Evaluating system of rice intensification using a modified transplanter: A smart farming solution toward sustainability of paddy fields in Malaysia

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Abstract: This paper presents the study reports on evaluating a new transplanting operation by taking into accounts the interactions between soil, plant, and machine in line with the System of Rice Intensification (SRI) practices. The objective was to modify planting claw (kuku-kambing) of a paddy transplanter in compliance with SRI guidelines to determine the best planting spacing (*S*), seed rate (*G*) and planting pattern that results in a maximum number of seedling, tillers per hill, and yield. Two separate experiments were carried out in two different paddy fields, one to determine the best planting spacing (*S*=4 levels: s_1=0.16 m×0.3 m, s_2= 0.18 m×0.3 m, s_3=0.21 m×0.3 m, and s_4=0.24 m×0.3 m) for a specific planting pattern (row mat or scattered planting pattern), and the other to determine the best combination of spacing with seed rate treatments (*G*=2 levels: g_1=75 g/tray, and g_2= 240 g/tray). Main SRI management practices such as soil characteristics of the sites, planting depth, missing hill, hill population, the number of seedling per hill, and yield components were evaluated. Results of two-way analysis of variance with three replications showed that spacing, planting pattern and seed rate affected the number of one-seedling in all experiment. It was also observed that the increase in spacing resulted in more tillers and more panicle per plant, however hill population and sterility ratio increased with the decrease in spacing. While the maximum number of panicles were resulted from scattered planting at s_4=0.24 m×0.3 m spacing with the seed rate of g_1=75 g/tray, the maximum number of one seedling were observed at s_4=0.16 m×0.3 m. The highest and lowest yields were obtained from 75 g seeds per tray scattered and 70 g seeds per tray scattered treatment respectively. For all treatments, the result clearly indicates an increase in yield with an increase in spacing.

Keywords: system of rice intensification, sustainable cultivation, smart farming, modified transplanter, paddy fields, Malaysia
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1 Introduction

The global increase in population and limitation of agricultural lands necessitate mechanization, efficiency, and productivity in all stages of rice production. For most Asian countries, rice is a staple food and a strategic crop[1]. System of Rice Intensification (SRI) is an agricultural system consistent with Sustainable Agriculture (SA) as well as Conservative Agriculture (CA) contributing in the preservation of natural resources like water and land and reducing chemical applied to crops and the pollution of the environment. The method was first introduced and implemented by de Laulanié[2] to improve rice yield through manipulation of genetic capability, creating conducive environment, improving soil condition, and reducing production inputs[3]. Several technical reviews for adaptation and improvement of SRI[4-8], along with comprehensive discussions on water management[9-11], productivity, and other research issues in the past ten years are available in the published literatures[12-15]. Research attempts have been made to develop fully-automated mechanical paddy transplanters in compliance with SRI guidelines[16,17] that reduce man-days per hectare and increase output. A good example of such efforts is a mechanized water-wheeled semi-automated transplanter that was custom designed and developed in Punjab, India[7]. More recently, a modern rice seed broadcasting approach was designed and tested by Li et al.[18] using an unmanned aerial vehicle. Another novel technique was introduced by Zhang et al.[19] by means of a pneumatic rice seed metering device that has sucking hole plates through which 3 to 4 seeds are sucked synchronously and released into paddy fields for hybrid rice direct seeding.

Malaysia's paddy fields are suffering from lack of modern cultivation practices, a threat that heavily affects optimum rice production capacity. Some of the challenges for Malaysian rice growers include proper management of land and water resources, declining yields due to operational holding-size shrinkage and

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stagnation, infestation of weeds, diseases outbreaks due to over usage of pesticides, labor shortage and efficient solution for shifting from manual to automated transplanting, and sustainability of the production. Visits to several paddy fields also revealed that plant population in manually operated fields is also very low and yield-decreasing. Local farmers reported that transplanting delays due to labor shortage result in a progressive decrease in yield. Implementation of smart farming solutions in commercial scale requires extensive research for evaluation of the proposed methods and the machinery involved. In order to keep the paddy fields profitable, it is necessary to provide Malaysian farmers with automated single-planting transplanters that eliminate manual operation.

The system of rice intensification suggests planting one seedling per hill to improve plant water intake, nutrient balance, and pest management. The space between planting seeds is recommended at 0.25 m. This transplanting spacing has been reported to result in the best rice performance[20-22]. The effects of hill and plant spacing on yield and quality of rice have been discussed in numerous published works[9,23-35]. In general, rice yield can be significantly boosted with modern cultural practices such as control of inputs (i.e., fertilizer, nutrient, water, and spaying, and chemicals), ideal environmental parameters (air and soil temperature, humidity, solar radiation, soil moisture content and fertility), sensible planting and nursery, and optimum transplanting adjustments for best tillering[21,29,36].

Right spacing between seeds results into underground and aerial development by reducing the competing for nutrient and light, hence vegetative growth and grain yield will be increased. The effect of hill spacing's (0.10 m×0.15 m, 0.2 m×0.15 m and 0.3 m×0.15 m) on the quality and productivity of rice CV "Giza 177" was studied by Kandil et al.[28] showing that the spacing of 0.2 m×0.15 m resulted the highest grain yield.ha^{-1}, 1000-grain weight, panicle length, harvest index, head rice percentage, the best milling and protein content. In a different study, Salem[37] investigated plant spacing in rice productivity and showed that that narrower spacing of 0.2 m×0.15 m (compared with wider spacing of 0.2 m×0.2 m and 0.2 m×0.25 m) had the highest values of plant height, panicles/m^2, leaf area index, straw and grain yields, and number of days to heading. Same study also reported that the two wider spacing recorded the highest values for panicle weight and length, the number of filled grains per panicle, and 1000-grain weight. More studies on the effects of planting density on agronomical characteristics of rice are available in the previous works[24,38-43]. For the effects of row spacing on canopy structure and yield in different rice cultivars, Zhao et al. [31] showed that the percentage of productive tiller was first reduced before it was increased with increasing of row-spacing following a quadratic regression pattern between row spacing and the percentage of productive tiller. Studying the effects of narrow spacing on yield loss for aerobic rice showed that regardless of the weed species and weed emergence date[44], rice grain yields were higher in narrower rows[29,30]. Similar results was reported by Omin et al.[45], where narrow spacing of 0.1×0.20 m led to the highest yield and yield components of Giza177 rice cultivar compared with the two other treatments of 0.20×0.20 m or 0.3×0.2 m. The best pattern for rice planting was reported by Islam et al.[46] to be 0.25×0.12 m compared with 0.15×0.10 m and 0.20×0.12 m. Two different studies[47,48] reported that space of 0.15 m between hills gives the highest number of panicles/m^2, the tallest plants, and maximum grains and straw yield, while hill spacing of 0.25 m gives the highest number of filled grains per panicle and 1000-grain weight. Practicing the best planting pattern, optimum transplanting spacing, and seed rate in compliance with SRI guideline is expected to significantly improve rice yield. Other than the works of Durairaj et al.[49,50], the amount of published study that investigated the efficiency of a fully automated paddy transplanter for SRI is limited.

The demand for producing rice with higher yield and quality at lower costs necessitates practicing sustainable methods and smart farming technology in order to keep the production competitive through mechanization and automation. In this content, modification and development of a transplanter that comply with SRI specification should be investigated based on the plant physical and mechanical properties. Such machine design involves good understanding of the SRI operation and its functional requirements. For the purpose of this research, we modified planting claw (kuku-kambing) of an existing paddy transplanter (Kubota SPU-68C), as well as seed rate on tray and planting technique in such a way that it only picks one to two seedlings at a time to satisfy the specified guidelines of SRI for transplant seedlings at the recommended, spacing, quantity, moisture content, and age[51]. Seed selection criteria were embarked upon selecting healthier and vigorous seeds, while germination was count to determine the suitability of the planting medium in relation to the growth and development of the rice seedling and its easiness in single removal. The existing transplanter claw picked between 5-8 seedlings per hill for planting. Modification was required to allow planting pattern of different spacing with single seedling per hill at 2-3 cm planting depths. This paper reports the utilization of this modified transplanter in compliance with SRI guidelines to determine the best spacing, seed rate and planting pattern that resulted in a maximum number of seedling and tillers per hill.

