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An Overview of the System of Rice Intensification for Paddy Fields of Malaysia

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Abstract

Objectives: To present a general overview of rice agronomic practices and transplanting operations by considering the interactions of soil, plant, and machine relationship in line with the System of Rice Intensification (SRI) cultivation practice. **Methods:** Some of the problems challenging Malaysian rice growers, as well as yield increase and total rice production in the last four decades, were first addressed and discussed. The trend in the world rice production between 1961 and 2014 was used to predict the production in 2020 and to show that Southeast Asian countries are expected to increase their production by 27.2%. **Findings**: A consistently increasing pattern from 3.1 tons/ha during 1981 to 4.1 tons/ha in 2014 was observed in the rice yield of Malaysia due to the advances in technology and improved farming operations coupled with integrated management and control of resources. Various literatures were reviewed and their findings of the best transplanting practices were summarized to discuss how SRI contributes to the production of higher rice yield with improved transplanting practices through a more effective root system. Our review shows that wider spacing, availability of solar radiation, medium temperature, soil aeration, and nutrient supply promote shorter Phyllochrons which increase the number of tillers in rice. In this regard, modification and development of a transplanter that complies with SRI specification require determination of optimum transplanting spacing, seed rate, and planting pattern to significantly improve yield. **Improvement:** It was concluded that for maximum yield, the SRI method in Malaysia should emphasize on planting of one seedling per hill with space of 0.25 m for optimum water consumption, nutrient and pest management.

Keywords: Nursery Management, Paddy, Seedling, System of Rice Intensification, Transplanting

1. Introduction

Asian Rice (*Oryza sativa*) is one of the most widely and leading cultivated cereal in the world, second to wheat in its annual contribution to food consumption[1]. It is a strategic crop for many Asian countries and is sometimes referred to as the "wonder cereal", commanding respect and recognition because of being a staple food for more than half the ethnic groups around the world. Rice is also a superior food commodity to mankind, ranked as life, culture, tradition, and means of livelihood for millions of people. Its cultivation requires a temperate climate, rainfall between 120 and 140 mm, temperature between 21 and 37 °C, and a heavy to sandy loam soil. It is planted in different ecological regions with diverse production potentials, mostly as the main source of food for Asian and southeast Asian countries including Malaysia. The total world production of rice in 2014 was 740.955973 million tons[2], of which Asian countries contributed 90% (667.258311 million tons). Major Rice producer countries in 2014 and their shared percentage of world production were China (28.1%), India (21.22%), Vietnam (6.07%), Thailand (4.4%), Pakistan (5.13%), and the United States (1.35%), with Malaysia contributing as low as 0.36% (Figure 1).

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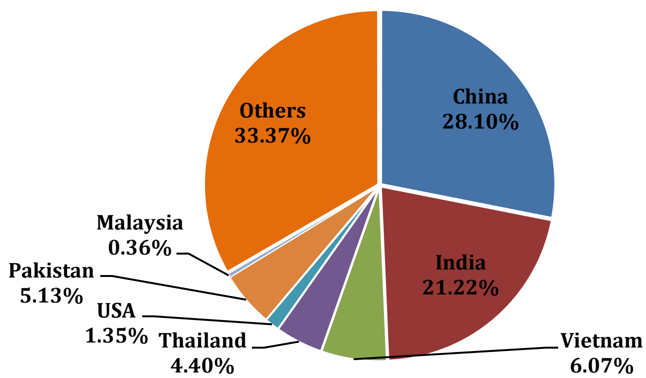

Figure 1. Comparison between total rice production in Malaysia with respect to the six major producer countries and the rest of the world. Source of data: FAO, 2015.

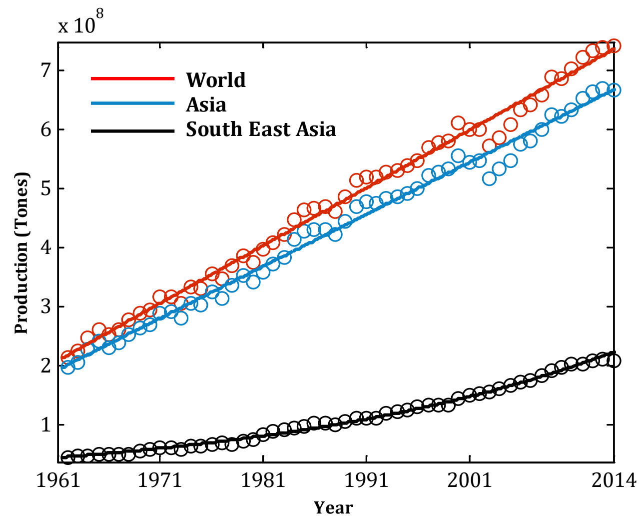

Figure 2. Total world production of rice, between 1961 and 2014, the trend predicts 7% increase for 2020.

The increasing world population calls for more research and technological advancement to increase rice production for consumption in different countries. Yield and qualities of rice have an increasingly higher demand on daily basis due to population expansion. This however necessitates practicing of more production through user and environmentally friendly modern technologies in different field of rice production management in order to produce higher yield at the lowest production cost, and at the same time keeping production competitive through mechanization and automation. The trend in world rice production between 1961 and 2014 Figure 2 predicts that in 2020, total world production will be increased by 7% and reach to 792.84 million tons. Southeast Asian countries are therefore expected to increase their production by 27.2%. Such demand calls for new methods and improvement of current cultivation techniques. Currently, main production constraints are the lack of sound integrated management principles in labor, land, water, crop, and inputs (including seeds, and fertilizer) and the required plant population. Plant population in manual labor is very low and decreases yield. In addition, due to the shortage of labor, transplanting is sometimes delayed, resulting in a progressive yield decline. Different attempts have been made in many countries, with Japan the first to develop a mechanical paddy transplanter that reduces workload from 15 to 30 man-days per hectare[3].

