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Effect of Plant Spacings and Seed Germination Methods on Performance of Spring Rice (*Oryza Sativa* L. cv. Hardinath-1) under the System of Rice Intensification (SRI)

Suraj Dhakal [1, 2*], Bibek Gauli[1], Samser G.C.[1]

[1]Institute of Agriculture and Animal Science, Tribhuvan University, Kathmandu, Nepal
[2]College of Agriculture, Tennessee State University, TN 37209, USA
[*] Corresponding author's email: surajeetdhakal19@gmail.com
[*] ORCID: https://orcid.org/0009-0000-7338-5835

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ABSTRACT
Rice (*Oryza sativa* L.) is a major staple crop in Nepal. This study evaluated the effects of plant spacing and germination methods on the performance of spring rice (Hardinath-1) planted under System of Rice Intensification (SRI) in Gauradaha, Jhapa, Nepal, in 2022. The seed germination methods (pre-germinated, Ps, vs. normal, Ns) and plant spacings (20 cm × 20 cm, 30 cm × 30 cm, 40 cm × 40 cm) were used as treatments. The experiment was conducted using a randomized complete block design (RCBD) with six treatment combinations and four replications, assessing major agronomic traits and yield attributes. The study involves nursery and field preparation, transplanting 16 days old seedlings, fertilizer management, and intercultural operations, following SRI guidelines. Results revealed that the pre-germinated seeds (Ps) initially produced taller plants compared to normal seeds (Ns), but had no significant impact on any parameter from either type. The 20 cm × 20 cm spacing showed the highest grain yield (4.29 mt/ha) due to higher planting density, despite fewer tillers per plant and inferior growth performance compared to wider spacings. The spacings of 30 cm × 30 cm and 40 cm × 40 cm enhanced individual plant performance with lesser yield attributes (3.48 mt/ha and 3.10 mt/ha) due to the wasted area. Grain moisture and thousand-grain weight also showed no significant differences across all treatments. The findings recommend 20 cm × 20 cm spacing under SRI to maximize spring rice productivity in Jhapa, accentuating efficient use of resources and sustainable practices.

Keywords: SRI, spring rice, pre-germination, plant spacing, yield optimization

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INTRODUCTION
Rice (*Oryza sativa* L.) is the most important staple food crop in developing countries, serving half of the world's population (Akondo and Hossain 2020). It is a major cereal crop in Nepal, accounting for approximately 20% of the Agricultural Gross Domestic Product (AGDP) of the country (Pandey et al 2023), with an average productivity of 4.86 mt/ha in every rice-producing district, exceeding the national average of 3.47 mt/ha (Sah et al 2024). An analysis of Nepal's rice production and cultivation patterns shows that, during the fiscal years from 2011/12 to 2021/22, the annual rates of cultivation decreased by 0.81%, output increased by 1.5%, and yield improved at a rate of 1.97% (Lamichhane et al 2024). Despite the potential, the declining amount of arable land and increasing import dependency raise concerns about Nepal's long-term food security. To solve these issues, a multifaceted approach is required, involving investments and deep scrutiny of agricultural technology and sustainable practices.

In Nepal, rice is grown especially in two distinct seasons: the summer and spring seasons, where 92% of rice is produced in the summer season and 8% in the spring season, as per MOALD, Nepal. Spring season rice is planted in the month of February/March and harvested during June/July, while main season rice is planted in the month of June/July (summer) and harvested during October/November. Since the transplanting month coincides with the Nepali month of "*Chaitra*" (March-April), the spring rice is named *Chaite Dhaan,* with a short cultivation duration. According to the comparison by (Bhatt et al 2024), underscoring the possibility of commercial practices and advantages, spring rice has a greater production and economic ratio than main-season rice. Spring rice is not only more efficient in reducing output loss rates, but it also withstands a wide range of diseases and pests (Regmi et al 2023). Several varieties of spring rice include

Bindeshwori, CH45, Chaite-2, Chaite-5, Chaite-6, and Hardinath-1. Chaite 2 is more common in the eastern Terai, while Hardinath-1 and CH45 are the most widely grown types throughout the country (Khatiwada and Upreti 2008).