2 Materials and methods

2.1 Experiment setup

The study was conducted during 2014 planting season (Jan-May) in two different rice irrigation schemes in the state of Selangor in Northwest of Malaysia. Selangor covers an approximate area of 20 000 hm^2, extending over a length of 40 kilometers along the coast with a width of 5 km on average. About 17 510 hm^2 of the total area are under paddy cultivation, while the remaining area, including 760 hm^2 is allocated for vegetables, 460 hm^2 for tree crops and 510 hm^2 lying idle. The main drainage and irrigation canals run parallel to the coast, which originated from the Bernam river, serving as the main source of water supply to the scheme. Two separate experiments were carried out in split block format with three replications, first to determine the best transplanting spacing (S=4 levels: s_1=0.16 m×0.3 m, s_2=0.18 m×0.3 m, s_3=0.21 m×0.3 m and s_4=0.24 m×0.3 m) for a specific planting pattern (row mat or scattered planting pattern), and the second to determine the best combination of transplanting spacing with seed rate treatments (G=2 levels: g_1=75 g/tray, and g_2=240 g/tray). The first experiment was conducted on a field size of width=30 m by height=12.4 m, located at Ladang Sepuluh agricultural experimental station, inside the campus of Universiti Putra Malaysia (latitude: 3.002725, longitude: 101.703137). This field was split into two blocks, A and B, respectively assigned to row and scattered planting pattern using seed rate of 70 g/tray. The second experiment was conducted on a field size of width=48 m by height=27 m in the rice granary area of Tanjung Karang located at the flat coastal plain of Northwest

Selangor Agricultural Development project (Latitude: 3.486775, Longitude: 101.163586). This field was also split into two blocks, C and D, respectively assigned to the seed rate treatments of 75 g/tray and 240 g/tray, both with scattered planting pattern. Each block was divided into four experimental plots of equal size that were randomly assigned to the four levels of spacing treatment and the two levels of seed rate treatment as shown in Figure 1. Balanced factorial design with two-way analysis of variance (ANOVA) was used with equal replication of 3 measurements in each experimental plot to determine variation effects in the number of seedling per hill and tiller per hill due to different spacing, planting pattern and their interaction in block A and B, and different spacing, seed rate and their interaction in block C and D. For the k^{th} number of seedling per hill (or tiller per hill) under the i^{th} level of spacing factor and the j^{th} level of seed rate factor, the two-way ANOVA model was stated as $Y_{ijk}=\mu+s_i+g_j+(s.g)_{ij}+\varepsilon_{ijk}$. Table 1 provides a descriptive summary of the field blocks, experimental plots, and treatments.

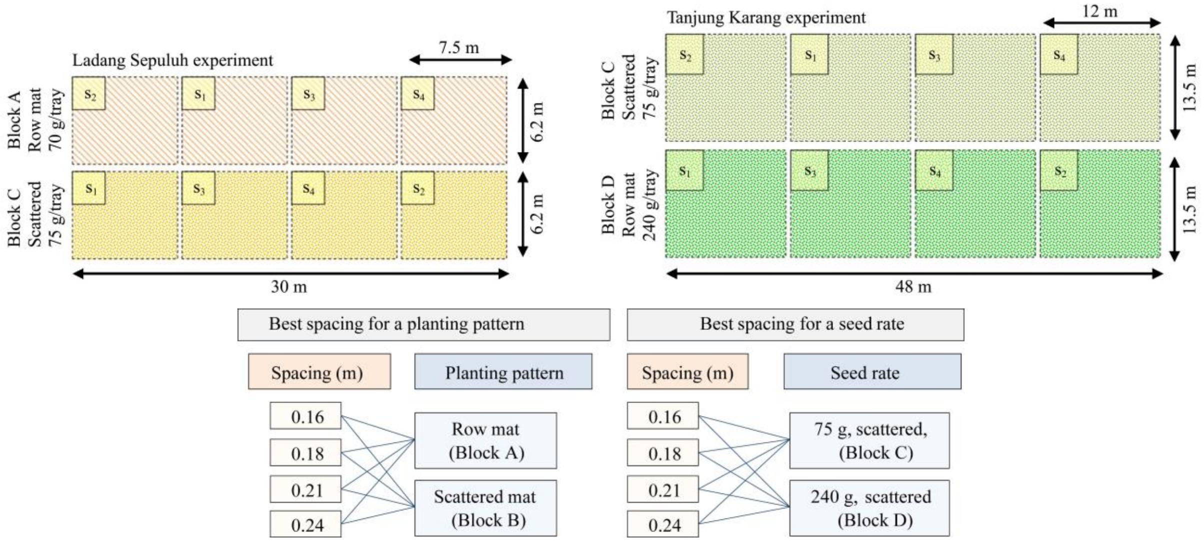

Figure 1 Schematic view of the rice fields under study and corresponding experimental design

Table 1 Description of field blocks and experimental fields

Field name	Field size (W×H)/m	Plot size (W×H)/m	Seed (g/tray)	Planting pattern
Ladang Sepuluh Block A	30×6.2	7.5×6.2	70	Scattered
Ladang Sepuluh Block B	30×6.2	7.5×6.2	70	Row
Tanjung Karang Block C	48×13.5	13.5×12	75	Scattered
Tanjung Karang Block D	48×13.5	13.5×12	240	Scattered

2.2 Field and seedling preparation

Prior to tillage, both fields were prepared according to the paddy production practices recommended in the rice manual provided by the Department of Agriculture of Malaysia[52,53]. Residues and straw from the previous season's crop were burnt, and then tilled by rotary tillage pass in dry soil condition followed by two rotary tillage passes in 20-50 mm flooded condition of standing water. The field was cleared, harrowed, ploughed twice and puddled to create a comfortable growing condition to help the young delicate seedlings overcome the transplanting shock for quicker and easier establishment. The field was drained from the excess water a day before transplanting operation in order to meet the moisture requirements. The preparation of the land was similar to the conventional practice as suggested by Uphoff et al.[6,54] in which land leveling was pursuit vigorously for efficient distributing of the limited water across the whole land mass and at the same time providing drainage channels to manage the excess water either through irrigation or rainfall. Seeds were visually inspected to ensure that they are healthy and viable for sowing. Selected seeds based on health and vigorous criteria were incubated in moist gunny material for 2 d. In order to attain the best seedling establishment, seeds were then put into a 2.5% solution of salt and water before laying them in fresh water for 24 h before sowing on January, 1st, 2014. It should be noted that the quality of seed is the primary mean used by paddy farmers in attaining the best seedling establishment as well as higher yield through uniformly free stress robust seedlings. Hence the seeds were submerged in different concentrations of $NaCl_2$ (with 50 g/L, 60 g/L, and 80 g/L of water, and distilled water only). The selected sunken seeds were set for the germination test to find the parameter that gives the best germination. Table 2 shows that the seeds soaked in distilled water had 99% germination potential while the seeds soaked in distilled water were used in the experiments in order to avoid missing hills during transplanting operation.

Table 2 Percentage of seed germination with respect to germination count

Solution of $NaCl_2$/g L^{-1}	Day after sowing									
	1	2	3	4	5	6	7	8	9	10
50	0	0	32	36	66	74	74	74	74	74
60	0	0	30	78	84	90	90	90	90	90
80	0	0	24	58	64	68	68	70	70	70
0 (Distilled water only)	0	0	78	80	96	99	99	99	99	99

Prepared seeds were uniformly scattered while some were planted in rows in the nursery beds at different seed rates of 70 g/tray, 75 g/tray and 240 g/tray, followed by half burnt rice husk of 1 cm thickness to cover the seeds, then tendering and watering for 14 d. Transplanting operation was performed on January, 15th, 2014. Duration of uprooting seedling from seedling tray to transplanting in the main field was 15-30 min. A summary of the nursery practice involved in raising the conventional seedlings is provided in Figure 2. A tray was designed (Figure 3) for a special seedling raising technique called mat or dapog. In this technique sprouted seeds are spread uniformly on a half burnt rice husk covered with the seedling tray for a duration of four days, watered with rose can, and transplanted to the field when the seedlings are about 2-3 leaf stage (14 d) as shown in Figure 4.

