**EVALUATION OF OPTIMUM SEEDING RATE ON SEEDLING VIGOR AND EARLY PLANT GROWTH OF MECHANICALY TRANSPLANTED RICE**

by

G.K. Nilupuli

AG/AT/2014/3880

DEPARTMENT OF CROP SCIENCE

FACULTY OF AGRICULTURE

UNIVERSITY OF RUHUNA

SRI LANKA

2018

**CONTENTS**

[**CHAPTER 01 3**](#_Toc531804660)

[**INTRODUCTION 3**](#_Toc531804661)

[**1.1 Objectives 6**](#_Toc531804662)

[**1.1.1 General Objective 6**](#_Toc531804663)

[**1.1.2 Specific Objective 6**](#_Toc531804664)

[**CHAPTER 02 7**](#_Toc531804665)

[**LITERATURE REVIEW 7**](#_Toc531804666)

[**2.1 Rice plant 7**](#_Toc531804667)

[**2.11 Botanical Classification 7**](#_Toc531804668)

[**2.2 Paddy Cultivation in Sri Lanka 8**](#_Toc531804669)

[**2.3 Constrains to the Rice Cultivation in Sri Lanka 9**](#_Toc531804670)

[**2.4 Direct seeding of Rice 12**](#_Toc531804671)

[**2.5 Transplanting of Rice 14**](#_Toc531804672)

[**2.51 Wet bed for Random transplanting 16**](#_Toc531804673)

[**2.52 Parachute method 18**](#_Toc531804674)

[**2.53 Mechanical transplanting 19**](#_Toc531804675)

[**2.531 Transplanter 21**](#_Toc531804676)

[**2.532 Problems with Mechanical Transplanting in Sri Lanka 24**](#_Toc531804677)

[**2.6 Seeding rate 27**](#_Toc531804678)

[**2.7 Seedling Vigor 28**](#_Toc531804679)

[**3 References 30**](#_Toc531804680)

# **CHAPTER 01**

# **INTRODUCTION**

The Asian rice (*Oryza sativa*) can be classified as the foremost cereal crop in Sri Lanka. The rice cultivation is distributed in most parts of Asian countries which is more than ninety per cent of the lands total cultivated lands extent as the staple food. Rice act as the principal contributor of Sri Lankan rural economy. Sri Lanka is a developing country with estimated total land devoted for cultivation is about 792,000 ha (CBSL, 2017). The national average rice yield of Sri Lanka in kilogram per net hectare is 4,349 in Maha and 3092 in Yala season (Department of census and statistics, 2016). And also the annual per capita consumption of the rice is 105kg (Sri Lanka World Bank Group, 2008). According to the annual report of the Central Bank of Sri Lanka in 2017 about 748,000mt rice imported to our country. The demand for the rice is increasing rapidly due to the increment in the population and the per capita rice consumption. The production and the productivity of the rice should be increased rather than increasing the cultivated land extent through better field practices to meet the increasing demand of rice(Dushani and Sandika, 2009)

The cultivation of rice is practised in all the parts of the country as a wetland crop except at the high altitudes, which act as the principal contributor on the rural economy (Henegedara, G.M., 2002). Mainly two cultivation seasons known as Maha and Yala which are equivalent with two monsoons are practised in Sri Lanka. In generally transplanting and the direct seeding of rice are the two main methods of rice cultivation practised in Sri Lanka considering the variations in different ecological regions at where rice is cultivated. The sowing of seeds directly in the field is practised in direct seeding method and the seedlings are raised in seedbeds and then planted in the field in the transplanting method.

In Sri Lanka DSR is practiced by more than 95% of total land extent devoted for rice cultivation as it is considered as an alternative option to lack of sufficient labour force and high cost for labors at the peak transplanting period which cause delayed transplanting and reduced yield in transplanting method (Weerakoon et al., 2011; Santhi et' al., 1998). The problems associated with DSR are, no proper spacing, management practices are difficult and most disastrous problem is the invasion of weeds and weedy rice (Gunawardana et al., 2013; Marambe, 2009). As a solution for this farmer tends to use agrochemicals to control weeds which is not an environmentally friendly practice.

Transplanting is commonly practised in most parts of the Asian countries (Mabbayad and Bordo, 1971). Transplanting of the seedlings on the puddled soil can be done manually as rows or randomly and through machine transplanting. Transplanting of rice gives a significantly higher yield than the direct seeding as it produces more number of productive tillers which bares panicles with an increased number of spikelet’s than the direct seeded rice plants (Fan et al., 2003). Although the labour intensity and labour costs are high in transplanting compared to the direct seeding of rice, highest yield and income is reported from it(Manjappa and Kataraki, 2004; Rani and Jayakiran, 2010).

As the most feasible solutions to increase the yield from rice cultivation proper nursery management practices which gives vigorous seedlings and transplanting of them at the correct time can be used. Mainly in Sri Lanka transplanting is done using dapog nurseries, parachute nurseries, wet bed and dry bed nurseries.

Mechanical transplanting of rice is the best solution for the problems with transplanting method including high labor intensity and delayed transplanting of seedlings. Mechanical Transplanting is the method of transplanting the seedlings which are raised on trays or mats uniformly with optimum plant density and less transplanting shock compared to other transplanting methods, using self-propelled mechanical transplanter. The self-propelled walk behind type transplanter is considered as a popular transplanter among the farmers in Asian countries which gives significantly increased the rice yield. A plastic tray is introduced to as nursery trays in modified dapog nurseries which is compatible with the dimensions of the feeding platform in the transplanter, to increase the convenience of handling seedlings, rather than using mat type nurseries which needed to be cut into parts according to the size of the feeding platform. Although the Ministry of Agriculture and the Department of Agriculture implemented programmes to promote the Mechanical Transplanting in Sri Lanka, very low adaptability of farmers to this method due to the constraints with nursery establishment, lack of technical knowledge and socio-economic reasons. So, it is a timely requirement to do studies on efficient utilization of the mechanical transplanter and introduced them to the farmers to increase the rice production. As introduced recently there is no recommended seeding rate to be used in the nursery trays used for Mechanical transplanting, it is understudied. Generally, use seeding rate between 60g - 150g per tray (Alizadeh et al., 2011; Columbia and Division, 2013; Islam and Khan, 2017).

Seeding rate can be defined as the amount of the seeds from an individual plant species required to achieve optimum seedling density in the nursery with an increment in the vigor of seedlings (Louisiana, 2009). The seedling vigor is the ability of the plant to emerge from the substrate rapidly and cover the ground surface rapidly (Deseo, 2012). Planting of vigorous seedlings is important factor on the early plant growth of the plants after the establishment which increases the number of productive tillers and the rice yield per unit area by decreasing the mortality rate of seedlings due to the transplanting stress (Panda et al., 1991; Tekrony and Egli, 1991).

Following proper nursery management practices is very important factor which effects on the seedling vigor and early plant growth of rice after field establishment in all the transplanting methods. Studies on the optimum seed rate for the nursery trays of Mechanicaly transplanted rice on seedling vigor and the early plant growth of rice have not been yet investigated properly in Sri Lanka. The main intention of this study is to identify the optimum seeding rate for the nursery trays use for mechanical transplanting and compare the seedling vigor and early plant growth with direct seedling, wet bed nurseries used for random transplanting and with parachute method of transplanting.

## **Objectives**

### **1.1.1 General Objective**

To identify the optimum seeding rate in nursery trays for Machine transplanting and comparison of seedling vigor and early plant growth with other nursery methods

### **1.1.2 Specific Objective**

To find out the effect of seeding rate on different growth parameters of the seedlings in modified dapog nursery trays.

To identify the effect of different nursery methods on the vigor of the seedlings and early plant growth.

# **CHAPTER 02**

# **LITERATURE REVIEW**

## **2.1 Rice plant**

Rice plant is a member of the grass family which belongs to the tribe *Oryzae* and the genus Oryza. There are 25 recorganized species in the genus *Oryza* including, 23 wild species and two well-known cultivated species *Oryza sativa* and *Oryza glaberrima*. The Asian *O. sativa* is the post popularize cultivated variety among the farmers in all around the world when compared with the African *Oryza glaberrima*. The *Oryza sativa indica* and the *Oryza sativa japonica* are the main two rice varieties widely cultivated in the world which are belong to the species *Oryza sativa*. In generally the origin of Oryza sativa is identified as river valleys of Mekon river, Yangtze river and the Delta of Niger river is identified as the origin of *Oryza glaberrima* (Tripathi et al., 2011; Yoshida, 1981).

