and stored separately. Further, the biomass yield of the harvested rice was measured, and grains were weighed after winnowing and cleaning.

### Data collection

Destructive sampling was performed every 15 days, from 15 to 75 days after transplanting (DAT). Three samples were systematically collected per plot along an eastern transect, moving from south to north. Growth and yield parameters recorded included plant height, panicle length, and the density of effective and non-effective tillers per $m^2$. At maturity, we determined the number of filled and unfilled grains per panicle, sterility percentage, and thousand-grain weight (test weight). Economic and biological yields were measured from the net plot area, while the Leaf Area Index (LAI), sterility percentage, and Harvest Index (HI) were calculated using standard agronomic methods.

**Biological Yield (BY):** The Biological yield of any crop is the total biomass produced by a crop, including grain and straw yields (Donald & Hamblin, 1976).

$$BY = Grain\ Yield + Straw\ Yield$$

**Harvest Index (HI):** The HI is the grain yield over total aboveground biomass (Yang & Zhang, 2010).

$$HI = Grain\ yield/Total\ above\ ground\ biomass(BY) \times 100$$

**Leaf Area Index (LAI):** The LAI is the ratio of ground area to the leaf area above it, indicating the density of leaf coverage (Watson, 1947).

$$LAI = Ground\ Area\ /\ Leaf\ Area$$

**Sterility %:** The percentage of spikelets that are sterile, calculated as the ratio of sterile spikelets to total spikelets (Yoshida, 1973).

$$Sterility\ \% = (Total\ Number\ of\ Spikelets/Number\ of\ Sterile\ Spikelets) \times 100$$

**Test weight (TW):** The weight of 1000 grains, used as a standard measure of grain quality, is the test weight (Gomez & Gomez, 1984).

$$TW = Weight\ of\ 1000\ Grains/\ 1000$$

**Economic Yield (EY):** The optimal yield that a farm can attain when resources are used efficiently, accounting for typical inefficiencies in resource management (Okello *et al.*, 2019).

### Statistical analysis

All the observed data were arranged using MS Excel, and all statistical analyses were done using R-programming 4.3.3 Version with R-Studio, and word processing was done through MS Word.

Analysis of variance (ANOVA) for two factors RCBD was done to evaluate the effects of rice varieties and the number of seedling hill[-1] along with their interaction on crop performance. Significant differences among treatments were compared using Least Significant Difference (LSD) at the 5% level of significance. The relationship among measured rice traits was evaluated using Pearson's correlation analysis, which determines the positive and negative association among growth, yield, and yield attributing traits in rice.

## RESULTS AND DISCUSSION

### Plant height

Seedling numbers hill[-1] were found to be statistically significant at ($p>00.1$) while no significant difference between rice varieties was observed for plant height. Likewise, the interaction between variety and number of seedlings hill[-1] was non-significant. Improved variety (Ramdhan) showed taller plants than hybrid rice (US-305). The average plant height of Ramdhan was 124.72 cm, while the average height of US-305 was 117.93 cm (Table 2). The reason behind these findings could be due to the modern hybrid varieties often being shorter than improved or local varieties due to reduced internode length, as reported by (Wei *et al.*, 2021) Further, hybrid rice is more influenced by the additive effects of parental genes that have some restorer lines, which have negative effects on plant height, therefore, enhancing lodging resistance (Wang *et al.*, 2023) Moreover, seedling density significantly influenced plant height in rice. The tallest plants were found with two seedlings hill[-1] (124.72 cm), while four seedlings hill[-1] showed shorter plants (117.60 cm). Similar results were reported by (Khatun *et al.*, 2022; Rajput *et al.*, 2023), who observed taller plants at two seedling hills[-1] and a reduction in height with increasing seedling numbers. The decrease in plant height with an increased number of seedlings hill[-1] was due to the competition between the plants for space, light, and nutrients (Postma *et al.*, 2021) Several other studies have also reported similar findings, stating that when there is more crowding of the seedlings, there will be higher chances of competition and mortality, which leads to shorter heights of the plant (Khatun *et al.*, 2022; Paudel *et al.*, 2021) However, a study conducted by (Ali Khan Imran *et al.*, 2015), reported contrasting results, where the tallest plants were found with three seedlings hill[-1] and the shortest with one seedling hill[-1], suggesting some of the varietal response and environmental factors might affect plant height under different seedlings hill[-1].

