UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A HIGH CLEARANCE ANDROID-CONTROLLED INTER-ROW WEEDER FOR RICE INTENSIFICATION SYSTEM

SAMAILA SULEIMAN

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By

SAMAILA SULEIMAN

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Chairman : Professor Wan Ishak Wan Ismail, PhD
Faculty : Engineering

Research was carried out to develop a high clearance inter-row weeder machine with Android control system, to address the challenge of high crop damage associated existing inter-row weeding machines due to low ground clearance under the system of rice intensification. This research was carried out in three main stages namely: Preliminary studies to evaluation of some existing inter-row weeders, Development of a prototype high clearance Android controlled weeding machine and Evaluation of the prototype machine.

Four existing mechanical inter-row weeding machines with different design configurations used by farmers in Tanjung Karang Malaysia under system of rice intensification were selected and evaluated in terms of crop damage factor at forty days after transplanting. The result revealed that none of the four existing machines could weed up to forty days after transplanting (40DAT) due high crop damage as a result of inadequate machine ground clearance. The frequency of weeding cycles was found to increase rice yield, with 13.1tons/ha for the three cycle weeded plots, whereas a maximum of only 9 tons/ha was recorded with two cycle weeded plots.

A prototype hydraulic powered inter-row weeder having 60cm ground with Android control was developed to weed in paddy field at different stages of paddy heights under the system of rice intensification. The machine was built on Kubota S125 engine as its prime mover. A 120cm diameter cage wheel designed with lugs to aid traction, adequate adjustable track width of 25cm to 30cm to accommodate variation in inter-row distance to reduce crop damage. Other components of the machine are the main frame attached to the prime mover; five row rotary weeding assembly units with hydraulic depth control attached to the main frame. A 12V 3-2 way solenoid directional control valves mounted on MMC-01-4 Manifold block regulate flow to and out of actuators. An android application was developed to automate the prototype machine via Android phone Bluetooth within 100m operating radius. A 2.4G wireless video module on the machines as the mobile node transmits real time video signal, thus enabling tele-operation of the machine via android phone.

The prototype machine was evaluated to establish its performance parameters at block D, Sawah Sempandan, Tanjung Karang, Selangor Malaysia. The experiment was a Split Plot Design experiment with five (5) main and sub-plots were studied. The plot size of 2.3m x 16.5m (37.95m^2) each was used for the evaluation. The main plots are two levels of plant spacing of 30cm x 21cm and 30cm x 18cm, Number of weeding cycles (5 levels), two level of rotor 500 RPM & 600 RPM, Seed rate (two levels). Mechanical weeding was carried out using the high clearance inter-row weeder at 10 days interval as recommended by the system of rice intensification (SRI). Data collected on machine weeding performance were subjected to ANOVA and DUNCAN test analysis using the SAS (version 9.3) statistical software.

Result showed that the prototype machine was able to weed up to fifty days after transplanting with low percentage of crop damage of 2.54%. The mean comparison of rice vegetative height were 61.90cm and 62.18cm while yield were 7.09tons/ha and 7.01tons/ha respectively for the fourth and fifth weeding cycles. These results suggest no significant difference between the fourth and fifth weeding cycles, thus implying weeding can be stopped at the fourth cycle without significant loss in yield. The seed rate and hill spacing were also observed to significantly influence the yield positively. The single seedling plots yielded an average of 9tons/ha both for four and five weeding cycles, while the 2-3 seedling per hill plots yielded an average 5.5 tons/ha to 6 tons/ha for same level of weeding. The analysis of machine rotor rpm was shown to be significant on weeding efficiency and fuel consumption at $P \leq 0.05$ level, having 92.93% and 1.29 lit/hr respectively at 600 rpm. However, a similar trend was observed in the percentage of crop damage with increase in rotor speed. The android control user interface design implementation among three groups of planters (A) 18-25 years, (B) 26-32 years and (C) above 32 years, revealed no significant different in the scores of the three age groups that participated in the evaluation. This suggests the ability of all age groups to satisfactorily operate the machine via the android control.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PEMBANGUNAN JENTERA MERUMPAI BERKELEGAAN TINGGI KAWALAN ANDROID UNTUK SISTEM INTENSIFIKASI PADI