Similarly, a new approach to rice cultivation, the system of rice intensification (SRI), was developed by French Priest Father Henri de Laulanié four decades ago in Madagascar, solely based on field experiments and practical observations, devoid of any prior assumptions (Uphoff 2024). The principle of SRI concentrates on optimizing plant growth conditions involving (i) transplanting young seedlings in shallow submergence (preferably 8–12 days old), (ii) sparse planting in square geometry (preferably 25 cm × 25 cm), (iii) providing intermittent irrigation and drainage, (iv) supplying nutrients from organic or inorganic sources, (v) Cono-weeding or hand-weeding at different stages, and (vi) completing transplanting quickly (preferably within 15 minutes of uprooting), with roots placed horizontally (L-shaped) and not bent upwards (J-shaped) (Dass et al 2015).

Two important agronomic considerations in rice are plant spacing and seed-raising techniques. Farmers frequently transplant seedlings in clumps with relatively tight spacing while growing standard transplanted rice. However, with SRI, a single seedling is transplanted at a wider interval (often 25 cm × 25 cm or more) per hill. This reduced density minimizes competition for light, nutrients, and water, enhancing plant performance, according to (Akondo and Hossain 2020), compared to closer spacings. Therefore, spacing must be optimized, too broad spacing can waste field area, while too close spacing results in crowded and low-vigour plants. In the same way, the method of seed establishment significantly influences plant vigour and subsequent performance in the field. This study tested two methods of seed establishment: pre-germinated seeds, which were sprouted before placement in the nursery bed, and non-germinated seeds, which were directly sown into the nursery bed without prior germination, to comprehend their impact on plant performance. Compared to regular seeds, pre-germinated seeds show significant growth and improved physiological quality due to their early establishment, rapid root growth, and appropriate moisture levels (Franzin et al 2007).

SRI enhances resource usage, crop management techniques, and yield, improving plant morphology and physiology, including tillering and photosynthetic rates, even under biotic and abiotic stresses (Doni et al 2023). Farmers adopting SRI significantly enhance their economies in Nepal by increasing grain yield and net returns, as evidenced by the study of (Dahal and Khadka 2013). Through the promotion of healthier plant establishment and reduced plant density, SRI contributes to resource efficiency by dropping input costs and conserving water (Dahal 2014). SRI practices promote sustainable agricultural practices by fostering beneficial microbial populations, like *Trichoderma*, in soil ecology (Doni et al 2023) and also reduce greenhouse gas emissions, especially methane, when compared to conventional rice farming (Raut et al 2020).

Despite the potential of SRI to boost rice production, there is limited location-specific information and studies on optimal plant spacing and seed establishment methods in eastern Nepal. In particular, not enough research has been done to evaluate the combined effects of plant density and germination methods on the performance of the widely cultivated variety Hardinath-1 under SRI conditions. Therefore, this study was undertaken to identify the suitable plant spacing and germination strategies under SRI to maximize spring rice productivity, promoting sustainable and efficient rice production systems that minimize excessive input use and overcome the drawbacks of conventional farming practices. Hence, the main objectives of the study are to evaluate the effects of plant spacings and seed establishment methods on growth and yield components of spring rice (Hardinath-1) in Gauradaha, Jhapa.

MATERIALS and METHODS

Experiment Site

The experiment was held near the premises of Gauradaha Agriculture Campus, a constituent campus of Tribhuvan University in eastern Nepal, in 2022. It is situated at Gauradaha Municipality, Jhapa, at an altitude of 70 metres above sea level and experiences a tropical climate characterized by hot-rainy summers and cold-foggy winters. The area receives annual precipitation ranging from 2,500 mm to 3,000 mm. Assessing soil fertility in Jhapa, (Vista et al 2018) discovered that the soil was predominantly loamy, with sandy, silty, and clay loam types. The soil pH ranges from 4.6 to 7.89, making it suitable for rice cultivation, with organic matter content ranging from 0.4% to 4.06%.

Experimental Details and Layout

The experiment followed a randomized complete block design (RCBD) with 4 replications and a total of 6 treatments. The treatments comprised combinations of two factors: seed germination methods and plant spacings. The germination methods included two levels: pre-germinated seeds (Ps) and normally germinated seeds (Ns). The plant spacing factor consisted of three levels: 20 cm × 20 cm (S_1), 30 cm × 30 cm (S_2), and 40 cm × 40 cm (S_3). The treatment combinations and layout of the experimental field are presented in Tables 1 and 2, respectively.

Table 1: Different treatment combinations applied to every replication.