### **2.11 Botanical Classification**

Kingdom – Plantae

Division - Magnoliophyta

Class - Liliopsida

Order - Poales

Family - Gramineae or Poaceae

Tribe - Oryzeae

Genus - Oryza

Species - sativa (Tripathi et al., 2011)

The genus *Oryza* contains basically 12 chromosomes. The *Oryza sativa* and Oryza *glaberrima* are diploids which are rich with 24 chromosomes. when compare the two rice species *Oryza sativa* and *Oryza glaberrima* the seed dormancy is high in *Oryza glaberrima.* Although *Oryza sativa* is cultivated as annual crop in botanically it is a perennial plant whereas the *Oryza glaberrima* is botanically and agronomically both act as an annual crop (OECD, 1999).

The duration of the rice starts from the germination of the seedlings and ends with the maturity of the plants which ranges from 3-6 months according to the variety and the environmental condition of the area where it is grown. The rice plant completes 3 growth phases sequentially including vegetative phase, reproduction phase, ripening phase. The vegetative phase starts from the emergence of the seedlings at the nursery and completes the tillering and stem elongation stages. The vegetative phase ends at the panicle initiation stage and the reproduction phase started. In the reproduction phase the plant grow through the booting, heading stages and finally reaches the flowering stage at the end. The ripening stage starts at the flowering and passes the milking stage, dough grain stage and enter to the mature grain stage at last (Tripathi et al., 2011; Yoshida, 1981).

## **2.2 Paddy Cultivation in Sri Lanka**

Rice is the main cereal crop cultivated in Sri Lanka which act as the main contributor of the rural economy by occupying more than 26.1 percent of the labor force (CBSL, 2018). Sri Lanka is consisting with different ecological regions which contains wide range of climatic conditions most suitable for rice. The cultivation of rice is practiced in all the parts of the country except at higher elevations (Dhanapala, 2000; Henegedara GM, 2002). The land area under rice cultivation acquires about 34 percent of the total land area devoted for cultivation in Sri Lanka which is about 792,000 hectare in 2017, including 543,00 hectare in Maha season and 249,000 hectares in Yala season (CBSL, 2017; “The importance of rice in Sri Lanka | Blue Lanka,” 2018).

According to the Sri Lanka World Bank Group, 2008, the average per capita consumption of rice by the Sri Lankans is 105kg per year. The average yield obtained from the rice cultivation per hectare is 4297 kg which is not sufficient to fulfill the total requirement of the country. The annual rice production in the year 2017 is estimated as 1.7 million metric tons which is sufficient for only 8 months period to fulfill the total requirement in the country. So, on behalf of the food security in the country the deficit amount, 800,000 metric tons is imported (CBSL, 2017).

Rice is the staple food of 20.8 million Sri Lankans which has 0.5 percent contribution on the GDP which is 72,809 million rupees in value (CBSL, 2018). About 1.8 million farmers in all around the country depends on the rice cultivation from which they earn their livelihood (“The importance of rice in Sri Lanka | Blue Lanka,” 2018). According to the Department of Agriculture rice consumption accounts for 45% of the total calorie requirement and 40% of the total protein requirement of an average Sri Lankan.(Rice Research & Development Institute Bathalagoda, 2017)

## **2.3 Constrains to the Rice Cultivation in Sri Lanka**

Most of the developing countries situated in the Asia-Pacific Region including Sri Lanka are extremely affected by the yield gap between the potential yield and the actual yield received due to many circumstances (Food and Agriculture Organization of the United Nations, 2000). The demand on the rice is increasing with increase of the population as 1.2% annually (Thiruchelvam, 2005). The total land extent utilized by the paddy cultivation is decreasing rapidly. According to the CBSL, 2017, the land extent cultivated in 2017 is 791,679 hectares which is a 28.9% reduction compared to past few years. The average yield gained per hectare from the past decades including 2015,2016,2017 is respectively 4429kg, 4372kg, 4292kg. It proves that there is no increment in the yield obtained although the population and the demand for the rice increased annually(CBSL, 2017)

The aim of the Asian countries including Sri Lanka to reduce the rice yield gap through increasing the production to confirm the food security and economic stability in the country (FAO Sri Lanka, 2012; Food and Agriculture Organization of the United Nations, 2000). The output from the rice cultivation can be increased and generate a surplus for the exportation through expanding of the area cultivated, improving the yield or using the both options. The problem with Sri Lanka is that there is no any additional land that can be occupied to improve the production. So the most logical solution to tackle with this problem is to increase the productivity of rice (“Sri Lanka as a Rice Exporting Country: Possibilities and Problems,” 2011). The highest yield potential areas can achieve a high yield which is about 6 metric tons per hectare whereas the average annual yield in Sri Lanka for past few years is around 4.5 metric tons per hectare. So, to achieve the self-sufficiency and generate surplus to export, a quantum jump is required in the Rice cultivation sector in the Sri Lanka, otherwise there is no any solution to cope with the increasing demand rather increasing the amount of rice importation proportionally (“Sri Lanka as a Rice Exporting Country: Possibilities and Problems,” 2011).

The major constrains associated with the farmers’ in rice cultivation except the rice yield gap are, invasive weeds, weedy rice, high occurrence of damages from pests and diseases, increased cost on the inputs including labor and the chemicals applied (Akbar et al., 2007; Perera et al., 1990). The aggressive weeds and weedy rice considered as a very common problem found in Sri Lanka. It is serious constraint that reduced the final yield and the occurrence is highly observed in the Direct seeded fields.(Caton et al., 1999; Ratnasekera, 2015; Zhao et al., 2006).

The prevalence of the pest and diseases which adversely make an impact on the yield, also among the major problems associated with Rice cultivation. The root cause for the invasion of pests and diseases is the improper field establishment of plants without maintaining the optimum spacing between the plants. The susceptibility of the plants in the direct seeded field for pest and diseased also high compared to the other methods of establishment (Iqbal et al., 2017). It is a more critical problem in Sri Lanka as more than 90 percent of the farmers choose the direct seeding as a solution to the labor shortage and high cost of production in transplanting method, although the yield gained from the transplanting is high compared to the direct seeding (MoADR, 1989; Weerakoon et al., 2011).

So as the most suitable solution farmers select the application of chemicals to control the pests, diseases, weeds and weedy rice. As it is available at cost effective prices, they tend to use in excessive amounts than the recommendations with the aim of annihilating them from the field. This is the root cause for health risks including kidney diseases which is a most popular sympathetic problem among the rural farmers (“Agrochemical pesticides and kidney related diseases, Sri Lanka | EJAtlas,” 2016; Rajapakse et al., 2016).

Another problem associated with the rice cultivation is high cost of production. The most expenditure of Manual transplanting is occupied by the labor charges which accounts for about 40% - 50% of the total expenditure (Clayton, 2010; Vidanapathirana, 2003). And also, improper nursery management practices, delayed transplanting of seedlings, careless transplanting by the labors with increased missing hill percentage and reduced plant density are commonly observed consequences between the Sri Lankan farmers which reduced the rice yield obtained (Columbia and Division, 2013; Das, 2012; Farooq et al., 2001; Illangakoon et al., 2017).

The most feasible solution to reduce the problems associated with rice cultivation in Sri Lanka is to find out the possible substitutes to avoid these constraints with the help of new technological changes. For that the research efforts are very important because the evaluation of each modern technology considering their suitability for Sri Lankan conditions and make adjustments accordingly before introducing to the farmers is very essential. The problem is only a small proportion of the GDP is allocated for Agricultural Research and Extension in Sri Lanka during the past decades (“Sri Lanka as a Rice Exporting Country: Possibilities and Problems,” 2011).

## **2.4 Direct seeding of Rice**

In the Direct Seeding method of crop establishment, the rice seeds are sown directly in the field. Direct seeding of rice is practiced in both wet and dry soil as wet direct seeding and dry direct seeding and water seeding through broadcasting, dibbling, drilling or sowing of seeds in lines (IRRI Rice Knowledge Bank, 2018a). Wet direct seeding is the method of sowing pre-germinated rice seeds in to the puddled soil whereas sowing of dry seeds is practiced in Dry direct seeding of rice. The seeds are sown in the standing water conditions at the Water seeding method which is sub divided in to aerobic and anerobic according to the oxygen content available in the ambient water of the germinating seeds (Hassan Akhgari, 2011). The main purpose of the Water seeding is to control the invasive weeds and weedy rice which are the major constraints in Direct seeding (Hill et al., 1990). Dry direct seeding is practiced in the areas which are prone to floods and in low lands, uplands where rainfed paddy cultivation is done. The lands where irrigated cultivation of rice is done commonly used the Wet direct seeding method (Pandey et al., 2000). The cultivation of rice through direct seeding is widely practiced in America, Russia, Japan, Cuba, India, Western Europe including Italy, French as a result of the deficit in agricultural labor and high wages demanded by them (Iqbal et al., 2017). According to the Weerakoon et al., 2011 direct seeding is practiced in about 95% of the total cultivated area of rice in Sri Lanka and the wet direct seeding is the most commonly practiced method of direct seeding primarily as a solution to the labor intensity. The Direct seeding of rice became the most common method practiced by the farmers in spite of the efforts of the Department of Agriculture to popularize the transplanting method as the most favorable planting technique for rainfed and irrigated environments (Pathinayake et al., 1990).