Oleh

SAMAILA SULEIMAN

Jun 2017

Pengerusi : Profesor Wan Ishak Wan Ismail, PhD
Fakulti : Kejuruteraan

Penyelidikan telah dijalankan untuk membangunkan mesin merumpai antara baris barkelegaan tinggi dengan sistem kawalan Android, untuk menangani cabaran kerosakan tanaman yang tinggi yang dikaitkan dengan mesin merumpai antara baris yang sedia ada kerana berkelegaan rendah di bawah sistem intensifikasi padi. Penyelidikan ini dijalankan dalam tiga peringkat utama iaitu: Kajian permulaan untuk menilai beberapa mesin merumpai yang sedia ada, Pembangunan prototaip mesin merumpai berkelegaan kawalan Adroid dan Penilaian mesin prototaip.

Empat mesin merumpai antara baris yang sedia ada dengan konfigurasi reka bentuk yang berbeza yang digunakan oleh petani di Tanjung Karang Malaysia di bawah sistem intensifikasi padi telah dipilih dan dinilai dari segi faktor kerosakan tanaman pada empat puluh hari selepas pemindahan. Hasilnya menunjukkan bahawa kesemua empat mesin yang sedia ada tidak boleh merumpai sehingga empat puluh hari selepas pemindahan (40DAT) mengakibatkan kerosakan tanaman yang tinggi kerana kelegaan tanah yang tidak mencukupi. Kekerapan kitaran rumpai didapati meningkatkan hasil beras, dengan 13.1 ton / ha untuk tiga plot rumpai, sedangkan maksimum hanya 9 tan / ha dicatatkan dengan dua plot kitaran .merumpai.

Prototaip mesin merumpai antara baris berkuasa hidraulik dengan kelegaan 60cm tanah dengan kawalan Android telah dibangunkan untuk merumpai di sawah padi pada tahap ketinggian yang berbeza di bawah sistem intensifikasi padi. Mesin ini di bangunkan di atas enjin Kubota S125 sebagai penggerak utamanya. Roda sangkar bergarispusat 120cm yang direka bentuk dengan 5baris perumpai berputar untuk membantu daya tarikan, lebar trek laras yang boleh disesuaikan 25cm hingga 30cm untuk menampung variasi jarak antara baris untuk mengurangkan kerosakan tanaman. Komponen lain mesin ini adalah bingkai utama yang dipasang pada

penggerak utama melalui perhimpunan penyangkut kerangka utama. Lima baris unit dengan kawalan kedalaman hidraulik dilampirkan pada bingkai utama. Injap kawalan arah solenoid 12V 3-2 yang dipasang pada blok MMC-01-4 Manifold mengawal aliran kepada dan daripda penggerak. Aplikasi android telah dibangunkan untuk automasi mesin prototaip melalui Bluetooth telefon Android dalam lingkungan radius 100m. Modul video tanpa wayar 2.4G pada mesin merumpai sebagai nod mudah alih menghantar isyarat video masa nyata, sekali gus membolehkan operasi mesin melalui telefon android.

Mesin prototaip dinilai untuk menentukan parameter prestasinya di blok D, Sawah Sempandan, Tanjung Karang, Selangor Malaysia. Eksperimen ini adalah Eksperimen rekabentuk plot tapak lima (5) plot utama dan sub-plot dipelajari. Saiz plot 2.3m x 16.5m (37.95m2) masing-masing digunakan untuk penilaian. Plot utama adalah dua peringkat jarak tumbuhan 30cm x 21cm dan 30cm x 18cm, Bilangan kitaran merumpai (5 tahap), dua tahap rotor 500 RPM & 600 RPM, Kadar biji (dua peringkat). merumpai mekanikal dilakukan dengan menggunakan mesin merumpai berkelegaan tinggi pada selang 10 hari seperti yang diperakukan oleh sistem intensifikasi padi (SRI). Data yang dikumpul pada prestasi merumpai mesin dikenakan analisis ujian ANOVA dan TURKEY menggunakan perisian statistik SAS (versi 9.3).