The System of Rice Intensification (SRI) was introduced to increase rice production through the exploitation of genetic capability, creating a favorable environment, improving soil condition, reducing production inputs (seeds, labor, and water) and alleviating the suffering of rural dwellers[4]. SRI is entirely different compared to most agricultural innovations in the sense that farmers willingly spare their resources, time and alliance among the diverse cultures and organizations to disseminate and adjust the farming methodology as recommended by[5,6]. It should be noted that these recommendations are based on the extensive research that was conducted for 34 years with rice farmers in Madagascar. The study focused on the existence and development of rice transplanting machines which led to a great deviation in varieties, outcomes, and labor. Several machines have been studies for their suitability in the cultivation of paddy, ranging from land preparation, seeding, transplanting of seedlings, weeding, fertigation practices and crop husbandry operations to comply with SRI specifications. A semi-automated water-wheeled transplant was designed and developed in Punjab, India[7], but up to this date, there is no fully automated paddy transplanter for SRI. As a result, there is the need to modify the existing transplanter to transplant seedlings at recommended quantity, spacing, moisture content, and age to meet the specified guidelines of SRI. The objective of this paper is to presents a general overview of relevant literature on rice agronomic practices and transplanting operations, by considering the interactions of soil, plant, and machine relationship in line with SRI cultivation practice.

2. Rice Production in Malaysia

Malaysia has a total of 7.839 million hectares of agricultural land of which 8.5% (671679 ha) was under rice cultivation in[2]. Rice is a crucial part of everyday Malaysian meals, consuming about 82.3 kilograms per annum on the average. In 2013, Malaysia produced about 2,603,654 tons of rice. Figure 3 shows a simple analysis of rice production in Malaysia between 1961 and 2014. Plots of yield, harvested area, total production, and import/export quantity reflect the extent of mechanization and improvement in the farming operations as a result of innovations in operations and government support. It can be observed that both yield and production experienced a series of rises and falls between 1961 and 2000. With small margin, the patterns however show a consistent increase due to advances in technology and improved farming operations coupled with integrated management and control of resources without necessarily increasing land area under cultivation. The hectares of land for paddy rice has been relatively stable around 0.7 million hectares since 1980's, but despite the unchanging condition of the land, yield continued to increase yearly from 3.1 tons/ha during 1981 to 4.1 tons/ha in 2014. These statistics show that the country has been able to satisfy 65.8% of its huge demand at best, and therefore, an additional 889,820 tons were imported in[2]. Some of the problems challenging Malaysian growers include stagnation and declining yield in some growing areas, operational holding-size shrinkage, land and water resources that are becoming degraded, minor diseases resulting in over-dosage and increased usage of pesticides, shifting from transplanting of seedlings to direct seeding due to labor and water constraints, putting considerable stress on sustainability of rice production resulting from infestation of weeds as well as incidence of disease outbreaks. Plant population in manual labor is very low and yield decreasing. Transplanting delays due to labor shortage result in a progressive decrease in yield.

A comparison between rice production in Malaysia and 6 major producer countries during 2012 to 20114 is provided in Figure 4. The government policies that affected rice production industry in Malaysian were the second Outline Perspective Plan 1991 to 2000 (OPP2) and the National Agricultural Policy 1992 to 2010 (NAP) as discussed in[8]. The OPP2 stated that the agricultural sector had to compete for various resources with other

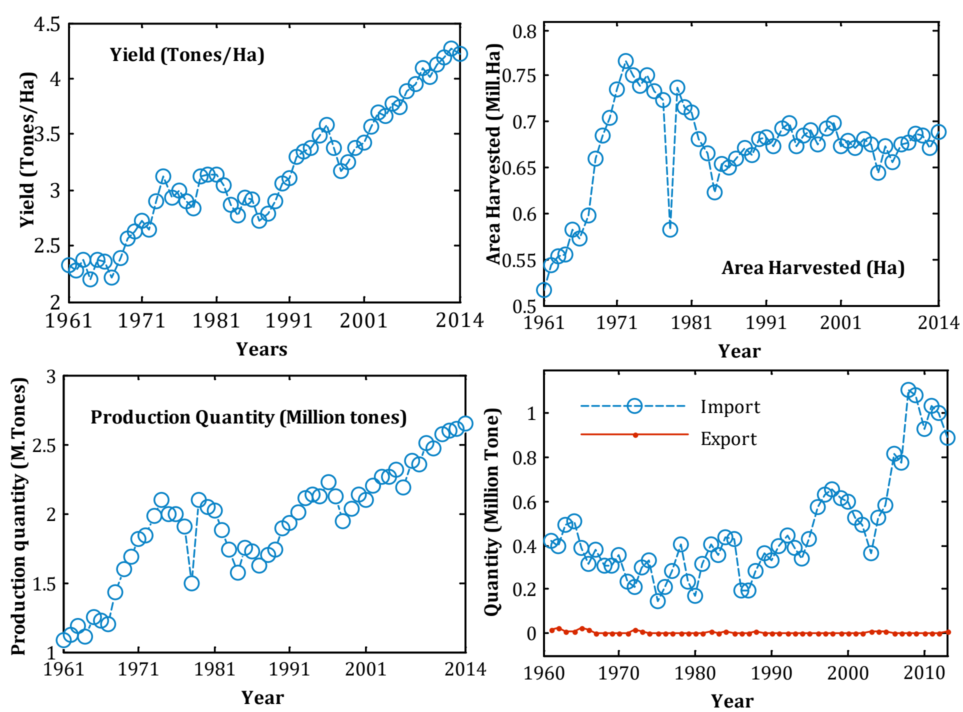

Figure 3. Total rice yield, harvested area, production and import/export quantity in Malaysia between 1961 and 2014. Source of data: FAO, 2015

higher growing sectors like manufacturing and services industries. In 1992, the NAP targeted rice production in Malaysia to achieve self-sufficiency level of 65%. It went on to state that, the level of production should be met in the eight granary areas with a combine paddy area of 28,500 hectares. These granary areas included Muda Agricultural Development Authority (MADA) in Kedah, Kemubu Agricultural Development Authority (KADA) in Kelantan, Integrated Agricultural Development Project (IADP) Kerian/Sungai Manik in Perak, IADP Barat Laut Selangor, IADP Pulau Pinang in Penang, Seberang in Perak, IADP Kemasin-Semerak in Kelantan and Project Pembangunan Pertanian Terengganu Utara (KETARA) in Terengganu, with MADA having the largest area of about 97000 ha while KETARA had the smallest area of 100 ha[9]. The main irrigation sites were situated at Muda and Kemubu with a higher level of mechanization practiced. In these places, increasing crop yield is the major concern for all stakeholders (local paddy and government growers) through the introduction of new cultivars, changing of land preparation activities from manual labor to utilization of tractors or machines in operations, i.e. type and amount of fertilizer and pesticide usage, the cycle and the intensity and frequency of cycles. In 1984, rice farmers changed to a direct seeding system of transplanting with more than 90% participating in the lowland cultivation of the crop. Shortly after these programs, reports indicate that changing from the old system of seeding to improved pattern in Beranang resulted greatly in more yield and farmers income[10]. Although there was little or no fertiliza-