### Leaf area (cm² per plant)

The variety of rice significantly affects the leaf area. The hybrid variety (US-305) showed a higher leaf area (1273.54 cm² plant[-1]) as compared to the improved variety Ramdhan (883.0375 cm² plant[-1]), as shown in Table 2. This might be because the hybrid variety consists of superior genetic traits that support better

leaf development (Huang *et al.*, 2018). At the same time, hybrids, resulting from a mix of different parent lines, might exhibit traits that enhance vegetative growth in rice (Sun *et al.*, 2025; WEI *et al.*, 2020). The number of seedlings also significantly affected the leaf area, showing the highest leaf area (1287.50 cm² plant⁻¹) with two seedlings hill⁻¹ while the lowest leaf area (909.8567 cm² plant⁻¹) was observed in four seedlings hill⁻¹. This is because increasing the number of seedlings above the optimum levels tends to reduce leaf area due to higher competition for resources, which limits the vegetative growth (TIAN *et al.*, 2023). More seedlings hill⁻¹ may increase panicle numbers but may reduce the spikelet per panicle and leaf size, which affects the leaf area of rice (Deng *et al.*, 2022). Several studies have supported findings that suitable seedling density improves the canopy structure and light utilization, which increases the rate of photosynthesis and leaf area (Deng *et al.*, 2022; Rajput *et al.*, 2023)

### Panicle length

Variety of rice had non-significant results, while the number of seedlings showed significant results on panicle length ($p<0.01$). The interaction between variety and number of seedlings in hill⁻¹ was non-significant. The hybrid variety (US-305) had a slightly higher panicle length (26.15 cm) than Ramdhan (25.78 cm), with no significant difference, as shown in Table 2. Hybrid rice may produce longer panicles due to its genetic characteristics, like qPEL10.2, which supports yield-related traits in rice (Deng *et al.*, 2022). Additionally, hybrid rice varieties have ideal larger top leaves, which positively correlate with grain yield and increase sunlight energy utilization efficiency, leading to larger panicle length (Zhong *et al.*, 2020). In the case of the number of seedlings hill⁻¹, the longest panicle length (28.45 cm) was recorded in two seedlings hill⁻¹, while the shortest panicle length (23.04 cm) was observed in four seedlings hill⁻¹. Panicle length found in three seedlings, hill⁻¹ (26.26 cm), was statistically similar to that observed in one seedling, hill⁻¹ (26.10 cm). Similar results were observed by (Paudel *et al.*, 2021), who observed the highest panicle length with two seedling hill⁻¹. Whereas Berhanu (2017) reported shorter panicle length at higher seedling density. The short panicle length at higher densities may be due to increased competition for light, nutrients, and moisture. This reduction in panicle length is linked with lower biomass accumulation, smaller leaf area, and reduced nutrients due to higher densities (Rajput *et al.*, 2023). While with an optimum number of seedlings, plants can mobilize the available resources more efficiently, supporting better growth and panicle length (TIAN *et al.*, 2023).

### Effective grains per panicle

The number of seedlings hill⁻¹ has a significant effect on the number of effective grains per panicle, whereas no significant differences were found between rice variety and the interaction between variety and seedling number. Although the difference was not significant, the hybrid variety (US-305) produced more effective grains per panicle (152.08), compared to the improved variety (Ramdhan-100.50), as presented in Table 3. This is because the hybrid varieties provide more resources for grain production rather than vegetative growth (Zhong *et al.*, 2020). The seedling number hill⁻¹ influenced the number of effective grains per panicle. The number of seedlings in hill⁻¹ had a substantial impact on the effective grains per panicle. The highest grains were found with one seedling hill⁻¹ (142.66), whereas the lowest was found with four seedling hill⁻¹ (112). A similar finding was reported by Huang *et al.* (2018), where fewer effective grains were found with four seedling densities. Lower seedlings hill⁻¹ reduces the competition for nutrients and other resources, reducing pest/ disease infestation, which supports better grain filling (Pokharel *et al.*, 2018). Additionally, the genetic factors that control grain filling might contribute to higher grains per panicle (Gunasekaran *et al.*, 2023).

