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

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By

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**Affectionately Dedicated to**

**My Loving Parents**

**And**

**Teachers**

# **ABSTRACT**

Labor scarcity is becoming a serious problem in rice cultivation of Sri Lanka and Mechanical Transplanting (MT) can be considered as one of the feasible solutions. MT using automated walk behind type transplanter has been introduced to Sri Lanka 3 – 4 years back, but experimental information related correct seeding rates to be used in nursery trays to obtain vigorous seedlings to transplant in MT is still lacking.

Two field experiments were conducted (i) to determine the optimum seeding rate for MT and (ii) to compare the selected seedling rate for MT with recommended establishment methods. In experiment (i), four seeding rates (75g/tray, 100g/tray, 150g /tray, 200g/tray) were tested using two varieties (Bg 360 and Bg 374). Experiment (ii) compared MT with Broadcasting (BC), Random Transplanting (RT) and Parachute method (PA). Considering seedling height, total root length, seedling dry weight and cost effectiveness 100 g/tray and 150 g/tray were selected as the optimum seed rates for Bg 360 and Bg 374 respectively. The seed rate had a strong correlation with the total root length, seedling height and dry weight.

Establishment method had a significant impact on seedling height, total root length and seedling dry weight. The seedlings produced by MT were comparatively less in seedling height, total root length and dry weight compared to the PA but higher than RT. The ground cover % and number of plants per square meter in MT were less comparatively to the RT, PA, BC but irrespectively produced significantly higher number of tillers/m2. By considering the plant growth parameters at vegetative phase, optimum plant spacing and better placement of seedlings by the transplanter gives plants with significantly higher growth rate compared to the conventional RT. Identification of the correct seeding rates for the nursery trays in MT is having a good potential for achieving the sustainability of rice production in Sri Lanka.

**Key words: Mechanical Transplanting, Optimum Seed Rate, Establishment Methods**

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# **ABBREVIATIONS**

|  |  |
| --- | --- |
| Bg | Bathalegoda |
| MT | Machine Transplanting |
| RT | Random Transplanting |
| BC | Broadcasting |
| PA | Parachute |
| ANOVA | Analysis of variance |
| SAS | Statistical Analysis Software |
| CRD | Complete Randomized Design |
| RCBD | Randomized Complete Block Design |
| DAS | Days After Sowing |
| DAE | Days After Establishment |
|  |  |

# **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, 2017a). The national average rice yield of Sri Lanka is 4,349 kg/ha in Maha and 3092 kg/ha in Yala season (Department of census and statistics, 2016). And also the annual per capita consumption of the rice is 105 kg (Sri Lanka World Bank Group, 2008). According to the annual report of the Central Bank of Sri Lanka in 2017 about 748,000 MT 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, 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 direct seeding of rice 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 labor 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). The problems associated with direct seeding of rice 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 (IRRI, 2018a). Transplanting of the seedlings on the puddled soil can be done manually as rows or randomly and through machine transplanting. Transplanting of rice gives 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 labor intensity and labor 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 rice yield (Gaikwad *et al*., 2015; Murumkar *et al*., 2015). A plastic tray is introduced 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 programs 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; Islam and Khan, 2017; Mathew, 2015).

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 an 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 in mechanical transplanting and compare the seedling vigor and early plant growth with direct seedling, 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 establishment 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 establishment 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 *Oryza sativa* is the most popularize cultivated variety among the farmers in all around the world when compared with the African *Oryza glaberrima*. The *indica* and the *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).

### **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*,* 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).

## 

## **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% 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, 2002). The land area under rice cultivation acquires about 34 % of the total land area devoted for cultivation in Sri Lanka which is about 792,000 ha in 2017, including 543,00 ha in Maha season and 249,000 ha in Yala season (CBSL, 2017b).

According to the Sri Lanka World Bank Group, 2008, the average per capita consumption of rice by the Sri Lankans is 105 kg per year. The average yield obtained from the rice cultivation is 4297 kg/ha 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 MT 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 MT is imported (CBSL, 2017).

Rice is the staple food of 20.8 million Sri Lankans which has 0.5 % contribution on the GDP which is 72,809 million rupees in value. About 1.8 million farmers in all around the country depends on the rice cultivation from which they earn their livelihood (CBSL, 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 (RRDI, 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 (FAO 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 ha 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 4429 kg, 4372 kg, 4292 kg. It proves that there is no increment in the yield obtained although the population and the demand for the rice increased annually (CBSL, 2017a).

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; FAO 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 (Samaratunga, 2011). The highest yield potential areas can achieve a high yield which is about 6 MT/ha whereas the average annual yield in Sri Lanka for past few years is around 4.5 MT/ha. 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 (Samaratunga, 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 improper field establishment of plants without maintaining the optimum spacing between the plants is one of the main reasons that cause the invasion of pests and diseases. The susceptibility of the plants in the direct seeded field for pest and diseases 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% 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 (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 cost effective, they tend to use in excessive amounts than the recommendations with the aim of annihilating them from the field. This is one of the main reason for health risks including kidney diseases which is a most popular sympathetic problem among the rural farmers (Bandara, 2012; 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 (Das, 2012; Farooq *et al*., 2001; Illangakoon *et al*., 2017; Mamun *et al*., 2013).

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 fund is allocated for Agricultural Research and Extension in Sri Lanka by the government during the past decades (Samaratunga, 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, 2018b). 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 (Weerakoon *et al*., 2011).

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, 2018b). 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 most commonly practiced by the farmers in the Asian region (IRRI, 2018c). 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 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 grain 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 (Jamil and Hussain, 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 (Please refer Section 2.5.2) 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).

### **2.5.1 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 from 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 (IRRI, 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 15\*15 cm spacing between the plants (Bautista and Javier, 2008; DOA, 2017).

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 3-5 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, 2009, 2018d; Wopereis *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).

### **2.5.2 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 12-15 days 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 shock (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)

### **2.5.3 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; Islam et al., 2016b; 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 Closing Rice Yield Gaps in Asia (CORIGAP) and Yaya II, to develop an instinct on them to adopt to this new technology (Bandara *et al*., 2017; Economynext, 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 (Islam *et al*., 2016b; Islam and Khan, 2017). For the manual transplanting of rice requires 8-12 labors for 1 ha whereas mechanical transplanting covers 4 ha with in one day using only 3 labors. Mechanical transplanting can be considered as an operation with low health risk on labors when compared with the fatigue manual transplanting of rice with frequent bending and straighten up process which is not an ergonomically friendly (Pradhan and Mohanty, 2014; Rickman *et al*., 2015).

The tray nurseries for mechanical transplanting 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 ( Mamun et al., 2013; DailyFT, 2013; Gaikwad *et al*., 2015). The production cost can be reduced from 25% - 30% through the mechanical transplanting than the manual transplanting (Mahbubur *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).

#### **2.5.3.1 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 (Awal and Ziauddin, 2013; Gaikwad *et al*., 2015). 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 (DailyFT, 2013; Singh and Rao, 2010).

##### **2.5.3.1.1 Transplanters used in Asian Countries**

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 ha/hr 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 in order to maintain the economical consistency which occurs due to the transposition of the manpower from agriculture towards the industry and service sector (Islam *et al*., 2016a; 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 to transplant with in a day increased from 0.7 to 1 ha/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; Awal and Ziauddin, 2013; A. K. M. S. Islam et al., 2015a, 2015b; Islam and Khan, 2017; 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).

#### **2.5.3.2 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 (Awal and Ziauddin, 2013; Guru *et al*., 2018; Pradhan and Mohanty, 2014). The government should pay attention to give subsidies to the farmers on machinery, trays in order to induce the farmers more on mechanical transplanting. (Farooq *et a*l., 2001; Guru *et al*., 2018; Mathew, 2015; Rashid *et* al., 2015; Senthilkumar and Naik, 2016).