Hasilnya menunjukkan bahawa mesin prototaip dapat merumpai sehingga lima puluh hari selepas pemindahan dengan peratusan rendah kerosakan tanaman sebanyak 2.54%. Perbandingan purata ketinggian vegetasi padi adalah 61.90cm dan 62.18cm manakala hasil masing-masing adalah 7.09 ton / ha dan 7.01 ton / ha untuk kitaran merumpai keempat dan kelima. Keputusan ini menunjukkan tiada perbezaan yang ketara antara kitaran merumpai keempat dan kelima, dengan itu menyimpulkan merumpai boleh dihentikan pada kitaran keempat tanpa kehilangan hasil yang ketara. Kadar biji dan jarak pokok juga diperhatikan dengan ketara mempengaruhi hasilnya secara positif. Plot anak benih tunggal menghasilkan purata 9 ton / ha untuk empat dan lima pusingan merumpai, sementara plot 2-3 anak setiap plot menghasilkan rata-rata 5.5 ton / ha hingga 6 ton / ha untuk tahap merumpai yang sama. Analisis rpm rotor mesin ditunjukkan dengan ketara pada kecekapan pemotongan dan penggunaan bahan api pada tahap $P \leq 0.05$, masing-masing mempunyai 92.93% dan 1.29 liter /jam pada 600 rpm. Walau bagaimanapun, gaya yang sama diperhatikan dalam peratusan kerosakan tanaman dengan peningkatan kelajuan rotor. Pelaksanaan reka bentuk antara muka pengguna kawalan android di antara tiga kumpulan penanam (A) 18-25 tahun, (B) 26-32 tahun dan (C) di atas 32 tahun, menunjukkan tiada perbezaan yang signifikan dalam skor tiga kumpulan umur yang menyertai penilaiannya. Ini mencadangkan keupayaan semua kumpulan umur untuk mengendalikan mesin dengan memuaskan melalui kawalan android.

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I certify that a Thesis Examination Committee has met on 21 June 2017 to conduct the final examination of Samaila Suleiman on his thesis entitled "Development of a High Clearance Android-Controlled Inter-Row Weeder for Rice Intensification System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Desa bin Ahmad, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

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Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Khalina binti Abdan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Ray A. Bucklin, PhD
Professor
University of Florida
United States
(External Examiner)

NOR AINI AB. SHUKOR, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 8 August 2017

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Wan Ishak Wan Ismail, PhD
Professor, Ir
Faculty of Engineering
Universti Putra Malaysia
(Chairman)

Muhammad Razif Mahdi, PhD
Senior Lecturer
Faculty of Engineering
Universti Putra Malaysia
(Member)

Muhamad Saufi Mohd Kassim, PhD
Senior Lecturer
Faculty of Engineering
Universti Putra Malaysia
(Member)

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Name of Chairman of Supervisory Committee: Professor Dr. Wan Ishak Wan Ismail

Signature: ________________________________

Name of Member of Supervisory Committee: Dr. Muhammad Razif Mahdi

Signature: ________________________________

Name of Member of Supervisory Committee: Dr. Muhamad Saufi Mohd Kassim

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AISC	American Institute of Steel Construction
ASME	American Society of Mechanical Engineers
ASABE	American Society of Agricultural and Biological Engineers
MARDI	Malaysian Agricultural Research and Development Institute
CCD	Charge-coupled device
DAT	Days after Transplanting
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agricultural Organization. Statistics
GM	Genetically Modified
GPS	Global Positioning System
IPM	Integrated Pest Management
IADA	Integrated Agricultural Development Area
IRRI	International Rice Research Institute
KADA	Agricultural Development Authority
MADA	Muda Agricultural Development Authority
NIR	Near Infrared
NOSC	National Organic SRI Center
OA	Organic Agriculture
RMP	Recommended Management practice
RM	Malaysian Ringgit
SRI	System of Rice Intensification
USDA	United States Department of Agriculture
UPM	Universiti Putra Malaysia

UKM	National University of Malaysia
MMS	Multimedia Messaging Service
3D	Three dimensions
P	Pressure (N/m^2)
F	Force (N)
A	Area (m^2)
W	Work done (Nm)
P_w	Power (Nm/s)
t	Time (s)
HP	Horsepower
V	Displacement in $in^3/stroke$
A	Cross section of the bore in in^2
L	Cylinder stroke in $in.$
Q	Flow rate gal/min or$liter/min$
N	Speed (rpm)
T	Torque $(N.m)$
ηp	Overall pump efficiency (%)
Tt	Theoretical torque $(lbf - in)$
Vp	Displacement (in^3)
Fs	Factor of safety
Sal	Allowable strength
σap	Applied stress
η_w	Weeding Efficiency
$W1$	Weight of weeds before weeding (g)

