UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF BIO-MULCHING MATERIALS FOR WEED CONTROL, SOIL MOISTURE CONSERVATION AND INSECT REPELLENCY IN SYSTEM OF RICE INTENSIFICATION

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FK 2015 180

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By

MOHAMMED UMAR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science.

May 2015

DEDICATION

This thesis has been dedicated to Umaru Fulani's family and the entire Muslim Umma, May Almighty Allah (SWT) shower His blessings and mercies abundantly on them.

Abstract of the thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

DEVELOPMENT OF BIO-MULCHING MATERIALS FOR WEED CONTROL, SOIL MOISTURE CONSERVATION AND INSECT REPELLENCY IN SYSTEM OF RICE INTENSIFICATION

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MOHAMMED UMAR

May 2015

Chairman: Aimrun Wayayok, PhD
Faculty: Engineering

Weed growth is one of the main constrains of System of Rice Intensification (SRI) due to wide planting spacing (25 × 25 cm or more) and alternate wetting and drying (AWD), thereby reducing rice crop yields up to 70% if there is no weed control attempted. Also, evaporation from the available space due to wide planting pattern and transpiration by the weeds in the SRI field reduces the additional water saving which affect the potential of SRI water productivity. This research was designed to develop a bio-mulching material for weed control, soil moisture conservation with the ability to control insects in SRI farming. Two types of soil cover were made in the study namely; SRImat and UMAR-SRImat. SRImat was made using ground rice straw and plastic net, while UMAR-SRImat was made using flaked rice straw and biodegradable adhesive. The first experiment (field work I) was laid out using randomized complete design (RCD) with five treatments [No soil cover (T1), 0.19 mm thickness of commercialized black Plastic (CBP) (T2), 0.57 mm thickness of CBP (T3), 0.95 mm thickness of CBP (T4) and 2.00 mm thickness of SRImat (T5)] and three replications. The transplanting spacing pattern was 25 cm × 25 cm. While the second experiment (field work II) was laid out using randomized complete block design (RCBD) with four treatments [without soil cover (T1), SRImat (T2), UMAR-SRImat without lemon grass extract (LGE) (T3) and UMAR-SRImat with LGE (T4)] and three replications. The transplanting spacing pattern was 30 cm × 30 cm. The analysis was conducted using analysis of variance (ANOVA) and T-test. Volumetric moisture content (VMC) was determined at 24 days after transplanting (DAT) in the first experiment, but at 18 and 25 DAT in the second experiment. Weeds were observed and recorded from the treatment plots to determine the weed density (WD), weed density ratio (WDR), weed dry weight (DW), weed dry weight ratio (DWR) (weed control efficiency), and summed dominance ratio at 24 DAT in the first experiment, while in the second experiment at 20 and 40 DAT. Growth performance was determined by collecting the number of tillers at 24 DAT in the first experiment, but at 30 and 40 DAT in the second experiment with additional data of plant height per hill at 30 DAT. The insect population were observed and recorded at 10 DAT, 20 DAT, 30 DAT and 40 DAT.

The result of volumetric moisture content showed that both SRImat and UMAR-SRImat significantly saved water (253.0447[a] m^3/ha and 3100.0[a] m^3/ha respectively) higher than the control treatment. The effectiveness of SRImat on weed control was 98.5% (WCE) at 24 DAT, while the effectiveness of UMAR-SRImat mulched was 100% at 20 DAT and 99.64% at 40 DAT. The least average number of insect at 20 DAT (3.3 No./m^2) appeared in the plots treated with Umar-SRImat comprised of LGE. This research revealed that UMAR-SRImat mulch could control weeds up to 40 DAT as recommended in SRI, retained soil moisture, and repelled insect population up to 20 DAT.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PEMBANGUNAN BAHANBIO-SUNGKAPAN UNTUK KAWALAN RUMPAI, PEMULIHARAAN KELEMBAPAN TANAH DAN PENGHALAU SERANGGA DALAM SISTEM PENANAMAN PADI INTENSIF