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., 2015b; 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 is required to find alternations associated with the machine to deal with the soils in which pebbles are present. The uneven seedling population is 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-scale field establishments, 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; 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; Samarathunga, 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 (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(Islam *et al*., 2015a; Islam and Khan, 2017)**.** So, it is important to have an optimum seeding rate to use in the nursery trays 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; A. K. M. S. Islam et al., 2015a; Islam et al., 2016b; Islam and Khan, 2017; Mamun et al., 2013).

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; 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., 2015b 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, 2012 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 transplanting showed morphological differences in the growth of both above ground and below ground parts (Mishra and Salokhe, 2008). 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 (Rani, 2012).

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, 2004; Rani, 2012). 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 (Mishra and Salokhe, 2008; Nachit, n.d.; Rani, 2012; Sarwar *et al*., 2014, 2011).

# **CHAPTER 03**

# **MATERIALS AND METHODS**

## **3.1 Experimental location**

The field experiment was carried out at the Rice Research and Development Institute (RRDI), Bathalagoda (Longitude-80.2640, Latitude-7.5310) in the Low country Intermediate Zone (IL3) of Sri Lanka. The experiment was conducted in the “Maha” season from September to December 2018. The annual rainfall of the area is 1500-2285mm and the daily mean temperature is 230C – 280C. The soil type was Red Yellow Podzolic.

## **3.2 Treatments and Experimental Design**

The experiment for determination of optimum seeding rate for nursery trays use for mechanical transplanting was conducted using the Complete Randomized Design (CRD) separately for the two varieties Bg 360 (three and half month’s variety with white short round shape, Keera Samba) and Bg 374 (three and half month’s variety with white intermediate bold shape, Nadu) in order to generalize the experiment. The experiment was consisted with four treatments and three replicates (Table 3.1), which included with twelve experimental units for each variety. One nursery tray was considered as an experimental unit.

**Table 3. 2 Treatment combination for Experiment 1**

|  |
| --- |
| 75g / tray  100g / tray  150g / tray  200g / tray  T1  T2  T3  T4  Treatment  Seed rate |

|  |
| --- |
|  |

Comparison of mechanical transplanting with other establishment methods was conducted using Randomized Complete Block Design (RCBD). Two trials were conducted separately for Bg 360 and Bg 374. Experiment was conducted in two stages including the nursery period and period after field establishment to the end of vegetative phase in the field. The experimental design was consisted with three replicates and four treatments; therefore, twelve experimental units were assigned to one variety (Table 3.2). One block was considered as one experimental unit and two fields were used separately for the two varieties.

**Table 3. 3 Treatment combinations for Experiment 2**

|  |
| --- |
| Broadcasting (BC)  Manual / Random Transplanting (RT)  Mechanical Transplanting (MT)  Parachute method (PA)  1  2  3  4  Treatment  Establishment method |
|  |

## **3.3 Agronomic practices**

### **3.3.1 Nursery management**

To determine the optimum seed rate for nursery trays, raised beds were prepared with a height of 5 cm, width of 60 cm and the length of 360 cm separately for the two varieties. The trays (30x 60cm) were arranged in two rows. Fine textured soil without any pebbles or plant debris was filled uniformly in to each tray up to 2.5cm thickness. The treatments were randomized and allocated to the trays accordingly. The trays were labelled according to the treatments (Figure 3.1).

The seeds having germination over 90% were selected. They were soaked 24 hours in water and incubated for 24 hours before sowing. They were distributed uniformly on the trays according to the seed rates allocated by each treatment. The nursery beds were covered with coconut leaves for about 3 to 4 days, in order to avoid the damage from the high rain condition prevailed during that period and the damages from animals. Then the seedlings were hardened to the environment by exposing them to the sunlight during the morning then for the whole day. The seedlings were raised for 12 days period and then uprooted for taking measurements to select the optimum seed rate for seedling vigor.

R3, T4

R1, T1

R1, T3

R2, T2

R2, T4

R1, T4

R3, T2

R3, T1

R2, T1

R1, T2

R2, T3

R3, T3

**Figure 3. 2 Layout of nursery tray experiment**

****

**Plate 3. 1 Arrangement of the nursery trays for the experiment**

For the second experiment wet bed nursery, modified dapog nursery and parachute nursery were prepared for manual transplanting, mechanical transplanting and for seedling broadcasting respectively. The nursery beds for the wet bed and parachute method are prepared according to the seed rates recommended by the Department of Agriculture (DOA) Sri Lanka. For dapog nursery, the optimum seed rate identified from the first experiment was used.

The raised beds were prepared for wet beds by puddling, leveling the soil well and constructing of drainage canals to facilitate removal of water by occupying 1/10 of the area from the total area to be established (IRRI, 2007). The seed rate was used as the recommendations which was 40 kg/ha for Bg 360 and 50 kg/ha for Bg 374. The germinated seeds were scattered evenly on the nursery bed after 24 hours of water soaking followed by 48 hours of incubation.

The raised beds were prepared for parachute trays (30\*60 cm, with 434 plugs) with 10 cm height, width of 60 cm and the length was adjusted according to the number of trays required. The trays were kept on the raised beds and filled with fine mud up to the 2/3 height of the cavities in the parachute trays. The seed rate used were 12 kg/ha and 25 kg/ha for Bg 360 and Bg 374 respectively. The germinated seeds after water soaked for 24 hours followed by incubation period of 24 hours, were distributed uniformly on the nursery trays as 3 seeds per each cavity and covered with a thin layer of mud. The nursery trays (60x 30 cm) were kept on levelled raised beds and the fine mud was filled up to the thickness of 2.5cm.

For the modified dapog nurseries use in mechanical transplanting, the seed rate used for Bg 360 was 100g per tray and the seed rate used for the variety Bg 374 was 150g per tray according to the results of the previous experiment. The germinated seeds were scattered uniformly on the trays after water soaked and incubated for 24 hours.

All the three nurseries were covered with coconut leaves from about 3 to 4 days period to prevent damages from high rain, animals’ and to conserve the moisture. The hardening of the seedlings was done by gradually increasing the time period of seedlings exposing to the sunlight.

The direct sowing of seeds was done on the date of nursery establishment in order to get an even aged plants to get data for comparison of growth parameters. The seed rate used for Bg 360 was 75 kg/ha and 100 kg/ha used for Bg 374 according to the recommendations of Department of Agriculture (DOA), Sri Lanka. The germinated seeds were scattered evenly in the field after 24 hours of water soaking followed by 48 hours of incubation.

### **3.3.2 Land preparation**

The land preparation was done according to the recommendation of Department of Agriculture (DOA) Sri Lanka. After the basic land preparation practices the land was laid down according to the layout (Figure 3.2). The blocks were prepared with the dimensions of 7 m length and 4.5 m width. Between each block 30cm space was kept. The experiment was conducted in two fields for two varieties using the same layout.

R1,MT

R1, BC

R1, PA

R1, RT

R1,PA

R1, RT

R1, MT

R1, BC

R1,BC

R1, PA

R1, RT

R1, MT

**Figure 3. 3 Layout of the field experiment**

### **3.3.3 Crop establishment**

The seedlings in the nurseries were uprooted and transplanted in the field when the seedlings were 12 days old as it was identified as the optimum seedling age (SA) for mechanical transplanting of seedlings. In all the establishment methods transplanting of tender seedlings increased the production (Illangakoon *et al*., 2017; Krishna and Biradarpatil, 2009; Mamun *et al*., 2013). The Wet beds were flooded before uprooting of seedlings to facilitate easiness of uprooting and to avoid breakage of seedlings, washed the soil from the roots and buddle them in convenient sizes. In Random Transplanting the seedlings were poked in to the soil as three seedlings per hill without standard row spacing by the labors, in the blocks according to the layout.