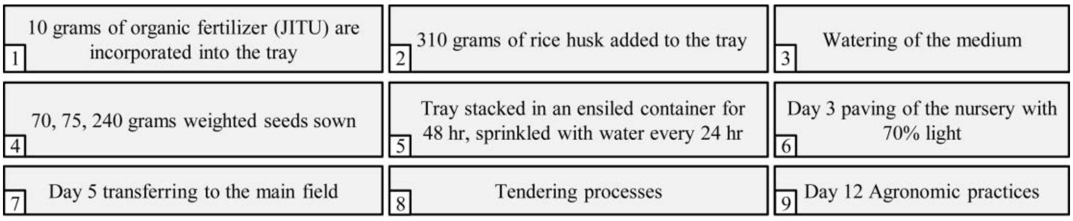

Figure 2 Schematic illustration procedures for nursery tray practice requirements

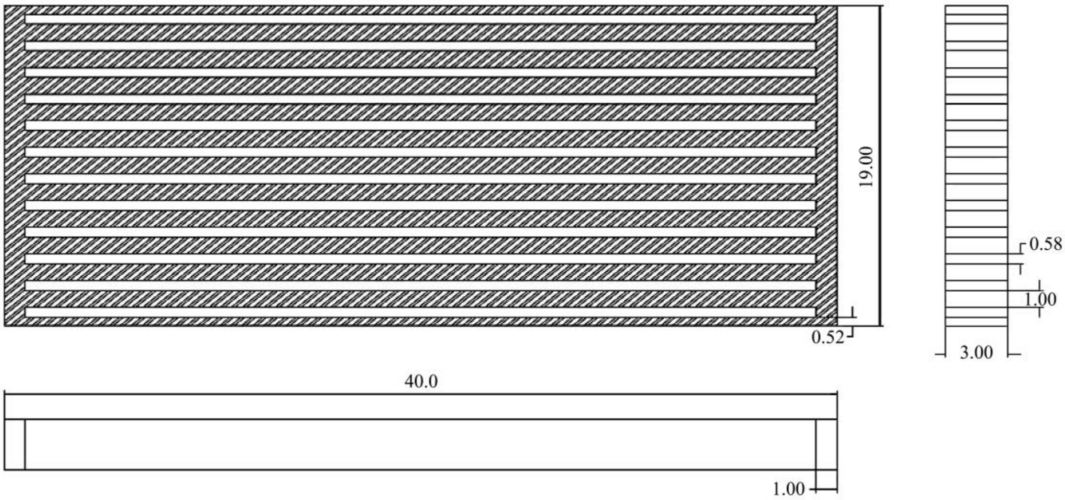

Figure 3 Tray design for modified seedling raising technique (mm)

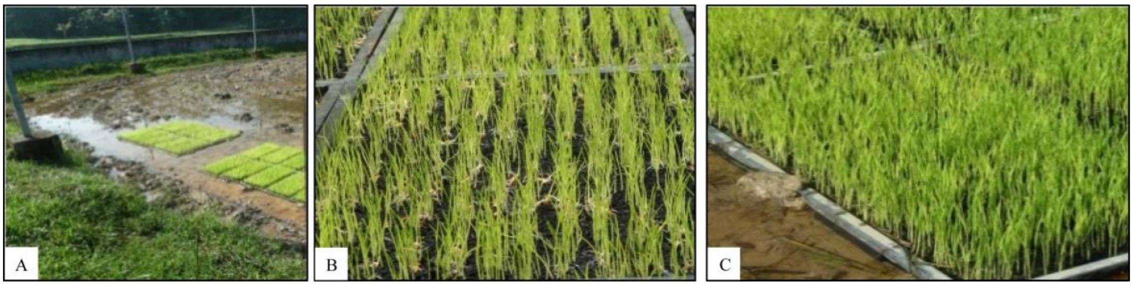

Figure 4 (A) Seedlings ready for transplanting, (B): Modified row pattern seed raising technique and (C) Modified scattered pattern seed raising technique

2.3 Transplanting and harvesting

Transplanting was carried out using Kubota self-propelled transplanter model NSPU-68C (Kubota Corporation, Osaka, Japan) operating lengthwise of the prepared fields at different hills spacing, with the soil kept moist enough to prevent floating of the tiny friable seedlings. The plant characteristics at transplanting time consisted of 2-3 leaves, 2 mm stem thickness, 19 mm stem length and 3.5 mm root length. The machine was operating at gear position 3 and transplanting at 3 mm depth. It had a fixed row to row spacing of 0.30 m and a variable plant to plant spacing of 0.14 m, 0.16 m, 0.18 m, 0.21 m and 0.24 m. Two modifications were applied on the existing transplanter, one on the planting claw (kuku kambing) in a way that it only catches one to two seedlings at a time and place it in moist soil (the original setup removed 5-8 seedlings per hill), and the second involved redesigning and modification of the seedling raising techniques to reduce plant density per unit area. To this aim, the original 12 mm conventional claw of the transplanter was replaced with a modified claw consisting of 9 mm claw size shown in Figure 5 to reduce planting density. The transplanting operation and the appearance of the seedlings after transplanting are shown in Figure 6. The soil was continuously flooded for 30 d after transplanting and was then irrigated at weekly intervals. A new high-yield local cultivar, MR219, developed by the Malaysian Agricultural Research and Development Institute (MARDI) was used in the experiment. Conventional recommendations for insects and disease control were followed. Rotary weeding was done during the entire crop growth period. Alternate wetting and drying were maintained at the vegetative stage, while during the flowering stage until 10-12 d prior to harvesting, a thin layer of water maintained through irrigation at frequent interval. Fields were drained two weeks prior to harvesting. Harvesting operation was performed at full physiological maturity using New Howland 1545 self-propelled combine harvester model 1545 (New Holland Agriculture, Turin, Italy) powered by an 82.06 kW diesel engine. The numbers of transplanted hills in each block are given in Table 3.

Table 3 Number of transplanted hills

Spacing	Actual hill transplanted	
	A and B	C and D
16	779	3317
18	685	2968
21	498	2531
24	514	2240

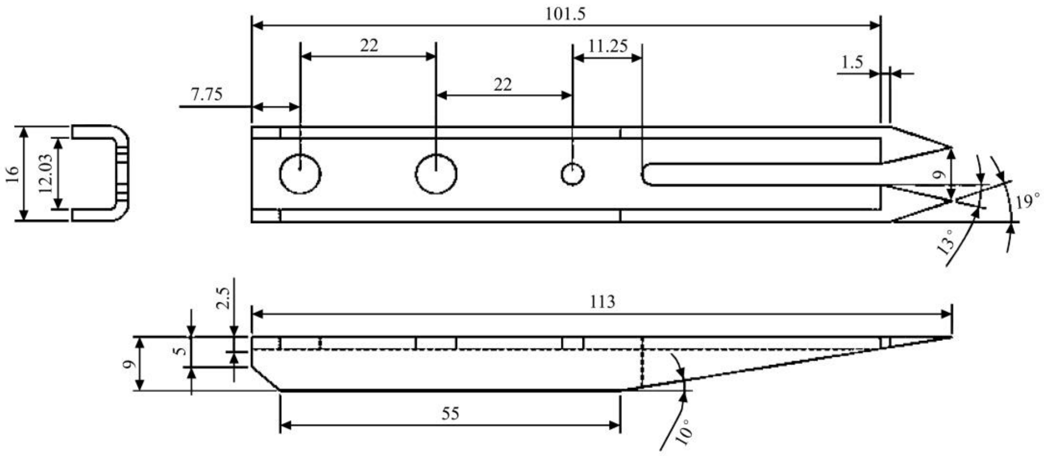

Figure 5 Dimensional specification of the modified UPM Kuku-kambing

Figure 6 (A) Transplanting operation, (B) Single seedling transplanting on the go, and (C) three days seedlings after transplanting

2.4 Soil Physical and chemical properties analysis

Physiochemical characteristics of the experimental soil were analyzed to determine soil properties in both fields. The materials used in soil analysis experiment included a set of sieves, containers, weighing scale with an accuracy of 0.001 g, shaker, soil auger, electrical drying oven, hammer, measuring cylinder and pipette. Two soil samples were collected from each experimental plots with a core sampler from top soil layer at a depth of 0-100 mm. The sampler was driven manually using a hammer. Collected samples were wrapped in plastic bags for immediate analysis in the soil laboratory to determine dry bulk density and particles properties. The air dried samples were used for soil particle size (texture) analysis. The standard gravimetric method by oven-dry at the temperature of 105 ℃[55] was used to determine moisture content. The initial samples were first weighed to determine weight mass and were then placed in an electric oven at a temperature setting of 105 ℃ for 24 h for weighing the dry mass. The percentage of water content (W) was defined as the ratio between the differences in sample's wet and dry mass according to Equation (1)[56].

$$W = 100\frac{M_{cws} - M_{CS}}{M_{CS} - M_{C}} \tag{1}$$

where, M_{cws} is the mass of container and wet specimen, g; M_{CS} is the mass of container and oven dry specimen, g; M_C is the mass of container, g.