Although in the Asian region farmers mainly followed the traditional transplanting method of rice, at present the farmers tend to adopt to the direct seeding as the most suitable option to the increasing labor shortage during the peak transplantation period and high costs on wages. The land area at which the direct seeding method of rice is followed in Asia, is rapidly increasing because the ultimate goal of the farmers in this area who earn their lives through rice cultivation is to increase the productivity and profitability to gain high net retain as the income (Pandey et al., 2000).

Mainly the farmers tend to use direct seeding when there is lack of available resources like land, labor and if there is a necessity for the early maturity of the plants (IRRI Rice Knowledge Bank, 2018a). The improved short duration rice varieties and the availability of selective herbicides at cost effective prices impelled the farmers more on the Direct seeding (Pandey et al., 2000). The direct seeding of rice helps to reduce the water usage for about 30% compared to the conventional transplanting method which requires water for raising seedlings, puddling the soil and also for maintaining the water level at the height of 4 to 5 inches after transplanted in the field (Sangeetha and Baskar, 2015).

The invasion of the weeds and weedy rice is concerned as the most distractive problem in direct seeding of rice (Gunawardana et al., 2013; Marambe, 2009). The damages from the diseases and the insect pest attacks, severe in the direct seeding compared to the transplanting as the increased plant density creates a shadier, humid, cooler environment inside the plant canopy which is favorable for the multiplication of them (Pandey et al., 2000). As the chemicals are available at cost effective prices the farmers tend to use excessive amount of them to control the weeds, weedy rice, pest and diseases which cause the contamination of ground water that laid the foundation for the kidney diseases and also weed varieties with resistant genes for the herbicides are formed due to frequent application of chemicals (Illangakoon et al., 2017; Rajapakse et al., 2016). The available nutrients and the moisture content for the direct seeded plants is at low level compared to transplanting, due to the increased weed density and the shallow nature of the roots which caused it unable to absorb sufficient amount of nutrients to the plants through deep penetration (Singh et al., 1981). As a result of these reasons there is a significant reduction in the grain yield obtained from direct seeding compared to the transplanting of rice (Akbar et al., 2007)

## **2.5 Transplanting of Rice**

The transplanting of rice is the most commonly practiced traditional establishment method by the farmers in the Asian region (Mabbayad and Bordo, 1971). The pre-germinated seeds are sowed at the nursery beds at where the seedlings are raised until they reached the correct age for transplanting. The type of nursery bed use for raising seedlings is decided according to the availability of water, labor, land and the mechanization methods followed. The nursery types which are used for transplanting are Wet bed, Dry bed, Dapog, Modified dapog nurseries in mats and trays, Parachute nurseries in the trays (bubble trays). The transplanting of rice is the process of uprooting the seedlings form the when at the correct seedling age for the field establishment and replanting of them in the fields in which puddling and leveling is done. The transplanting of rice can be done either manually or mechanically. The manual transplanting of rice is the most popular transplanting method among the Asian farmers (IRRI, 2007).

The most important factors to concern in the transplanting of rice in order to achieve a vigorous stand of plants in the field after established in the field are, properly managed nutrient application to the plants, optimum seed rate for seed beds and transplanting of tender seedlings at the correct age by avoiding the delayed transplanting of seedlings (Himeda, 1994; Lal and Roy, 1996). The advantages of the transplanting of rice compared to other establishment methods are, optimum spacing between the plants in facilitating the agronomic practices like weeding, low seed rate required for the nurseries, ability of the plants to withstand over the weeds and the uniform maturity of the crop can be obtained (Desai, 2012). As the transplanted rice plants has the ability to compete and suppress the weed growth, higher economic yield can be obtained from the transplanted rice through proper weed management measures (Hossain et al., 2002). And also due to the optimum space between rice plants maintained by the transplanting method, a significant increase in the yield can be observed as the low plant density and proper penetration of sunlight through the canopy of the plants reduced the occurrence of pest and disease damages compared to direct seeding of rice (Baloch et al., 2002).

The transplanted rice cultivation gives significantly increased number of productive tillers per hill and increment in number of spikelets per panicle which ultimately gives an increased gran yield compared to the direct seeding. The deep penetrated and the wide spread root system of the rice plants facilitate the plants with sufficient amount of nutrients and moisture content during the panicle initiation and flowering stages which are considered as more critical stages having a noticeable impact on the final yield (Septiningsih et al., 2003).

The main problems associated with the transplanting are, the deficit and overhead costs on the labors at the peak transplanting period which is the root cause for the delayed transplanting of seedlings. It is a time consuming establishment method and requires more expenditure on the nursery management, uprooting of seedlings and transplanting of them to the field (Das, 2012; Singh et al., 2018).

The highest gross economic return can be obtained from the transplanting of rice than other establishment methods with the availability of ample amount of labors for field practices. The throwing of seedlings which is known as the parachute method can be used as an appropriate solution to tackle the problem scarcity of labors and improve the harvest (Akbar et al., 2007; Manjappa and Kataraki, 2004; Rani and Jayakiran, 2010). The mechanical transplanters can be named as the most attractive suggestion to the areas with shortage of labor (Singh et al., 2018).

### **2.51 Wet bed for Random transplanting**

Wet bed is the conventional nursery method practiced by the farmers when they are rich with sufficient amount of land and water to be used in the nursery management practices. The seed bed should be equivalent to the 1/10 of the area of the field which is to be transplanted. The seed bed is puddled and leveled properly with drainage canals to facilitate the removal of water. The pre-germinated seeds should be broadcasted uniformly in to the light soil to facilitate easy pulling with less damages on the roots at the transplanting process. It is very essential to take care of the nurseries after seeds sown for weeds, pests and disease attacks (Bautista and Javier, 2008; Gaikwad et al., 2015; IRRI, 2007).

In manual transplanting the seedlings are uprooted from the nursery and transplanted in the puddled soil. There are mainly two methods of transplanting including Straight row method and Random transplanting method. The straight row method follows a uniform spacing between the plants using guides made of wood, wires or twines (Rice Knowledge Bank, 2009; Sangeetha and Baskar, 2015).

The distance use for the transplanting and density of the plants used changed according to the variety, soil fertility but as the most economically feasible method to get increased yield, 3-4 seedlings are transplanted per hill with 20-30 cm spacing between the plants (Bautista and Javier, 2008).

In the Random transplanting method of rice seedlings are transplanted without a standard spacing between the plants (IRRI, 2007). Random transplanting method of plant establishment is the most common transplanting method followed by the farmers. It is mostly practiced by the women or sometimes entirely by the men, depending on the regions were farming practices are done. In Random transplanting three to five seedlings are poked in to the puddled field at about 1.5-2.5 cm depth using the first two fingers and the thumb through walking backward while covering the space until they reached the other end. The farmers prefer the Random transplanting mostly as it is faster than the straight row planting method which reduced the time spend and cost on labors, ultimately reducing the cost of production (IRRI Rice Knowledge Bank, 2018b; Rice Knowledge Bank, 2009; Wopereis, M.C.S. et al., 2009).

The number of plants per unit area, numbers of tillers per plant is reduced in the Random transplanted fields which is commonly used by the farmers than the Standard line transplanting method as there is no uniform plant stand in the field. The intercultural operations using machineries are difficult in Random transplanted fields like weeding through rotary-weeder due to un even spacing between the plants (Awan et al., 2011; Negalur and Halepyati, 2017).

### **2.52 Parachute method**

The Parachute method which is known as Broadcasting of seedlings, introduced recently with the aim to cope with the problems in conventional transplanting method of rice (Akbar et al., 2007). In the Parachute method the seedlings raised in plastic sheets are broadcasted in to the puddled soil using a machine or manually (IRRI, 2007).

The nurseries are prepared using plastic sheets which are known as bubbled trays by adding 2-3 seeds per each hole. The time require for establishment of nurseries is less and the management practices of nurseries is easy compared to traditional methods of transplanting. The plastic sheets used for the parachute nurseries is a durable sheet available at low cost which can be utilized for about three years duration. When compared with the manual broadcasting of seedlings in parachute method it also consumes less time compared to manual transplanting. And with the use of power blower for field establishment of seedlings, the cost on labors can be reduced as the women and the children in the farm families are engaged in this process. The Mechanical transplanting of rice requires specialized machineries and skilled labors which make it more expensive for the rural farmers to bare up although the final yield can be increased. The farmers tend to adopt to this new technology due cost effectiveness and as a potential solution to overcome the shortage of labor (Akbar et al., 2007; Akhter and Sabar, 2002; Cheng, 2000; Nabii et al., 2003; Sabar, 2003).