Treatments	Combinations	Symbols
T_1	Pre-germinated (Ps) + 20 cm × 20 cm (S_1)	PsS_1
T_2	Pre-germinated (Ps) + 30 cm × 30 cm (S_2)	PsS_2
T_3	Pre-germinated (Ps) + 40 cm × 40 cm (S_3)	PsS_3
T_4	Normal (Ns) + 20 cm × 20 cm (S_1)	NsS_1
T_5	Normal (Ns) + 30 cm × 30 cm (S_2)	NsS_2
T_6	Normal (Ns) + 40 cm × 40 cm (S_3)	NsS_3

A total of 24 plots were established to randomly distribute the 6 treatments across each replication, as detailed in Table 2. Each plot measured 4 m × 3 m, with 3 plots arranged in a row. There was a spacing of 1 m between replications and 0.5 m between treatments. The overall dimensions of the field were 31 m in length and 15 m in width, resulting in a total expansion of 465 square metres.

Table 2: Layout of the experimental field.

Replication 1	Plot 3 (T_3)	Plot 4 (T_4)	Replication 2	Plot 9 (T_6)	Plot 10 (T_5)	Replication 3	Plot 15 (T_4)	Plot 16 (T_1)	Replication 4	Plot 21 (T_3)	Plot 22 (T_6)
	Plot 2 (T_2)	Plot 5 (T_5)		Plot 8 (T_4)	Plot 11 (T_2)		Plot 14 (T_6)	Plot 17 (T_3)		Plot 20 (T_2)	Plot 23 (T_5)
	Plot 1 (T_1)	Plot 6 (T_6)		Plot 7 (T_3)	Plot 12 (T_1)		Plot 13 (T_2)	Plot 18 (T_5)		Plot 19 (T_1)	Plot 24 (T_4)

Propagation Material

A spring season rice variety known as 'Hardinath-1' was selected for cultivation due to its impressive average yield potential of over 4.5 metric tons per hectare (mt/ha). Released in 2004, this variety has gained popularity in the Terai region because of its high yield, short maturation period, disease resistance, and suitability for intercropping systems (Yadaw et al 2005).

Seed Rate and Priming

A total of 200 grams of seeds (equivalent to 5 kg/ha), a bit more amount was taken considering the potential seed loss due to unstable germination rates, were to be transplanted in an area of 288 m² (each 12 m^2 plot × 24 total plots). The seeds were spread sparsely in seedbeds to prevent overcrowding of the seeds. For pre-germinated seeds, 100 grams (g) were soaked in clean water for 12 hours and then placed on a damp cloth for proper germination over the next 48 hours.

Bed Preparation

In the SRI method, careful preparation of the nursery bed is essential, as 16-day-old seedlings (at the 3-4 leaf stage) were transplanted. The nursery bed was preferably prepared near the plot for quick and efficient transplantation. For the transplantation of an area of 288 m², a nursery bed of 10 m² was made. Depending on the specific situation, two nursery beds, each measuring 5 m², were prepared for growing pre-germinated seeds and normal dry seeds, with a total of 200 g of seeds. To prevent excess water accumulation, proper drainage channels were established on one side of the beds. Preparatory tillage was conducted twice during early spring, depending on field conditions. After proper irrigation and puddling, the beds were left for 12 hours before broadcasting the seeds.

Field Preparation

The field was ploughed 25 days before the transplantation, which helped to decompose the weeds and stubble as well as level the field for proper stagnation of water. While transplanting, the field was ploughed two times by a tractor for uniform levelling. For better levelling, locally available tools like a levelling rake were used. After levelling, the field was divided into 24 plots, each with a 12 m² area. For proper drainage, small channels were provided on both sides at the bottom of the field.

Method of Transplantation

After proper levelling, the seedlings of pre-germinated and normally germinated seeds were uprooted at the 3-4 leaf stage. The uprooted seedlings were collected in separate trays. Three plant spacings (20 cm × 20 cm, 30 cm × 30 cm, and 40 cm × 40 cm) were laid out and marked on the plots of 6 treatments and 4 replications. The seedlings in the 3-4 leaves stage were planted shallowly and horizontally, one seed per hill, thus establishing quickly. Seedlings were transplanted with the index finger and thumb by gently placing them at the intersection of the markings. After transplanting, the field was left without irrigation for 1 week and provided with light irrigation afterwards.

Cultural Operations

Nutrient Management: Application of FYM @ 300 kg in a 288 m² area (equivalent to 10-12 mt/ha) was done after ploughing. 100:30:30 kg NPK/ha was recommended, so a full dose of 5.50 kg urea was divided into two split doses to provide sufficient nitrogen. The first split dose of 2.75 kg urea, about 2 kg diammonium phosphate (DAP), and 1.5 kg muriate of potash (MOP) was applied in every plot equally. The second split dose of urea was applied at 38 DAT.