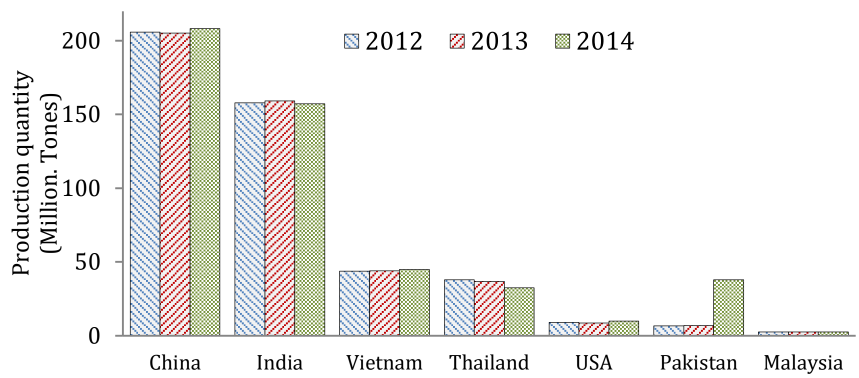

Figure 4. A comparison between Malaysia and the six major Rice producer countries between 2012 and 2014. Source of data: FAO, 2015.

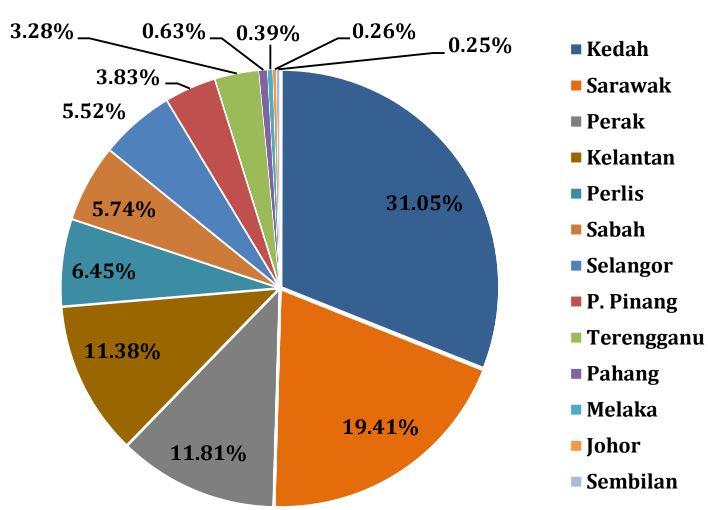

Figure 5. Rice-harvested areas in different states of Malaysia, Source of data: Malaysia Agriculture, (2012).

tion of field in some parts of Sabah and Sarawak (because of farmers practicing a system called slash-and-burn shifting cultivation), while yields rose significantly from the year 1985 to 1999, there was a shortfall in yield during 2000 season (Table 1). In addition, during the same period, Kedah and Sembilan respectively had the highest (31.0%) and lowest (0.25%) of the total harvested areas as shown in Figure 5. Tractorization program was promoted by the government during the years of 1985 through 2000, and immensely raised irrigated agricultural land. Within the SRI conceptual and practical framework, yield increase was witnessed by farmers and verified by researchers. SRI crops are highly resistance to the majority of pest and diseases and are better adaptable to tolerate adverse climatic fluctuations such as storms, drought, hot spells or cold snaps, resulting in a decrease in the crop cycle, leading to higher yield[11].

3. SRI as a Break-through Production System

SRI was initiated in 1983 in Madagascar by[5,6] and has been promoted in rice growing countries with the help of SRI International Network and Resource Center at the Cornell University (http://sri.cals.cornell.edu). The method involves a labor intensive operation by selecting young seedlings and singly spacing them in low water. SRI is an agricultural innovation, it cannot be claimed, owned or monopolized and does not have an intellectual barrier to its adoption as it is seen in other sectors such as new improved seeds, chemicals, and farm machineries. Currently, about 500,000 farmers in more than 20 countries are participating extensively in the SRI program using its technical know-how which is changing and raising their rice production, and at the same time reducing utilization of limited resources such as water, labor, land, and finance. Within its initial concepts, SRI farmers have advanced many techniques aimed at enhancing their production potential of changing the system to suit their conveniences and farming conditions. Several technical reviews of SRI, improvements, and discussion about water management, productivity and other research issues can be found in[3,12–14].

SRI has proven to provide farmers with the several impacts in comparison with their conventional or traditional system of paddy rice cultivation. Rice yield is increased from a minimum of 20% to 50% and up to 200% depending on the initial input (there are less unfilled grains), with production cost reducing between 10 and 20% (depending on the farmer's input-intensity of the current production). For instance, reports in Ghana[11] indicate that, the averaged conventional yield versus SRI yield was 2.3 to 7.1 tons/ha, with maximum yield using SRI raising up to 8.8 tons/ha, recording an overall yield increase of 209%. Water requirements drastically reduce saving about 25 to 50% of the conventional practice because the field is not flooded. The system does not involve purchase of inputs (i.e. new variety of seeds or chemical fertilizer). SRI shortens growing crop cycle by about 5 to 10 days.