The seedlings were thrown to the field from 1 m above the ground in the Parachute method. The seedling density was maintained as 35 to 40 plants per square meter according to the recommendations of Department of Agriculture, Sri Lanka.



**Plate 3. 2 Kubota NSP-4W self-propelled walking behind type transplanter**

The transplanter used for the mechanical transplanting was Kubota NSP-4W self-propelled walking behind type transplanter. The transplanter was capable of adjusting the within row space (WRS), per hill number of seedlings (PHNS), planting depth of seedlings (PD) and the between row space (BRS) was fixed as 30 cm. The machine was consisted with 5 within row space (12 cm, 14 cm, 16 cm, 18 cm, 21 cm), as the spacing of plants 30x 18 cm was used. The per hill number of seedlings was adjusted as 3 - 4 seedlings per hill as it was identified as the optimum rate which should dispersed per hill to gain the maximum yield (Islam and Salam, 2017; Negalur and Halepyati, 2017; Rasool *et al*., 2013). There are 5 planting depth of seedlings in the machine as 1.5 cm, 2 cm, 2.3 cm, 2.7 cm, 3 cm, 3.7 cm the middle gear which plants at 2.3 cm depth was used for planting the seedlings considering the soil type and the level of pudding the soil. The seedlings grown in the trays were introduced to the feeding platform of the transplanter.

### **3.3.4 Management practices**

#### **3.3.4.1 Fertilizer application**

The Fertilizer was applied according to the recommendation given by the Department of Agriculture (DOA) according to the three- and half-month age varieties and the method of establishment.

**Table 3. 4 Fertilizer recommendation for the three- and half--month age transplanted varieties**

|  |  |  |  |
| --- | --- | --- | --- |
| Time of Application | Urea (kg/ha) | TSP (kg/ha) | MOP (kg/ha) |
| Basal dressing |  | 55 |  |
| Top dressing 1 (2 WAS) | 50 |  |  |
| Top dressing 2 (4 WAS) | 75 |  | 25 |
| Top dressing 3 (6 WAS) | 65 |  | 35 |
| Top dressing 4 (7 WAS) | 35 |  |  |

Source – Rice cultivation by DOA

TSP – Triple Super Phosphate MOP – Murate of Potash

WAS – Weeks After Establishment

**Table 3. 5 Fertilizer recommendation for the three- and half--month age direct seeded varieties**

|  |  |  |  |
| --- | --- | --- | --- |
| Time of Application | Urea (kg/ha) | TSP (kg/ha) | MOP (kg/ha) |
| Basal dressing |  | 55 |  |
| Top dressing 1 (3 WAS) | 50 |  |  |
| Top dressing 2 (5 WAS) | 75 |  | 25 |
| Top dressing 3 (7 WAS) | 65 |  | 35 |
| Top dressing 4 (8 WAS) | 35 |  |  |

Source – Rice cultivation by DOA

#### **3.3.4.2 Weed, pest and disease control**

Weeds were controlled through the manual weeding and flooding. The herbicide Sofit 300 EC (Pretilachlor + Safener) was applied to the field for control the weeds. Mimic 20F (Tebufenozide) was applied to control the brown plant hoppers. Tatamida (Imidacloprid) was added to control the thrips attack and stem borer was controlled through the application of Diazinon. The Klerat pellets (Brodifacoum 0.005%) and gliricidia leaves were added to control the rat damages in the broadcasted blocks.

## **3.4 Data Collection**

### **3.4.1 Rice seedlings during nursery stage**

Seedling height was recorded at 3 DAS (Days After Sowing), 6 DAS, 9 DAS and 12 DAS. Height was measured from the collar region to the apex of the seedlings. Randomly selected ten seedlings from the trays or nursery bed was taken to measure the seedling height.

The total root length was measured using the WinRhizo 2016 root scanning device which was used for morphological, architectural, topological and color analyzing of roots. Randomly selected ten seedlings used to measure the seedling height at 12 DAS were used to measure the total root length by separating the root system from collar region. The roots were placed in a tray with water and inserted in to the scanner to get the total root length (Plate 3,2).

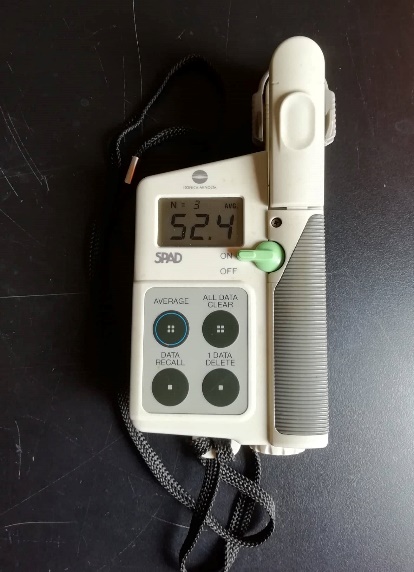


1. **(b)**

**Plate 3. 3 (a) The root scanner WinRhizo 2016 and (b) scanned image produced by the scanner.**

The dry weight of the seedling was recorded from the same sample of seedlings which were used to measure the total root length and the seedling height at 12 DAS. The seedling samples were oven dried in the oven at 600 C for 24 hours and the dry weight was taken after cooling in the desiccators (Rani, 2012; Vasudevan *et al*., 2014).

The leaf greenness was measured using the SPAD meter (MINOLTA 502). Ten randomly selected leaves from each plot were selected for the measurements.



**Plate 3. 4 SPAD meter (MINOLTA 502)**

The number of seedlings dispersed per hill according to the low gear, mid gear and the high gear from the transplanter with each seed rate was counted using the transplanter which was planned to use for mechanical transplanting in order to evaluate whether there was an impact of seed rate on the number of seedlings dispersed per hill.

### **3.4.2 Rice plants during the early growth stage**

### The plant height and leaf greenness were recorded at one-week interval until the end of vegetative period, as described in section 3.4.1 using randomly selected 10 plants.

The ground cover percentage was measured using the beaded string method until the varieties reached 100%. Two strings with 2 m length were taken and 20 knots were made on each string at 10 cm apart. The two strings were diagonally placed in two locations of each block and counted the number of knots hitting the plant canopy by looking perpendicularly from the top. The ground cover percentage was taken by multiplying the number of knots hitting the plants by 5 (Sarrantonio, 1991).



**1**

**2**

**Plate 3. 5 Layout for measuring ground cover percentage in the blocks.**

The number of plants per square meter and total number of tillers per square were measured by randomly placing the 0.5 **x** 0.5 m quadrant randomly in two places of each block. The total number of tillers per square meter measured 2 months after field establishment at the end of the vegetative growth phase of the plants.

## **3.5 Data analysis**

The data were statistically analyzed by ANOVA using SAS 9.1.3 Portable software and mean separation was done by LSD.

# **CHAPTER 04**

# **RESULTS AND DISCUSSION**

This study was undertaken for the evaluation of optimum seeding rate on seedling vigor and early plant growth of mechanicaly transplanted rice and compare it with other establishment methods of rice.

## **4.1 Determination of optimum seeding rate for modified dapog nursery**

### **4.1.1 Seedling growth parameters**

The seedling growth analysis was considered to be standard approach to study the seedling vigor and early plant growth after field establishment as rapid growth of the seedlings after germination facilitate better establishment of seedlings at the field (Sasaki *et al*., 2005). In this study the estimation of seedling vigor according to the seed rate of nursery tray was done using the seedling growth parameters.