In the parachute method the seedlings were thrown with in one-meter distance above the field in order to facilitate the seedlings to be settled in puddled field in upward position. The seedlings are flowing down under the gravity using the weight of seedling clumps, towards the ground and roots penetrated to the soil (Akhter and Sabar, 2002). In the uprooting of seedlings for the field establishment the damages to the roots is at a minimum level compared to other transplanting methods. The reason for this is seedlings are grown inside the small cups in the plastic trays in which roots remained intact. So at the uprooting of 12-15days old tender seedlings for transplanting the roots are not damaged and the transplanting shock is reduced because the damaged roots are the main contributor to the transplanting shock (Akhter and Sabar, 2002; IRRI, 2007; Nabii et al., 2003; Sabar, 2003).

The seedlings transplanted through parachute method contains greater root length and a greater number of roots than the conventional transplanting method due to minimum damage on the roots at the transplanting. So the plant growth started immediately after transplanting without being suffered from the transplanting (Nabii et al., 2003). A optimum plant population with uniform stand of plants can be obtained (Akhter and Sabar, 2002; Awan et al., 2008). And also, the number of tillers obtained for square meter is increased compared to the conventional transplanted fields. A high yield per hectare can be obtained from the Parachute method when considering with the other transplanting methods which is the ultimate goal required by the farmers (Akhter and Sabar, 2002; Awan et al., 2008; Nabii et al., 2003; Sabar, 2003)

### **2.53 Mechanical transplanting**

The mechanical transplanting is the field establishment of the seedings raised in a modified dapog nursery as mat type or nursery trays, using the rice transplanters (Rickman et al., 2015). Mechanical transplanting is reorganized as the most provable solution to tackle with the problems related with the conventional methods of transplanting, in order to increase the productivity and the profitability obtained by the farmers (Illangakoon et al., 2017). The final yield is significantly increased by the mechanical transplanting method of plant establishment compared to other methods, through optimum plant density with adjustable spacing between the plants, less amount of missing hills and reduced transplanting shock with the seedling friendly transplanting method followed in the self-propelled walk behind type transplanter which is commonly used in Asian countries (Gaikwad et al., 2015; A. Islam et al., 2016; Rickman et al., 2015).

The popularization of the Mechanical transplanting between the farmers in the Asian region at where the farmers are highly adopted to the manual transplanting of rice has become a very important factor (Farooq et al., 2001). The Department of Agriculture, Sri Lanka has launched programs to give the technical knowledge to the farmers under the projects KOPIA and Yaya II, to develop an instinct on them to adopt to this new technology. (Bandara et al., 2017; Sri Lanka raises rice productivity with Korean technology, 2016)

The mechanical transplanting of rice increases the labor use efficiency which assures timeliness transplanting with speed transplanting while generating an alternative income source for the rural youth as operators in machines and in different nursery management practices. (A. Islam et al., 2016; Islam and Khan, 2017) For the manual transplanting of rice requires 8-12 labors for one hectare whereas only 3 labors are required to transplant 4 hectares with in one day. Mechanical transplanting can be considered as an operation with low health risk on labors when compared with the fatigue manual transplanting of rice with frequend bending and straighten up process which is not an ergonomically friendly. (Pradhan and Mohanty, 2014; Rickman et al., 2015)

The area required for the nurseries used for the mechanical transplanting is smaller than the space requirement for the conventional nurseries and it requires soil alone without pebbles to use as the media for raising seedlings. The amount of seed paddy requirement also low when compared with the direct seeding method of plant establishment. Through mechanical transplanting about 50% saving of seed paddy compared to the direct seeding can be obtained. (Columbia and Division, 2013; Gaikwad et al., 2015; Hayleys empowers greater productivity via mechanised rice transplanter, 2013) The production cost can be reduced from 25% - 30%through the mechanical transplanting than the manual transplanting (Mahbubur Rashid et al., 2015).

The optimum space between the plants in this method ensures the photosynthesis efficiency and the vigorous growth of the plants through better penetration of sunlight, increased air circulation with the wide spread and deep percolated root system that facilitates efficient utilization of moisture and nutrients. The low plant population in the manual transplanted field ,which is a critical factor that affect the final grain yield can be avoided through mechanical transplanting. (Baloch et al., 2002; Farooq et al., 2001) The seedlings are pegged firmly in to the soil which reduced the transplanting shock and a uniform crop stand with vigorous growth can be obtained after field established using the transplanter (Illangakoon et al., 2017; Rickman et al., 2015).

#### **2.531 Transplanter**

The Rice Transplanter is a specialized machine which is having the capability of transplanting the seedlings in the puddled field according to the adjustments done by the operator as proper number of seedlings at proper place, in the given planting depth and within row spacing (Gaikwad et al., 2015; “Present status of Rice Transplanter use for Paddy Cultivation in Bangladesh,” 2013). The common transplanter contains mainly a feeding tray where the seedlings in the nursery tray or the mat type is placed, pick up forks which contains needles for the process of picking up the seedlings from the nurseries on the feeding platform and placing that seedlings on the puddled soil. The nurseries are separated in to the rectangular blocks according to the dimensions of the feeding tray on the feeding platform when mat type nurseries are used and if the nursery trays are used the can be directly inserted to the feeding tray. The transplanter pegged the rice seedlings in the puddled soil according to the planting depth, fixed between row space in the machine, with in row space, number of seedlings dispersed per hill as adjusted by the operator by giving a uniform plant stand (“Hayleys empowers greater productivity via mechanised rice transplanter | FT Online,” 2013; Singh and Rao, 2010).

There are mainly two types of rice transplanters used by the farmers as Manual Transplanter and Mechanical Transplanter. The manual and mechanical transplanters reduced the labor requirement from 75-80% and the cost of transplanting from 45-80% (Das, 2012). The rice transplanters are first introduced at 1960 by the Japan (Behera, 2000). Manual transplanter is higher in capacity when compared to the fatigue operation manual transplanting of rice. So, the manual transplanter can be named as a good solution for the marginal and small-scale farmers to replace the manual transplanting of rice. Manual transplanter is a single operated machine which is operated through the simultaneous push and pull action. First the operator has to move backward pull the machine and simultaneously push the handle to cut the nursery for transplanting in the soil (Guru et al., 2018). Working with the manual transplanter in the puddled field through the multiple action push and pull is a very fatigue task for the operator. The operation of the mechanical transplanter is classified as a heavy work after evaluating ergonomically (Pradhan and Mohanty, 2014). The use of manual transplanter reduced the working capacity from 0.01 to 0.015 hectares per hour with increased fatigue on the operator. Therefore the researchers focused their attention on shifting to the mechanical transplanting from manual transplanting (Behera, 2000).

The reduced labor availability due to the movement of human force towards the urban area with the industrialization is one of the main problems associated with the transplanting of rice. The prevalence of these circumstances increased the need for mechanization inorder to maintain the economical consistency which occurs due to the transposition of the manpower from agriculture towards the industry and service sector (A. K. M. S. Islam et al., 2016; Tripathi et al., 2004). The mechanical transplanter act as a conserving method of land and labor compared to the manual transplanter. The capacity of the transplanter is increased and the proximate area that the operated is able transplant with in a day increased from 0.7 to 1 hectare per day. The mechanized transplanter facilitate the operator in working faster than the manual transplanter without any fatigue compared to the manual transplanter. The mechanical transplanter pegged the seedlings in the puddled soil at uniform depth and spacing which increased the number of tillers and ultimately increased the rice yield (Alizadeh et al., 2011; A. K. M. S. Islam et al., 2015; A. K. M.S. Islam et al., 2015; Islam and Khan, 2017; “Present status of Rice Transplanter use for Paddy Cultivation in Bangladesh,” 2013; Singh and Rao, 2010; Singh and Vasta, 2006).

In mechanical transplanting the selection of the most suitable transplanter should be done according to the field condition, available resources and the cost feasibility. The self-propelled transplanter act as an labor saving method which conserves labor consumption up to 90% when compared with the manual transplanter (Vasudevan et al., 2014). The self-propelled walk behind type facilitate better establishment of seedlings which increases the number of panicles per square meter and proportionally the yield is increased when compared with the self-propelled four wheel type and self-propelled single wheel transplanters (Manes et al., 2013). The self-propelled walk behind type 6 row and 8 row transplanters are able to reduce the labor intensity in to a large extent. But these transplanters can performs well under the large-scale farms and the purchasing cost of these machines are also high. The four row self-propelled walk behind transplanter has become more popular among the farmers in Asian countries as it is most suitable for small size lands and affordable for the small marginal farmers (Gaikward et al., 2015). And also the labor requirement is reduced to 2 man days per hectare whereas for manual transplanting required 32 man days of labor per hectare (Murumkar et al., 2015).