### Non-effective grains per panicle

The variety of rice did not affect non-effective grains per panicle, while the number of seedlings showed significant results. The interaction between variety and number of seedlings in Hill⁻¹ was non-significant. The improved variety had more non-effective grains per panicle (16.91) than the hybrid variety (15.08). The number of non-effective grains per panicle for the four seedlings hill⁻¹ was greater (19.83), as compared to one seedling hill⁻¹ (11.83), as presented in Table 3. A similar result was observed by (Mahato *et al.*, 2018) where three and four-seedling hill⁻¹ had higher numbers of non-effective grains per panicle. These findings are consistent with the findings of (TIAN *et al.*, 2023) who observed that the highest number of unfilled grains per panicle was obtained with three seedlings in hill⁻¹. This is because inter and intra-plant competition increased because of transplanting more seedlings hill⁻¹, decreasing the number of filled grains per panicle, which increased the number of

**Table 2.** Plant height, LAI, and panicle length as influenced by the number of seedlings hill⁻¹ and two varieties in Chitwan, Nepal, 2022.

| Traits | Plant height (cm) | LAI | Panicle length (cm) |
|---|---|---|---|
| Variety (a) | ns | *** | ns |
| No. of seedlings (b) | ** | ns | *** |
| A×B | ns | ns | ns |
| Mean | 121.32 | 1078.29 | 25.96 |
| CV (a) | 5.60 | 3.27 | 5.22 |
| CV (b) | 2.28 | 11.16 | 4.06 |
| LSD (a) | 11.95 | 62.09 | 2.38 |
| LSD (b) | 3.49 | 151.50 | 1.32 |

Note: Tables show the effect of treatment and their interaction in the studied traits '***' represents the significance at (P<0.000), '**' represents the significance at (P<0.001), '*' represents the significance at (P<0.01) and '.' represents the significance at (P<0.05).

**Table 3.** Effective and non-effective grains per panicle, number of hills, sterility, and test weight as influenced by the number of seedlings hill[-1] and two varieties in Chitwan, Nepal, 2022.

| Traits | Effective grains per panicle | Non-effective grains per panicle | Number of hills | Sterility | Test wt. |
|---|---|---|---|---|---|
| Variety (a) | ns | ns | ns | ns | ns |
| Seedlings Number (b) | * | * | *** | ** | ns |
| A×B | ns | ns | ns | ns | ns |
| Mean | 126.2917 | 16 | 12.67 | 288.08 | 23.58 |
| CV (a) | 6.489365 | 52.30681 | 28.51 | 12.74 | 5.84 |
| CV(b) | 9.113553 | 22.15838 | 16.9 | 12.74 | 2.42 |
| LSD (a) | 14.39586 | 14.70073 | 6.34 | 64.47 | 1.47 |
| LSD (b) | 14.47844 | 4.45982 | 2.69 | 128.94 | 4.95 |

Note: Tables show the effect of treatment and their interaction in the studied traits '***' represents the significance at (P<0.001), '**' represents the significance at (P<0.01), and '*' represents the significance at (P<0.05).

unfilled grains per panicle (Hu *et al.*, 2025). Increasing the number of seedlings in hill[-1] leads to more panicles but fewer spikelets per panicle, resulting in more ineffective grains (Zhang *et al.*, 2023). As the number of seedlings in hill[-1] increases, the percentage of ripened grains decreases, leading to more ineffective grains.

### Number of hills

Rice variety did not significantly affect the number of hills, as shown in Table 3. The Hybrid variety US-305 (24.08) and the improved variety Ramdhan (24.25) showed similar results. However, the number of seedlings hill[-1] significantly influenced the number of hills. The highest number of hills was observed in two seedlings, hill[-1] (25.00), which was statistically similar to one seedling (24.50) and three seedlings (24.00). Previous studies have also reported similar results, where better grain yield, effective tillers, and overall growth performance were found with two seedling hill[-1] (Hossain *et al.*, 2022; Ngawang *et al.*, 2022). Similar results were obtained by the study of (Paudel *et al.*, 2021), which may be attributed to reduced competition among hills for light, nutrients, and space under two seedling planting, which promotes better root development, higher tiller survival, and improved assimilate partitioning towards productive tillers. This is because higher seedling hill[-1] numbers increase competition, leading to higher tiller mortality and reduced yield (Deng *et al.*, 2022).