Water Management: After transplanting, the field was left for about a week till sufficient moisture remained, and then light irrigation was applied. Subsequent irrigation was done in the case of fine cracks with regular wetting and drying of the field. A 2-3 cm shallow level of water was maintained as it fosters microbial activity in the soil and eases the availability of nutrients to the plants (Buresh et al 2013). During the panicle initiation stage until maturity, a shallow depth of water was maintained in the field and drained after 70% of the grains in the panicle were hardened.

Weed Management: After 2 days of transplantation, a pre-emergence herbicide, Pendimethalin @ 10 ml/litre of water, was applied. Several *Cyperus* and *Echinochloa* species were observed, and a second weeding was done at 20 DAT. 10-11-day intervals were kept for weeding until the plants reached the panicle initiation phase. Hand weeding was preferred, and weeds were incorporated into the soil to enhance fertility.

Insect and Pest Management: Different insects, such as the yellow stem borer, leaf folder, and brown plant hopper, were seen in small numbers in the field with minimal infestation in the rice plant. Rice bugs and rice ear head bugs were present in large numbers at the grain formation stage of rice. They damaged the developing grains, from the pre-flowering spikelet to the soft dough stage, causing grain discolouration. Both mature and immature rice bugs feed on rice grains, causing the latter to become tiny, shriveled, spotty, or malformed. Cypermethrin 10 % EC @ 5 ml/litre of water was sprayed to control those rice bugs onwards.

Harvesting

Manual harvesting was conducted using a rough, serrated sickle to tear the plants. Plants from the 3rd, 4th, 5th, 6th, and 7th rows were selected from every plot, neglecting the plants at borders, with cuts made 6-7 cm above the ground. From these, 10 plants were chosen to determine the yield attributes for the study.

Threshing

After harvesting, bundles of paddy plants were collected and dried for one day. Threshing involved detaching the paddy kernels from the panicles, which was achieved through a beating action. This process was carried out by thrashing each bundle of paddy plants with a stick on a clean concrete floor.

Observation and Measurement

Plant Growth Parameters:

10 plants were selected randomly from each plot, omitting the border plants. Data were collected at 15 DAT and 30-day intervals after it to observe various growth features such as plant height, leaf number, and tiller number.

Yield Attributing Parameters: Yield attributing data, such as tillers per square metre, moisture level at harvesting, 1000-grain weight, and final yield, were taken after harvesting. **Tillers per m^2:** A 1 m^2 frame was made to count the number of tillers per m^2 from the middle of every plot.

Moisture percentage at harvesting: After harvest, the moisture percentage was measured using a moisture meter on every plot sample.

Thousand-grain weight: The number of filled grains from each plot was counted and weighed using an electronic balance to figure out the test weight.

Yield: Grain yield was determined from the central 1 m² area of each plot, then the yield for every 12 m² plot was calculated. The final yield was expressed in metric tons per hectare (mt/ha) and calculated by using the formula (Mautante and Mala 2024):

$$\text{Yield (mt/ha)} = \frac{Yield\ per\ \text{m}^2(kg) \times 10000\ \text{m}^2}{1000\ kg} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Data Analysis Data was arranged systematically based on various observed parameters and analysed using R Studio with R software version 2025. Analysis of variance (ANOVA) was employed for all variables, and Duncan's Multiple Range Test (DMRT) was used for mean separations at $p < 0.05$.

RESULTS and DISCUSSION

Growth Parameters

Pre-germinated seeds (Ps) consistently produced taller plants than normal seeds (Ns) initially, despite the non-significant results as in Table 3, which may be due to earlier establishment and vigorous root growth, as well as optimal moisture levels, which enhanced their physiological quality compared to the normal method, aligning with the study by (Franzin et al 2007). Likewise, the 20 cm × 20 cm spacing consistently exhibited inferior performance across all plant growth parameters compared to other spacings, indicating a significant impact of the different spacing configurations. The increased plant height observed in the wider spacings can be attributed to improved space availability and reduced competition for nutrients, leading to better nutrient utilization, stimulating greater cellular development in the meristematic tissue, thus increasing the plant height, according to (Pandey et al 2023). However, a small interaction between the two parameters after 75 days of transplantation was observed at a 10% significance level, as shown in Figure 1 (A), which is deemed unacceptable for this study, and concludes that there was no significant interaction regarding plant height and germination methods.