#### **2.532 Problems with Mechanical Transplanting in Sri Lanka**

Mechanical Transplanters can be name as the most feasible option to the problems associated with the manual transplanting of rice which is very tedious process that consumes for time, energy of the workers and finally gives a low yield than expected by the farmers. Although the researches have proved about higher production, income that can be obtained from mechanical transplanting over manual transplanting, the adoption of the farmers to the mechanical transplanting is very low due to socio economic problems associated with them and lack of technical information regarding this technology (Illangakoon et al., 2017).

In the Asian region most of the farmers in developing countries are having small lands by which they earned their livelihoods. So, their economic position is not powerful enough to purchase a mechanical transplanter and the trays required for the nurseries in their own selves. The other reason is farmers are not willing to buy the transplanter with the idea that it is useless to spend large amount of money on a machine which is consumed for only about 15-30 days in the year. Some farmers are willing to use the mechanical transplanter in hire basis rather than buying a transplanter (Guru et al., 2018; Pradhan and Mohanty, 2014; “Present Status of Rice Transplanter Use for Paddy Cultivation in Bangladesh,” 2013). The government should pay attention to give subsidies to the farmers on machinery, trays in order to induce the farmers more on mechanical transplanting. (Agriculture et al., 2015; Farooq et al., 2001; Guru et al., 2018; Mahbubur Rashid et al., 2015; Senthilkumar and Naik, 2016; “Standardization of Media for Tray,” 2015).

As the cost of large transplanter is high and those are difficulty to use in the small lands it is better to introduce a small transplanter at low cost which is more feasible to the small-scale farmers. The small self-propelled walking type transplanter should be introduced to the small and medium scale land owners of rice. The farmers are not having proper knowledge about how to operate the transplanter, so they have to pay more wages on the skilled man power which increases the cost of production. So, the way of operating the machines correctly, maintenance practices that are required should be introduced to the farmers and trained them properly before delivering to the farmers. Development of automated transplanting machine will increase the efficiency of transplanting by reducing the workload on the operator as a single operator can operate multiple number of machines without any fatigue easily (Guru et al., 2018).

The nursery management can be named as the most crucial operation in transplanting of rice which act as one of the main factors contributing to the final yield. The farmers are not having a proper knowledge about how to handle the infant, tender seedlings used for the mechanical transplanting although it is required for avoiding root damages and better anchorage of the seedlings (Islam et al., 2015; Islam and Khan, 2017). In mechanical transplanting of rice for the nursery preparation farmers are using mat type nursery and the nursery trays. The firm soil free of pebbles are required for this both methods as the presence of pebbles cause damages to both seedlings and the pegging needles of the transplanting machine. The problem is farmers are not practicing this method correctly and also it is difficult to practice in large scale nurseries. So, it required to find alternations associated with the machine to deal with the soils in which pebbles are present. The uneven seedling population a common problem in mat type nurseries that negatively affect the performance of transplanters. The mat thickness, number of seedlings per square meter and the seedling age are the major factors that should be considered in nursery preparation, but neglected by the farmers due to the absence of technical knowledge. The preparation of mat type nurseries is complex process with high labor intensity which accounts for about 40% of the total energy requirement of mechanical transplanting (Baruah et al., 2001; Farooq et al., 2001; Guru et al., 2018).

The cutting of the nursery according to the size of the feeding tray of the machine is required when the mat type nurseries are practiced. The handling of mat type nursery is difficult and also in case of large establishment are the nursery size also should increase proportionally which make it more difficult to handle. As an option to the mat type nursery, the nursery trays which are light in weight and easy to handle as compatible with size of the feeding tray in the machine was introduced to the farmers. The nursery tray method is not still popular among the farmers as introduced recently and they have to pay money on buying the trays. The development of transplanter which can work with long mat nurseries will be more beneficial as no need to cut the nurseries and the time spend for feeding the nursery also reduced. Providing a proper hands on training about nursery preparation and handling of properly at the transplanting to the farmers is very essential to overcome these circumstances (Farooq et al., 2001; Guru et al., 2018).

One of the main advantages in the mechanical transplanting over manual transplanting is the seedlings are properly pegged in to the soil. The precise leveling is required for proper pegging in the transplanters. The perfect leveling is not done by the farmers which caused missing hills in the field and they can’t obtain a uniform transplantation. It is important to pay attention on introducing a transplanter capable of working precisely at uneven surfaces. The poor metering of the number of seedlings that dispersed per hill by the machine is another mistake done by the farmers because it should be adjusted properly according to the seed rate applied for nursery. (Farooq et al., 2001; Guru et al., 2018; IRRI-PAK Agri. Machinery Program, 1978; Khan et al., 1979; Sangeetha and Baskar, 2015).

As introduced recently the studies on use of mechanical transplanter to increase the yield of rice under Sri Lankan conditions have not yet been investigated properly, still under studied (Illangakoon et al., 2017; “Sri Lanka as a Rice Exporting Country: Possibilities and Problems,” 2011). The funds should be supplied for the relevant Agricultural Research institutes and Universities on researches in machinery, development and for the extension programs to avoid the constrains associated with mechanical transplanting and increase production (Agriculture et al., 2015; Mahbubur Rashid et al., 2015).

## **2.6 Seeding rate**

Seeding rate can be defined as the amount of seeds required to achieve the adequate seedling density in the nursery bed or the field (Louisiana, 2009). Better seeding density is an important factor to consider among the components of nursery management practices for vigorous plant growth (Lal and Roy, 1996).

The method of crop establishment preferred by the farmers has an direct impact on the seeding rate as it changes accordingly (Bautista and Javier, 2008). The seeding rate applied for the nursery trays depends on the variety and the germination percentage. The seedling density is decided according to the seeding rate applied and it eventually decided the requirement of nursery trays for the field establishment(A. K. M.S. Islam et al., 2015; Islam and Khan, 2017)**.** So, it is important to have an optimum seeding rate to use in the nursery trays used for the machine transplanting to optimize the yield in a cost-effective manner. The seeding rate which is applied for the nursey trays ranged from 60g – 150g seeds per tray (Alizadeh et al., 2011; Columbia and Division, 2013; A. Islam et al., 2016; A. K. M.S. Islam et al., 2015; Islam and Khan, 2017)

The seeding rate is having an influence naturally on the growth and the density of seedlings in the nursery. The thin sowing seeds give strong, tall, vigorous, tillered seedlings that can withstand over the adverse climatic conditions with better stand of plants after field establishment whereas the thick sowing produced thin, weak seedlings without tillers that susceptible highly for the transplanting shock which retarded the growth of plants after field establishment (Hossain et al., 2002; Oparka and Gates, 1982; Sarwar et al., 2014).

The farmers tend to use high seed rate in the nursery on behalf of avoiding the weed competition and make it easy for uprooting the seedlings for transplanting. The uprooting of seedlings and separation of them for transplanting, is the most critical process at which the root damages occurred. The proportion of roots damaged is increasing with the seed rate which is considered as the major reason for the transplanting shock that adversely effect on the early plant growth of the plants after established in the field. As the early plant growth is one of the main contributors on the final grain yield the optimum seed rate for the nursery trays is an important factor to consider at nursery establishment (Lal and Roy, 1996; Panda et al., 1991; Sarwar et al., 2014; Singh et al., 2005). According to the Islam et al., 2015 the number of seedlings which are dispensed per stroke, the amount of missing hills and the uniformity in the establishment of seedlings in the machine transplanting depends on the seeding rate used in nursery trays.

## **2.7 Seedling Vigor**

The Seedling vigor is the ability of plants to arise rapidly through the substrate including soil or water and cover the surface fast (Fukai, 2002). Seedling vigor is having an interaction with the all phases of the seedling development from emergence up to the field establishment which enables the seedlings to grow in an agile manner after the germination (Rani, 2012). Seedling vigor is a quality character of the seedlings which represents the potency of the seedlings to rapid growth in the nursery stage and this potential change according to the inheritance and the environmental conditions (Rani, 2012).

The key factor on the successful growth of the transplanted plants is the vigor of the seedlings (Lal and Roy, 1996). The production of vigorous seedlings through better care of the nursery and transplanting them at the correct age is very essential to obtain high yield in rice cultivation (Rani, 2012; Sarwar et al., 2011). According to the Deseo, 2015 increased seedling vigor can be classified as an important attribute which determines the final grain yield obtained. An extra care on the nursery is very important to get vigorous seedlings to transplant in the field (Islam and Salam, 2017). The improved nursery management practices including better applications of nutrients, pest and disease management, irrigation at optimum level will ensure the vigor of the seedlings in the nursery rather than the conventional nursery management practices (Ghosh and Suman, 2011).