#### **4.1.1.1 Seedling height**

The height of the seedlings in the nursery trays recorded at 3 days interval until 12 days age of two varieties Bg 360 and Bg 374 were presented in Figure 4.1. As regarded with different seed rates T1 (75 g/ tray) contributed to the maximum height in both varieties. It was followed by T2 (100 g/ tray) and T3 (150 g/ tray). The shorter seedlings were produced in T4 (200 g/ tray) in both varieties. The mean seedling height of the two varieties in 3, 6, 9 and 12 DAS showed significant reduction with the increased seed rate. The similar results were recorded by the Gorgy (2012) and Lal and Roy (1996) that proved seedling height increased with the reduced seed rate. The reason for this would be the increase growth rate of the seedlings with low seed rate through the efficient utilization of resources. The seedling height showed a strong negative correlation with the seed rate in both varieties Bg 360 (R = -0.99045) and 374 (R = -0.95804).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **0.64** | **0.42** | **0.55** | **1.04** |

1. **Mean seedling height at 3, 6, 9 and 12 DAS in variety Bg 360**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **0.49** | **0.45** | **1.46** | **0.96** |

1. **Mean seedling height at 3, 6, 9 and 12 DAS in variety Bg 374**

**Figure 4. 1 Mean seedling height of (a) Bg 360 and (b) Bg 374**

#### **4.1.1.2 Seedling dry weight**

The data pertaining to dry weight of 10 seedlings in the two varieties at 12 DAS were presented in Figure 4.2. The seedling dry weight is having a strong negative relationship in both varieties Bg 360 (R = 0.9223) and Bg 374 (R = 0.9421) with the increment of seed rate use for nursery trays. The maximum seedling dry weight was recorded in T1 (75 g/tray), followed by T2 (100 g/tray) and the lowest seedling dry weight was in T4 (200 g/tray).

In Bg 360 the two mean values of the T1 and T2 were not significantly differ. And also, there was no significant difference between the mean seedling dry weights of the T3 (150 g/tray) and T4 (200 g/tray).

Gorgy (2012) and Pathania *et al*., (2016) also recorded the similar findings that there was a significant positive influence on seedling dry matter production by the lower seed rate in the nursery due to increased growth rate and seedling vigor. The seedling dry weight showed a strong positive correlation with the seedling height and the total root length in both varieties.

**CV – 10.38**

1. **Variation of mean dry weight of seedlings according to different seed rates at 12 DAS in variety Bg 360**

**CV – 5.56**

1. **Variation of mean dry weight of seedlings according to different seed rates at 12 DAS in variety Bg 374**

(Means with the same letter are not significantly different)

**Figure 4. 2 Variation of Mean seedling dry weight of (a) Bg 360 and (b) Bg 374**

#### **4.1.1.3 Total root length**

The mean total root length of 10 seedlings in two varieties at 12 DAS were illustrated in the Figure 4.3. There was a strong negative relationship between the mean total root length of seedlings with increment of seed rate in the both varieties Bg 360 (R = 0.9883) and Bg 374 (R = 0.9421). The highest mean value for total root length was recorded in T1 (75 g/tray) and the lowest value in T4 (200 g/tray).

In the variety Bg 360 there is no significant difference in the mean total root lengths of T1, T2 and also between T3, T4 treatments. In the variety Bg 374 there was no significant difference in the total root length of T1, T2, T3 treatments.

Gorgy in 2012 recorded the similar results that the root length of the seedlings decreased with increased seed rate. The reason for this was when the seed rate increased the roots are not having the opportunity to penetrate well towards the nursery medium. The adequate root length was required for the better establishment of seedlings after transplanting in the field through proper anchorage to the soil.

**CV – 6.78**

1. **Variation of mean total root length of seedlings according to different seed rates at 12 DAS in variety Bg 360**

**CV – 6.55**

1. **Variation of mean total root length of seedlings according to different seed rates at 12 DAS in variety Bg 374**

(Means with the same letter are not significantly different)

**Figure 4. 3 Variation of Mean total root length of seedlings (a) Bg 360 and (b) Bg 374**

#### **4.1.1.4 Number of seedlings dispensed per hill**

The mean number of seedlings dispensed per hill in low, mid and the high gears of the transplanter according to the nursery seed rate in two varieties Bg 360 and Bg 374 were presented in the Figure 4.4. According to the graphs, the mean number of seedlings per hill in the low, mid and high gears were having a strong positive relationship with the increase of nursery tray seed rate in both varieties Bg 360 and Bg 374.

As defined by the Islam and Salam (2017), Negalur and Halepyati (2017) and Oparka and Gates (1982) the planting of 3 - 4 seedlings per hill significantly increased the growth of plants and the final yield. And also, there was no any impact in use of increased number of seedlings than that optimum level which caused miss use of seedlings resulting and extra expense on it.

In the section 4.1.1.6, the treatments T2 (100g/tray) and T3 (150g/tray) were selected as optimum seed rate to use for the nursery trays in the varieties respectively Bg 360 and Bg 374. The mid gear of the transplanter which gave average 3 – 4 seedlings per hill in that seed rates was selected for transplanting.

1. **Mean number of seedlings dispensed per hill in mechanical transplanting according to seed rates in variety Bg 360**
2. **Mean number of seedlings dispensed per hill in mechanical transplanting according to seed rate in variety Bg 374**

**Figure 4. 4 Mean number of seedlings dispensed per hill from the transplanter in (a) Bg 360 and (b) Bg 374**

#### **4.1.1.5 Leaf greenness of seedlings (SPAD meter)**

The mean chlorophyll content of the leaves in two varieties Bg 360 and Bg 374 were recorded at 12 DAS displayed in the Figure 4.5. There was no significant difference between the mean chlorophyll content of the leaves in the both varieties with the increment of the nursery seed rate. According to the Esfahani *et al* (2008), the reason may be due to the fertility condition available in the soil is same and as the leaf thickness is very small during the seedling stage, the accurate detection of chlorophyll content is difficult.

**CV – 5.59**

1. **Leaf greenness of seedlings in variety Bg 360**
2. **Leaf greenness of seedlingsin variety Bg 374**

**CV – 3.76**

(Means with the same letter are not significantly different)

**Figure 4. 5 Leaf greenness of seedlings (SPAD meter) (a) Bg 360 and (b) Bg 374**

#### **4.1.1.6 Selection of the optimum seed rate for nursery trays**

The seedling vigor can be expressed in terms of root length, seedling height, dry matter production which changes according to the nursery seed rate (Gorgy, 2012; Lal and Roy, 1996; Matsuo and Hoshikawa, 1993; Rajendran *et al*., 2005)**.** When consider about these parameters the highest vigorous seedlings were produced at low nursery seed rate T1 (75g/tray) in both varieties Bg 360 and Bg 374 because with the increment of the seed rate, the inter plant competition for the resource utilization was high which negatively effects on the seedling vigor.

The seedling height recommended for machine transplanting was 12 cm according to the Mamun *et al* (2013). In the variety Bg 360 only the T1 (75g/tray) and T2 (100g/tray) fulfills this requirement. And in Bg 374, T1 (75g/tray), T2 (100g/tray), T3 (150g/tray) produced seedlings with more than 12 cm height.

The nursery tray requirement depends on the seed rate used for the nursery. So, the cost effectiveness also should be considered when selecting the seed rates.