This equation can be expressed as W=100M_W/M_S is mass of solid particles, g; M_W is mass of water, g. Soil bulk density was measured by the standard core method[57]. The particle size distribution (PSD) of the soil was determined using the Pipette method for Malaysian soils as described in [58]. Percentages of sand (>50 μm), silt (2-50 μm) and clay (<2 μm) were determined and used in identifying the textural class from the textural triangle. Soil samples were sieved through 2 mm sieve size. The organic matter was removed by heating 100 g sample with hydrogen peroxide which absorbed cations were removed by treating the sample with 0.2 drops of hydrochloric acid and then dispersed in Calgon. The sand (2-50 μm) was separated through sieving process while silt (2-5 μm) and clay (<2 μm) were determined by Pipette Method.

Soil texture at planting time was analyzed in the laboratory for all four experimental blocks and was found to be fine to fine granular structure classified as clay silt loam texture based on the soil charts[58]. The percentage of sand, silt, and clay, as well as the pH level, moisture content (MC), bulk density (BD), amount of nitrogen (N), phosphorous (P), potassium (K), electrical conductivity are reported in Table 4. A bulk density of 0.86 g/cm^3 and 0.88 g/cm^3 for Ladang sepuluh (block A and B) and Tanjung Karang (block C and D) was respectively obtained using standard technique of core sample method[57], which are in agreement with Garg et al.[59] recommendations that transplanting should not be done either on too soft nor too hard soil. Statistic summary of air temperature, relative humidity and wind speed during the five months of experiments were collected using a precision data acquisition system[60] and are provided in Table 5.

2.5 Data collection

The number of plants per square meter was recorded 8 days after transplanting. After transplanting, from each of the experimental plots 20 samples of the seedling hill were uprooted and the depth measured, and later on re-planted manually. Randomly selected samples of 20 stands from each experimental plot were counted for the number of seedlings per hill and tillers per hill. After harvesting and threshing, the moisture content in grain was measured using MMG608 grain moisture meter (General tools, Secaucus, NJ) while the grain weight yield was expressed in t/hm^2. Observations on missing hill, number of seedlings per hill, tillers, panicle, and grain weight (yield) for the operation were recorded in order to evaluate the performance of the transplanter in the experimental sites. To determine the number of tillers per square meter, the numbers of panicle-bearing tillers were recorded at the harvesting time for one square meter from three different places in the experimental plots of each field and were averaged. Moreover, twenty panicles of primary tillers were selected randomly from earmarked areas in the plots during the harvesting period in order to find the number of grains per panicle. A demonstration of the field with rice seedling per stand and rice seedling at 90 days is shown in Figure 8. The performance of rice cultivation under SRI was determined by the higher number of tillers per hill, higher grains per panicles, lower percentage of empty seeds and higher yield. Yield component and yield data were collected prior to harvesting.

Figure 7 Soil analysis setup (A: weighing of soil sample, B: bulk density determinations, and C: soil particle determinations)

Table 4 Result of soil analysis in different experimental field

Sample	Sand/%	Silt/%	Clay/%	pH	MC/%	BD/g cm^{-3}	N/%	P/ppm	K/ppm	EC/ds m^{-1}	Texture
A	42.82	32	25.18	5.5	64	0.86	0.18	36.8	28.2	1.8	Clay silt loam
B	43.35	31.8	24.85	5.5	64	0.86	0.18	36.8	28.2	1.8	Clay silt loam
C	42.45	31.3	26.25	7.1	67	0.88	0.17	35.4	26.7	1.9	Clay silt loam
D	41.8	31.65	26.55	7.1	66	0.88	0.18	35.6	27.4	1.9	Clay silt loam

Table 5 Statistic summary of basic climate parameters during the experiment

Month	Temperature/℃				Relative humidity/%				Wind speed/km h^{-1}			
	Avg	Std	Min	Max	Avg	Std	Min	Max	Avg	Std	Min	Max
Jan	28.1	3.3	21.6	37.2	80.6	13.6	45.1	100	6.5	4.6	0.1	44.2
Feb	28.7	2.9	24.2	35.3	79.9	12.0	52.2	99.8	6.8	3.4	0.1	21.2
Mar	29.0	2.8	23.3	35.4	78.1	12.6	49.3	99.5	7.4	5.0	0.2	32
Apr	28.4	2.7	23.2	35.3	81.8	12.1	52.1	100	7.6	5.2	0.0	30.7
May	27.9	2.6	23.1	35.0	85.9	11.5	55.9	99.9	6.0	4.3	0.2	35.5

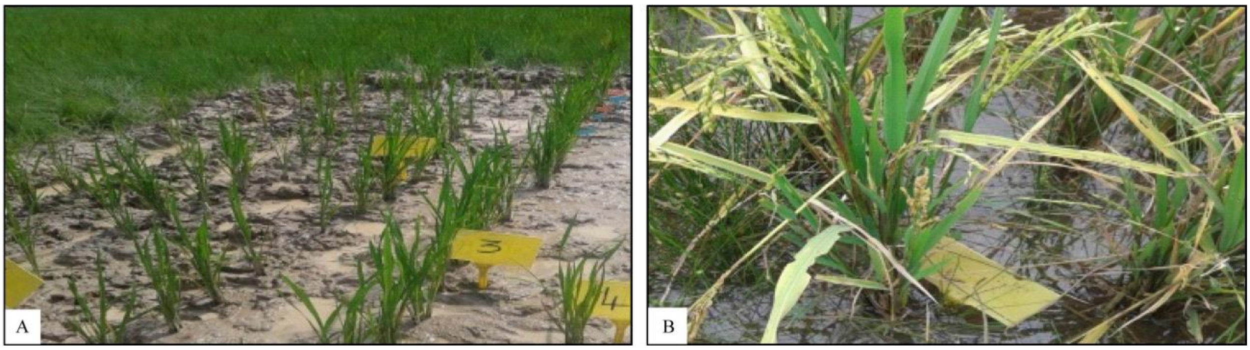

Figure 8 Rice seedling per stand (A) and rice seedling at 90 d (B)

3 Results

Major findings of this research are provided by means of tables and figures, with minor trends or non-significant trends covered through the text. We have summarized our findings in the following order: (i) hill population and missing hills, (ii) tiller population and seedling count, (iii) yield components, (v) and germination count. Moreover performance of the rice cultivation under SRI was determined by higher number of tillers per hill, higher grains per panicles, lower percentage of empty seeds and higher yield.

3.1 Hill population and missing hills

A summary of data for the effects of spacing and seed rate treatment on the number of hill population, percentage of missing hills, combined percentage of one and two-seedlings, and the percentage of good seeds is given in Table 6. Measurements from all experimental blocks showed that plants had mean stem thickness of 2.048±0.1 cm and mean root length of 3.538±0.07 cm. The percentage of missing hill was observed to be fluctuating with increasing in hill spacing in 70 g row tray planting pattern, which is similar to the results obtained by Behera et al.[61,62], while in the scattered tray planting pattern we had 1%, 2.5%, 2% and 2%, of missing hill which shows the large dependency to the transplanter claw as well as the seedling density and the uniformity in the mat as reported by Mufti et al.[63]. It should be noted that the seedling needs to be smooth flowing to avoid problem of non-linearity in sliding of the mat on the tray in compliance with the SRI recommendations. Other noticeable factors in causing missing hill were the speed of lateral movement of the seedling tray, the thickness of the seedling mat, status of the standing water in the field as well as the accuracy of the different parts of the machine. It should be noted that at low sedimentation period, high water level leads to wave action resulting in seedlings wash-off which in turns might increase the missing hill as reported of Behera[61]. This is because at lower sedimentation period, the majority of the seedlings were not released from the fingers because of the insufficient soil gripping force. Consequently, these seedlings are trapped in the fingers resulting in excessive missing hills. It was also found that throughout the experimental plots hill population increases with the decreased in hill spacing, the seeds quantity of 70 g seeds per tray decreased from 781 to 517. The seeds quantity of 240 g of seeds per tray recorded 3375 reducing to 2250. However, missing hill is controllable and a function of seedling mat density, uniformity and also hill mortality. Therefore to prevent mortality of hill resulting from snail, mechanical damage, buried and floating hill should be carefully avoided using standard procedures in order to have the optimum plant population. In other words, since the working accuracy of transplanter varies based on the field and seedling conditions, the number of missing hills depended significantly on growing density and uniformity of the seedlings in the mat. The depth of planting and the angle of transplanting were affected primarily by field conditions.