SRI began by collecting and analyzing age-old cultural operations of paddy rice cultivation techniques, which were later modified in Madagascar[6]. These modifications involves six procedures including (i) the use of young seedlings, (ii) avoiding damage to the roots, (iii) giving the plants wider spacing, (iv) creating an aerobic soil con-

Table 1. Rice Production Parameters (1980-2013)

Parameter	1980	1985	1990	1995	2000	2005	2010	2013
Harvested Area (Ha)	716800	654974	680647	672787	698700	676200	677884	671679
Yield (Ton/Ha)	3.14	2.94	3.05	3.49	3.38	3.77	4.01	4.27
Production (Tons)	2044604	1745367	1884984	2127271	2140800	2314000	2464830	2603654
Seed (Tons)	20619	18875	19826	19879	19534	18705	19938	19958
Import quantity (Tons)	167593	428017	330336	427556	595581	583654	930583	889820
Import Value	59537	103474	99739	141995	181585	182598	500369	503580
Export Quantity (Tons)	200	2002	106	2422	103	5387	413	10762
Export Value (1000 USD)	23	672	43	771	60	1183	396	6662

Source of data: FAO, 2015

dition, (v) enhancing soil organic matter content, and (vi) keeping the paddy field area adequately moist. The first three procedures contribute to the stimulation of plants, overall growth and development initiative, while the latter aids in improving the rooting systems and the soil nutrients fixation capability. If a farmer is using direct seeding then one plant per hill per square meter is ideal, if however, the plant is to be established by seedling transplanting, it is recommended to use 8 and 12 days old and lastly 15 days before the seedling starts the 4^{th} Phyllochron. Transplanting of the seedling should be done quickly and carefully in a shallow depth of 1 to 2 cm within 30 minutes after removal from nursery bed to avoid transplanting shock. Wider spacing plays a vital role in roots growth and development, as well as providing ample space for the canopy to absorb sunlight for photosynthesis, which also helps in tillering (both 25 by 25 cm and 20 by 20 cm have been found to give higher yields). To create an aerobic soil condition, the soil does not need to be flooded, (i.e. saturated soil culture). The idea is to avoid suffocation and death of plant roots while supporting the population of soil micro-flora and fauna. Soil organic matter content can be enhanced using locally made compost from rice straw, and by adding mulch and manure to improve the soil fertility of poor soils. Keeping the paddy field area adequately moist is also known as alternate wetting and drying (AWD), which provide water requirements of the crop but not continuously flooded. The mentioned parameters play a significant role in conservative agriculture which SRI program benefited from. It should be noted that several practices that are involved in SRI were known and implemented by early paddy farmers in Japan after the World War II[15]. Therefore, SRI program per say was not a creation or discovery of something new but only a collection and synthesis of old practices that utilize the productive capabilities inherent in the genome of paddy rice because they prove to provide a conducive and a better performance of different grass family.

The most apparent signs of plant growth in line with SRI management include (i) advanced tillering potential of the seedlings which manifest itself after a month of transplanting, (ii) bigger and more grain panicles, not always associated with grain weight, (iii) a living soil composing of fauna and flora, and (iv) a robust and healthier rooting system. The first two features are visible and can be assessed and quantified by naked eyes. The last sign can also be observed directly by the farmer and researcher when the plant is uprooted for examination, however, the third and the most important factor cannot be observed and measured without proper instrumentation. Agronomic practices involved in rice production as set aside by SRI include (i) land preparation, (ii) nursery management practice, (iii) seed selection and priming, (iv) soil solarization, and (v) soil enrichment with micro-organisms. Land preparation is performed in the same way as the conventional methods, with the only difference in the degree of land leveling requirement, so that the water introduced into the field can be evenly distributed to all areas, while drainage needs to be managed in areas of higher rainfall. Appropriates leveling prevents furrows and ripples resulting from the difference in water level to avert seedling tumbling and floating. For the nursery management practice, the seedlings should be raised on suitable garden-like (i.e., raised beds), boxes or paper mat to help facilitate the growth and development of the rooting system[16]. Seed selection and priming involve salt-water solution used to separate healthy and vigorous seeds from weaker ones, which was found beneficial in improving output by 10 to 20%. Soil solarization is a process of soil pathogens annihilation, to manage soil micro-organism. Soil enrichment with micro-organisms is a practice to improve and activate micro-organism activities in the soil leading to the formation of more nutrients and minerals. Some paddy cultivators use the commercially available or home-made 'Indigenous Micro-Organisms' (IMO) to improve the soil nutrient contents[17].

Seedlings age at the time of transplanting plays an important role, by determining the growth, as well as the yield output[5]. Younger seedlings for transplanting of rice plant aids higher total numbers of tillers and leaf, bigger leaf area and leaf area per shoot as well as leaf lamina favoring greater height. Rice seedling rate of establishment is a function of four important parameters; the environment where the seedling is kept, the manner of seedling metering techniques, the pattern of placement into soil horizon, and the time it takes before transplanting to the permanent field. The intra and inter-row spacing in-between plants are basic requirements to ensure seedlings grow better and help to avert the problems of lodging and weed management. This allows for easier operation, providing a good atmosphere for seedling survival free of competition for sunlight, water, nutrients, space and mineral salts. Depth of planting also plays a significant role in the seedling survival and its subsequent development by favoring greater leaf area per shoot and per leaf lamina and greater tiller number and reduce the percentage tiller mortality.

The SRI planting method suggests 1 to 3 cm depth, taking care not to invert seedlings root tips when transplanting. The right cohesiveness of soil will cover the root firmly in the soil. The right soil is one that is sufficiently moist rather than continuously flooded to avoid sticking of planting claw with mud.

The total grain weight compared with transplanting of the older seedling of higher ages result in vigor seedling, utilizing their potentials in root structure to absorb nutrients because of little or less damage occurred during uprooting process. This is while older seedlings need to use their carbohydrates to repair damaged root tissues before it continues to grow. The effects of SRI, as observed in different parts of the world, is not only on grain yield, but also the growing plant itself in terms of the significant difference in phenotype and its tillering potential, which is between 30 to 50 and up to 80 or even more. Equally-vigorous root growth is also resulted because plants are planted individually in a wider space, which reduces the seed rate to 5 to 10 kg/ha compared to farmer's conventional system of 40 kg/ha, or 100 kg/ha as in direct seeding. With the reduction in seeds and water, maximum utilization of soil microorganisms, and an increase of 50 to 100% yield gain, farmers' profits are improved.

SRI also reduces water cost requirement on paddy fields since soil is not continuously flooded but rather kept moist or alternatively wet and dry, reducing the quantity of water from 25% (sometimes reaching up to 50%), providing a suitable environment for root development and growth, producing robust stalks, and improving soil health through microbial activities. SRI shortens paddy rice production cycle by 10 days or more leading to a reduction in production cost. Indeed, SRI paves the way to profitability by reducing external input cost that allows farmers to utilize locally and readily available organic materials (like animal manure, straw, and leaves) in the preparation of compost rather than purchasing expensive inorganic fertilizers. The problem associated with lodging due to water (rain and irrigated water) is also eliminated through SRI.