The seed rate used for mechanical transplanting according to the recommendation of Department of Agriculture (DOA), Sri Lanka was

Bg 374 – 15 kg/acre and

Bg 360 – (10 – 12) kg/acre

(For the nursery tray requirement calculation, the seed rates of two varieties that gives the proper seedling height for mechanical transplanting were selected)

|  |  |  |  |
| --- | --- | --- | --- |
| Variety | Seed rate | Tray requirement /acre | Cost on trays (Rs) |
| Bg 360 | 75g /tray | 134 | 3752 |
| Bg 360 | 100g /tray | 100 | 2800 |
| Bg 374 | 75g /tray | 200 | 5600 |
| Bg 374 | 100g /tray | 150 | 4200 |
| Bg 374 | 150g /tray | 100 | 2800 |

**Table 4. 2 Tray requirement and cost on tray according to the seed rate**

(Price of one nursery tray used for mechanical transplanting = Rs 28)

The most economical feasible method is to use 100 trays as 100 g/tray in Bg 360 and 150 g/ tray in Bg 374.

**Table 4. 3 Calculation of number of seeds applied to a tray according to the optimum seed rate selected in the both varieties**

|  |  |  |
| --- | --- | --- |
| Variety | 1000 Grain Weight | Number of seeds applied to a tray according to the selected seed rate |
| Bg 360 | 13.26 g | 7541 |
| Bg 374 | 19.57 g | 7664 |

The number of seeds applied to the nursery trays in both varieties Bg 360 and Bg 374 were more or less same.

## **4.2 Comparison of Mechanical transplanting with other Establishment methods**

The mechanicaly transplanted rice according to the optimum seed rate selected at the previous experiment were compared with parachute method, random Transplanting, broadcasting by analyzing the growth parameters of seedlings and growth parameters of plants after field established**.**

### **4.2.1 Seedling growth parameters**

The growth of the seedlings depended on the above ground and below ground morphological characteristics that defined the seedling vigor and better growth of transplanted rice after field establishment (Hoshikawa and Ishi, 1974).

#### **4.2.1.1 Seedling height**

The mean seedling height of the four establishment methods during the nursery period of two varieties Bg 360 and Bg 374 were indicated in the Figure 4.6. The measurements were taken at 3 days interval until the 12 DAS.

In the both varieties the mean seedling height of broadcasting at 3 DAS showed a reduced value which was significantly reduced compared to other methods. The reason for this was nurseries of random transplanting, mechanical transplanting and parachute method were covered from coconut leaves during the early period to avoid the damages from the rain. At 12 DAS there was a significant difference in the seedling height of the four establishment methods in both varieties. In Bg 360 and Bg 374 the maximum seedling height was recorded from broadcasting and the shortest seedlings were at wet bed nurseries for random transplanting.

1. **Mean seedling height at 3, 6, 9 and 12 DAS according to the Establishment method in variety Bg 360**
2. **Mean seedling height at 3, 6, 9 and 12 DAS according to the Establishment method in variety Bg 374**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **1.05** | **1.39** | **1.37** | **0.62** |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **0.99** | **0.43** | **0.26** | **0.19** |

(Means with the same letter are not significantly different)

**Figure 4. 6 Mean seedling height (a) Bg 360 and (b) Bg 374**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **1.056568** | **1.394993** | **1.378190** | **0.623783** |

#### **4.2.1.2 Seedling dry weight**

The data on mean seedling dry weight of 10 seedlings in the two varieties Bg 360 and Bg 374 at 12 DAS were statistically analyzed and depicted in the Figure 4.7. In the both varieties the mean total dry weight at broadcasting and parachute method were not significantly differ. And also, there was no significant differ between the Random transplanting and Mechanical transplanting in two varieties. In Bg 360, the highest mean seedling dry weight was recorded from Broadcasting and lowest mean dry weight in seedlings for Random Transplanting. Similar variation was observed in variety Bg 374.

(Means with the same letter are not significantly different)

1. **Mean dry weight of 10 seedlings at 12 DAS in variety Bg 360**
2. **Mean dry weight of 10 seedlings at 12 DAS in variety Bg 374**

**Figure 4. 7 Mean dry weight of seedlings (a) Bg 360 and (b) Bg 374**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **1.056568** | **1.394993** | **1.378190** | **0.623783** |

**4.2.1.3 Total root length of seedlings**

The data pertaining to mean total root length of 10 seedlings in the two varieties at 12 DAS were presented in the Figure 4.8. The seedlings were taken for the measurement of total root length at the time of uprooting for transplanting. In both varieties there was no any significant difference between mean total root length of seedlings from broadcasting and parachute method. And the highest mean root length was recorded from the broadcasting whereas the shortest mean root length from the wet bed for random transplanting.

Bridgit and Potty (2002) and Naklang *et al* (1996) indicated the same findings that higher root length in the direct seeded rice seedlings than the transplanted seedlings. The reason was root damages when uprooting for transplanting. When compared with the three transplanting methods the mean total root length was higher in parachute method compared to the mechanical transplanting and random transplanting as the root system was remained intact at uprooting. The similar findings were reported by Mamun *et al* (2013)and Nabii *et al* (2003).

1. **Mean total root length of seedlings at 12 DAS in variety Bg 360**
2. **Mean total root length of seedlings at 12 DAS in variety Bg 374**

**CV – 4.24**

**CV – 2.31**

(Means with the same letter are not significantly different)

**Figure 4. 8 Mean total root length of seedlings (a) Bg 360 and (b) Bg 374**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CV** | **1.056568** | **1.394993** | **1.378190** | **0.623783** |

**4.2.1.4 Leaf greenness of seedlings (SPAD meter)**

The data on the mean Chlorophyll content of the both varieties at 12 DAS were indicated in the Figure 4.9. According to the statistical analysis there was no any significant difference in the mean Chlorophyll content of the leaves in the both varieties. The reason may be due the similarity of soil fertility level in the field or biotic and abiotic factors as according to the Esfahan*i et al* (2008) and Peng *et al* (1993) these factors affected on the leaf greenness measured from the SPAD meter.

**CV** **– 2.29**

**CV** **– 1.62**

1. **Leaf greenness of seedlings at 12 DAS in variety Bg 360**
2. **Leaf greenness of seedlings at 12 DAS in variety Bg 374**

(Means with the same letter are not significantly different)

**Figure 4. 9 Leaf greenness of seedlings (SPAD meter) (a) Bg 360 and (b) Bg 374**

### **4.2.2 Plant growth parameters**

The analysis of plant growth parameters was considered as a standard approach to study the plant growth and productivity (Wilson, 1981). In this study the early plant growth was analyzed using plant growth parameters. Plant growth parameters allow to study the growth pattern over its growth stage.

**4.2.2.1 Plant height**

Plant height of two varieties recorded at 7 days interval until 42 days after establishment (DAE), was statistically analyzed and furnished in the Figure 4.10. The transplanted plants including random transplanted, mechanicaly transplanted and parachute shows significantly low height at early period after field establishment compared to the Broadcasting in the two varieties Bg 360 and Bg 374. The reason for this may be the growth of the plants was disturbed as roots were damaged when uprooting for field establishment.

In both varieties the mechanicaly transplanted and random transplanted plants there was no significant difference of plant height in 7 DAE and 14 DAE as the transplanting shock due to the root damages occur in transplanting. A rapid increase in the plant height of the parachute transplanted plants was observed compared to the mechanicaly transplanted and random transplanted plants as low percentage of root damage compared to them. So in parachute methods the transplanted plants started early plant growth immediately after transplanting with quick recover from the transplanting shock (Nabii et al., 2003). At 42 DAE a significant different was observed in the plant height of four establishment methods in both varieties.

In both varieties at 42 DAE the maximum mean plant height was observed at Broadcasting and shortest plants at the Random transplanting. The mean plant height at 42 DAE was having a strong positive correlation with the seedling height, dry weight and the total root length at 12 DAS.