$W2$	Weight of weeds after weeding (g)
DF	Damage factor
$Q1$	Number of tillers in 10 m row length before weeding.
$Q2$	Number of tillers damaged along 10 m row length after weeding
Ce	Effective field capacity (hah^{-1})
S	Travel speed of the weeder (kmh^{-1})
Wc	Width of work (m)
Fe	Field efficiency of the weeder (%)
Tt	Total time (h)
Te	Useful time working (h)
Wc	Working capacity (hha^{-1})
RPM	Revolution per minute
Awc	Area of weeding claw (cm^2)
Aru	Number of claws on each rotor
Edf	Effective draft force (N)
Aru	Area of rotor unit (cm^2)
Ss	Shear stress of soil (Ncm^{-2})
Pr	Power requirement for the rotor unit (Hp)
Ks	Maximum tangential force (kg)
Cs	Reliability factor, 1.5 for non-rocky soils and 1 for rocky soil
Nc	Power rating of the prime mover (Hp)
ηc	Tractive efficiency value for forward rotation of rotor shafts
ηz	Coefficient of engine power reservation between 0.7 to 0.8
μmin	Minimum tangential speed of the rotor (m/s)

F	Force applied (N)
$-K$	Spring constant
x	Spring extension (cm)
Q_{act}	Actual pump flow rate (gpm)
D	Displacement (cc/rev)
V_{eff}	Volumetric efficiency (%,)
$\boldsymbol{E_p}$	Pump's mechanical efficiency (%)
Ls	Lug spacing (mm)
h	Depth of lug sinkage (mm)
s	Minimum shear spacing (mm)
i	Maximum slip
r	Wheel radius (mm)
M	Mobility number (dimensionless)
CI	Cone Index (kPa)
W	Weight on tyre (kN)
b, d & h	Tyre width, tyre diameter & tyre section height (m)
δ	Tyre deflection underweight W, (1m)
ρ	Coefficient of rolling resistance
Wv	Dynamic weight on the tyres
Dpull	Draw bar pull (N)
H	Tractive force (N)
R	Rolling resistance (N)
Ψ	Tractive coefficient
V_f	Dynamic weight on the front wheel (N)
V_r	Dynamic weight on the rear wheel (N)

ρ_f	Coefficient of rolling resistance on the front wheel
W_f	Static weight on the front wheel (N)
W_r	Static weight on the rear wheel (N)
x	Distance between the front and rear axel (m)
y'	Distance between the point of action of the draw bar and ground level (m)
W1	One weeding plot
W2	Two weeding plot
W3	Three weeding plot
W4	Four weeding plot
W5	Five weeding plot
R1	Rotor 500 rpm
R2	Rotor 600 rpm
FS1	Forward speed 0.6m/s speed
FS2	Forward speed 0.8m/s speed
H1	Hill spacing (30cm x 18cm)
H2	Hill spacing (30cm x 21cm)
SR1	Seed rate (1 seedling)
SR2	Seed rate (2 to 3 seedlings)
$Adj.Wt$	Adjusted weight (ton)
$Adj.Mc$	Adjusted moisture content (%)
$Aact.Mc$	Actual moisture content at harvest (%)
$Measured\ Wt$	Measured weight at harvest (ton)

CHAPTER 1

INTRODUCTION

1.1 Overview of the chapter

This chapter describes the background of rice production, its increasing demand and concern for sustainability, environment and health. The growing need organic rice and the challenge that impede the adoption of organic practice such as the System of Rice Intensification (SRI) are highlighted. The problems identified with mechanical weeding in SRI, the objectives set to be achieved and the scope of work is presented.