Oleh

MOHAMMED UMAR

Mei 2015

Pengerusi: Aimrun Wayayok, PhD
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Pertumbuhan rumpai adalah salahsatu kekangan utama Sistem Penanaman PadiIntensif (SRI) kerana jarak penanaman yang luas (25 × 25 cm atau lebih) dan kaedah pembasahan dan pengeringan alternatif (AWD), yang menyebabkan pengurangan hasil tanaman padi sehingga 70% jika tidak ada pengawalan rumpai. Juga, sejatan dari ruang yang ada kerana corak penanaman yang luas dan transpirasi oleh rumpai di ladang SRI mengurangkan penjimatan air yang ditambah akhirnya memberi kesan kepada potensi produktiviti air. Penyelidikan ini telah dirancang untuk membangunkan bahan bio-sungkapan untuk kawalan rumpai dan pemuliharaan kelembapan tanah dengan keupayaan untuk mengawal serangga dalam perladangan SRI. Dua jenis perlindungan tanah telah dibuat dalam kajian ini iaitu; SRImat dan UMAR-SRImat. SRImat dibuat menggunakan jerami padi dan jaring plastik, manakala UMAR-SRImat telah dibuat menggunakan jerami padi yang telah diparut dan pelekat. Percubaanpertama (bidangkerja I) telah didirikan dengan menggunakan rekabentuk rawak lengkap (RCD) dengan lima rawatan [Tiada penutup tanah (T1), CBP berketebalan 0.19 mm (T2), CBP berketebalan 0.57 mm (T3), CBP berketebalan 0.95 mm (T4) dan SRImat berketebalan 2.00 mm (T5)] dan tiga ulangan. Jarak tanaman adalah 25 cm × 25 cm. Manakala eksperimen kedua (kerjalapangan II) telah dijalankan menggunakan rekabentuk blok rawak lengkap (RCBD) dengan empat rawatan [tanpa penutup tanah (T1), SRImat (T2), UMAR-SRImat tanpa LGE (T3) dan UMAR-SRImat dengan LGE (T4)] dan tiga ulangan. Jarak tanaman adalah 30 cm × 30 cm. Analisis ini dijalankan dengan menggunakan analisis varians (ANOVA) dan ujian-T. Kandungan kelembapan isipadu (VMC) telah ditentukan pada 24 Hari Lepas Tanam (DAT) dalam eksperimen pertama namun, pada 18 dan 25 DAT bagi eksperimen kedua. Rumpai telah diperhatikan dan dirakamkan dari plot rawatan untuk penentuan kepadatan rumpai (WD), nisbah kepadatan rumpai (WDR), berat kering rumpai (DW), nisbah berat kering rumpai (DWR) (kecekapan kawalan rumpai) dan nisbah penguasaan terkumpul dalam eksperimen pertama, manakala dalam eksperimen kedua telah dirakamkan pada 20 dan 40 DAT. Prestasi pertumbuhan telah ditentukan dengan pengumpulan bilangan anak padi pada 24 DAT dalam eksperimen pertama, tetapi tidak pada umur 30 dan 40 DAT

dalam eksperimen kedua bersama dengan data tambahan iaitu ketinggian pokok setiap rumpun pada 30 DAT. Bilangan serangga telah diperhatikan dan direkodkan pada 10, 20, 30 dan 40 DAT. Hasil dari pada kandungan kelembapan isipadu menunjukkan SRImat dan UMAR-SRImat dapat menjimatkan air (253.0447[a] m^3/ha dan 3100.0[a] m^3/ha) lebih tinggi dari pada rawatan kawalan dengan ketara. Keberkesanan SRImat pada kawalan rumpai adalah 98.5% (WCE) pada 24 DAT, manakala keberkesanan UMAR-SRImat sebagai sungkapan adalah 100% di 20 DAT dan 99.64% pada 40 DAT. Bilangan purata serangga yang paling kurang adalah pada 20 DAT (3.3 No./m^2) berlaku pada plot yang dirawat mengguna UMAR-SRImat yang mengandungi LGE. Kajian ini menunjukkan bahawa sungkapan UMAR-SRImat dapat mengawal rumpai sehingga 40 DAT seperti saranan oleh SRI, mengekalkan kelembapan tanah dan menghalaukan populasi serangga sehingga 20 DAT.

ACKNOWLEDGEMENTS

I would greatly like to extent gratitude to Allah Subhanahu Wata'ala for the good health condition blessed upon me throughout the period of this study.