1. **Mean Plant height at 7, 14, 21, 28, 35 and 42 DAE in variety Bg 360**
2. **Mean Plant height at 7, 14, 21, 28, 35 and 42 DAE in variety Bg 374**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CV** | **0.68** | **1.07** | **0.31** | **0.44** | **0.27** | **0.41** |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CV** | **1.11** | **1.20** | **0.60** | **0.67** | **0.48** | **0.48** |

(Means with the same letter are not significantly different)

**Figure 4.10 Mean Plant height at in (a) Bg 360 and (b) Bg 374**

#### **4.2.2.2 Ground cover percentage**

Ground cover % was measured in weekly interval during the vegetative phase. The ground cover % of both varieties measured up to the 42 DAE (6 th week) was illustrated in the Figure 4.11. It increased above 50 % at 28 DAE (4th week) in all the establishment methods of both varieties but always higher in the broadcasting compared to transplanting methods, which was 100 %. There was no any significant difference in ground cover % of random transplanting, mechanicaly transplanting and parachute method of both varieties at 7 DAE. In both varieties at 42 DAE, when compared with transplanting methods the lowest ground cover % was recorded from mechanical transplanting but always higher in random transplanting compared to parachute and mechanical transplanting. So, the results emphasize that more attention on weed management was required for mechanical transplanting compared to other establishment methods during the early growth period after field establishment. The ground cover % was having a strong positive correlation with the seedling height, total root length, seedling dry weight which were taken at the time of uprooting for transplanting (12 DAS) in the both varieties.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CV** | **16.05** | **12.94** | **9.67** | **11.70** | **7.67** | **5.84** |

1. **Ground Cover % at 7, 14, 21, 28, 35 and 42 DAE in the variety Bg 360**
2. **Ground Cover % at 7, 14, 21, 28, 35 and 42 DAE in the variety Bg 374**

**AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CV** | **16.63** | **7.11** | **10.73** | **8.46** | **5.80** | **6.10** |

(Means with the same letter are not significantly different)

**Figure 4. 11 Ground cover % (a) Bg 360 and (b) Bg 374**

#### **4.2.2.3 Number of plants per square meter**

The number of plants per square meter in the two varieties at each establishment method were analyzed statistically displayed in the Figure 4.12. In the both varieties the highest number of plants per square meter was recorded at broadcasting than the transplanting. The reason for this was in broadcasting the spacing between the plants were not maintained properly which caused increased plant density. The lowest number of plants per square meter was in the mechanical transplanted blocks in the both varieties as optimum spacing was maintained between the plants.

According to the Department of Agriculture the average number of plants expected per square meter (3 ½ month varieties) for increased rice yield in random transplanting and parachute method was 35 – 45 plants. The plant density obtained per square meter for both varieties in the trial had reached that level.

1. **Number of plants per square meter in variety Bg 360**
2. **Number of plants per square meter in variety Bg 374**

#### 

**CV – 3.43**

#### 

**CV – 2.36**

(Means with the same letter are not significantly different)

**Figure 4. 12 Number of plants per square meter in (a) Bg 360 (b) Bg 374**

#### **4.2.2.4 Number of tillers per square meter**

The data pertaining to tiller density per square meter at the end of the vegetative phase of the two varieties were recorded and illustrated in the Figure 4.13. The tiller density was significantly influenced from the method of establishment. Significantly low tiller density was obtained in the broadcasting compared to the transplanting in both varieties. The similar results were reported by the Awan *et al* (2011) and Javaid *et al* (2012). In transplanting methods, the mechanical transplanting produced the highest tiller density. The number of tillers per square meter was high in parachute method compared to the random transplanting in both varieties which concluded the results of Akbar *et al* (2007) and Reddy (2013).

According to the recommendation of Department of Agriculture, 400 – 350 tillers were expected to get increased rice yield. In Bg 360 only the mechanical transplanting had reached that level and in Bg 374 all the establishment methods were unable to reach that level. The reason might be due to prevalence of more pest and disease attacks in the field where Bg 374 was established. And also, the occurrence of pest and diseases were high in other establishment methods compared to mechanical transplanting.

Mechanical transplanting gave the highest tiller density irrespectively to the lesser number of plants per square meter. The enhanced tillering at mechanical transplanting compared to other establishment methods may be due to efficient utilization of nutrients at the active tillering stage and the availability of sufficient amount of light, water etc. as optimum spacing was maintained between the plants. The number of per square meter was having a strong negative correlation with the number of plants per square meter in the both varieties Bg 360 (R= - 0.86868) and Bg 374 (R= -0.94651). This result agreed with the Illangakoon *et al* (2017), Javaid *et al* (2012) and Sasaki *et al* (2005).

1. **Number of tillers per square meter in variety Bg 360**
2. **Number of tillers per square meter in variety Bg 374**

(Means with the same letter are not significantly different)

**Figure 4. 13 Number of tillers per square meter in (a) Bg 360 and (b) Bg 374**

#### **4.2.2.5 Leaf greenness of plants (SPAD meter)**

The data on the leaf greenness of the both varieties at 42 DAE were illustrated in the Figure 4.14. According to the statistical analysis there was no any significant difference in the mean chlorophyll content of the leaves in the both varieties. The SPAD meter reading varies markedly depending on the growth stage, genotype and the environment conditions (Esfahani *et al*., 2008; Xiong *et al*., 2015). So, the reason for no significant difference might be due to more or less same environmental conditions in the both fields including location, soil fertility level, solar radiation etc.

1. **Leaf greenness of plants at 42 DAE in variety Bg 360**
2. **Leaf greenness of plants at 42 DAE in variety Bg 374**

**CV – 4.47**

**CV – 2.97**

(Means with the same letter are not significantly different)

**Figure 4. 14 Leaf greenness of plants (SPAD meter) (a) Bg 360 and (b) Bg 374**

# **CONCLUSIONS**

The most appropriate method is to use 100 trays for Mechanical Transplanting as 100g/tray in Bg 360 and 150g /try in Bg 374 by considering the seedling vigor and economic feasibility.

Mechanical transplanting produces low ground cover %, and a comparatively low number of plants per square meter than broadcasting, random transplanting and parachute method during the early growth phase as optimum spacing was maintained. Mechanical transplanting produces the highest number of tillers per square meter compared to other establishment methods. As increased number of tillers was considered as main contributor for increased yield in paddy cultivation, the final yield can be increased through mechanical transplanting. Identification of the correct seeding rates for the nursery trays in mechanical transplanting is having a good potential for achieving the sustainability of Rice production in Sri Lanka.

The farmers should be given with the technical knowledge about the proper management practices to follow in mechanical transplanting and also, enhancing them about the long-term benefits of the mechanical transplanting like cost effectiveness, labor use efficiency and increased yield, has become a timely requirement as most of the farmers tend to relinquish the mechanical transplanting only concerning the weed management problems.

The Rice Research and Development Institute (RRDI) had planned to conduct more research on possibility of increasing the rice yield with mechanical transplanting of rice, for selecting optimum seed rate, proper weed management options for mechanically transplanted fields etc. under the project “Closing Rice Yield Gaps in Asia (CORIGAP)”.

**REFFERENCES**

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). Parkistan Journal of Agricultural Science. 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., 2004. Inheritance of seed and seedling vigor in rice (*Oryza sativa* L.). University of Arid Agriculture, Rawalpindi, Pakistan, 179-185.

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.

Awal, A., Ziauddin, A.T.M., 2013. Present status of rice transplanter use for paddy cultivation in Bangladesh. Bangladesh Agricultural University, Mymensingh, Parkistan. 2-15.