1.2 Background of the Study

Rice a semi-aquatic grass species that comprises about twenty two species of the class Oryza, out of which twenty are wild. Thus, two classes or species of rice are essentially consumed by humans: *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) are the main food for about three quarter of the world population and fundamental to food security since majority of the global population depends on it. This translates to approximately about three to four billion people that depend on rice daily as staple food. It's been estimated that nearly 144 million hectares of land is cultivated with rice each year, with the annual global rice production and average yield at 454.6 million tons and 4.25 ton/ha respectively (Sumithra et al., 2014; Harijono and Desa, 2014 and International Rice Research Institute (IRRI), 2012). Rice production and consumption has been expanding in the last decade outside the traditional rice producing areas, especially in western Asia and Europe (Seck et al., 2012 and Cherati et al., 2012). Food habits, demand due to population, economic needs and related issues are encouraging people to produce rice anywhere water is available (Seck et al., 2012 and SRI, 2006). Rice a consistent constituent of cuisines of Asians, producing about 95% of the global rice, and provides up to 50% of the calories of Asian nourishment (Sumithra et al., 2014; Wayayok et al., 2014; Alizadeh, 2011 and Chamhuri et al., 2014). With current global rice yield of 454.6 million tons, it is uncertain if yield increases can be attained to keep leap with the increasing food demand. To this regard, Nellemann (2009) reported that current projections reveals that 50% raise in rice production is needed by 2050 to withstand the demand, taken into considerations the losses in yield and land mass due to environmental impact. Hence, Remesan et al., (2007) reported that the existing increasing domestic and international demand for rice as food can only be achieved through enhanced productivity and intensive cropping. These views suggest that, it is very vital to improve yield through intensive agriculture, meaning better inputs and management practices.

Rice is considered the number three most important crop in Malaysia, mostly cultivated in the eight granary areas of Peninsular Malaysia (Chamhuri et al., 2014; FAO, 2014 and Rezaul et al., 2004). Rice is cultivated on about 600,000 ha in

Malaysia; two-third of which are situated in Peninsula Malaysia's eight major granary areas (Muazu et al., 2014 and Cheong, 1998). These granary areas collectively produce about seventy percent (75%) of paddy cultivated in the country. About 150,000 farmers in Malaysia solely depend on rice production as their major source of income Najim et al., (2007). With Malaysia's current population figure of about 28, 401,000 and rice consumption per capita of 110kg/year, to achieve 100% self-sufficiency from the 75% level, rice production targets 3,216,100 tons and average yield of 5.32 tons/ha. Malaysia's high annual rainfall and humidity in conjunction with its tropical temperature supports double cropping system, thus a potential to increased yield and the desired self-sufficiency. However, notwithstanding yearly government expenditure to support paddy cultivation, the mean national rice yield standing at about 3.782 tons/ha is still about 10% less than global average yield (Muazu, 2015; Man and Sami, 2009 and Murad et al., 2008). Hence, increasing rice production in Malaysia is achievable if the limited (yet productive) land resource are matched with improve cultivation organic practices such as the system of rice intensification (SRI) in conjunction with high yielding seed such as MR219 developed by the Malaysian Agricultural Research and Development Institute (MARDI), with potential output of up to 10 tons/ha. On the other hand, increasing output should be pursued along with sustainability, environment and consumers growing interest in organic food.

The system of rice intensification (SRI), an Organic agriculture (OA) practice follows the principle of circular relationship and has arisen in response to questions about health, environment and sustainability issues Jitendra & Singh, (2012), advocates against use of chemical and genetically modified (GM) materials on farms Nandwani & Nwosisi, (2016). OA shuns the use of synthetic fertilizers, herbicides, and growth controllers. In its place encourages crop rotations, natural manures, mechanical method of weed control, and biological weed/pest control to preserve soil health, provide plant nutrient needs, minimize insects and control weed. Most agricultural producer's especially organic farmer's rank weed management as their major production cost. Thus, weed management has progressively turned out to be important in organic products such as SRI due to increased market stake and drawing greater courtesy in recent years (Fumitaka et al.,2015; Young and Pierce, 2014 and Ana, 2010). The challenge in mechanical weed control is further amplified due to rising choice of farmers and consumers for safety and healthy organic products (Fumitaka et al., 2015; Willer & Kilcher, 2011). The system of rice intensification (SRI), has been reported as a potential way to save resources (water, seed) in growing organic rice with an impressive average yield of about 7tons/ha under irrigated or rain-fed conditions. However, water management and controlling weeds through mechanical weeding are the main challenges connected with rice production under SRI (Preston,2014). Therefore, SRI researchers and farmers as well have invented and deployed scientific methods in mechanical weed control (Kwesi & Datti, 1991; Merry et al., 2015).