I am specially gratefull to Dr. Aimrun Wayayok, The chairman of my Supervisory Committee, Prof. Ir. Dr. Mohd Amin B. Mohd Soom (member) and Associate Prof. Dr. Khalina Abdan (member), Department of Biological and Agricultural Engineering, Universiti Putra Malaysia for their constructive criticism, encouragement, valuable suggestions and cordial health throughout the research period.

I also profoundly wish to thank the management of Umar Suleiman College of Education Gashua for allocated TETFund. Especially, Dr. Usman Mohammed Dakasku (The Provost).

However, I am also thankful to all my colleagues, friends and well-wishers especially to our research group, for their guidance, understanding and encouraging advices.

My deepest appreciation goes to my wife (Fatimah Zubairu Masaya) and her unborn baby (Sumayya Mohammed Umar) for their endless support and prayers to the success of the study.

I would fairly conclude by expressing my appreciation to my parent for their continuous patience, sacrifices, blessings, moral, counselling and financial support during the study period.

I certify that a Thesis Examination Committee has met on (15 May 2015) to conduct the final examination of (Mohammed Umar) on his thesis entitled "Development of bio-mulching materials for weed control, soil moisture conservation and insect repellency in system of rice intensification" 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 Master of Science.

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I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision
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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of variance
ATS	-	Association Tefi Saina
AWD	-	Alternate wetting and drying
BERNAS	-	Padiberas Nasional Berhad
CBP	-	Commercialized Black Plastic
CIIFAD	-	Cornell International Institute for Food, Agriculture and Development
cm	-	Centimetre
cm^2	-	Centimetre square
cm^3	-	Centimetre cube
CV	-	Coefficient of variation
DAT	-	Days after transplanting
Fe^{2+}	-	Ferrous iron
FELCRA	-	Federal Land Consolidation and Rehabilitation Authority of Malaysia
FOFIFA	-	Foibem-pirenena hoan'ny fikarohana ampiharina Ho fampandrosoana ny eny Ambanivohitra
g	-	Gramme
g/cm^3	-	Gramme per centimetre cube
g/m^2	-	Gramme per metre square
GSRI	-	SRI Group of Madagascar
H_2S	-	hydrogen sulphide
ha	-	Hectare
HP	-	Horse power

hrs	-	Hours
INTROP	-	Institute of Tropical Forestry and Forest Products
IPM	-	Intergrated pest management
JIS	-	Japanese Industrial Standard
K	-	Pottasium
kg	-	Kilogram
kg/ha	-	Kilogram per hectare
kg/m^2	-	Kilogramme per metre square
L	-	Litre
L/kg	-	Litre per kilogramme
LGE	-	Lemon grass extract
LSD	-	Least significance difference
m	-	Metre
m^2	-	Metre square
m^3/ha	-	Metre cube per hectare
$m^3/ha/season$	-	Metre cube per hectare per season
m^3/m^3	-	Metre cube per metre cube
MARDI	-	Malaysia Agricultural and Rural Development Institute
MC	-	Moisture content
mL	-	Millilitre
mm	-	Millimetre
mm^3	-	millimetre cube
MOU	-	Memorandum of understanding
MR	-	Malaysian ringgit
MRRS	-	Al-Mishkhab Rice Research Station

M_s	-	Mass of oven-dried soil in the soil sample
M_w	-	Mass of water in the soil sample
N	-	Nitrogen
N/mm^2	-	Newton per millimetre square
NGO	-	Non-governmental Organization
NOSC	-	National Organic SRI Centre
O	-	Oxygen
^oC	-	Degree Celcius
P	-	Phosphorus
RCD	-	Randomized Complete Design
RCBD	-	Randomized complete block design
RD	-	Relative dry weight
RDW	-	Relative dry weight
RPM	-	Revolution per minutes
SDR	-	Summed dominance ratio
SEACON	-	Southeast Asian Council for Food Security and Fair Trade
SMC	-	Soil moisture content
SRI	-	System of Rice Intensification
t/ha	-	Tonnes per hectare
T_c	-	Weed number in unmulched plots
T_{dc}	-	Dry weight of weeds in unmulched plot
T_{dt}	-	Dry weight of weeds in a mulched plot
TS	-	Thickness swelling
T_t	-	Weed number in mulched plots
U.S.	-	United States