4. SRI in Malaysia

SRI started relatively late in Malaysia compared to its counterparts Asian countries. The system emerged from the government to Universities, then to private organizations and business owner. Between 1980 and 2009, paddy yields in Malaysia almost doubled growing from 1.85 to 3.68 tons/ha. This raised the country's rice input from 167,000 tons to 1.07 million tons showing a population increase and a higher per capita income as a result of shifting from 1.5 to 2.4 million tons, with a domestic supply increase from 1.3 million tons in 1980 to 1.6 million tons in 2010. Major limiting factor in utilizing SRI in Malaysia is the labor force requirement in different farm operations such as raising of seedlings delicately in a protective nursery, accurate transplanting of young seedlings (8 to 15 days old) at wider spacing starting from 25 by 25cm to 50 by 50 cm, intermittent irrigation to avoid flooding during the vegetative growth, field leveling to distribute the limited water, and the intensive manual or mechanical weeding. Nevertheless, if these operations could be entirely replaced by the machine, it would be economically feasible to adopt SRI due to its high yielding potentials and efficiency.

Seedlings transplanting is the first step taken by SRI towards rice intensification program aimed at increasing output per hectare. When early Malaysian farmers started planting tiny and feeble seedlings, they were concerned until a month later, when plants began to grow vigorously and tiller prosperously. Based on data survey conducted with Malaysian paddy farmers, they are willing and ready to shift from manual transplanting methods to automated systems. It is in fact very rare to see Malaysian farmers involved in the manual transplanting of paddy seedlings without hiring immigrant labors. This makes it necessary for research in single seedling transplanter to meet the farmers demand and aspirations. On the financial viewpoint of comparison, SRI was found to have an operational cost of about RM531.10 per acre, while the traditional or conventional system brings RM462.60 per acre, however, SRI reduces water consumption to the least minimum.

Some of the features that make SRI a much better option for sustaining agricultural productivity in Malaysia in comparison with other innovative technology can be stated as follow: (i) most of the existing innovations are demanding "thirsty" technology, whereas SRI aimed at reducing water requirements, making less cost in water demand for rice cultivation, (ii) majority of innovation rely on purchase of inputs which are derived from petrochemical origin, SRI on the other hand reduces dependency which plays a significant role in demand and supply of other commodity (i.e., petroleum is more strained in the near future), and (iii) most of the technologies today are reducing biodiversity while SRI is making a greater biodiversity in paddy rice sector and creates a more profitable venture.

5. Methods of Rice Planting

In most parts of the world, rice is cultivated through transplanting of the seedlings on puddle soils, with 90% or more of their cultivated area being transplanted. This practice has a lot of setbacks such as increasing water percolation losses, destroying the soil aggregates which lead to reduced permeability in sub soil and hard pans at small depth. There are two ways through which paddy rice is planted based on location and climatic variation; transplanting, and direct seedling rice (DSR). The transplanting method is normally practiced on lowland rice cultivation where the crop is flooded so that paddy root could utilize the nutrient content of the soil. Firstly farmers raise the seedlings in a protected nursery bed or greenhouse where a good condition is provided before transplanting in the main field. Alternatively, planting the seeds directly using broadcasting, seed drilling or dibbling method for the already leveled field after which it is flooded by either irrigation or rain water. In areas where moisture and rain are the limiting factors, water upland rice cultivation is practiced on soil with roots penetrating to absorb available nutrients. Some of the major benefits of the transplanting operation can be summarized as (i) assisting in extending the growing season by growing the plants indoors before outdoor conditions become favorable for their growth and development (i.e., hot spill, fog, and snow), (ii) reducing problems associated with germination by setting out seedlings that have grown to certain stage rather than direct seeding, and (iii) protecting the young seedling from the infestation, pest and diseases attacks until they are sufficiently established. Reports indicate that transplanted rice increased all of the growth and yield attributes of rice over direct seeding[18,19]. The DSR method is classified as wet or dry-seeded rice. In wet-DSR, the germinating seeds are manually scattered evenly on rice fields, using broadcasters or by hand, whereas in dry-DSR, the seedlings are first soaked for 24 hours in a solution containing Topsin M at 2.5 g/kg seed prior to broadcasting operation.

5.1 Manual Transplanting

Manual transplanting is an age long system of paddy rice transplanting, and is characterized as less costly operation because it does not require employment of heavy machines. It is most suitable in areas with available surplus labor or small fields. In manual transplanting, seedlings are individually transplanted one at a time by hand. Major issues are the cumbersome labor operation (labors bending fatigue which leads to spinal cord health hazard), lower area coverage, and non-uniformity in quantity and spacing. The operation involves holding of seedlings in one hand and using the other hand to remove the seedlings and fix it to the soil in bending posture. It is a tedious operation with labor requirement of about 200-250 man/hr/ha[3]. In another study, labor requirement in hand transplanting in the Philippines revealed between 80 and 160 man/hr/ha, which is 26 to 53 times more than the labor required in broadcasting[20]. Total labor requirement for rice cultivation of one hectare is reported 156 man days, of which 46 man days were consumed in raising seedlings and transplanting, involving 28.48% of the total labor requirements. Studies on human energy input for different tasks in rice production revealed that hand transplanting had the highest energy requirements (17937.25 k-Cal/ha) with the high energy input due to the high labor demand in hand transplanting crop culture[21]. The only available solution to manual operation lies in shifting to automated mechanical transplanters with engines usually mounted at the rear end of the planter.

5.2 Automated Transplanter

The application of mechanical seedling transplanting dates back as far as 1955 in Taiwan, where gravity hand operated machine was designed and fabricated. China invention came in 1956 with the manufacturing of six rows transplanter doubling the efficiency of human labor. These machines were neglected due to the constraints associated with uneven placement of seedlings (missing hills) and the associate intensive laborious operation. Machine transplanters considerably take less time and labor compared to manual operation and increase area coverage per person from 700 to 10,000 square meters per day.

Researchers have made different approaches in tackling the guidelines and principles of SRI requirements in order to design and build a successful transplanting machine by considering several factors, including (i) planting of seeds in the greenhouse or seed bed trays in the nursery, (ii) gentle removal of the seedling on seed bed free of soil clusters, (iii) storage of the single seedlings on the transplanter carrier, (iv) feeding of seedlings to the planting mechanism one at a time, (v) opening of hole or furrow for placement and implanting of seedling, and (vi) closing and firming of seedling after implanting. An example of such efforts includes a mechanized "semi-automated" water-wheeled transplanting machine that was designed and developed in Punjab, India[7]. Another example of a modern cultivation approach is an unmanned aerial vehicle for rice air broadcasting that was designed and tested in China[22]. A novel approach was also introduced in the form of a precise pneumatic rice seed metering device with sucking hole-plates through which 3 to 4 seeds can be synchronously sucked and dropped into the paddy field to meet the agronomy demand for hybrid rice direct seeding[23].

