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RESEARCH

Effects of Seedling and Plant Spacing on the System of Rice Intensification (SRI) for Spring Rice (*Oryza sativa* L. Chaite 2)

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Abstract

System of Rice Intensification (SRI technology) increases rice yields while requiring less water and other inputs. It involves the use of specific management strategies that, when used together, provide rice plants with better-growing conditions than those grown using traditional methods, especially in the root zone. An SRI experiment was conducted from February 27, 2022, to July 11, 2022, in rice farmers' fields in Buddhabhumi Municipality, Nepal, using different spacing and seedlings. Spring rice was grown using the SRI with a variety of seeding and plant spacing. The experiment consisted of three plant spacings: 20 × 20, 30 × 30, and 40 × 40 cm, and two seeding groups: regular seeding and pregerminated seedlings. Characteristics were counted, including the number of tillers per mound, leaves, plant height, tillers per square meter, grain yield, and 1000 kernel weight. The result shows that the 20 cm × 20 cm spacing increased tillers per square meter. The spacing also resulted in much higher grain production of 4.29337 Mt/ha. The 30 × 30 cm plot had the tallest plants at 78.10 cm, much higher than the other plots. Similar crops produced significantly more tillers per mound (22.5) when planted at 40 × 40 cm spacing. Since the crops were planted at 40 × 40 cm, the spacing produced significantly more tillers per mound (22.57) and leaves per mound (73.54). Spacing did not affect test weight, nor did the type of seedlings used.

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Statement of Sustainability: This study focuses on the role of seedling methods and spacing in maintaining food security and nutrition, which directly affect the yield and quality of rice production. We focused on selecting appropriate spacing and planting methods to ensure grain yield that will not be significantly affected by future climatic variability.

1. Introduction

Rice (*Oryza sativa* L.) is an important cereal crop and a staple food for more than half of the world's population, particularly in Asia (Khush, 1997). Rice is a member of the Gramineae family and a staple food for most of the world's population. Rice is the most important cereal crop, feeding almost half of the world's population. Environmental factors, soil characteristics, biotic conditions, and cultural practices all affect the growth and yield of rice. Rice can be grown in different environments depending on water availability. The three main cereals grown in the Terai region of Nepal are wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and rice (*O. sativa*). Wet sown, dry sown and transplanted rice are the three main cropping systems. Rice yield was reduced by 67.9% due to weeds compared to weed-free (Dangol et al., 2020). The government, donor agencies, and farmers are increasingly accepting the effectiveness of SRI management practices, but more evaluation and research are needed (Thakur and Uphoff, 2017).

In many states of India, farmers are adopting the System of Rice Intensification (SRI), and their response has been overwhelming as they see the benefits of the method (Dhananchezhiyan et al., 2013). Globally, rice is second only to wheat in terms of area harvested, but rice produces more calories per hectare than other cereal crops (Bhandari et al., 2020). In Nepal, cereals provide 65% of the total dietary energy (TDE) for the Nepalese population, with rice alone contributing 30% (Awan, 2011). Rice is the major crop grown in almost all areas of Kapilvastu. The area, production, and productivity in the fiscal year 2020/21 were 64,362 ha, 234,878 Mt, and 3.64 Mt/ha, of which only 12 ha area is used for spring season rice, so the productivity of spring season rice was poor (MoALD, 2022). Kapilvastu is the super zone of rice in the PMAMP project of the Government of Nepal to increase rice production and productivity and to modernize the rice sector (MoALD, 2020). In the SRI practice, rice production was significantly higher with reduced inputs (Sato and Uphoff, 2007). Increased family labor increased the yield of SRI (Nguyen and Hung, 2022). Commercial rice production in Nepal is thought to have begun about 500 years ago (Agrama et al., 2010). Rice cultivation has a long history, with evidence of domestication dating back more than 10,000 years (Second et al., 2011).

Global demand for rice continues to rise due to population growth, urbanization, and changing dietary patterns. According to the Food and Agriculture Organization (FAO), rice production must increase by at least 25 percent by 2030 to meet projected demand (FAO, 2017). However, there are several challenges to achieving this increase in production, including limited arable land, water scarcity, and the need for sustainable agricultural practices. Rice is traditionally grown in two main systems: irrigated lowland rice and rainfed upland rice. Irrigated rice, grown in flooded fields, accounts for most of the world's rice production. It benefits from controlled water availability, which supports high yields but requires significant water inputs. In contrast, upland rice is grown in non-flooded, rainfed conditions, often on sloping or marginal land without access to irrigation (Joshi et al., 2011). Purposely, this study was conducted to assess the impact of seedling and plant spacing on the SRI for spring rice.