Mechanical weeding an important and labour intensive unit operation in organic rice is fatiguing and time consuming. In practice, quite a number of weeding cycles may be required to ensure the crops are weed free crop to prevent yield losses. Globally, rice yield loss as a result of weeds is put at 10% of estimated yield (Fletcher, 1983), between 16 to 42 % depending on crop and location (Rangasamy et al.,1993) and 75-100% loss in yield (Mahdi et al., 2005; Cordill and Grift, 2011). These reports indicate that to achieve high yield in organic rice production, good agronomic practices such as intensive weeding are required. Thus, Dale et al., (2014); Olaoye et al., (2012); Cordill and Grift, (2011) and Tony et al., (2008) opined that the only sustainable solution to weed control is high-speed mechanical weed control or the deployment of weeding robots that can replace chemical application especially in organic agriculture. On the other hand, manual weeding though effective and its labour demand are high and time consuming (Marenya,2009). It was reported that averagely, the energy requirement of manual tillage (hoe) ranges from 7 to 9.5kJ/min in comparison to 4.5 kJ/min (75 watts) the optimum limit of constant energy output of man (Silas & Husseni, 2015 and Nwuba, 1981).

Mechanical weeding implements are available based on cutting, burying and uprooting of weeds. Based on the cutting and burying of weed, mechanical weeding implements are classified into inter-row and intra-row weeders. According to Pullen & Cowel, (1997) there are six categories of inter-row mechanical weeders deployed to control weeds namely: harrow, rotary hoe, duck foot, ground wheel driven rotary hoes and brush weeders. The efficacy of mechanical weeding operations according to Ahmad, (2012) depends on factors such as plant height, rooting depth and forward speed. He further opined that more aggressive operations, generally result in higher weeding efficiency, but often increase the risk of damaging crop plant. Similarly, it was reported in Uphoff et al (2002) and Uphoff (2006) that, rotary inter-row weeding increases aeration and better root growth development. Hence, choosing and deploying appropriate method of weed control for organic and system of rice intensification has been focused on increased yield, environment and health (Bhatt, 2015). On the other hand, the System of Rice Intensification (SRI) methodologies for producing rice under irrigated or rain-fed conditions, containing set of simple principles help produce more productive and robust organic rice with high yield. The main SRI Practices are: (a) Transplanting tender seedlings of 8-15days grown in an un-flooded nursery at 25cm x 25cm inter-row and intra-row. (b) Transplant seedlings carefully at shallow depth. (c) Controlled water management (no permanent flooding) (d) Intensive mechanical weeding at 10 days interval, up to 40 days after transplanting and (e) Application of organic matter or manure. These practices according to Barison & Uphoff (2010) and Uphoff (2006) can yield a better root and vegetative development of rice under SRI as compared to Non-SRI is shown in Figure 1.0 below. Under SRI, the MR219 variety developed by Malaysian Agricultural Research and Development Institute (MARDI), records yield of up to 13 tons per hectare as reported in Melati, (2012) and Styger et al. (2011). The success story of SRI prompted research interest to make comparative studies with other known cultural practices in rice cultivation. Thus, Alfred et al., (2016) studied and analyzed yield per hectare and opined that SRI present a substantial and economic advantage with about 60% of yield gains and reduced production cost per hectare. Earlier Thura, (2010) compared the performance of SRI and Recommended Management Practice (RMP), and reported that both practices resulted in high yield gains at row and intra-row spacing of 25cm x 25cm, however the yield under SRI was 40% higher than recommended practice. The result indicates that even the recommended Management practice (RMP) yields better at SRI recommended spacing. Despite the potential of increased yield, cost and water saving potential under SRI, a major constraint to adoption by farmers is the high labor demands for mechanical weeding and single seedling transplanting (Alam et al., 2015; Ramachandra et al., 2012b; Reddy, 2009; Tilahun et al., 2015). The high labour demand in SRI practices may be due to the intensive mechanical weeding required, principally due lack of high clearance mechanical weeders. The limitation of low ground clearance weeders was further highlighted by Cloutier et al.,(2007) they reported that, the constraint to mechanical weeding is that weed control can only be achieved at early stages of crop growth because of limited machine ground clearance and machine-crop contact can lead to substantial damage to the foliage or vegetative component of the crop at advanced state of growth. Similarly, Alam et al. (2015) and. Van der et al. (2008) further reported that the efficacy of mechanical weeding procedures usually depends on often factors such as crop height and depth of the root zone. Thus, the constraint for effective SRI recommended intensive weeding in rice by farmers, is lack of a high clearance weeder that can effectively weed when rice are at advanced stage of growth (height). However, high clearance machine for weed control in rice only exist in the form of sprayers, no documented mechanical inter-row weeders was found in literature capable of weeding up to forty days after transplanting (40DAT) in paddy fields at different stages of paddy height as recommended by the system of rice intensification. With mechanical rotary weeding, weeds are incorporated into the soil; build up soil organic matter and increase microbial activity in the soil, resulting in better rice yield (Styger et al, 2011; Uphoff et al., 2006 and Barison & Uphoff, 2010).To address the need for intensive mechanical weeding requirement under SRI, research was carried out to develop a high clearance inter-row weeder with android tele-oprated control for System of Rice Intensification (SRI), specifically for MR219. The new high clearance machine will enable weeding at stages of paddy growth, reduce high labour demand due to intensive weeding requirement in SRI, reduce drudgery, promotes organic rice production and making farming an interesting business venture. The research will also add to existing body of literature on android application in the control of agricultural machinery. Entrepreneurs in agricultural machinery development will also benefit from the technology by way of patronage from SRI/organic rice farmers.