Japan was the first country to develop a unit called rice transplanter whose patent was obtained as early as 1898, thereafter development effort proceeds in[24]. In 1965 a transplanter using washed seedling came into commercial production and a year later another transplanter that used mat type of seedling emerges subsequently. Researchers worked on the aspects of developing methodological automated rice transplanter that could be guided by global positioning and inertia measurement using the controller area network bus[25]. This automated transplanter was designed to turn at the headland of rice field and move to the next desired path, improving the timeliness of operation and reliability, as well as being suitable in areas of shortage manpower during peak periods of labor demand. Another study formulated the relationship between steering angle and turning radius of a four-wheeled transplanter working at different speeds in flooded paddy fields in circular pattern[26]. Their result showed that the experimental values varied greatly from theoretical values.

During 2000's, automated steering systems of machine transplanting units became operational, although the image-processing computers were still considered very expensive. The software was unable to handle diverse climatic conditions. This resulted to obsolesce in trend and therefore a need for advanced research on the conventional elementary steering system. Development of continuous feed and synchronous cave hole-alignment precision transplanter using electromagnetic directional valve as well as a pneumatic cylinder is addressed in[27]. It was proven that adopting the two alignment aid in minimizing of labor requirements improves the seedling transplanting quality and ensures orientation of precision in the placement of seedlings, paving way for further researchers in paddy precision seedling. In 2012, The Agri-Equipment Division of Hayleys Agriculture Holdings Ltd (Hayleys Agro Products Limited, Colombo, Sri Lanka) demonstrated the first trials on Kubota mechanized rice transplanter model NSP-4W that can cover one hectare per day with labor requirement of only two persons (Figure 6). It was shown that compared to the traditional broadcasting method, yield was increased by 10-20% as a result of higher tillering per hill (20-25). Results also proved that utilization of mechanized transplanting and right nursery management leads to as much as 50% saving on seed paddy.

Figure 6. Demonstration Hayleys trials with Kubota NSP-4W mechanized rice transplanter.

Source: http://www.hayleysagriculture.com/

Researchers studied non-rice stubble bed for planting seedlings which favor less soil pulverization and stronger ability to penetrate the soil, resulting in plant cohesion, water absorption and nutrient uptake potential of seedlings[28]. This idea proves feasible, reliable and the efficiency of operations, i.e., trenching, seeding meeting the agronomic requirements of rice and hence the expected result (higher yields). Another study was contributed to the development of software theory model adopting optimization algorithm in mechanical design to various applications in transplanting mechanism and other machinery of theoretical analysis and the design of new products[29]. This software aided tremendously in today's automated transplanter designs, another step toward paddy cultivation break through. A motorized modification of rice transplanter capable of planting seedlings at 20 by 20cm intervals is introduced in[30]. This machine is simple in construction and easy to operate, repair, and manage the maintenance service, with spare parts within the reach of the farmers. A 6-row automated transplanter was designed and demonstrated by Yanmar Corporation manufacturing company (Osaka, Japan) which had a base wheel of PV14 utilizing the principle of RTKPS, to detect the position of transplanter while FOG measures the angle as well as the inclination of heading. Compared with the existing transplanters of its time, Yanmar transplanter wheel base was bigger, resulting in a higher turning radius, spending more time at row ends. Consequently, in 2002, the wheel was removed and replaced with smaller wheelbase PH6 by a transplanter manufacturing company, Iseki Corporation (Matsuyama, Japan)[31]. A single computer was then used to process the data and controlling the actuators. In 2004 the controlling unit was also changed to Programmable Logic Controller.

6. Classification of Paddy Transplanter

Transplanters are broadly classified based on two parameters, type of nursery requirements, and prime mover. On the basis of nursery requirements, two types are identified, washed seedlings, and mat-type on polythene sheet. In washed seedling, transplanters use washed roots seedling on mat that has 4 to 6 leaves appearance. About 20 to 30 cm long seedlings are washed thoroughly at the time of transplanting. If roots have overgrown, they are pruned to facilitate easier transplanting operation. This requires about 175 people per hour per hectare. In mat-type on polythene sheet, the seedlings are raised on a mixed soil sample with known quantity of nutrient additives followed later by sprinkling pre-germinated seeds on the soil thickness of 1.5 to 2.0cm and then allowed to grow for a period of between 20 to 25 days in the nursery before uprooting for transplanting in the permanent site. The method is the most preferred because it requires less labor of about 50 workers in an hour per days' work[3].

Prime mover transplanters are classified as manual, animal drawn, power tillers, tractor mounted, and self-propelled. Manual or hand-operated traditional transplanter was designed to imitate manual system, using one hand to operate the transplanter while the other hand propels the transplanter forward. The number of transplanting rows varies from 2 to 6. Figure 7(A) shows a six-row transplanter that uses mat raised seedlings. It consists of a main frame to house the seedling tray as well as mat movement mechanism, two wooden floats, picker arrangement and handle. The machine weighs almost 20 kg with row spacing of 20 by 20 cm between plants and is adjustable to suite conveniences of the working conditions. While in operation, the handle is pulled back to retract planting fingers, and at the same time propelled the machine forward. The machine output is about 0.4 ha/day and it saves about 45% production cost and 50% labor requirements[32].