Table 3: Impact of different seed germination methods and spacings on plant height and number of leaves in Hardinath-1.

Treatments	Plant height at 15 DAT (cm)	Plant height at 45 DAT (cm)	Plant height at 75 DAT (cm)	No. of leaves at 15 DAT	No. of leaves at 45 DAT	No. of leaves at 75 DAT
Germination Methods						
Ps (Pre)	34.25 ^{a}	81.91 ^{a}	105.08 ^{a}	8.64 ^{b}	115.69 ^{a}	88.35 ^{a}
Ns (Normal)	33.44 ^{a}	80.31 ^{a}	105.25 ^{a}	12.67 ^{a}	120.00 ^{a}	85.66 ^{a}
F-test	NS	NS	NS	***	NS	NS
LSD (0.05)	2.77	2.26	1.56	1.51	19.71	11.18
SE_m (+-)	1.13	0.92	0.63	0.61	8.01	4.54
Spacings						
S_1 (20×20) cm	32.98 ^{a}	78.71 ^{b}	102.75 ^{b}	10.64 ^{ab}	70.16 ^{c}	47.88 ^{c}
S_2 (30×30) cm	35.17 ^{a}	82.22 ^{a}	106.50 ^{a}	9.39 ^{b}	121.06 ^{b}	87.26 ^{b}
S_3 (40×40) cm	33.39 ^{a}	82.40 ^{a}	106.25 ^{a}	11.94 ^{a}	162.31 ^{a}	125.88 ^{a}
F-test	NS	*	**	*	***	***
LSD (0.05)	3.39	2.77	1.91	1.85	24.13	13.69
SE_m (+-)	0.92	0.75	0.52	0.5	6.54	3.71
Ger.: Spacings	NS	NS	NS	NS	NS	NS
LSD (0.05)	4.8	3.91	2.7	2.61	34.14	19.37
SE_m (+-)	1.59	1.3	0.9	0.87	11.33	6.42
CV%	9.40%	3.20%	1.70%	16.26%	19.23%	14.77%
Grand Mean	33.85	81.11	105.17	10.65	117.85	87

The common letter(s) within the column indicate a non-significant difference based on the DMRT at the 5% level of significance. *** indicates a 0.1% level of significance, ** indicates a 1% level of significance, * indicates a 5% level of significance, NS: non-significant, DAT: days after transplantation, LSD: Least Significant Difference, SEM: Standard error of the mean, CV: Coefficient of Variation.

In 15 DAT, the leaf number in the Ps was significantly lower, possibly due to rapid root growth during pre-germination, which allocated resources differently, with less initial distribution to leaf development. (Dhami et al 2024) also linked root length to priming therapies affecting its development, which modify hormones or signaling pathways, in their study to assess the impacts of priming treatments in rice. Additionally, the 20 cm × 20 cm spacing significantly yielded fewer leaves compared to the other wider spacings, as in Table 3. In comparison to closer spacings, the wider spacings may have resulted in more vigorous plant performance, improved photosynthetic ability with an extra conducive situation to access solar radiation, and increased nutrient availability for more production (Akondo and Hossain 2020). There was also no significant interaction regarding the number of leaves and germination methods, as shown in Figure 1 (B).

Table 4: Impact of different seed germination methods and spacings on the effective tiller number in Hardinath-1.

Treatments	No. of tillers at 15 DAT	No. of tillers at 45 DAT	No. of tillers at 75 DAT
Germination Methods			
Ps (Pre)	4.73 [a]	33.84 [a]	26.00 [a]
Ns (Normal)	5.34 [a]	34.25 [a]	25.26 [a]
F-test	NS	NS	NS
LSD (0.05)	1.18	3.60	3.12
SE_m (+-)	0.48	1.46	1.27
Spacings			
S_1 (20×20) cm	5.46 [a]	21.63 [c]	14.85 [c]
S_2 (30×30) cm	5.03 [a]	34.89 [b]	25.94 [b]
S_3 (40×40) cm	4.61 [a]	45.63 [a]	36.10 [a]
F-test	NS	***	***
LSD (0.05)	1.44	4.40	3.83
SE_m (+-)	0.39	1.19	1.04
Ger.: Spacings	NS	NS	NS
LSD (0.05)	2.04	6.23	5.41
SE_m (+-)	0.68	2.07	1.8
CV%	26.87%	12.14%	14.01%
Grand Mean	5.03	34.05	25.63

The common letter(s) within the column indicate a non-significant difference based on the DMRT at the 5% level of significance. *** indicates a 0.1% level of significance, ** indicates a 1% level of significance, * indicates a 5% level of significance, NS: non-significant, DAT: days after transplantation, LSD: Least Significant Difference, SEM: Standard error of the mean, CV: Coefficient of Variation.