The seedling vigor is having an positive correlation with the early crop vigor after field established which decided the effectiveness of the transplanted rice (Panda et al., 1991). The vigorous seedlings after transplanted showed morphological differences in the growth of both above ground and below ground parts (Hoshikawa and Ishi, 1974). The seedling vigor associated with the shoot length, root length, leaf area, seedling dry weight, plant viability and the uniformity (Lal and Roy, 1996; Matsuo and Hoshikawa, 1993; Rajendran et al., 2005). The newly established vigorous seedlings are able to cope with the transplanting shock well and recover within a short period of time and start the vegetative growth in successful manner than the weak seedlings. The dense root system available in the healthy seedlings produced new shoots and absorb nutrients, moisture well which increased the early plant growth of transplanted rice (Grist, 1975).

The strong seedlings with the early crop vigor is desirable character for increased grain yield from the transplanted crops as the strong seedling are having the ability to compete with weeds , weedy rice, pest attacks and grow well which subsequently increase the dry matter accumulation in the plants (Akram, n.d.; Ellis, 1992). The main factor which decides the final rice yield obtain from the transplanted rice is due to the seedling vigor obtained through different nursery treatments (Deseo, 2015; Nachit, n.d.; Rani, 2012; Ros et al., 2003). The increased growth vigor at the nursery stage is having a significant co relation with the tillering ability in the field which subsequently increases the final yield (Nachit, n.d.; Rani, 2012; Sarwar et al., 2014; Tekrony and Egli, 1991).

# **3 References**

Agriculture, L., Asia, S., Rice, G.S., 2015. Transplanting Rice Seedling Using Machine Transplanter : a Potential Step.

Agrochemical pesticides and kidney related diseases, Sri Lanka | EJAtlas [WWW Document], 2016. URL https://ejatlas.org/conflict/agrochemical-pesticides-and-kidney-related-diseases-in-sri-lanka (accessed 12.1.18).

Akbar, N., Jabran, K., Habib, T., 2007. Comparison of different Planting Methods for Optimization of plant population of fine rice ( Oryza sativa L .) in Punjab (Parkistan) 44, 597–599.

Akhter, M., Sabar, M., 2002. Evaluation of Rice Line-transplanting and Parachute Planting Methods, in: Reddy, R.P. (Ed.), Proceedings of the National Workshop on Rice-Wheat Systems in Pakistan. Pakistan Agricultural Research Council & Rice-Wheat Consortium for the Indo-Gangetic Plains, Islamabad, Pakistan, pp. 38–39.

Akram, M., n.d. INHERITANCE OF SEED AND SEEDLING VIGOR IN RICE (Oryza sativa L.). University of Arid Agriculture, Rawalpindi, Pakistan.

Alizadeh, M.R., Yadollahinia, A.R., Rahimi-AjdadiI, F., 2011. Techno-Economic Performance of a Self-Propelled Rice Transplanter and Comparison with Hand Transplanting for Hybrid Rice Variety 5, 27–30.

Awan, T.H., Ahmad, M., Ashraf, M.M., Ali, I., 2011. Effect of different transplanting methods on paddy yield and its components at farmer’s field in rice zone of Punjab. J. Anim. Plant Sci. 21, 498–502.

Awan, T.H., Ali, I., Safdar, M.E., Ahmad, M., Akhtar, M.S., 2008. Comparison of Parachute , Line and Traditional rice Transplanting methods at farmer’s field in rice growing area. Park. J. Agric. Sci. 45, 432–438.

Baloch, A.W., Soomro, A.M., Javed, M. a., Ahmed, M., Bughio, H.R., Bughio, M.S., Mastoi, .N. N., 2002. Optimum Plant Density for High Yield in Rice (Oryza sativa L.). Asian J. Plant Sci. 1, 25–27. https://doi.org/10.3923/ajps.2002.25.27

Bandara, R.M.U.S., Silva, Y.M.S.H.I.U. De, Dissanayaka, H.M.M.K.K.H., 2017. Rice Varieties Suitable for Machine Transplanting in Rajanganaya. Open. Minds Res. Sustain. Dev. 407–409.

Baruah, D.C., Goswami, N.G., Saikia, R., R, 2001. Journal of agricultural engineering. J. Agric. Eng. 38, 66–72.

Bautista, E.U., Javier, E.F., 2008. Rice Production Practices. Res. Pap. Ser. (Philippine Inst. Dev. Stud. I,VI,1-0\_2. https://doi.org/10.1166/jnn.2011.5046

Behera, B.K., 2000. INVESTIGATIONS ON PUDDLED SOIL CHARACTERISTICS IN RELATION TO PERFORMANCE OF SELF .. PROPELLED RICE TRANSPLANTER Submitted to the) INDIA.

Caton, B.., Foin, T.., Hill, J.., 1999. A plant growth model for integrated weed management in direct-seeded rice. III. Interspecific competition for light. F. Crop. Res. 63, 47–61. https://doi.org/10.1016/S0378-4290(99)00026-X

CBSL, 2018. Economics and Social Statistics of Sri Lanka.

CBSL, 2017. National Output, Expenditure and Income.

Cheng, Y.G., 2000. The condition of extension and service of the rice production technique in China.China Rice, in: Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopez, K., Hardy, B. (Eds.), Direct Sseding: Reserach Issues and Opportunities. Proceedings of the International Workshop on Direct Seeding in Asian Systems: Strategic Researcg Issues and Opportunities. International Rice Research Institute, Philippines., Los Banos, pp. 21–24.

Clayton, S., 2010. 50 years of Rice Science for a better world-and it’s just the start. Rice Today,IRRI pp.12.

Columbia, B., Division, A., 2013. Tray Soil Management in Raising Seedlings for Rice Transplanter 7, 2481–2489.

Das, F.C., 2012. Status and prospects of mechanization in rice. Rice Knowl. Manag. P ortal,〈 http//www. rkmp. co. 753006, 1–24.

Department of census and statistics, 2016. Paddy statistics 2015/2016 Maha season.

Desai, K.S., 2012. Development and Performance Testing of Two Row Paddy Transplanter. College of Agricultural Engineering and Technology.

Deseo, N., 2015. Early Vigor Traits in Selected Upland and Rainfed Lowland Rice ( Oryza sativa L .) Genotypes 0–47. https://doi.org/10.13140/RG.2.1.1434.6720

Deseo, N., 2012. Early Vigor Traits in Selected Upland and Rainfed Lowland Rice (Oryza sativa L.) Genotypes.

Dhanapala, M.P., 2000. Bridging the Rice Yield gap in Sri Lanka, in: Papademetriou, M.K., Dent, F.J., Herath, E.M. (Eds.), Bridging the Rice Yield Gap in the Asia Pacific Region. FAO, Bangkok, Thailand, pp. 135–146.

Dushani, A.L., Sandika, S.N., 2009. Growth Performance of Rice Sector : the Present Scenario in Sri Lanka. Trop. Agric. Res. Ext. 12, 71–76.

Ellis, R.H., 1992. Seed and seedling vigour in relation to crop growth and yield. Plant Growth Regul. 11, 249–255.

Fan, Y., Song, Y., Septiningsih, E.M., Prasetiyono, J., Lubis, E., Tai, T.H., Tjubaryat, T., Moeljopawiro, S., McCouch, S.R., 2003. IPGWAS : An Integrated Pipeline for Genome-Wide Association Studies User Manual Li Ka Shing Faculty of Medicine The University of Hong Kong control and association analysis of genome-wide genetic studies . Biochemical and. Theor. Appl. Genet. 107, 363–368. https://doi.org/10.1073/pnas.1317360111.

FAO Sri Lanka, 2012. FAO Country Programming Framework 2013-2017 Sri Lanka.

Farooq, U., Sheikh, A.D., Iqbal, M., Bashir, A., Anwar, Z., 2001. Diffusion Possibilities of Mechanical Rice Transplanters. Int. J. Agric. Biol. 17–20.

Food and Agriculture Organization of the United Nations, 2000. Bridging the rice yield gap in the Asia-Pacific Region, FAO. Bangkok, Thailand.

Fukai, S., 2002. Rice cultivar requirement for direct-seeding in rainfed lowlands, in: Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopez, K., Hardy, B. (Eds.), ‘ Direct Seeding: Research Strategies and Opportunities. Proceedings of a Workshop. International Rice Research Institute (IRRI): Manil, pp. 257–270.

Gaikwad, P.B., Shahare, P.U., Pathak, S. V, Aware, V. V, 2015. Development and performance evaluation of four row self propelled paddy transplanter. Int. J. Agric. Eng. 8, 9–14. https://doi.org/10.15740/HAS/IJAE/8.1/9-14

Gaikward, P.B., Shahare, P.U., Pathak, S.V., Aware, V.V., 2015. Development and performance evaluation of four row self propelled paddy transplanter. Int. J. Agric. Eng. College of Agriculture Engineering and Technology. https://doi.org/10.15740/HAS/IJAE/8.1/9-14

Ghosh, A., Suman, K.K., 2011. Exploring seedling vigour for post flood stand establishment of rice (Oryza sativa) under flood prone waterlogged deepwater condition. Indian J. Agric. Sci. 81, 371–373.