### Sterility (%)

The variety of rice did not affect sterility percentage, while the seedlings hill[-1] showed significant results, as shown in Table 3. The interaction between variety and number of seedlings hill[-1] was non-significant. The improved variety, Ramdhan (14.14%), showed a higher sterility % than the hybrid variety, US-305 (10.63%). Sterility % in rice is affected by the genetic and environmental factors, such as high temperature and moisture, which affect pollen viability and grain filling (Chidambaranathan *et al.*, 2021). Similar findings were reported by Shi *et al.* (2018), where environmental stressors like high temperatures and pollen tubes failing to reach the viable embryo sac under heat stress affect fertility. Similarly, hybrid sterility in rice is mainly controlled by a few orthologous loci with different alleles, and understanding these interactions can help overcome it for rice breeding purpos-

es (Li *et al.*, 2020). In the case of seedlings, two seedlings hill[-1] had less sterility% (7.67), while more sterility % (15.70) was observed in four seedlings hill[-1]. A similar result was also recorded by Mahato *et al.* (2018), where the lowest number of sterile grains per panicle was found in two seedling hill[-1]. This is because lower seedling numbers hill[-1] reduce competition, allowing for better resource allocation per plant, which results in a lower sterility percentage and better overall plant health (Thapa *et al.*, 2019). Whereas four seedlings in hill[-1] leads to increased competition among plants, resulting in a higher sterility percentage due to reduced resources per plant and smaller growth of culms (Shamshiri *et al.*, 2019).

### Test weight

Results showed that the test weight was not significantly affected by rice variety or the number of seedlings hill[-1] as shown in Table 3. The interaction between variety and number of seedlings hill[-1] was also non-significant. Although the difference was not significant, the improved variety Ramdhan (24.11 g) showed higher test weight compared to the hybrid variety US-305 (23.05 g). Similar results were reported by (Paudel *et al.*, 2021). The differences in grain weight can be due to morphological and varietal variation within cultivars, as reported by several studies (Bai *et al.*, 2023; Chen *et al.*, 2021; Singh Yadav *et al.*, 2024). In addition to this, there are several environmental factors, like moisture and temperature, along with methods of drying, which might have affected grain weight. In the case of seedlings hill[-1], the highest test weight (24.23) was recorded in one number of seedlings, while the lowest was in four seedlings hill[-1] (22.92). This decrease in test weight might be due to the competition for maternal resources among developing embryos with insufficient nutrients, moisture, or the resources to develop a higher test weight (Khatun *et al.*, 2022). This is because the yield-contributing traits, such as effective tillers, panicle length, and grain weight per panicle, were higher in lower density compared to higher seedling densities (TIAN *et al.*, 2023).

### Number of effective tillers/m$^2$

The variety of rice did not affect the number of effective tillers/m$^2$, while the number of seedlings showed significant results. The interaction between variety and number of seedlings hill[-1] was non-significant. The hybrid variety (290.83) had a greater

**Table 4.** Number of effective tillers/m$^2$, Number of non-effective tillers/m$^2$, economic yield, biological yield, Straw yield, and HI as influenced by the number of seedlings hill$^{-1}$ and two varieties in Chitwan, Nepal, 2022.

| Traits | Effective tiller/m$^2$ | Non-effective tiller/m$^2$ | Economic yield | Biological yield | Straw yield | HI |
|---|---|---|---|---|---|---|
| Variety (a) | ns | ns | * | ns | ns | ns |
| No of seedlings (b) | *** | *** | *** | * | ns | ** |
| A×B | ns | ns | ** | ns | ns | ns |
| Mean | 288.0833 | 12.6667 | 5.06 | 15.3 | 10.24 | 32.96 |
| CV (a) | 12.74048 | 28.51046 | 5.15 | 3.23 | 7.88 | 10.11 |
| CV(b) | 6.349815 | 16.90162 | 4.46 | 7.11 | 11.17 | 8.93 |
| LSD (a) | 64.47103 | 6.343475 | 0.46 | 0.87 | 1.42 | 5.85 |

Note: Table shows the effect of treatment and their interaction in the studied trait '***' represents the significance at (P<0.001), '**' represents the significance at (P<0.01), and '*' represents the significance at (P<0.05).

number of tillers/m$^2$ than the improved variety (285.33), but both varieties were at par with each other. In the case of the number of seedlings hill$^{-1}$, a higher number of effective tillers/m$^2$ (342) was recorded with two numbers of seedlings hill$^{-1}$, while the lowest (226.16) was observed with four numbers of seedlings hill$^{-1}$ (Table 4). This might be because the higher density can lead to more competition and resource consumption, leading to lower effective tillers due to suppressed tiller growth. Additionally, higher density might lead to disease and pest infestation attacks within tillers, reducing the effective number of tillers. Similar results were reported by Paudel *et al.* (2021), where the highest number of effective tillers/m$^2$ was found with two seedlings hill$^{-1}$, followed by three seedlings hill$^{-1}$. Several other studies conducted by (Masum *et al.*, 2014; Sarker & Nahar, 2022; Sun *et al.*, 2025) observed that the highest effective tillers were with two seedling hill$^{-1}$ and the lowest with four seedlings hill$^{-1}$.