Yield Attributing Parameters

The number of tillers per m^2 was also not much impacted by either Ps or Ns, as shown in Table 5. It was observed that the 20 cm × 20 cm spacing yielded a significant number of tillers (341.55) per m^2 of a plot, followed by 30 cm × 30 cm (275.38), and 40 cm × 40 cm (216.60), due to the higher transplantation density. (Karki and Thapa 2024) also discovered that a spacing of 20 cm × 20 cm and 25 cm × 25 cm greatly produced a higher number of effective tillers per m^2 compared to the broader arrangement of 30 cm × 30 cm spacing, in their study of evaluating planting spacing of rice in SRI.

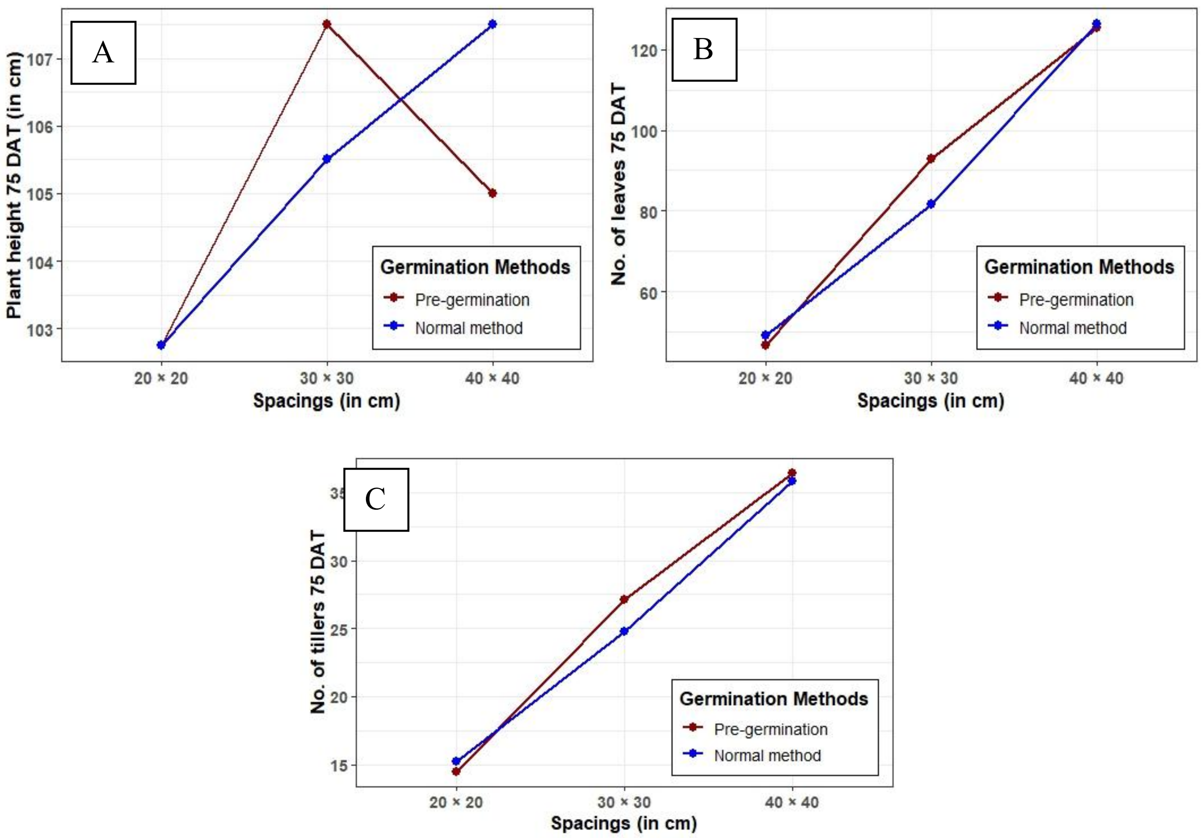
There was no noticeable impact resulting from either germination methods or spacings separately on the grain moisture percentage at harvesting, but they show significant interaction, as in Figure 1 (E). Similarly, no impact was observed by either of the factors on the 1000-grain weight of rice, with no statistical interaction between them, as in Table 5. The study by Dahal and Khadka (2013) found a significant impact on the 1000-grain weight due to narrower and wider spacings, with performance differences, but revealed corroborating results for broader spacings with no impact on the test weight.