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. Journal of Animal and Plant Sciences. 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. Parkistan Journal of Agricultural Science. 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, H., 2012. FAO blamed for spread of chronic kidney disease [WWW Document]. Sunday Times. URL http://www.sundaytimes.lk/121021/news/fao-blamed-for-spread-of-chronic-kidney-disease-17441.html (accessed 10.17.18).

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. Opening Minds: Research for Sustainable Development. 407–409.

Baruah, D.C., Goswami, N.G., Saikia, R., R, 2001. Performance of an eight-row self propelled paddy transplanter. Journal of agricultural engineering. 38, 66–72.

Bautista, E.U., Javier, E.F., 2008. Rice Production Practices. Research Paper Series No. 2008-02. 2, 6-14.

Behera, B.K., 2000. Investigations on puddled soil characteristics in relation to performance of self propelled rice transplanter. G. B. Pant University of Agriculture & Technology, Pantnagar, India. 6-38.

Bridgit, A.T., Potty, N.N., 2002. Influence of root characteristics on rice productivity in iron rich lateric soil of Keral, India. Int. Rice Res. Notes 27, 45–46.

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

Central Bank of Sri Lanka, 2018. Economics and Social Statistics of Sri Lanka.

Central Bank of Sri Lanka, 2017a. National Output, Expenditure and Income.

Central Bank of Sri Lanka, 2017b. Second Quarter 2017 Central Bank of Sri Lanka. URL https://www.cbsl.gov.lk (accessed 11.6.18).

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 research 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.

DailyFT, 2013. Hayleys empowers greater productivity via mechanised rice transplanter [WWW Document]. URL http://www.ft.lk/article/188536/Hayleys-empowers-greater-productivity-via-mechanised-rice-transplanter (accessed 1.23.19).

Das, F.C., 2012. Status and prospects of mechanization in rice. Rice Knowledge Management Portal. 7, 1–24.

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

Deseo, N., 2012. Early vigor traits in selected upland and rainfed lowland Rice ( Oryza sativa L .) Genotypes. University of the Philippines Los Banos. 4-11.

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.

Department of Agriculture Sri Lanka, 2017. Rice Cultivation. Publication unit of Agriculture, Gannoruwa. 27-28.

Dushani, A.L., Sandika, S.N., 2009. Growth Performance of Rice Sector : The Present Scenario in Sri Lanka. Tropical Agricultural Research and Extension. 12, 71–76.

Economynext, 2016. Sri Lanka raises rice productivity with Korean technology [WWW Document]. URL https://economynext.com/Sri-Lanka-raises-rice-productivity-with-Korean-technology-3-5503-.html (accessed 1.23.19).

Esfahani, M., Abbasi, H.R.A., Rabiei, B., Kavousi, M., 2008. Improvement of nitrogen management in rice paddy fields using chlorophyll meter (SPAD). Paddy Water Environment. 6, 181–188.

Fan, Y., Song, Y., Septiningsih, E.M., Prasetiyono, J., Lubis, E., Tai, T.H., Tjubaryat, T., Moeljopawiro, S., McCouch, S.R., 2003. Effect of differentplanting methods and nitrogen levels on growth and yield of rice. Theoretical and Applied Genetics. 107, 363–368.

FAO Sri Lanka, 2012. FAO Country programming framework 2013-2017 Sri Lanka. 4-5.

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

FAO United Nations, 2000. Bridging the rice yield gap in the Asia-Pacific Region, FAO. Bangkok, Thailand. 135-146.

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.

Gaikward, P.B., Shahare, P.U., Pathak, S.V., Aware, V.V., 2015. Development and performance evaluation of four row self propelled paddy transplanter. College of Agriculture Engineering and Technology, Dapoli,India. 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 Journal of Agricultural Sciences. 81, 371–373.

Gorgy, R.N., 2012. Performance of transplanted hybrid rice varieties under different seed rates and nitrogen levels. Journal of Plant Production. 3, 75–89.

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., in: Bakar, B.H., Kurniadie, D., Tjitrosoedrirdjo, S. (Eds.), The Role of Weed Science in Supporting Food Security by 2020. Weed Science Society of Indonesia, Indonesia, pp. 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, 2013. Assessment of direct seeded and transplanting methods of rice cultivars in the northern part of Iran. International Journal of Pharmaceutical sciences and Business management. 1, 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. 91–102.

Himeda, M., 1994. Cultivation technique of rice nurseling seeding: Review of research papers and its future implementation. Agriculture and Horticulture. 69, 679–683.

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. Annals of Sri Lanka Department of Agriculture 2017. 19, 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, 2018a. Transplanting - IRRI Rice Knowledge Bank [WWW Document]. URL http://knowledgebank.irri.org/stepbystepproduction/growth/planting/transplanting/mechanical-transplanting (accessed 9.7.18).

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

IRRI, 2018c. Transplanting - IRRI Rice Knowledge Bank [WWW Document]. URL http://www.knowledgebank.irri.org/stepbystepproduction/growth/planting/transplanting (accessed 1.17.19).

IRRI, 2018d. 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).

IRRI, 2009. Planting the Rice - IRRI Rice Knowledge Bank [WWW Document]. URL http://www.knowledgebank.irri.org/riceproduction/Transplanting (accessed 12.1.18).

IRRI, 2007. Rice Production Manual.

Islam, A.K.M.S., Islam, M.D.T., Rahman, M.D., Shakilur, M.D. Rahman, Kim, Y., 2016a. Investigation on selective mechanization for wet season rice cultivation in Bangladesh. Journal of Biosystems Engineering. 41, 294–303.

Islam, A.K.M.S., Islam, M.T., Rabbani, M.A., Rahman, M.A., Ziaur Rahman, A.B.M., 2015a. Commercial mechanical rice transplanting under public private partnership in Bangladesh. Journal of Bioscience and Agriculture Research. 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. International Journal of Science and Technology. 44, 2562–2573.

Islam, A.K.M.S., Rahman, M.A., Rahman, A.K.M.L., Islam, M.T., Rahman, M.I., 2016b. Techno-economic performance of 4-row self-propelled mechanical rice transplanter at farmers field in Bangladesh. Progressive Agriculture. 27, 369.

Islam, A.K.M.S., Rahman, M.A., Rahman, A.K.M.L., Islam, M.T., Rahman, M.T., 2015b. 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. Progressive Agriculture. 28, 279–286. https://doi.org/10.3329/pa.v28i4.36367

Javaid, T., Awan, I.U., Baloch, M.S., Shah, I.H., Nadim, M.A., Khan, E.A., Khakwani, A.A., Abuzar, M.R., 2012. Effect of planting methods on the growth and yield of coarse rice. J. Anim. Plant Sci. 22, 358–362. https://doi.org/10.4236/ajps.2014.53033

Krishna, A., Biradarpatil, N.K., 2009. Influence of seedling age and spacing on seed yield and quality of short duration rice under system of rice intensification cultivation \*. System 22, 53–55.

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

Central Bank of Sri Lanka, 2017. Second Quarter 2017 Central Bank of Sri Lanka [WWW Document]. URL https://www.cbsl.gov.lk (accessed 11.6.18).

Jamil, M., Hussain, A., 2003. Effect of different planting methods and nitrogen levels on growthand yield of rice (Basmati·385). Theoretical and Applied Genetics. 107(8), 1419–1432.

Louisiana, A., 2009. Understanding seeding rates, recommended planting rates and pure live seed (PLS). Technical Notes. 1–2.

Mamun, M.A.A., Rana, M.M., Mridha, A.J., 2013. Tray Soil Management in Raising Seedlings for Rice Transplanter. Canadian Journal of pure and applied sciences. 7, 2481–2489.