Power tillers such as KPP315 series possess two-lines and single wheel powered by gasoline engine which provide efficient working durability and capability. Weighing

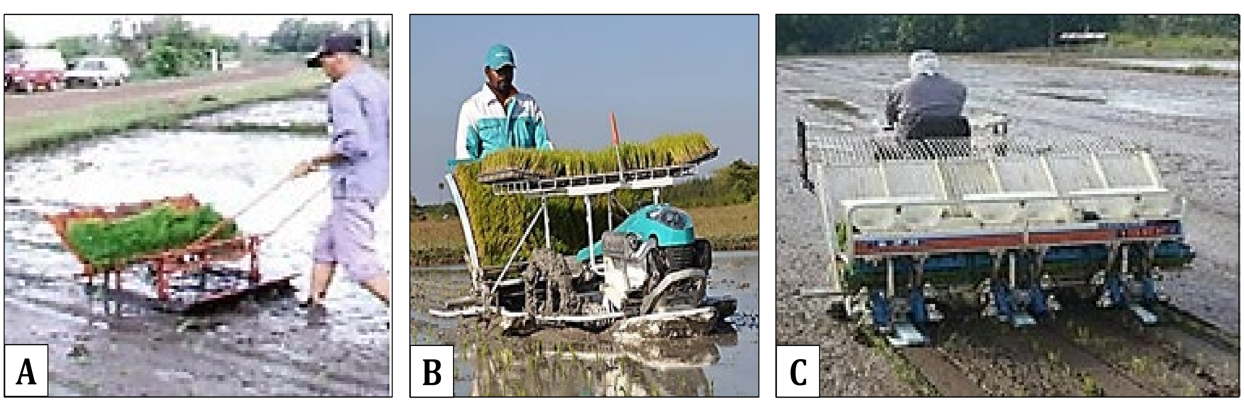

Figure 7. Different transplanting system, A: Manual, B: Self-propelled walk behind transplanter and C: Chinese self-propelled transplanter.

Source: www.kubota.global.net/english

about 70kg, the main advantages are easily transferable from one paddy ridge to slope, adequate row spacing to accommodate plants requirements and favoring root transplanting stability. It increases production up to 25%, a hydraulic facility that helps to facilitate wet land operation and a provision of a pump to clean the machine after operation. Tractor mounted transplanters have a capacity of 6 to 10 rows transplanting width, and are powered by 25 hp tractor engine via the power take-up shaft connected to an arrangement of linking mechanism of pulley or belts. Provisions are made at tractor rear wheel of the transplanter to remove soil in puddle soil condition in order to facilitate smoother operation. Its major constrains are poor quality of work in undulated fields (about 50% missing hills has been recorded).

Self-propelled transplanters are available in two models, Japanese and Chinese, for mat-seedling and washed-seedlings. The Japanese model, known as "walk behind type" transplanter Figure 7(B), consists of components such as engine unit, drive wheel, planting claw, float, power transmission train, planting members, depth adjustment lever, and seedling platform. It is powered by a 1.7 hp gasoline engine, weighing about 60 to 70 kilogram and a width spacing of 30 cm with inter plant spacing of 13 to 18 cm. Its mechanical efficiency is 0.6 ha/day at speed of 2.0 km/hr. It's complicated actuating claw arrangement is considered as a major drawback. The Chinese model shown in Figure 7(C) utilizes washed seedlings; however it can be used with mat type seedling as well after minor modifications. The machine parameters are 8-row planting capacity, 22.5 cm width spacing with hill space of 15 to 20 cm, weighing about 280 kg. Major components include engine unit, main body, transmission system, transplanting mechanism, and float. Its engine provides traction power to the wheel as well as the transplanting system via a universal shaft. The spring arrangement is made at the transmission to provide safety in different field environmental condition. The movement of the claw is set to slide rollers mounted on the planting levers. The machine can cover an area of 0.15 to 0.20 ha/hr at a working speed of 1.08 to 1.3 km/hr, transplanting seedlings at 2 to 4 per hill, reducing 40% of the cost and 70% labor requirement compared with the traditional system. Simple and easy to operate, conforming ground undulation, and lastly better management of the crop are some of the advantages to be mentioned.

In 2005 Kubota (Kubota Corporation, Osaka, Japan) introduced a programmable transplanter model NSPU-68C (Figure 8), with motor sensors, 3CCD camera, and computer, used to sense RGB images and interprets the signals into graphical signs for the operator to determine seedling row locations as well as calculating the angle and movement. The motor steers the transplant in accordance with its angle, working velocity and displacement, but its limitation is the deviation of row angle. The seedling tray provides a smooth sliding flow of the young growing seedlings raised on a thin, poorly grown and soft nursery bed while a rod guides its downward movement against tumbling and missing during transplanting operations. The nursery tray is made of plastic, with dimensions of 40 by 19 by 3 cm depth. Bottom of the tray is perforated. A planting claw is employed to move young seedling from the seed mat into the soil horizon via the feeding members.

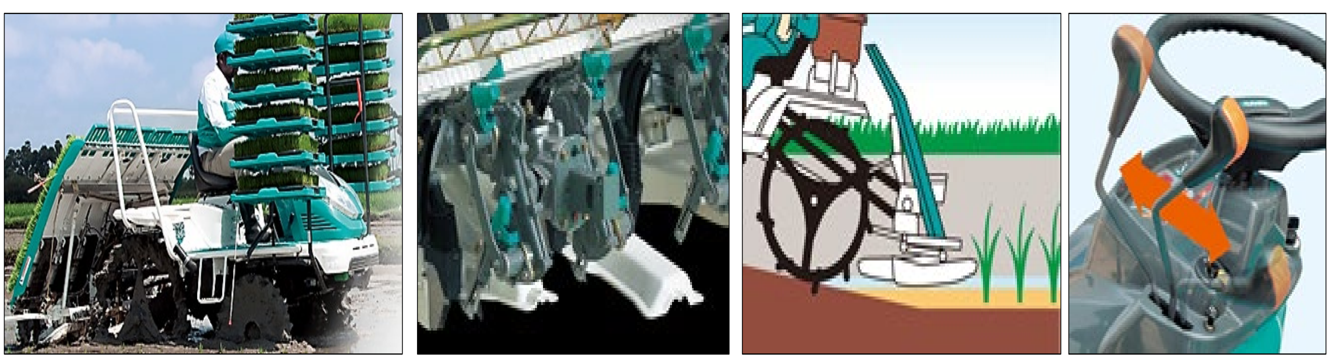

Figure 8. Technical specifications of Kubota NSPU-68C Transplanter, demonstrating planting claw, adjustable transplanting, and transplanter control knobs.