There was no variation of yield by the influence of Ps and Ns, though pre-germinated seeds enable early maturity and higher grain yields by reducing moisture stress than the normal dry seeds (Tadesse et al 2013). However, the superior performance of 20 cm × 20 cm spacing was observed, yielding 4.29 mt/ha, followed by 3.48 mt/ha in 30 cm × 30 cm and 3.10 mt/ha in 40 cm × 40 cm, with no clear interaction between germination methods and spacings. The inferior yield by 30 cm × 30 cm and 40 cm × 40 cm spacings may be due to the wider spacing arrangements, which squander the field area, while too close spacing may produce crowded and low-vigour plants. A study of spring rice IR 10L 152 by (Pandey et al 2023) also showed that 20 cm × 20 cm spacings produced more (4.88 mt/ha) than other denser spacings. While evaluating seedlings' age and spacing configurations in spring rice Chaite-5 in Bardiya, Nepal, (Mahato et al 2024) also found that the 20 cm × 20 cm spacing produced more (5.1 mt/ha) than the 15 cm × 15 cm and 25 cm × 25 cm spacings. According to the SRI principles, each hill should have a single seedling planted at an optimum interval, usually at 25 cm × 25 cm. Therefore, the 40 cm × 40 cm and 30 cm × 30 cm spacings were too wide for transplanting plants, wasting field space, and reducing rice plant quantity and potential production.

Table 5: Impact of different germination methods and spacings on yield attributes and yield of grains in Hardinath-1

Treatments	Number of tillers per m^2	Grain moisture percentage (%)	1000-grain weight (g)	Yield (mt/ha)
Germination Methods				
Ps (Pre)	274.19 ^{a}	21.16 ^{a}	23.66 ^{a}	3.62 ^{a}
Ns (Normal)	281.49 ^{a}	21.53 ^{a}	23.10 ^{a}	3.63 ^{a}
F-test	NS	NS	NS	NS
LSD (0.05)	25.09	0.71	1.19	0.018
SE_m (+-)	10.2	0.29	0.48	0.007
Spacings				
S_1 (20×20) cm	341.55 ^{a}	20.93 ^{b}	23.73 ^{a}	4.29 ^{a}
S_2 (30×30) cm	275.38 ^{b}	21.25 ^{ab}	22.82 ^{a}	3.48 ^{b}
S_3 (40×40) cm	216.60 ^{c}	21.85 ^{a}	23.59 ^{a}	3.10 ^{c}
F-test	***	NS	NS	***
LSD (0.05)	30.73	0.88	1.46	0.022
SE_m (+-)	8.33	0.24	0.39	0.006
Ger.: Spacings	NS	*	NS	NS
LSD (0.05)	43.47	1.24	2.06	0.031
SE_m (+-)	14.42	0.41	0.68	0.01
CV%	10.38%	3.85%	5.84%	0.57%
Grand Mean	277.84	21.34	23.38	3.62

The common letter(s) within the column indicate a non-significant difference based on the DMRT at the 5% level of significance. *** indicates a 0.1% level of significance, ** indicates a 1% level of significance, * indicates a 5% level of significance, NS: non-significant, LSD: Least Significant Difference, SEM: Standard error of the mean, CV: Coefficient of Variation.