Grist, D.H., 1975. Rice.

Gunawardana, W.G.N., Ariyaratne, M., Bandaranayake, P., Marambe, B., 2013. Control of Echinochloa colona in aerobic rice: effect of different rates of seed paddy and post-plant herbicides in the dry zone of Sri Lanka. role weed Sci. Support. food Secur. by 2020. Proc. 24th Asian-Pacific Weed Sci. Soc. Conf. Bandung, Indones. Oct. 22-25, 2013 431–437.

Guru, P.K., Chhuneja, N., Dixit, A., Tiwari, P., Kumar, A., 2018. Mechanical transplanting of rice in India: Status, technological gaps and future thrust. ORYZA- An Int. J. Rice 55, 100. https://doi.org/10.5958/2249-5266.2018.00012.7

Hassan Akhgari, 2011. Assessment of direct seeded and transplanting methods of rice cultivars in the northern part of Iran. African J. Agric. Reseearch 6. https://doi.org/10.5897/AJAR11.973

Hayleys empowers greater productivity via mechanised rice transplanter | FT Online [WWW Document], 2013. URL http://www.ft.lk/agriculture/hayleys-empowers-greater-productivity-via-mechanised-rice-transplanter/31-188536 (accessed 12.1.18).

Henegedara GM, 2002. Agricultural Policy reforms in paddy sector in Sri Lanka. An over view. Sri Lankan, J. Agrar. Stud. 10, 26–34.

Hill, J.E., Bochchi, S., Clampet, W.S., Bayen, D.E., 1990. Direct seeded rice in the temperate climates of Australia, Italy and the United Satates, in: Direct Seeded Flooded Rice in the Tropics. IRRI, Seoul,Korea, pp. 91–102.

Himeda, M., 1994. Cultivation technique of rice nurseling seeding: Review of research papers and its future implementation. Agric. Hortic. 69, 679–683, 791–796.

Hoshikawa, K., Ishi, R., 1974. Gas exchange characteristics of ‘young’ rice seedlings raised in box. Crop Sci. Soc. Japan 43, 5–6.

Hossain, M.F., Sallam, M.A., Uddin, M.R., Pervez, Z., Sarkar, M.A.R., 2002. A Comparative Study of Direct Seeding Versus Transplnting Method on Yield of Aus Rice. J. Agron. 1, 86–88.

Illangakoon, T.K., Piyasiri, C.H., Kumar, V., 2017. Impact of varieties, spacing and seedling management on growth and yield of mechanicaly transplanted rice 112–128.

Iqbal, M.F., Hussain, M., Rasheed, A., 2017. Direct seeded rice: purely a site specific technology. Int. J. Adv. Res. Biol. Sci. 4, 53–57. https://doi.org/10.22192/ijarbs

IRRI-PAK Agri. Machinery Program, 1978. Report on Modification and Testing of Korean Paddy Transplanter. 73-A, Satellite Town, Rawalpindi.

IRRI, 2007. Rice Production Manual 14.

IRRI Rice Knowledge Bank, 2018a. Direct seeding - IRRI Rice Knowledge Bank [WWW Document]. URL http://www.knowledgebank.irri.org/step-by-step-production/growth/planting/direct-seeding#wet-direct-seeding (accessed 11.28.18).

IRRI Rice Knowledge Bank, 2018b. Manual transplanting - IRRI Rice Knowledge Bank [WWW Document]. URL http://www.knowledgebank.irri.org/training/fact-sheets/crop-establishment/manual-transplanting (accessed 12.2.18).

Islam, A., Rahman, M., Rahman, A., Islam, M., Rahman, M., 2016. Techno-economic performance of 4-row self-propelled mechanical rice transplanter at farmers field in Bangladesh. Progress. Agric. 27, 369. https://doi.org/10.3329/pa.v27i3.30834

Islam, A.K.M.S., Islam, M.D.T., Rahman, M.D., Shakilur, M.D. Rahman, Kim, Y., 2016. Investigation on Selective Mechanization for Wet Season Rice Cultivation in Bangladesh. J. Biosyst. Eng. 41, 294–303.

Islam, A.K.M.S., Islam, M.T., Rabbani, M.A., Rahman, M.A., Ziaur Rahman, A.B.M., 2015. Commercial mechanical rice transplanting under public private partnership in Bangladesh. J. Biosci. Agric. Res. 6, 501–511. https://doi.org/10.18801/jbar.060115.60

Islam, A.K.M.S., Khan, M.A.I., 2017. Effect of row spacing of Rice transplanter on seedling requirement and grain yield. Int. J. Sci. Technol. 44, 2562–2573.

Islam, A.K.M.S., Rahman, M.A., Rahman, A.K.M.L., Islam, M.T., Rahman, M.T., 2015. Evaluation of mechanical rice transplanter in cold season at farmers. Banani, Dhaka.

Islam, T., Salam, M.A., 2017. Effect of number of seedlings hill-1 on the yield and yield contributing characters of short duration Aman rice cultivars. Progress. Agric. 28, 279–286. https://doi.org/10.3329/pa.v28i4.36367

Khan, A., Shakoor, A.D., Chaudhry, F.M., Rehman, H., 1979. Modification and Testing of Korean Paddy Transplanter in Pakistan. gricultural Mech. Asia, Winter 1979 79–85.

Lal, M., Roy, R.K., 1996. Effect of nursery seeding density and fertilizer on seedling growth and yeild of rice (Oryza sativa). Int. J. Agron. 41, 642–644.

Louisiana, A., 2009. Plant materials technical note no. 11. Tech. Notes.

Mabbayad, B.B. and, Bordo, R.A.O., 1971. Transplanting vs. direct seeding. World Farming 13, 6–7.

Mahbubur Rashid, M., Ahmed, A., Ul Kabir, A., 2015. Transplanting Rice Seedling Using Machine Transplanter: a Potential Step for Mechanization in Agriculture.

Manes, G.S., Dixit, A., Singh, A., Mahal, J.S., Mahajan, G., 2013. Feasibility of Mechanical Transplanter for Paddy Transplanting in Punjab. Agric. Mech. Asia, Africa Lat. Am. 44, 14–17.

Manjappa, K., Kataraki, N.G., 2004. Use of Drum Seeder and Transplanter for Increasing Rice Profitability 17.

Marambe, B., 2009. WEEDY RICE: EVOLUTION, THREATS, AND MANAGEMENT B. Marambe Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka. Trop. Agric. 157, 0–15.

Matsuo, T., Hoshikawa, K., 1993. Sience of therice plant : morphology.

MoADR, 1989. Agricultural implementation programme. Peradeniya, Sri Lanka.

Murumkar, R.P., Dongarwar, U.R., Phad, D.S., Borkar, B.Y., Pisalkar, P.S., Deshmukh, P., Vidyapeeth, K., Akola, M.S., 2015. Performance Testing of Four Row Self Propelled. Interational J. Sci. Envronment Technol. 3, 2015–2019. https://doi.org/10.1016/ j.tiv.2018.06.019

Nabii, G., Akhtar, M.S., Hussan, M.M. ul, Gill, S.M., 2003. Root Growth in Parachute and Conventional Rice-Transplanting Methods, in: Reddy, R. (Ed.), Proceedings of the National Workshop on Rice-Wheat Systems in Pakistan. P akistan Agricultural Resear c h Council Rice-Wheat Consor tium f or the Indo-Gang etic Plains, Islamabad, Pakistan, pp. 62–66.

Nachit, M.M., n.d. Effect of seedling growth vigour on yield of triticale. Barley. Wheat Triticale Newsl. 1, 16.

Negalur, R.B., Halepyati, A.S., 2017. Growth and Yield of Machine Transplanted Rice ( Oryza sativa L .) as Influenced by Age and Number of Seedlings 6, 376–385.

OECD, 1999. Consensus document on the biology of Oryza sativa (Rice). Technical Report ENV/JM/MONO(99)26. Ser. Harminization Regul. Overs. Biotechnol. 1–52. https://doi.org/10.1107/S2056989015015029

Oparka, K.J., Gates, P.J., 1982. (Oryza sativa) 43, 108–109.

Panda, M.M., Reddy, M.D., Sharma, A.R., 1991. Yield performance of rainfed lowland rice as affected by nursery fertilization under conditions of intermediate deep water (15-50cm) and flash flood. Plant Soil 132, 65–71.

Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopez, K., Hardy, B., 2000. Direct seeding:research issues and opportunities. Proc. Int. Work. direct seeding Asian rice Syst. Res. issues Oppor. Work. direct seeding Asian rice Syst. Res. issues Oppor. 383.

Pathinayake, B.D., Nugaliyadde, L., Sandanayake, C.A., 1990. Direct Seeding practices for Rice in Sri Lanka, in: Direct Seeded Flooded Rice in the Tropics. IRRI, Seoul,Korea, pp. 77–90.