2. Material and Methods

2.1. Site Selection and Agroclimatic Conditions

The study activities were conducted in a secured area of Kernel Agro Farm in Lumbini Province of Gorusinge, Nepal (27.6° N, 83.03° E) as given in Figure 1. The average relative humidity and temperature of the area were 75% and 25.6 °C throughout the year, respectively. The soil type was sandy loam (Khanal and Bhattarai, 2020).

Figure 1. Experimental field layout with 24 plots containing four replications featuring spring rice crop growth.

2.2. Nursery Bed Preparation and Seed Sowing

For 500 m^2 of transplanting, the nursery bed was raised in a 12.5 m^2 plot. Depending on the situation, two beds of 6.25 m^2 each were raised for 222 g of seed. One side of the bed had gutters to drain excess water. Preparatory tillage was done twice in early spring, depending on field conditions. The nursery area is divided into two plots of approximately 6.25 m^2 for pregerminated and regular seed. After watering, the beds were puddled and left for 12 h. The next day the seeds were broadcast. Two hundred and 22 g of seed (5 kg/ha) was needed to transplant an area of 444 m^2. For pre-germinated seeds, 111 g were soaked in clean water for 12 h and kept in water-soaked cloth for 48 h for proper germination.

2.3. Design of Experiment and Treatment Details

The experiment followed a randomized complete block design (RCBD) with six treatments and four replications during the spring season. Each plot was 4 × 3 m, for a total of 24 plots. The cultivar used in this study was Chaite 2. Figure 1 shows the experimental images of the rice plants. The treatment combinations are spacing: 20 × 20, 30 × 30, and 40 × 40 cm, types: pre-geminated seed and normal seed.

2.4. Land Preparation and Agronomic Practices

The field was plowed 25 days before transplanting. On the day of transplanting, the field was plowed twice by a tractor to ensure uniform labeling. Perfect labeling was adopted for good water management and crop standards. After marking, the field was divided into 24 plots of 12 m^2 each, with small channels at the bottom for good drainage. After proper marking, the pregerminated and normal seedlings were uprooted at the 3-4 leaf stage. Three plant spacings were established on the plot. Farmyard manure (FYM; 444 kg) was applied after plowing. The recommended fertilizer application was 100:30:30 kg NPK/ha. A full dose of nitrogen (355 g) was applied in two split doses. The first split dose of N and a full dose of P and K were applied in each plot after the field was divided into plots. The second dose of N was applied at 38 days after showing (DAS). After one week, until sufficient moisture remained in the soil, the field was watered after transplanting. During weeding, the field was watered to a depth of 2-3 cm. Water was removed when 70% of the grains in the panicle were hardened. A pre-emergence herbicide (Pendimethalin @10 mL/L) was applied two days after transplanting. The second application was made 20 days after transplanting (DAT) and then, after weeding, at 10–11-day intervals until the plants reached panicle initiation. SRI with alternate wetting and drying resulted in excessive weed growth so hand weeding was preferred for weed control. Cypermethrin (@5 mL/L) 10% E.C. was sprayed for rice bug control. Manual harvesting was done, and the 3rd, 4th, 5th, and 6th rows were selected. From these, ten plants were selected to determine the test weight, grains per panicle. The threshing was done with a mechanical thresher after one day of harvesting.

2.5. Data Collection and Analysis

Data such as plant height, number of leaves, and number of tillers were collected from 10 randomly selected plants from each plot at 15-day intervals from DAT. Other data such as test weight, filled and unfilled grain, and yield weight were collected after harvest. All the collected data were analyzed in MS Excel 2013 (Microsoft Corp., USA) and R-Studio (R-Software, Boston Massachusetts, USA). A Tukey's mean comparison test was performed to check significant differences among different treatments ($p < 0.05$).

3. Results and Discussion

3.1.1. Effects on Plant Height (cm)

The parameters influenced by spacing analysis showed that plant height peaked in the 30 × 30 cm spacing plot, which was significantly ($p < 0.05$) different from other spacing configurations. Despite the significance of spacing and seedling age in the early stages of crop growth (Durga et al., 2015; Zhimomi et al., 2021), these factors did not significantly affect the overall plant height. The SRI method outperformed the non-SRI method, resulting in more panicles (Co et al., 2020). As given in Table 1, plant height was not affected by seedling spacing until 30 DAT. However, after 45 DAT, plant height in both the 30 × 30 and 40 × 40 cm spacing configurations differed significantly from the 20 × 20 cm spacing. Notably, the greatest plant height was observed in the 30 × 30 cm spacing, which was significantly different from the other configurations, a trend that was evident in the 60 DAT data. Older seedlings at ten days showed significantly greater height (Ram et al., 2014). In an experiment conducted to test the productivity of the SRI method over conventional rice farming systems in Sri Lanka, average plant height growth and leaf chlorophyll content during the growth stages were also similar between treatments (Cao, 2002).