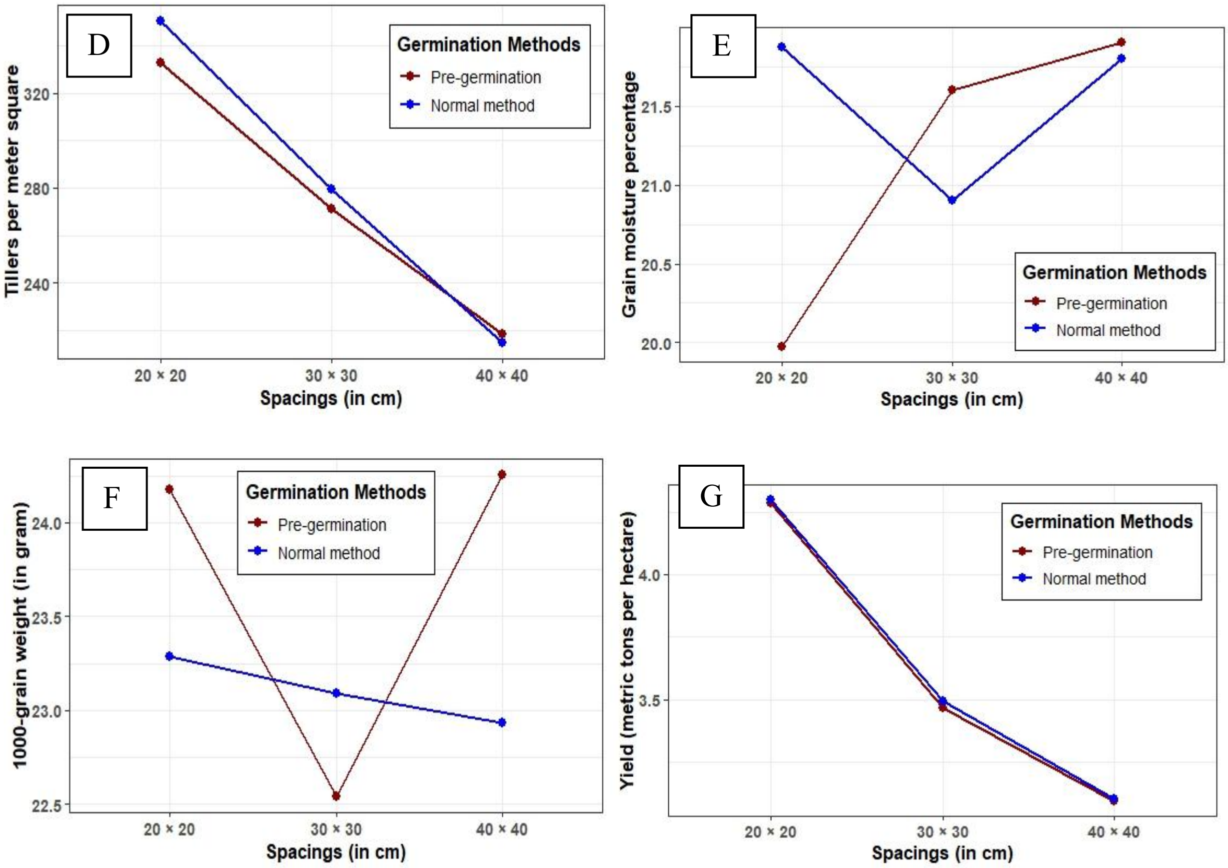


Figure 1: Interaction plots between spacings and germination methods, (A) for plant height after 75 days of transplantation, (B) for number of leaves after 75 days of transplantation, (C) for number of tillers after 75 days of transplantation, (D) for tillers per square meter, (E) for grain moisture percentage, (F) for 1000-grain weight, and (G) for final yield in kg/ha.

CONCLUSION

The study demonstrated that plant spacing had a more decisive role than seed germination methods, determining the productivity of the spring rice (var. Hardinath) under SRI in Jhapa, Nepal. Among the treatments, transplanting seedlings at 20 cm × 20 cm spacing had a more pronounced effect, maximizing grain yield (4.29 mt/ha) due to higher planting density and effective utilization of spaces, despite producing fewer tillers per plant and shorter plants. Although the wider spacings of 30 cm × 30 cm and 40 cm × 40 cm improved individual plant growth characteristics, they resulted in lower yield because of the reduced plant density. Pre-germinated seeds resulted in some advantages during early crop establishment, but this did not translate into a significant yield advantage at harvest. Also, there was no acceptable interaction among the germination methods and spacings in this experiment, except for the grain moisture level. Thus, based on these findings, a plant spacing of 20 cm × 20 cm under SRI is recommended for spring rice cultivation in Jhapa to achieve higher productivity while maintaining efficient resource use. So, further research is recommended to examine the interaction of seed germination methods with other agronomic and environmental factors, such as nutrient management, water regimes, and soil conditions, to enhance the yield potential and sustainability of spring rice production systems.

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AUTHORS' CONTRIBUTIONS

Suraj Dhakal conceptualized and prepared the manuscript as the lead author, while Bibek Gauli and Samser GC both assisted in fieldwork and write-up.

CONFLICT OF INTERESTS

The authors have no conflict of interest to disclose.

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