Table 6 Effects of spacing and seed rate treatment on the number of hill population, percentage of missing hills, combined percentage of one and two-seedlings, and the percentage of good seeds

Block	Hill population				Percentage of missing hills/%				Percentage of 1 and 2 seedlings/%				Percentage of good seeds/%			
	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
A	781	689	590	517	0.3	1	0.4	1	85	74	80	78	80	91	94	95
B	781	689	590	517	1	2.5	2	2	64	54	63	56	90	89	90	95
C	3375	3000	2571	2250	2	1	2	0.4	68	37	50	68	81	88	92	93
D	3375	3000	2571	2250	1	1	0.4	0	64	41	53	16	92	89	93	95

A well-prepared field increases the percentage of transplanting time[63], hence the quality of transplanting operation is assessed according to the percentage of missing hills, single, two, three, four and five seedlings. A comparison between the number of empty seeds, percentage of missing hills and number of panicles at different spacing is shown by means of bar plots in Figure 9. The number of seedling per hill influences formation of tiller and reflects nutrient uptake, solar radiation interception, and photosynthesis rate beside other physiological characteristics that affect growth and development of rice. The number of grain-bearing panicles was found to increase with increase in spacing in all the experimental plots (Figure 9), with the 70 g/tray scattered planting (block B) having the least at s_1=0.16 m×0.3 m spacing, and the 75 g of seeds/tray scattered planting (block C) setting the highest value of 39 grain bearing panicles at s_4=0.24 m× 0.3 m. These findings are in agreement with the result of literature[64], Aslam et al.[65] reported that transplanted rice increased all the growth and yield attributes of rice over direct seeding. It can be seen that except in block D (240 g/tray), empty seeds decreases with increasing of hill spacing, which may be attributed to more shading of plants, competition for water, nutrients, space and mineral due to the shortage of space. The higher percentage of empty seeds may also be attributed to nutrient deficiency[66]. The number of missing hills was found to fluctuate with increasing spacing in all experimental plots as shown in Figure 9 which is similar to the result observed by Behera et al.[61,62]. The percentage of missing hill is a function of seedling mat density, uniformity and hill mortality, and fluctuates with increasing hill spacing, i.e., from 2, 5, 3, and then 5 in 70 g/tray with row planting pattern, while in the scattered tray planting pattern it was 7, 22, 15 and 15. Results showed that the percentage of missing hills in Ladang Sepuluh field was significantly higher than Tanjung Karang experiment, and both were more than the allowable limit of 5%. Similar results have been reported by Behera et al.[61,62] The working performance of a transplanter was also measured by the time required to transplant a given area. Working time includes the productive (transplanting) and non-productive (time loss in the field). In another study[67] it has been reported that younger seedling has greater ability of producing a higher number of tillers per hill in comparison with older seedlings. Another study[68] suggested that compared to direct seeding, tiller production can be improved by transplanting seedlings at younger ages.

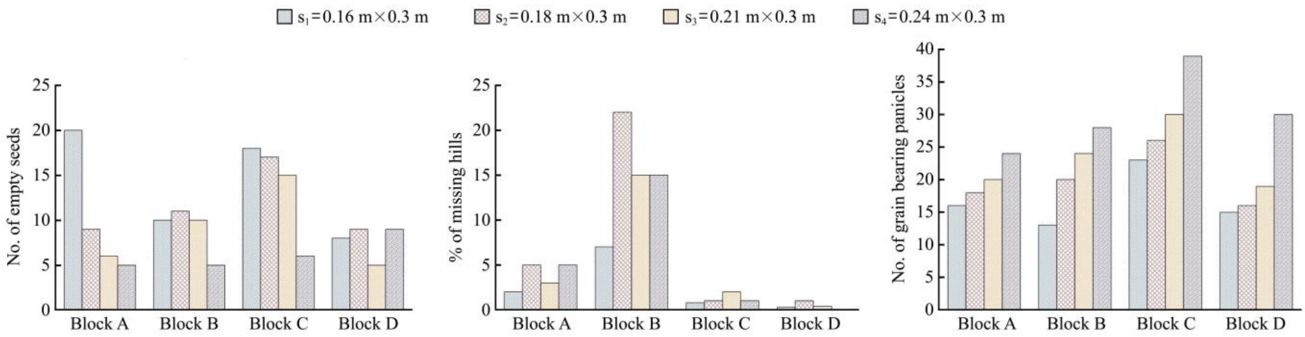

Figure 9 Comparison between percentage of missing hills (left) and number of empty seeds (right) in the four experimental blocks

3.2 Tiller population

Tillering influences grain yield because it is closely related to the panicle number produced per unit area of cultivated land[69]. The effects of spacing and seed rate treatment on the number of transplanted hills, tillers.m^{-2}, tillers per hill, seedlings per hill, and tillers per plant in each experimental block are reported in Table 7. It can be seen that the number of tillers produced per meter square in single seedling was significantly influenced by spacing's. In both treatments (row and scattered) and at the both sites (Ladang Sepuluh and Tanjung Karang), the highest and the lowest number of tillers were recorded from the widest and closest spacing's respectively. The number of tillers at Ladang Sepuluh was however, significantly greater than that of Tanjung Karang, this could probably be due to existing variation in the physico-chemical properties of the soil. Likewise, the number of tillers per meter square in double (two) seedlings is significantly determined by spacing. At Ladang sepuluh, the numbers of tillers per square meter were both 21 cm and 24 cm spacings, with both treatments. Similarly, the number of tillers per meter square in both 16cm and 18 cm spacing's were statistically equal under scattered treatment alone. At Tanjung Karang however, similar number of tillers was observed as what was obtained in single seedling. When hills with three seedlings were considered, significant decrease in number of seedlings per meter was observed with increase in spacings regardless of the treatment, however, at Ladang Sepuluh alone, except at 24 cm spacing under row planting where the number of tillers (420) per square meter was higher. The mean values of number of tillers at Tanjung Karang under three seedlings was statistically similar to what was earlier recorded from single seedling and double seedlings experiments. When four seedlings were considered, both treatments recorded their highest and lowest number of tillers per meter square at 16 cm and 24 cm spacings respectively. In all spacings, the row planting treatment had the highest mean tiller value per square meter than the scattered treatment. At Tanjung Karang however, the number of tillers per meter square was similar to what was previously obtained in other considered number of seedlings. When mean tillers number per square meter was considered under five seedlings condition, significance difference was observed. At Ladang Sepuluh, the mean tiller number per meter square was higher in scattered treatment than row at 16 and 18 cm spacings, the treatments were at par. However, at the widest 24 cm spacing, row treatment performed significantly better than the scattered. At Tanjung Karang however, the values obtained did not significantly differ with the values that were considered earlier. Generally clear visible differences in the plant morphology and physiological features were observed based on result from the study, the highest productive tillers per hill were recorded for 70 g row and scattered planting pattern at 24 cm×30 cm spacing an average of 65 tillers per hill was observed, while the lowest was recorded at 21 cm× 30 cm spacing. The higher productive tillers.m^{-2} were attributed to wider spacing and single seedling, as well as the ability for producing many tillers due to less competition for space, sunlight, water, nutrients, mineral and easier management practices. The importance of sufficient of sunlight can be seen clearly on the number of tillers and ears increases with an increase in the intensity and quantity of light. The results are in agreement with those of Tuong et al.[70,71] and Ginigaddara[67] who reported that younger seedling has greater ability of producing a higher number of tillers per hill in comparison with older seedlings. In fact, when seedlings are transplanted precisely at the initial growth stage, the shock of root damage due to uprooting time is minimized, following a rapid growth with short phyllochrons[72]. Moreover, rice seedlings transplanted before commencing the fourth phyllochron retained much of their tillering potential[73]. Table 7 also shows a higher number of 65 tillers was obtained in the planting spacing of 24 cm×30 cm, while the lowest number of 15 tillers at a planting spacing of 21 cm×30 cm, and recorded its highest number of 48 tillers per hill at the spacing of 24 cm× 30 cm, while the least number of 23 tillers was obtained at a planting spacing of 21 cm×30 cm.