Investigating the influence of seedling and plant spacing on plant height in the SRI for spring rice yielded remarkable results. Our results showed that variations in seedling density and plant spacing significantly affected the overall height of rice plants. Specifically, closer seedling spacing and optimal plant spacing correlated with increased plant height. This suggests a potential avenue for increasing crop productivity by optimizing these key factors within the SRI approach. The observed trends in plant height underscore the importance of fine-tuning seedling and plant spacing parameters to achieve optimal growth conditions and maximize yield in spring rice production.

Table 1. Plant height of spring rice as affected by the spacing of seedlings.

Treatments	Plant Height (cm)		
	30 DAT	45 DAT	60 DAT
20 × 20 cm	59.55 d	78.70 a	100.95 a
30 × 30 cm	59.05 c	82.22 c	107.71 d
40 × 40 cm	57.43 a	82.40 c	105.38 b
Pre-germinated seed	59.69 d	80.80 b	107.70 d
Normal seed	58.48 b	82.65 d	106.69 c

DAT: the day after transplanting; values are the mean of ten replicates; different letters (a-d) indicate significant differences among treatment groups based on Tukey's post-hoc test ($p < 0.05$).

3.2. Effects on Number of Leaves

The number of leaves per mound did not vary significantly with the type of seed, whether pregerminated or normal. At 30 DAT, 15-day-old seedlings spaced 25 × 25 cm had a significantly higher number of leaves per plant than alternative planting geometries (Karki, 2009). The number of leaves per hill showed a significant increase in the 40 × 40 cm spacing at 30 DAT, and at 45 DAT, this spacing configuration was significantly different from others. The maximum number of leaves per mound was recorded in the 40 × 40 cm spacing at 60 DAT, which was significantly different from other spacing options as shown in Figure 2. The rapid increase in plant length was indicative of the transition from the vegetative to the reproductive phase of plant growth (Krishnan et al., 2011). Optimal seedling and plant spacing configurations were found to positively influence leaf development, suggesting a potential avenue for improving leaf characteristics critical for photosynthesis and overall plant health. Plants grown with wider spacing also absorbed more solar radiation for photosynthesis, and plants had a linearly increasing effect on individual plant performance (Singh et al., 2017).

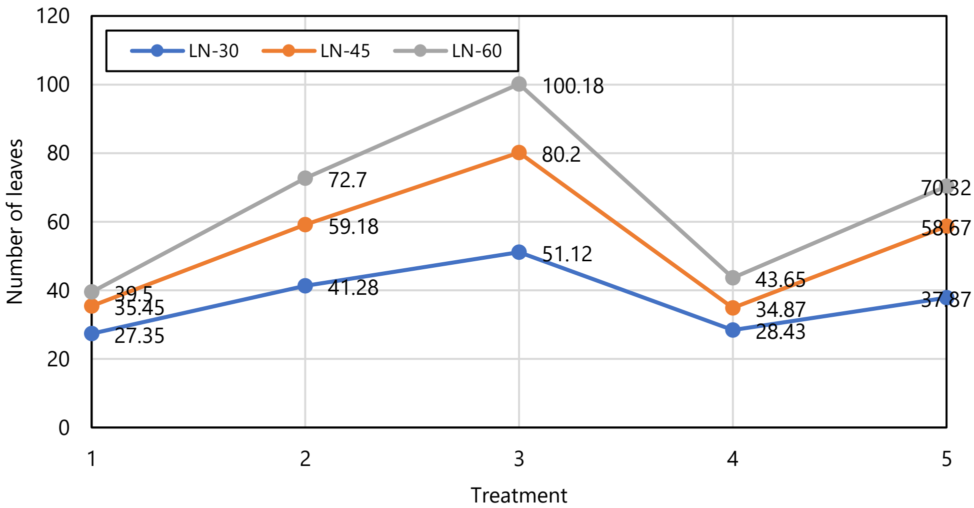

Figure 2. Effect on number of leaves of spring rice at different DATs (treatment label: 1: 20 × 20 cm; 2: 30 × 30 cm; 3: 40 × 40 cm; 4: pre-germinated seed; 5: normal seed).