**No of non - effective tiller/m$^2$**

The variety of rice did not affect the number of non-effective tillers/m$^2$, while the number of seedlings showed significant results. The interaction between variety and number of seedlings hill$^{-1}$ was non-significant. The improved Variety (13.25) had a larger number of non-effective tillers/m$^2$ than the hybrid variety (12.08). In the case of the number of seedlings hill$^{-1}$, fewer non-effective tillers/m$^2$ (8.16) were found with two numbers of seedlings hill$^{-1}$, while more non-effective tillers/m$^2$ (18.17) were observed in four numbers of seedlings hill$^{-1}$. This might be because of the existing competition for resources such as light, nutrients, and moisture within higher densities. A similar finding was reported by Masum *et al.* (2014), who recorded the minimum number of non-effective tillers in two seedling hill$^{-1}$. Individual plants compete more intensely in hills with four seedlings for light, nutrients, and water. Which results in a higher number of ineffective tillers (MAU *et al.*, 2022). This is further supported by (Thapa *et al.*, 2019), stating that excessive transplanting density leads to competition among plants and limits yield beyond an optimum level. With fewer seedlings, plants can regulate growth more effectively, ensuring that every tiller receives adequate resources to develop into an effective tiller (Sarker & Nahar, 2017).

**Economic yield (EY)**

Economic yield (EY) was significantly influenced by rice variety and the number of seedlings per hill (p < 0.01). The interaction

between variety and seedling number was also significant (p < 0.001). The EY of the hybrid variety (5.350 tons/hectare) was higher than that of the improved variety (4.767 tons/hectare). In the case of the number of seedlings hill$^{-1}$, the highest EY was recorded for two seedlings hill$^{-1}$ (6.167 ton/hectare), whereas the lowest was found for four seedlings hill$^{-1}$ (4.083 ton/hectare). The interaction between the hybrid variety and two seedlings hill$^{-1}$ showed the highest EY of 6.367 tons/hectare; however, the lowest EY was found in the interaction between a hybrid variety and four seedlings per head, i.e., 3.84 tons / hectare, as shown in Table 4. A similar result was found by Sah *et al.* (2022), where the hybrid produces more than the local variety due to heterosis, resulting in more spikelets per panicle and more panicles per unit length. Further, hybrid rice is better suited to simplified practices, with greater yield stability and lower input sensitivity, and yields more due to higher dry weight and better nitrogen use (Huang *et al.*, 2018). Paudel *et al.* (2021) reported similar results, showing a higher economic yield for two seedlings hill$^{-1}$, and the lowest was for four seedlings hill$^{-1}$. According to (Rajput *et al.*, 2023), a lower number of seedlings in hill$^{-1}$ supports healthy tillers, normal physiological growth, and yields more healthy panicles and filled spikelet, supporting high economic yield. Furthermore, the higher yield for low seedling density might be due to a higher number of effective tillers and light interception (Liao *et al.*, 2024; Thapa *et al.*, 2019). Hybrid rice varieties produced significantly higher grain yield than the conventional variety when transplanted with one or two seedlings of hill$^{-1}$ (Huang *et al.*, 2018). This study found that appropriate seeding density improves tiller number, dry matter accumulation, and photosynthetic capacity, which ultimately enhances rice yield. Similar trends were reported by Poudel *et al.* (2023), who observed that rice genotypes grown under optimal planting density produced a higher number of tillers and accumulated greater vegetative biomass.