Perera, B.M.K., Dhanapala, M.P., Wickremasinghe, D.B., Fazekas, C., Wetselaar, R., 1990. Agronomic aspects of the rice yield gap between farmer and researcher, in: Menz, K.M. (Ed.), Rice Production in Sri Lanka, A Combined Agronomic/Economic Study in the Internlediate and Dry Zones. Australian Centre for International Agricultural Research, Canberra, pp. 10–20.

Pradhan, S., Mohanty, S.K., 2014. Ergo-Economical Analysis of Different Paddy Transplanting Operations in Eastern India. IOSR J. Agric. Vet. Sci. 6, 2319–2372.

Present status of Rice Transplanter use for Paddy Cultivation in Bangladesh, 2013. . Bangladesh Agricultural University, Mymensingh.

Rajapakse, S., Shivanthan, M.C., Selvarajah, M., 2016. Chronic kidney disease of unknown etiology in Sri Lanka. Int. J. Occup. Environ. Health 22, 259–264. https://doi.org/10.1080/10773525.2016.1203097

Rajendran, V., Ravi, V., Valliappan, K., 2005. Early production of robust seedlings through modified mat nursery for enhancing rice (Oryza sativa) productivity and profit | Request PDF. ndian J. Agron. 50, 132–136.

Rani, A.S., 2012. RICE YIELD AS AFFECTED BY SEEDLING VIGOUR THROUGH NUTRIENT MANAGEMENT TECHNIQUES IN NURSERY BY. Agricultural College, Bapatla.

Rani, T.S., Jayakiran, K., 2010. Evaluation of different planting techniques for economic feasibility in rice. Electron. J. Environ. Agric. Food Chem. 9(1), 150–153.

Ratnasekera, D., 2015. Weedy rice: A threat to rice production in Sri Lanka. J. Univ. Ruhuna 1, 2–13. https://doi.org/10.1016/j.electacta.2007.04.013

Rice Knowledge Bank, I., 2009. Planting the Rice [WWW Document]. URL http://www.knowledgebank.irri.org/ericeproduction/II.4\_Transplanting.htm (accessed 12.1.18).

Rice Research & Development Institute Bathalagoda, 2017. Rice Cultivation [WWW Document]. URL http://doa.gov.lk/rrdi/index.php/en/crop/42-crop-rice-cultivation (accessed 8.28.18).

Rickman, J.F., Mussgnug, F., Khanda, C.M., Satpathy, S.D., Parida, N., Singla, K., Kumar, V., Banik, N.C., Iftikar, W., Mishra, A., Sudhir-Yadav, Kumar, V., Malik, R., McDonald, A., 2015. Operational manual for mechanical transplanting of rice 18 pages.

Ros, C., Bell, R.W., White, P.F., 2003. Seedling vigour and the early growth of transplanted rice (Oryza sativa). Plant Soil 252, 325–337. https://doi.org/10.1023/A:1024736104668

Sabar, M., 2003. Evaluation of Rice Line-transplanting and Parachute Planting Methods. Workshop on Rice-Wheat Systems in Pakistan, Islamabad, Pakistan.

Sangeetha, C., Baskar, P., 2015. Influence of different crop establishment methods on productivity of rice–A Review. Agric. Rev. 36, 113. https://doi.org/10.5958/0976-0741.2015.00013.6

Sarwar, N., Ali, H., Maqsood, M., Ahmad, A., Ullah, E., Khaliq, T., Hill, J.E., 2014. Influence of Nursery Management and Seedling Age on Growth and Economic Performance of Fine Rice. J. Plant Nutr. 37, 1287–1303. https://doi.org/10.1080/01904167.2014.881490

Sarwar, N., Maqsood, M., Wajid, S.A., Anwar-ul-Haq, M., 2011. Impact of Nursery Seeding Density, Nitrogen, and Seedling Age on Yield and Yield Attributes of Fine Rice. Chil. J. Agric. Res. 71, 343–349. https://doi.org/10.4067/S0718-58392011000300001

Senthilkumar, T., Naik, R., 2016. Study of Adoption of Mechanical Rice Transplanters through Custom Hiring in Tamil Nadu- a Case Study. J. Rice Res. 9, 35–42.

Septiningsih, E.M., Prasetiyono, J., Lubis, E., Tai, T.H., Tjubaryat, T., Moeljopawiro, S., McCouch, S.R., 2003. Identification of quantitative trait loci for yield and yield components in an advanced backcross population derived from the Oryza sativa variety IR64 and the wild relative O-rufipogon. Theor. Appl. Genet. 107, 1419–1432. https://doi.org/10.1073/pnas.1317360111.

Singh, F., Kang, J.S., Singh, A., Singh, T., 2018. Productivity of mechanically transplanted rice ( Oryza sativa L .) as influenced by time of nitrogen application Productivity of Mechanically Transplanted Rice ( Oryza sativa L .) as Influenced by Time of Nitrogen Application 0–5.

Singh, K.N., Hassan, B., Kanday, B.A., Bhat, A.K., 2005. Effect of nursery fertilization on seedling growth and yield of rice. Indian J. Agron. 50, 187–189.

Singh, R.., Rao, K.V.R., 2010. Impact of self propelled transplanter in rice. Electron. J. Environ. Agric. Food Chem. 9, 150–153.

Singh, R.K., Pande, R.S., Namdeo, N.K., 1981. Response of Ratna to mathods of planting and nitrogen levels.Oryza. F. Crop. Res. 18, 182–183.

Singh, S., Vasta, D.K., 2006. Performance of evaluation of PAU manual transplanter in hills of himachal Pradesh. Agricultural. Agric. Eng. today 30, 43–46.

Sri Lanka as a Rice Exporting Country: Possibilities and Problems [WWW Document], 2011. URL http://www.ips.lk/talkingeconomics/2011/12/07/sri-lanka-as-a-rice-exporting-country-possibilities-and-problems/ (accessed 12.1.18).

Sri Lanka raises rice productivity with Korean technology [WWW Document], 2016. URL https://economynext.com/Sri\_Lanka\_raises\_rice\_productivity\_with\_Korean\_technology-3-5503.html (accessed 11.30.18).

Sri Lanka World Bank Group, 2008. Appendix 6 : Sri Lanka.

Standardization of Media for Tray, 2015. . College of Horticulture.

Tekrony, D.M., Egli, D.B., 1991. Relationship of seed vigour to crop yield. A Rev. Crop Sci. 31, 816–822.

The importance of rice in Sri Lanka | Blue Lanka [WWW Document], 2018. URL https://www.bluelankatours.com/blog/the-importance-of-rice-in-sri-lanka (accessed 12.1.18).

Thiruchelvam, S., 2005. Efficiency of rice production and issues relating to cost of production in the districts of Anuradhapura and Polonnaruwa. J. Natl. Sci. Found. Sri Lanka 33, 247–256. https://doi.org/10.4038/jnsfsr.v33i4.2114

Tripathi, K.K., Warrier, R., Govila, O.P., Ahuja, V., 2011. Biology of Rice.Pdf. Departement of Biotechnology, Ministry of Environment and Forets, Government of India.

Tripathi, S.K., Jena, H.K., Panda, P.K., 2004. Self-propelled rice transplanter for economizing labour. Indian Fmg 54, 23–25.

Vasudevan, S.N., Basangouda, B., Mathad, R.C., Doddagoudar, S.R., Shakuntala, N.M., 2014. Standardization of Seedling Characteristics for Paddy Transplanter. J. Adv. Agric. Technol. 1, 141–146. https://doi.org/10.12720/joaat.1.2.141-146

Vidanapathirana, U., 2003. The Future of Paddy Farming Its Challenges and Constraints. Econ. Rev. 24–28.

Weerakoon, W.M.W., Mutunayake, M.M.P., Bandara, C., Rao, A.N., Bhandari, D.C., Ladha, J.K., 2011. Direct-seeded rice culture in Sri Lanka: Lessons from farmers. F. Crop. Res. 121, 53–63. https://doi.org/10.1016/J.FCR.2010.11.009

Wopereis, M.C.S., Defoer, T., Idinoba, P., Diack, S., Dugué, M.J., 2009. Transplanting Technical Manual, in: Participatory Learning and Action Research (PLAR) for Integrated Rice Management (IRM) in Inland Valleys of Sub-Saharan Africa: Technical Manual. A frica Rice Center (WARDA), pp. 63–64.

Yoshida, S., 1981. Fundamentals of Rice Crop Science. Fundam. rice Crop Sci. 65–109.

Zhao, D.L., Atlin, G.N., Bastiaans, L., Spiertz, J.H.J., 2006. Cultivar weed-competitiveness in aerobic rice: Heritability, correlated traits, and the potential for indirect selection in weed-free environments. Crop Sci. 46, 372–380. https://doi.org/10.2135/cropsci2005.0192