Table 7 Effects of spacing and seed rate treatment on the number of transplanted hills, tillers/m^2, tillers/hill, seedlings/hill, and tillers/plant in Ladang Sepuluh experiment (block A: row mat, block B: scattered mat) and in Tanjung Karang experiment (block C: 75 g/tray, block D: 240 g/tray)

Spacing /m	Block A					Block B					Block C					Block D				
	1S	2S	3S	4S	5S	1S	2S	3S	4S	5S	1S	2S	3S	4S	5S	1S	2S	3S	4S	5S
	No. of transplanted hills (Number of seedlings/hill)																			
0.16	484	180	62	39	16	351	148	203	55	23	1205	1080	675	270	135	810	1350	911	2362	34
0.18	345	165	76	69	34	234	138	220	90	14	594	504	1039	534	297	720	510	900	300	570
0.21	201	271	88	18	12	136	236	159	35	24	720	566	423	514	308	540	823	463	514	231
0.24	238	165	26	52	36	181	109	165	41	21	810	720	450	180	90	225	135	270	900	720
	Number of tillers/m																			
0.16	588	630	546	420	168	420	420	378	252	210	483	441	525	420	567	441	462	420	483	490
0.18	722	570	532	399	154	532	380	380	323	266	361	342	380	304	494	380	399	399	380	494
0.21	736	512	416	320	96	960	512	336	128	96	288	240	304	336	447	256	272	272	304	480
0.24	910	532	420	392	294	910	532	294	280	252	910	840	700	630	602	714	672	630	490	546
	Number of tillers/hill (Number of tillers/plant)																			
0.16	28	30	26	20	8	20	20	18	12	10	23	21	25	20	27	21	22	20	23	23
0.18	38	30	28	21	8	28	20	20	17	14	19	18	20	16	26	20	21	21	20	26
0.21	46	32	26	20	6	60	32	21	8	6	18	15	19	21	28	16	17	17	19	30
0.24	65	38	30	28	21	65	38	21	20	18	65	60	50	45	43	51	48	45	35	39

3.3 Seedling count

Different numbers of seedlings per hill and tillers per hill were observed due to different planting spacing and pattern Table 8 and planting spacing and seed density Table 9. It can be seen that the number of seedlings per hill varies with inter hill spacing in all treatments while the width of planting is fixed at 30 cm apart, a function of the transplanter parameter. A varied proportion was observed and recorded as shown in Table 8 in Blocks A and B using 70 g of seeds per tray at Ladang Sepuluh. The results indicated that spacing had significant effect on the number of single seedling establishment per hill regardless of planting pattern. In both the scattered and row planting patterns, the highest and the least number of single seedling per hill were obtained from spacings of 16 cm×30 cm and 2 cm×30 cm respectively. Likewise, plant spacings had significant effect on the number of two seedlings establishment per hill. In both planting patterns 21 cm×30 cm spacing had the highest number of two seedlings establishment per hill. Similarly 24 cm×30 cm recorded the least number of two seedlings establishment per hill. In the scattered planting pattern, 24 cm×30 cm and 18 cm×30 cm were numerically equal and statistically at par. Also spacing had significant effect on the number of three seedlings establishment per hill in both planting patterns. In the scattered planting pattern 21 cm×30 cm and 24 cm×30 cm spacings recorded the highest as well as the lowest number of three seedlings establishment per hill. Respectively in the row planting pattern however, 18 cm×30 cm and 21 cm×30 cm spacings recorded the highest and the lowest number of three seedlings establishment per hill.

Table 8 Comparison of mean effect of plant spacing and planting pattern on number of seedlings per hill and number of tillers per hill in Ladang Sepuluh experiment (block A: row mat, block B: scattered mat)

Seedlings per hill		One seedling				Two seedling				Three seedling				Four seedling				Five seedling			
		s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4
Row mat	A_1	53	37	22	28	20	19	31	18	7	8	9	3	4	9	2	5	2	5	1	4
	A_2	54	36	23	26	19	17	30	19	8	9	10	2	5	7	2	6	1	3	1	5
	A_3	52	38	24	27	21	18	32	20	6	7	11	4	3	8	2	7	3	4	1	3
Mean		53	37	23	27	20	18	31	19	7	8	10	3	4	8	2	6	2	4	1	4
Scattered	B_1	37	20	14	20	15	12	23	10	21	19	17	18	6	8	5	3	2	1	3	3
	B_2	38	21	13	18	17	13	24	12	22	20	16	17	7	7	3	4	3	0	2	1
	B_3	36	22	12	19	16	11	22	11	20	21	15	16	5	9	4	5	1	2	1	2
Mean		37	21	13	19	16	12	23	11	21	20	16	17	6	8	4	4	2	1	2	2
Tillers per hill																					
Row mat	A_1	29	38	46	66	30	34	36	38	26	30	32	34	20	22	20	28	8	6	7	20
	A_2	28	37	47	65	32	33	34	36	27	28	26	29	19	20	19	29	7	9	5	22
	A_3	27	39	45	64	28	30	31	34	28	27	25	30	21	21	21	27	9	9	6	21
Mean		28	38	46	65	30	32	33	36	27	28	27	31	20	21	20	28	8	8	6	21
Scattered	B_1	19	27	60	67	19	20	31	38	19	20	20	16	12	17	9	19	10	14	6	18
	B_2	21	28	58	64	20	21	33	37	18	19	19	18	13	16	7	21	9	15	5	17
	B_3	20	29	62	64	21	19	32	39	17	21	23	17	11	18	8	20	11	13	7	19
Mean		29	38	46	66	30	34	36	38	26	30	32	34	20	22	20	28	8	6	7	20

Table 9 Comparison of mean effect of plant spacing and seed rate per tray on number of seedlings per hill and number of tillers per hill in Tanjung Karang experiment (block C: 75 g/tray, block D: 240 g/tray)

Seedlings per hill		One seedling				Two seedling				Three seedling				Four seedling				Five seedling			
		s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4	s_1	s_2	s_3	s_4
75 g	C_1	2573	594	736	717	2287	505	579	637	1430	1039	473	398	573	535	527	159	286	298	315	81
	C_2	2572	595	737	716	2286	503	578	636	1429	1040	734	399	570	534	526	160	287	296	317	80
	C_3	2571	593	735	715	2285	504	580	638	1428	1038	732	397	573	353	525	158	285	296	316	79
Mean		2572	594	736	716	2286	504	579	637	1429	1039	646	398	572	474	526	159	286	296	316	80
240 g	D_1	1753	717	560	201	2863	508	852	120	1941	895	479	240	501	299	533	801	104	570	238	641
	D_2	1751	715	559	200	2862	506	851	121	1943	897	480	241	500	300	531	799	106	568	240	640
	D_3	1752	716	558	199	2861	507	850	199	1942	896	478	239	502	298	532	800	102	569	239	639
Mean		1752	716	559	200	2862	507	851	146	1942	896	479	240	501	299	532	800	104	569	239	640
Tillers per hill																					
75 g	C_1	27	29	27	43	27	27	27	42	27	28	28	44	28	27	29	16	25	27	29	16
	C_2	26	28	29	44	25	25	29	44	25	27	29	44	28	25	29	44	26	25	29	44
	C_3	28	27	28	42	26	28	28	44	28	29	28	43	27	27	28	42	28	27	28	42
Mean		27	28	28	43	26	26	28	43	26	28	28	43	27	26	287	34	26	26	28	34
240 g	D_1	24	28	30	40	23	26	30	42	22	28	29	40	21	27	30	38	20	25	30	40
	D_2	25	27	32	39	24	25	33	40	23	27	32	39	22	25	29	39	19	27	32	39
	D_3	26	26	29	38	23	27	29	38	20	29	32	38	19	27	30	40	20	25	29	38
Mean		25	27	30	39	23	26	30	40	21	28	31	39	20	26	29	39	19	25	30	39

For a fixed planting space, the number of seedlings per hill were found to change with inter-hill spacing in all blocks treatments. The effect of seed rate on the number of established seedlings per hill was found to be significant in plots with single and three seedlings per hill (p-values reported in Table 10); however, plots that had two, four and five seedlings per hill were not significantly influenced by seeding rate. Effects of plant spacing on averaged numbers of seedling per hill and tillers per hill in different experimental blocks are shown by means of bar plots in Figure 10. At both 70 g and 75 g seeding rates (block A and C), plots with single and two seedlings per hill had the highest number of seedling establishment that differed significantly with plots that had four and five seedlings per hill. This can be explained as the high lodging competition between the plants in dense fields, sometimes resulting gradual shading that decreases grain formation in favor of straw production. At a fixed spacing, the highest and least numbers of seedlings were respectively observed in plots with two and five seedling per hill. Plant spacing was found to have no significant effect on the number of seedling establishment per hill throughout the experiment. The highest productive tillers per square meter were recorded for 70 g/tray seed with row and scattered planting pattern at s_4=0.24 m×0.3 m spacing (Figure 10) with an average of 65 tillers per stand, while the lowest was recorded at s_3=0.21 m×0.3 m spacing. This is also consistent with the findings of Faruk et al.[74] who reported that all yield parameters except 1000-grain weight and panicle length was influenced by the number of seedling per hill. It can be concluded that the lowest number of bearing tillers and grains panicle per hill results the lowest grain and straw yield, while the highest number of non-bearing tillers per hill are resulted from single seedling per hill.