**Biological yield**

Biological yield was not significantly affected by rice variety (p > 0.05), although US-305 produced a slightly higher biological yield (15.54 t ha$^{-1}$) compared to Ramdhan (15.04 t ha$^{-1}$). In contrast, the number of seedlings per hill significantly influenced the biological yield at the 5% level of significance (p < 0.05). The highest biological yield was recorded using two seedlings hill$^{-1}$ (16.26 t ha$^{-1}$). This result was statistically at par with both one

**Table 5.** Correlation among the different parameters with the economic yield conducted research in Chitwan, Nepal, 2022.

| Trait | PH | PL | LAI 75 | Sterility | NET | ET | NH | EY | SY | BY | HI | TW |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | PH | | | | | | | | | | | |
| PL | 0.57 | PL | | | | | | | | | | |
| LAI 75 | 0.72 | 0.44 | LAI75 | | | | | | | | | |
| Sterility | -0.64 | -0.60 | -0.46 | Sterility | | | | | | | | |
| NET | -0.26 | -0.74 | -0.32 | -0.41 | NET | | | | | | | |
| ET | 0.50 | 0.82 | 0.39 | -0.51 | 0.76 | ET | | | | | | |
| NH | 0.40 | 0.64 | 0.48 | -0.38 | -0.49 | 0.63 | NH | | | | | |
| EY | 0.67 | 0.84 | 0.68 | -0.69 | -0.71 | 0.71 | 0.71 | EY | | | | |
| SY | -0.02 | 0.26 | 0.03 | 0.02 | -0.01 | 0.19 | 0.30 | 0.01 | SY | | | |
| BY | 0.44 | 0.76 | 0.47 | -0.45 | -0.48 | 0.62 | 0.69 | 0.67 | 0.74 | BY | | |
| HI | 0.61 | 0.63 | 0.59 | -0.63 | -0.64 | 0.56 | 0.49 | 0.88 | -0.46 | 0.25 | HI | |
| TW | 0.37 | 0.08 | 0.45 | -0.10 | 0.004 | 0.03 | 0.13 | 0.2 | 0.14 | 0.24 | 0.10 | TW |

seedling (15.74 t ha^{-1}) and three seedlings hill[-1] (15.37 t ha^{-1}), whereas the lowest yield (13.80 t ha^{-1}) was observed with four seedlings hill[-1]. These results align with the findings of (Paudel *et al.*, 2021), who similarly observed higher grain and straw yields with two seedlings hill[-1] and the lowest yields with four seedlings. Fundamentally, biological yield in rice is significantly and positively associated with the harvest index, number of tillers hill[-1], panicle length, spikelets per panicle, plant height, and test weight, with hybrids generally accumulating more biomass across all phenological phases. As supported by (Mahato *et al.*, 2018), planting one or two seedlings hill[-1] optimizes effective tillers, filled grains per panicle, and spikelet fertility. Conversely, higher planting densities, such as four seedlings hill[-1], induce resource competition that diminishes both tiller effectiveness and overall yield (Hu *et al.*, 2025).

### Straw yield

The straw yield was found to be non-significant with both varieties, the number of seedlings hill[-1], and the interaction between these two factors. The straw yield of the hybrid variety (10.28 tons/hectare) was higher than that of the improved variety (10.19 tons/hectare). In the case of the number of seedlings hill[-1], the highest straw yield was recorded for single seedlings hill[-1] (10.63 tons/hectare), whereas the lowest straw yield was seen for four seedlings hill[-1] (9.72 tons/hectare). The interaction between US-305 and single seedling hill[-1] showed the highest straw yield of 10.65 tons/hectare; however, the lowest straw yield was found in the interaction between Ramdhan and four seedlings hill[-1,] i.e., 9.356 tons /hectare, as reported in Table 4. A study conducted by Hossain *et al.* (2022) showed that the number of seedlings doesn't have a significant effect on straw yield. Similarly, a study conducted by (Mahato *et al.*, 2018; Paudel *et al.*, 2021) recorded the lowest straw yield for four seedlings hill[-1]. Yun (2023) found that when rice was transplanted at low densities (including one or two seedlings per hill), biomass and straw yield remained statistically similar.