1.3 Statement of Problem

The System of Rice Intensification (SRI), an organic rice production practice identified that mechanical weeding in paddy up to four times at ten days interval, increases yield up to above 7tons/ha. Weeds control under SRI however remains a serious challenge facing famers, due mainly to the practice of intensive mechanical weeding requirement up to 40DAT (Alam, 2015; Ramachandra, 2012c; Ramachandra, 2012b and Adusumilli et al. 2015). Studies on existing inter-row weeders used in SRI revealed no available machine with enough ground clearance to weed beyond thirty days after transplanting (30DAT) with minimum percentage of crop damage. Thus, there exist limitations to adoption of inter-row weeders, due to inadequate machine ground clearance. Currently cono-weeder and manual weeding are mainly used, they are however labour intensive and low field capacity (Adusumilli et al. 2015; Upadhyaya et al., 2007; Hegazy et al., 2014; Ahmad, 2012 and Cloutier et al., 2007). Hence, the constraint faced by SRI farmers for effective adoption of recommended intensive weeding needs is the lack of a high clearance weeding machine that can effectively weed with less crop damage when rice are at advanced stage of growth (height) and its labor intensive nature.

This research work was therefore aimed at developing a high clearance Inter-row weeding machine with android control to effectively weed in paddy fields at different stages of plant growth, without the need for the operator walking behind the machine along paddy field. Distinct parameters that could affect weed control efficacy will be studied. This research will add to the existing body of literature on mechanical weed control, and the application of android application to automate agricultural machinery to attract younger generation in paddy cultivation. Rice growers' especially those adopting SRI and organic rice producers can benefit from this research through access to a high clearance weeder suitable for multiple mechanical weeding at all stages of paddy growth with less fatigue and increase yield.

1.4 Research Objective

The general objective of this research is to develop a High Clearance Inter-row Weeder for the System of Rice Intensification (SRI), specifically for the MR2119 cultivar, widely grown by paddy farmers across the eight rice granary areas in Malaysia. The specific objectives of this study are:

1. To evaluate the existing inter-row weeders used for weed control in SRI
2. To develop a hydraulic powered inter-row rotor with appropriate clearance height to weed in paddy with less crop damage.
3. To develop an android operated control system to automate the high clearance inter-rwo weeder.
4. To evaluate the performance of the prototype high clearance inter-row weeder.

1.5 Scope of the Study

This study focuses on developing a new high clearance inter-row weeder with android control for SRI, to increase the frequency of weeding cycles to five times. Preliminary studies will be conducted on four selected inter-row weeders to assess their ability to weed up to 40DAT with less crop damage. The prototype will be evaluated with MR219 cultivar. Data collection on the cultivation practices was limited to those of mechanical weeding and yield, because of their direct relation with the operations of the high clearance inter-row weeding machine. Android application user interface for tele-operation of the machine via Android Hand-phone was equally evaluated in terms of obstacle avoidance.

1.6 Outline of the Thesis

This thesis is organized into five chapters. Chapter one explains the background of the research, provides an overview on rice production most especially on organic rice and the system of rice intensification along with the objective set to be achieved in the study. Literatures related rice production particularly on non-chemical weed control in paddy and factors considered for the design; development and control of the high clearance inter-row are presented in chapter two. The methodology, materials and evaluation procedure used to achieve the set objectives are explained carefully in chapter three. Chapter four contains the comprehensive results and subsequently discussed in relation to set objectives. The conclusions drawn at the end of the study and suggestions for further research are presented in chapter five.

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