Table 10 p-values corresponding to the two-way ANOVA tests in each experiment

Source	df	p-value for variation in seedling/hill					p-value for variation in tillers/hill				
		One seedling	Two seedling	Three seedling	Four seedling	Five seedling	One seedling	Two seedling	Three seedling	Four seedling	Five seedling
Spacing	3	0.0000	0.0000	0.0000	0.0000	**0.0698**	0.0000	0.0000	**0.4257**	0.0000	0.0000
Pattern	1	0.0000	0.0000	0.0000	**0.2089**	**0.0186**	**0.0727**	0.0000	0.0000	0.0000	**0.0146**
Interaction	3	0.0000	**0.0086**	0.0000	**0.0051**	**0.0074**	0.0000	0.0000	**0.0397**	0.0000	0.0000
Spacing	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	**0.0085**	**0.0047**
Seed rate	1	0.0000	0.0000	**0.6134**	0.0000	0.0000	**0.0176**	**0.0959**	**0.0024**	**0.9143**	**0.9430**
Interaction	3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	**0.0076**	0.0001	**0.3446**	**0.3603**

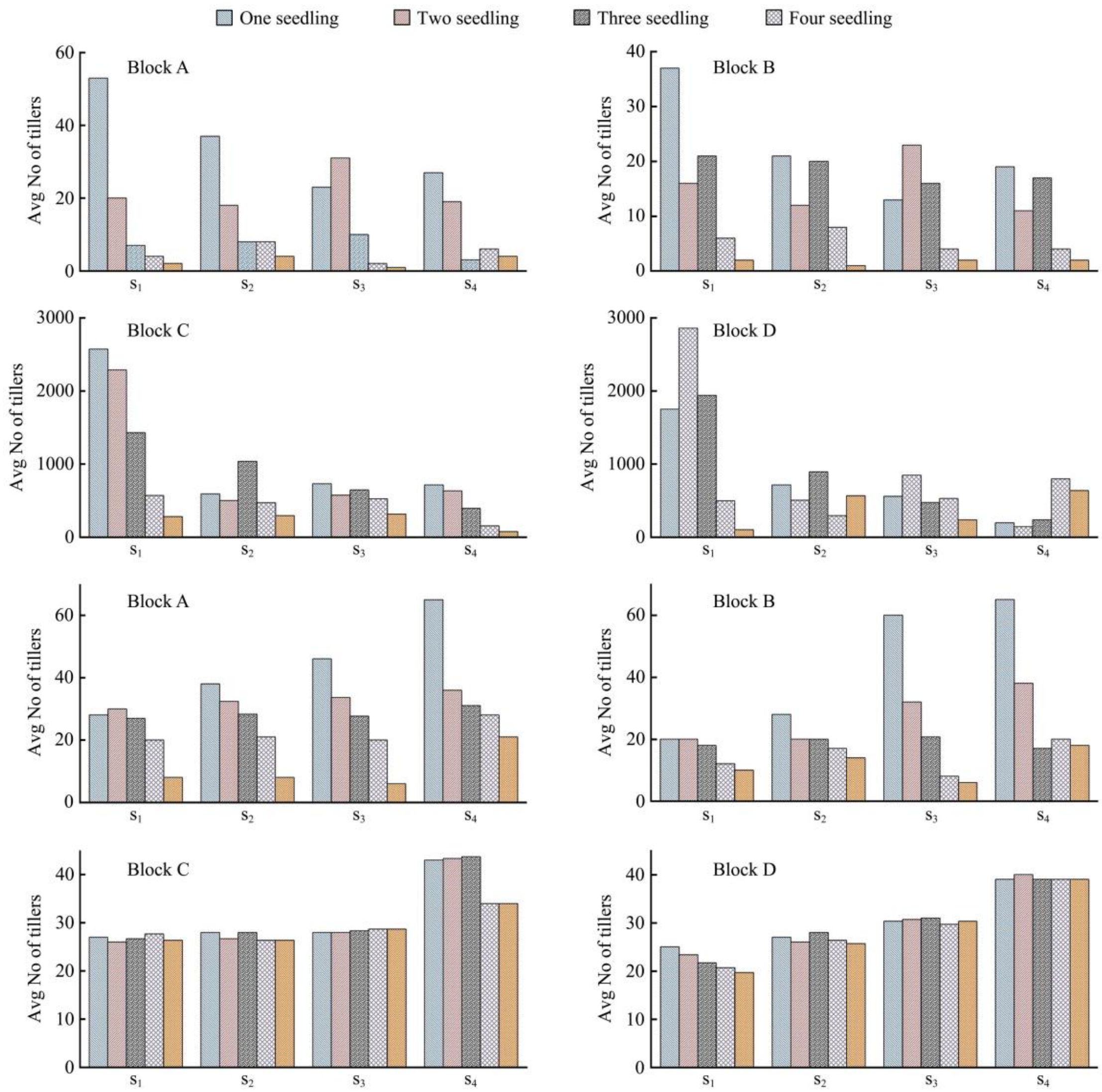

Figure 10 Effects of plant spacing on averaged numbers of seedling per hill and tillers per hill in different experimental blocks

3.4 Yield and yield component data

The yield and yield related parameter components of the rice crop harvested recorded at harvest time are given in Table 11 and Table 12. In these tables, *Yt* stands for the total seed yield (t/hm^2), *Yg* is the yield of good sees (t/hm^2), and *Ye* is the yield of empty grains (t/hm^2). The highest and lowest yields were obtained from 75 g seeds per tray scattered and 70 g seeds per tray scattered treatment respectively. For all spacings treatments the result clearly indicate increase in yield with increase in spacing (Figure 11). While the yield of 75 g seeds per tray scattered treatment was found to be higher than that of 240 g seeds per tray scattered treatment but the difference was not statistically significant. The yield performance of 70 g seeds per tray scattered treatment was significantly higher than that of 70 g seeds per tray row in all the spacings. It is also noticeable that the performance of 70 g seeds per tray row spacing at widest spacing 24 cm×30 cm was at par with 75 g seeds per tray scattered and 240 g seeds per tray treatments when at the closest 16 cm×30 cm spacing (Table 12). This can be explained by the fact that the highest number of tillers is inversely proportional to the length of the phyllochron[6,54], which is reliant on the extent of stresses. Moreover, wider spacing, abundant light, medium temperature and soil aeration, as well as good nutrient supply encourage shorter phyllochrons which increase the number of tillers[36,54]. In addition, transplanting impose a certain degree of stress by which the rate of phyllochron development would be depressed[72]. In contrast, the absence of transplanting shock with 7-21 d old seedlings has been reported[68]. The good performance of rice cultivation under the name of SRI may be seen through the higher number of tillers per hill, grains per panicles, the percentage of good seeds compared with empty and lastly the output per hectare. Our findings confirm previous reports[54,71,75,76] that by changing the management practices, increase in yield under SRI practice has been noted. The transplanting of young seedlings plays a great role in earlier crop establishment through the avoidance and minimization of transplanting shock, thus resulting in higher grain yield by allowing the plant to complete greater phyllochrons before onset of anthesis[71]. As mentioned earlier, wider spacing helps in reducing inter plant competition for air, water, nutrients and sunlight. While the higher percentage of empty seeds may be attributed to competition among the less spaced plant for space and nutrients as reported by Thomas et al.[66], our study suggests that planting density in rice crop play an important role for dry matter and grain yield. The optimum level of plant population together with better yield parameters (i.e. sufficient sunlight for photosynthesis, water, nutrients) have resulted in higher seed yield per hectare with 24 cm×30 cm spacing using 70 g/tray row planting pattern. These findings are consistence with findings of Ceesay et al.[75,77].