### Harvest Index (HI)

The number of seedlings per hill significantly influenced the Harvest Index. The highest HI was observed with two seedlings per hill (37.967). In contrast, four seedlings per hill yielded the lowest HI (29.64); a result found to be statistically comparable to the

HI of three seedlings per hill (31.78), as presented in Table 4. These results align with the findings of Hossain *et al.* (2022), who also reported a significant correlation between seedling density and HI, noting a peak at two seedlings and a decline at four. However, this contradicts the research of Dejen (2018) and Pokharel *et al.* (2018), who observed no significant impact of seedling numbers on the harvest index. Varietal differences did not yield a statistically significant effect on HI. While the hybrid variety produced a numerically higher value (34.34) compared to the improved variety, the two were considered statistically at par. Recent research in China shows that super-hybrid rice is not always better than regular popular rice when it comes to HI. Liao *et al.* (2024) found a difference at a specific location; the results changed depending on the site and the year. This suggests that any advantage in HI is usually small and depends entirely on the local environment rather than just the variety of rice. Furthermore, there was no significant interaction effect between the variety and the number of seedlings hill[-1]. This finding aligns with research on Tilki rice, which similarly showed non-significant differences in HI across seedling age, the number of seedlings hill[-1], and their interaction (Dhungana *et al.*, 2020).

### Correlation among agronomic traits in rice

The result shows that the economic yield is positively correlated with all traits explained in our methodology, except sterility percentage and the number of non-effective tillers. For these two traits, economic yield possesses a negative correlation, which signifies that an increase in the value of these traits will decrease the economic yield (Table 5). Banjare *et al.* (2023) found that sterility percentage was negatively and significantly associated with seed yield per plant, whereas filled grains per panicle, panicle length, HI, total grains per panicle, and effective tillers showed positive associations. Spikelet sterility shows a significant negative correlation with yield because it reduces the number of filled grains and thus grain yield sink capacity, which often arises from stress or genetic factors that disrupt fertilization, and diverts assimilates to non-productive structures, lowering HI and overall economic yield. In rice, grain yield shows positive associations with plant height, panicle length, number of tillers, effective tillers, LAI, and filled grains per panicle, although the strength/significance can vary by population and environment (Nachiketha *et al.*, 2024). The number of effective

tillers is positively correlated with economic yield, while non-effective tillers show a negative correlation (Nanda *et al.*, 2019). Effective tillers are positively correlated with economic yield because they carry panicles and directly increase grain number per unit area. Non-effective tillers, by contrast, intercept light and nutrients but fail to produce grain, so they dilute resources, reduce HI and nitrogen-use efficiency, and therefore show a negative correlation with economic yield. Higher filled grain number per panicle and 1000-grain weight are strongly and consistently positively correlated with grain yield, and grain-level yield traits like biological yield, straw yield, and HI also show positive associations with grain yield. This is corroborated by the findings of Hasan-Ud-Daula & Sarker (2020); Li *et al.* (2019); Oladosu *et al.* (2018); Rajasekhar *et al.* (2022); Perween *et al.* (2020); and Saha *et al.* (2019).

## Conclusion

Our research focused on evaluating the performance of two rice varieties under different numbers of seedlings hill$^{-1}$ at Khairahani, Chitwan, Nepal. The results of our study showed that the number of seedlings in hill$^{-1}$ significantly affects rice growth and yield, whereas the impact of the variety was mostly non-significant. Among the different treatments, two seedling hill$^{-1}$ produced the highest grain yield for both hybrid and improved varieties. The hybrid variety (US-305) with two seedlings hill$^{-1}$ produced the highest yield (6.36 tons/hectare), followed by the improved variety Ramdhan with two seedlings hill$^{-1}$ (5.967 tons/hectare). However, planting a higher density of rice seedlings hill$^{-1}$ decreases the yield due to increased competition for nutrients, light, and space. In addition, higher densities demand more seeds, fertilizers, and other resources, which are not economically feasible for farmers. Moreover, our study confirms that the economic yield is positively correlated with most growth and yield characters except sterility percentage and non-effective tillers. The research met its predetermined objectives by identifying the optimal seedling density for each variety. Hence, transplanting two seedlings from hill-1 of US 305 can be considered an appropriate planting practice for improving rice growth and yield under the conditions of Chitwan, Nepal. The study was conducted in a single research location and season, which might limit the broader application to other environments. Thus, further studies should be done across multiple locations and seasons to validate the optimal seedling number for different rice varieties.

## DECLARATIONS

**Author contribution statement:** Conceptualization: B.B. and S.B.; Methodology: S.S., S.P, H.S, S.S.; Software and validation: S.B. and S.B.; Formal analysis and investigation: S.B., H.S., S.S.; Resources: B.B.; Data curation: S.S., S.P; Writing-original draft preparation: S.B., S.S., S.P.; Writing-review and editing: H.S., S.S.; Visualization: S.P., S.S.; Supervision: S.B.; Project administration: B.B. All authors have read and agreed to the published version of the manuscript.

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