Source: www.kubota.co.jp

7. Optimum Transplanting Practices

Transplanting, as well as high and low temperature, creates a certain degree of stress, by which the rate of Phyllochron development after transplanting would be depressed[8,33]. Rice plants experience shorter Phyllochrons and increasing number of tillers when seedlings of less than 12 days (two-leaf stage) are transplanted[34]. In contrast, the absence of transplanting shock with 7 to 21 days old seedlings has been reported[35]. Research results indicate that optimum rice performance is obtained from properly transplanting spacing[36–38]. In general, rice yield can be significantly augmented through improved cultural practices, control of inputs (i.e., water, fertilizer and chemicals), timely planting, proper nursery and appropriate transplanting adjustments for the best tillering. Rice cultivation also depends on temperature and humidity, solar radiation, soil moisture content and fertility, and nutrient requirements. Since these parameters can be affected by dense planting population, it is necessary to determine optimum transplanting spacing for maximum yield. Various effects of plant spacing on growth and yield of rice have been addressed in[34,37–48]. 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[49]. The seedling quality index is a factor of age, leaf stage, thickness at base high, growing density and lateral root length. Mat quality is a factor of media type, composition, rapture strength, moisture content and lastly the degree of root entanglement.

Correct plant spacing contributes to both aerial and underground plant development by eliminating plants competition for light and nutrients, consequently improving vegetative growth and increasing grain yield. Results of studying the effect of three hill spacings (0.10m×0.15m, 0.2m ×0.15m and 0.3m ×0.15m) on productivity and quality of rice CV "Giza 177" showed that hill spacing of 0.2m ×0.15m gives the highest grain yield per hectare, harvest index, 1000-grain weight and panicle length as well as milling, head rice percentage, and protein content[43]. In another study for effects of plant spacing on the productivity of rice[41], it was found that narrower spacing of 0.2m×0.15m, compared with wider spacing of 0.2m×0.2m and 0.2m×0.25m set the highest values of leaf area index, plant height, and number of panicles per square meter, grain and straw yields, and the number of days to heading. It was also reported that both wider spacings of 0.2m×0.2m and 0.2m×0.25m recorded the highest values for the number of filled grains per panicle, panicle weight and length, and 1000 grain weight[41]. More effects of planting density on agronomical characteristics of rice can be found in[50–55].

Studying the effects of row spacing on canopy structure and yield in different plant type rice cultivars showed that the percentage of productive tiller reduced first, and then increased with increasing of row-spacing[56]. A quadratic regression between row spacing and the percentage of productive tiller fitted was observed by[56]. Similar relationship was also found between row spacing and leaf area index at later tillering stage and the highest stem number per unit area. Effects of narrow crop row spacing on crop yield loss for aerobic rice showed that regardless of the weed species and weed emergence date[57], rice grain yields were higher in narrow rows[58,59]. It was then suggested that narrowing row spacing and controlling early weeds will lead to increased grain yield in aerobic rice and decreased weed growth and seed production. Similar results are reported in[60], where the narrow spacing of 0.1×0.20 m gave the highest yield and yield components of Giza177 rice cultivar compared with 0.20×0.20 m or 0.3×0.2 m. Reports[36] indicate that plant spacing of 0.25×0.12 m was the best pattern for rice planting compared with 0.15×0.10 m and 0.20×0.12 m. In another studies[61,62], results showed that space of 0.15m between hills gives the tallest plants, highest number of panicles per square meter, and maximum grains and straw yield, while hill spacing of 0.25 m gives the highest values of the number of filled grains per panicle and 1000-grain weight.

The number of seedling hill^{-1} influences tiller formation and reflects nutrient uptake, light reception, solar radiation interception and photosynthesis rate as well as other physiological aspects affecting rice growth and development. Tillering influences grain yield of rice as it is closely linked to the final panicle number produced per unit area of cultivated land[63]. The higher productive tillers per square meter are attributed to single seedling and wider spacing capability of producing many tillers due to less competition for space, sunlight, water, nutrients, and mineral and easier management practices. Research findings[64] showed that all of the yield parameters except the 1000-grain weight and panicle length were influenced by the number of seedling hill^{-1}. Similar studies showed that the lowest number of bearing tillers and grains panicle per hill resulted in the lowest grain yield and straw yield, while the highest number of non-bearing tillers hill^{-1} were recorded from single seedling hill^{-1}. Missing hills also depends largely on the seedling density as well as on the uniformity in the mat[65]. Since a well-prepared field increases the percentage of transplanting time[65], the quality of transplanting operation can be evaluated based on the percentage of missing hills, single, two, three, four and five seedlings. High water level at low sedimentation period creates wave action resulting in washing off seedlings which in turns might increase hill missing[66]. This might be due to the reason that at lower sedimentation period majority of the seedlings were not released from the fingers due to insufficient soil gripping force. Therefore, these seedlings are jammed in the fingers resulting in excessive missing hills. Reports indicate that[67] younger seedling has a greater ability for producing higher number of tillers hill^{-1}. It is suggested[35] that tiller production can be optimized by transplanting seedlings at younger ages compared to direct seeding. Results of another study[68] found that the maximum number of tillers is inversely proportional to the length of Phyllochron, which is dependent upon the extent of stresses. In addition, when seedlings are transplanted carefully at the initial stage of growth, the trauma of root damage caused at uprooting time is minimized following a rapid growth with short Phyllochrons[46]. Rice seedlings transplanted before commencing the fourth Phyllochron retained much of their tillering potential[34]. Younger seedlings can relieve the transplanting stress in a shorter period of time compared to that of older seedlings due to the higher nitrogen content in the former[69,70], and the plants' ability to a faster resumption of the rate of Phyllochron development. Higher endosperm nutrient contents during the 2nd and 3rd Phyllochrons support a faster recovery of younger seedlings, and when seedlings transplanted after 4th Phyllochron stage take little longer time for recovery from the transplanting shock[69].

8. Conclusion

This paper highlighted how System of Rice Intensification (SRI) contributes to producing of higher rice yield with improved transplanting practices, sunlight absorption and nutrient, as well as producing a more effective root system. It can be concluded that determination of optimum transplanting spacing, seed rate and planting pattern in compliance with SRI guideline is required and should be topics of future studies to significantly improve rice yield. In this regard, the modification and development of a transplanter that comply with SRI specification will be based on the plant physical and mechanical properties. Such machine design would involve good understanding of the SRI operation and its functional requirements. Majority of Malaysian farmers are looking forward single-planting transplanters that eliminate manual operation. Our review showed that the SRI method emphasize on planting of one seedling per hill with space of 0.25 m for optimum water consumption, nutrient and pest management. In conclusion, wider spacing, availability of solar radiation, medium temperature, soil aeration, and nutrient supply promote shorter Phyllochrons which increase the number of tillers in rice.

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