Table 11 Effects of spacing and seed rate treatment on yield component in Ladang Sepuluh experiment (block A: row mat, block B: scattered mat). Y_t: Total seed yield (t/hm^2), Y_g: Yield of good sees (t/hm^2), Y_e: Yield of empty grains (t/hm^2)

Spacing/m	Number of seedling	Block A				Block B			
		No. of gains/panicle	Y_t	Y_g	Y_e	No. of gains/panicle	Y_t	Y_g	Y_e
0.16	One seedling	17	7	5.6	1.4	13	7.2	6.2	1
	Two seedling	15	6.8	5.4	1.1	13	6.6	5.2	1.4
	Three seedling	12	6.4	5.9	1.2	11	4.2	2.6	1.6
	Four seedling	12	6	5.4	1.1	12	3.6	2.2	1.4
	Five seedling	10	5.6	4.2	1.9	10	2.8	1.1	1.3
0.18	One seedling	25	8.2	7.4	0.8	20	5.7	5.1	0.6
	Two seedling	28	8	7.4	0.6	18	5.3	4.7	0.6
	Three seedling	24	7.6	5.6	2	18	4.2	3.2	1
	Four seedling	19	6	5.1	2.4	14	3.8	2.4	1.4
	Five seedling	17	5.6	5.3	0.3	10	3.6	2.6	1
0.21	One seedling	28	8.2	7.6	0.6	24	6	5.4	0.6
	Two seedling	27	8	7.2	0.8	20	5	4.5	0.5
	Three seedling	24	7.6	6.7	0.9	16	4	3.2	0.8
	Four seedling	22	6.8	5.8	1	14	3.8	2.8	1
	Five seedling	20	3.8	2.3	1.5	10	3.2	2.4	0.8
0.24	One seedling	28	8.6	8.2	0.4	28	7.5	7	0.5
	Two seedling	24	8.2	7.8	0.4	25	6.6	6	0.6
	Three seedling	20	8	7.5	0.5	22	4.2	3.8	0.4
	Four seedling	18	7.2	6.8	0.4	22	3.6	2.6	1
	Five seedling	16	6.2	5.9	0.3	19	2.8	2	0.8

Table 12 Effects of spacing and seed rate treatment on the yield component in Tanjung Karang experiment (block C: 75 g/tray, block D: 240 g/tray)

	Spacing/m	No. of plants	No. of grains/panicles	Moisture content/%	Temperature	Total harvested rice/kg	Y_t	Y_g	Y_e
Block C	0.16	3375	18	27.3	37.4	41	7.6	6.2	1.4
	0.18	3000	18	27.6	37.2	42	8.6	7.6	1
	0.21	2571	21	32.3	35.6	43	8.8	8.1	0.7
	0.24	2250	34	32.2	34.6	45	9.3	8.7	0.6
Block D	0.16	3375	15	27.5	33.2	38.4	7.5	6.9	0.6
	0.18	3000	16	29.1	34.1	39	8	7.1	0.9
	0.21	2571	19	25.5	33.5	41	8.4	7.8	0.6
	0.24	2250	30	27.9	33.2	46	9.1	8.6	0.5

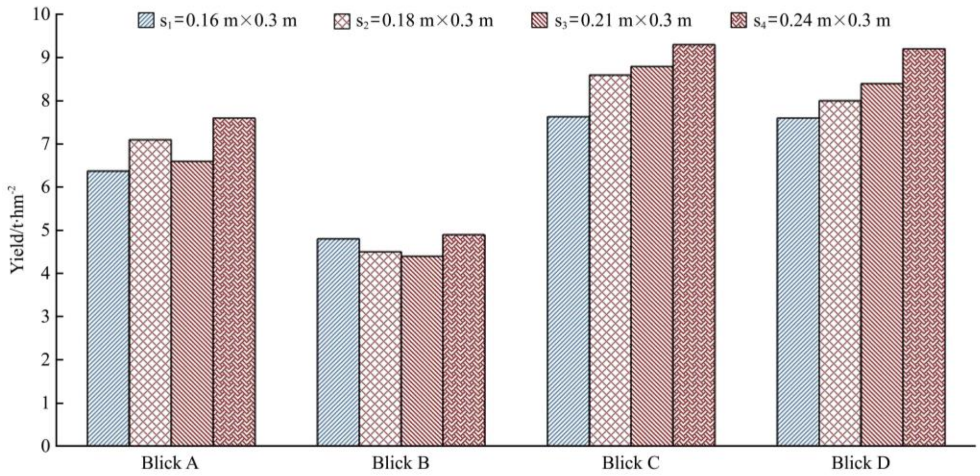

Figure 11 Summary of the effect of spacing and seed rate treatment on yield data (t/hm^2) in Ladang Sepuluh experiment (block A: row mat, block B: scattered mat) and Tanjung Karang experiment (block C: 75 g/tray, block D: 240 g/tray)

3.5 Germination count for improving plant establishment

Germination count was done to determine the suitability of the planting medium in relation to the growth and development of the rice seedling and its easiness in single removal. It was found that selected seeds soaked in distilled water had 99% germination potential; therefore they can be adopted in order to avoid missing hills during transplanting operation. Physical properties of 14 d SRI seedling showed that on the average, the transplanted seedling contained 2-3 numbers of leaves, stem thickness of 2 mm, stem length of 19mm and root length of 3.5 mm. Transplanting depth was measured and found to have a mean value of 3 mm. No significant difference was observed in the depth of transplanting among all the treatments due to the homogeneity of the soil throughout the two sites and equally receiving of land preparation practices. It was also found that the transplanter performance depended on seedling quality as well as the quality of the seedling mat media on which the seedlings were raised. It should be noted that seedling quality index is a factor of age, leaf stage, thickness at base high, growing density and lateral root length, while mat quality is a factor of media type, rapture strength, composition, moisture content and the degree of root entanglement.

One potential way of improving plant establishment is to develop seed treatments that can increase seed vigor or germination rates. The most common method employed is the seed priming. Seed priming is a controlled hydration process followed by re-drying that allows the seeds to imbibe water and begin the internal biological processes necessary for seed germination, but which also does not allow the seed to actually germinate. The priming process gives the seed what is called "*head-start*" at germination and emergence when planted in the soil. The method of priming as reported by Farooq et al.[78] aids in the improvement function of seeds as well as increasing quality of seeds at unfavorable environmental conditions. It is also reported that seeds priming improves seed germination in a range of environmental stresses, i.e. drought, salinity and temperature[79,80]. It should be noted that transplanting of young seedlings plays an important role in faster crop establishment by minimizing the transplanting shock, thus resulting in higher grain yield[71].

4 Conclusions and future work

This research provided a technical examination of the impacts of alternative transplanting approaches using a controlled experimental design in university-managed rice study plots at two sites in Malaysia. The goal of the paper was to inform good practices for the implementation of SRI-based rice cultivation practices using machine-based planting with alternative configurations. For this purpose we first provided a short review on how system of rice intensification contributes to producing higher rice yield with improved transplanting practices as well as producing a more effective root system. Field experiments were carried out to determine the effect of different seedling rates on various spacings (14 cm, 16 cm, 18 cm, 21 cm and 24 cm) on the performance of modified planting finger to single and double seedlings planting, using gear shift of position 3. The spacings were based on the Kubota SPU 68C transplanter settings. It was concluded that the transplanter performance was dependent on seedling quality as well as the quality of the seedling mat media on which the seedlings are raised. This can only be achieved through good seed selection to avoid missing hills and a good quality of rice husk that allows better distribution of roots. The research also introduces a new row planting pattern aimed at reducing seed rate requirements on the performance of the modified transplanter finger, with the overall aim of meeting the requirements of SRI guidelines in transplanting operation. It was found that over 70% of seeds could be saved, through reducing the plant population at same time boost plant performance and yield. Before the development of the planting finger, the physical properties of the MR219 rice seedling variety, commonly grown in Malaysia was determined i.e. stem thickness and root length and previous literatures to appropriate come-up with 9 mm planting finger. The row planting pattern tray was design to provide seedlings in a row mat for planting in paddy fields, best achieved through seeds cleaning and sorting. Statistical analysis showed the efficiency of the planting finger in SRI seedling planting requirement was at 75 g seeds/tray as the best option for the farmers. It was also concluded that 75 g seeds/tray manifested better in providing higher yield per hectare when compared to other treatments. This means farmers can conveniently use the modified planting finger SPU 68C Kubota transplanter for their field work to enhance their productivity from 3.7 t/hm^2 up to 9.3 t/hm^2 at planting spacing of 24 cm×30 cm, using 75 g of seeds per tray scattered pattern, instead of performing cultivation and crop establishment manually. The results of this research confirm the performance of SRI practices in raising grain yield, which is fact stating this was achieved with reduced water and lowering resources (which offers greater benefits for the farmers and the country at large scale).

The experiment can be employed to evaluate more rice cultivars with a view of comparing their performance to enhance granaries areas of rice production in different parts of Malaysia peninsula. Also the data collected from different parts of Malaysia will help assist commercial rice producers throughout the country on the management requirements of SRI i.e. nutrients and water application and control, land space, right age of seedling transplanting, morphological characteristics of young seedling and lastly the suitability of the modified planting finger (kukukambing) in meeting the requirements of SRI. Future research can be conducted to address the following questions of (i) the best age for seedlings to be transplanted using other modified transplanter and planting finger, (ii) the combination of other soil and other variety of rice plant characteristics, (iii) the expected response in terms of attainable yield and (iv) increase the yield of rice productivity in other major Asian rice producer countries in general and other Malaysian States in particular.

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