3.3. Effects on Yield Attributes

Effective tillers showed a higher percentage under the SRI method (87.9%) compared to conventional management (84.5%) (Khadka et al., 2014). The number of tillers per hill increased significantly at the 40 × 40 cm spacing at 30 DAT. After 45 DAT, the number of tillers per hill in the 40 × 40 cm spacing deviated significantly from the rest of the data. In addition, the 30 × 30 cm spacing resulted in more tillers per hill (Dahal and Khadka, 2012), especially for ear-bearing tillers (Durga et al., 2015). The maximum number of tillers per hill was observed in the 40 × 40 cm spacing, which was significantly different from other configurations in the 60 DAT dataset. Tillers per hill, panicles per hill, and grains per panicle were significantly higher in the wider 30 × 30 cm spacing than in the closer spacing (Ram et al., 2014). Seedling spacing had no significant effect on test weight but had a significant effect on tillers per square meter. The highest number of tillers per square meter was recorded at the 20 × 20 cm spacing, which was significantly different from the other spacing options. Optimal seedling and plant spacing configurations were found to positively influence tiller number, indicating a potential avenue for improving tillering in spring rice production. The observed correlations underscore the importance of careful management of seedling and plant spacing parameters in the SRI methodology to optimize tillering and consequently contribute to improved rice yield.

3.4. Effects on Grain Yield

Spacing influenced rice yield, with the highest yield obtained at 20 × 20 cm, which was significantly different from the rest of the data. Pregerminated seeds obtained a higher yield (3.64) followed by regular seeds. These results confirm the findings of (Ram et al., 2014). Notably, 9-day-old seedlings planted at 40 × 40 cm spacing yielded the highest results (Zhimomi et al., 2021). The practice of SRI is expected to reduce input costs, minimize water use, and increase rice yields (Dobermann, 2004; Sinha and Talati, 2007; Thakur et al., 2010; Styger et al., 2011; Dass et al., 2015; Choudhary and Suri, 2018; Barrett et al., 2022). The types of seedlings used did not significantly affect parameters such as test weight, yield, and tillers per square meter, as shown in Table 2. Optimal seedling and plant spacing configurations positively influenced grain yield, highlighting the potential for strategic management practices within the SRI framework to improve overall crop performance. These results underscore the importance of precision in seedling and plant spacing as critical factors in achieving higher grain yields in spring rice production. These findings provide valuable practical implications for farmers seeking to optimize their management practices for improved rice production under the SRI approach.

Table 2. Yield characteristics of spring rice as affected by the spacing and types of seedlings.

Treatments	Test Weight (g)	Tiller/m^2	Yield (Mt/ha)
20 × 20 cm	23.73 c	327.87 e	4.29 d
30 × 30 cm	22.81 a	294.00 c	3.48 b
40 × 40 cm	23.59 c	261.00 a	3.10 a
Pre-germinated seed	23.65 c	278.66 b	3.64 c
Normal seed	23.10 b	309.91 d	3.60 c

Values are the mean of ten replicates; different letters (a-e) indicate significant differences among treatment groups based on Tukey's post-hoc test ($p < 0.05$).

4. Conclusion

This study highlights the critical role of spacing in the SRI technique in promoting the growth and yield of spring rice. According to the results of our study, the SRI technique is particularly beneficial for small and marginal farmers who cultivate their land. It has increased productivity while reducing the use of seeds, water, and pesticides. Using locally available seeds and other inputs, farmers can produce about twice the yield from the same area at a lower cost. With better management, farmers can triple their output. In addition to this benefit, farmers can harvest their rice crop 15-25 days earlier, helping them to grow their subsequent crops. The research showed good leaf number, tiller number, and plant height performance in 30 × 30 and 40 × 40 cm spacing, respectively. At the same time, the yield and number of tillers per square meter were better in the 20 × 20 cm spacing. Weed control was found to be the biggest obstacle to SRI. SRI requires about 20-30 man-days more labor than conventional practices. In addition, some farmers used chemical weed control and one-time manual weeding to reduce labor. Another constraint was water management. The crop needs water in an alternating pattern. Soil type, weed infestation, FYM content, and fertilizer dose negatively affect the vegetative growth of rice (Chaite-2) under SRI. Overall, it suggests the importance of the SRI technique to achieve higher yields of crops and ensure food security.

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