Manes, G.S., Dixit, A., Singh, A., Mahal, J.S., Mahajan, G., 2013. Feasibility of Mechanical Transplanter for Paddy Transplanting in Punjab. Agricultural mechanization in Asia, Africa & Latin America. 44, 14–17.

Manjappa, K., Kataraki, N.G., 2004. Use of Drum Seeder and Transplanter for Increasing Rice Profitability. Karnataka Journal of Agricultural Sciences. 17, 682–685.

Marambe, B., 2009. Weedy rice: evolution, threats, and management. Tropical Agriculturist. 157, 11–15.

Mathew, G.V., 2015. Standardization of media for tray nursery technique in rice. Faculty of Agriculture, Kerala Agricultural University, Thrissur, India. 3-20 .

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

Mishra, A., Salokhe, V.M., 2008. Seedling characteristics and the early growth of transplanted rice under different water regimes. Experimental Agriculture. 44, 365–383. https://doi.org/10.1017/S0014479708006388

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.

Naklang, K., Shu, F., Nathabut, K., 1996. Growth of rice cultivars by direct seeding and transplanting under upland and lowland conditions. Field Crops Research. 48, 115–123. https://doi.org/10.1016/S0378-4290(96)01029-5

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. Series on Harmonization of Regulatory Oversight in Biotechnology. 1–52. https://doi.org/10.1107/S2056989015015029

Oparka, K.J., Gates, P.J., 1982. Origin of Rice *Oryza Sativa* [WWW Document]. URL https://farmer.gov.in/imagedefault/pestanddiseasescrops/rice (accessed 1.23.19).

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., Velasco, L., Fukai, S., 2000. Economics of direct seeding in Asia: patterns of adoption and research priorities, in: Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopez, K., Hardy, B. (Eds.), Direct Seeding:Research Issues and Opportunities. pp. 3–12.

Pathania, R., Shekhar, J., Rana, S.S., Sharma, S., 2016. Evaluation of seeding rates of rice nursery on seedling vigour and its effect on crop productivity under system of rice intensification. Journal of Applied and Natural Science. 8, 2224–2230.

Peng, S., Garcia, F. V, Laza, R.C., Cassman, K.G., 1993. Adjustment for specific leaf weight improves chlorophyll meter’s estimate of rice leaf nitrogen concentration. Agronomy Journal. 85, 987–990.

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. Journal of Agriculture and Veterinary Science. 6, 2319–2372.

Rajapakse, S., Shivanthan, M.C., Selvarajah, M., 2016. Chronic kidney disease of unknown etiology in Sri Lanka. International journal of Occupational and Environmental 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. Indian Journal of Agronomy. 50, 132–136.

Rani, A.S., 2012. Rice yield as affected by seedling vigour through nutrient managemet techniques in nursery. Agricultural College, Bapatla. 12-54.

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.

Rashid, M.M., Ahmed, A., Islam, M.S., Kabir, A.U., 2015. Transplanting rice seedling using machine transplanter: a potential step for mechanization in agriculture. Agronomy Journal. 14, 1–5.

Rasool, F., Habib, R., Bhat, M.I., 2013. Agronomic evaluation of rice ( *Oryza sativa* L .) for plant spacings and seedlings per hill under temperate conditions. African Journal of Agricultural Research. 8, 4650–4653. https://doi.org/10.5897/AJAR10.411

Ratnasekera, D., 2015. Weedy rice: a threat to rice production in Sri Lanka. Journal Univercity of Ruhuna 3(1), 2–13.

Reddy, R.P., 2013. Root Growth in Parachute and Conventional Rice- Transplanting Methods. J. Geol. Soc. India 81, 146–147. https://doi.org/10.1007/s12594-013-0016-8

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. 1-9.

Ros, C., Bell, R.W., White, P.F., 2003. Seedling vigour and the early growth of transplanted rice (*Oryza sativa*). Plant and Soil 252, 325–337.

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

Samarathunga, P., 2011. Sri Lanka as a Rice exporting country: possibilities and problems [WWW Document]. URL http://www.ips.lk/talkingeconomics/2011/12/07/sri-lanka-as-a-rice-exporting-country-possibilities-and-problems (accessed 1.22.19).

Sangeetha, C., Baskar, P., 2015. Influence of different crop establishment methods on productivity of rice–A Review. Agricultural Reviews. 36, 113.

Sarrantonio, M., 1991. Methodologies for screening soil-improving legumes. Rodale Research Centre, Pennsylvania. 310.

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. Journal of Plant Nutrients. 37, 1287–1303.

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. Chilean Journal of Agricultural Research. 71(3), 343–349. https://doi.org/10.4067/S0718-58392011000300001

Sasaki, K., Kishitani, S., Abe, F., Sato, T., 2005. Promotion of Seedling Growth of Seeds of Rice ( *Oryza sativa* L. cv. Hitomebore) by Treatment with H2O2 before Sowing. Plant Production Science. 8(5), 509–514. https://doi.org/10.1626/pps.8.509

Senthilkumar, T., Naik, R., 2016. Study of Adoption of Mechanical Rice Transplanters through Custom Hiring in Tamil Nadu- a Case Study. Journal of Rice Research. 9(4), 35–42.

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. Indian Journal of Ecology, 44(5), 569-573.

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

Singh, R.., Rao, K.V.R., 2010. Impact of self propelled transplanter in rice. Electronic Journal of Environmental, Agricultural and Food Chemistry. Food Chem. 9(1), 150–153.

Singh, R.K., Pande, R.S., Namdeo, N.K., 1981. Response of Ratna to mathods of planting and nitrogen levels. Field Crops Research. 18(2), 182–183.

Singh, S., Vasta, D.K., 2006. Performance of evaluation of PAU manual transplanter in hills of himachal Pradesh. Agricultural engineering today. 30(3), 43–46.

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

Tekrony, D.M., Egli, D.B., 1991. Relationship of seed vigour to crop yield. A Review of Crop Science. 31(3), 816–822.

Thiruchelvam, S., 2005. Efficiency of rice production and issues relating to cost of production in the districts of Anuradhapura and Polonnaruwa. Journal of the National Science Foundation of Sri Lanka. 33(4), 247–256.

Tripathi, K.K., Warrier, R., Govila, O.P., Ahuja, V., 2011. Biology of *Oryza sativa* L.(Rice). Departement of Biotechnology, Ministry of Environment and Forets, Government of India. 3-4.

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. Journal of Advanced Agricultural Technoy. 1(2), 141–146.

Vidanapathirana, U., 2003. The future of paddy farming, its challenges and constraints. Economic Review. 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. Field Crops Research. 121, 53–63. https://doi.org/10.1016/J.FCR.2010.11.009

Wilson, W.J., 1981. Analysis of growth, photosynthesis and light interception for single plant stand. Annalytical Botany. 48, 507–512.

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.

Xiong, D., Chen, J., Yu, T., Gao, W., Ling, X., Li, Y., Peng, S., Huang, J., 2015. SPAD-based leaf nitrogen estimation is impacted by environmental factors and crop leaf characteristics. Scientific Reports. 5(1), 13389. https://doi.org/10.1038/srep13389

Yoshida, S., 1981. Fundamentals of Rice Crop Science. Fundamentals of rice Crop Science. 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 Science. 46(1), 372–380.

# **Appendix: Plagiarism Report**

# Result of analysis

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

Statistics

**Suspicions on the Internet: 18.8%**

*Percentage of text with expressions found on the internet*

**Suspicions confirmed: 73.07%**

*Confirmed the existence of the sentences in the URLs found*

**Analyzed text: 42.69%**

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