UKM	-	National University of Malaysia
UPM	-	Universiti Putra Malaysia
USAID	-	United States Agency for International Development
UTM	-	Universal Testing Machine
V	-	Volume of dried soil sample
WCE	-	weed control efficiency
WDR	-	Weed density ration
WUE	-	water use efficiency
X	-	Mass of ring plus lid
Y	-	Mass of ring plus lid plus dried sample
β	-	Volumetric moisture content
ω	-	Soil moisture content
p_p	-	Dry bulk density
p_w	-	Density of water
x_c	-	Percentage of single content
A	-	Total weight of mixed composites
w_c	-	Weight of single content
T_1	-	Thickness (mm) before immersion in water
T_2	-	Thickness (mm) after immersion in water
P	-	Maximum load
L	-	Span
b	-	Width of sample
t	-	Thickness of the sample
m_1	-	Mass (g) before oven dried
m_0	-	Mass (g) after oven dried

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Rice (*Orizasativa L.*) is one of the most crucial foods within Asia, especially, Malaysia. But, certain obstacles delayed Malaysia's food security to be accomplished due to several problems - the rice farm field remained unmodified to about 40 years back, rapid increased of population caused large domestic need for rice (1.5 to 2.4 million tonnes), increased the importation of rice (167,000 to 1,070,000 tonnes), the declining of Malaysia's self-sufficiency in the previous time to 63% even with the higher yield produced by the conventional agricultural systems, in addition to yearly reduction in number of farmers participating in paddy farming (CIIFAD, 2014b). The conventional system of rice farming in Malaysia harvested average of 4 t/ha while SRI rice farming yielded 7 t/ha using MR 219 in 2009, and 9 t/ha in Sabah (2010) (CIIFAD, 2014d). To maintain and sustain the Malaysia's food security, rice yield has to be increased by using the available resources, particularly water. For rice crop to yield 1 kg of rice grain, it requires 3000-5000 litres of water depending on the cultivation practice of the rice crop (Geethalakshmi et al., 2011). However, Water evaporation from bare soil is up to 25 -50% of the whole amount of water applied to the farm (Hu et al., 1995).

Therefore, one of the important issues in rice farming is water requirement. The sustainability of irrigated rice farming system and food security is affected by water crisis, which influences different locations in the world (Satyanarayana et al., 2007). Hence, there is a huge challenge to increase paddy yield in order to attain food security, by using of new methodologies and cultural practices in paddy farming.

System of rice intensification, known as SRI is an innovation in rice farming cultural practice for increasing the productivity of water, capital, labour and land. SRI is all about altering the management of soil, water, rice plants and nutrients. It is environmentally friendly and makes the yield of rice to significantly increase, in addition to water productivity by using of less external inputs, which in turn will have a positive effect to the farmers, as well as, the country at large. Also, SRI plays important roles in term of water, land, labour and capital productivity in irrigated rice production area (Kassam et al., 2011).

SRI comprises of various components to be followed. The components are transplanting of young and single seedlings per hill at wider spacing, applying of organic inputs (e.g. pesticide, fertilizer, herbicide and insecticide) and less use of water through alternate wetting and drying (AWD) to provide moist environments (CIIFAD, 2014a), but it can be modified if the key components are adopted. The constituents of SRI was stated by Satyanarayana et al., (2007), which involve transplanting of young seedlings of less than 15 days, only one seedling per each hill, wide planting spacing of at least 25 × 25cm, and wet soil situation at the vegetative phase. SRI has many benefits more than the conventional method of paddy farming. It raises paddy grain yield by no less than 50% ((Lin et al., 2005), save seeds between the range of 80 - 90% (Miyazato et al., 2010a), save water by no less than 50% (Satyanarayana et al., 2007), in addition to reducing the expenditure of paddy production (Tech, 2004).

Therefore, SRI is divided in to three different approaches (CIIFAD, 2014a). Firstly, is the basic SRI, which was initiated by Fr. Henri de Laulanie i.e. transplanting of younger seedlings at disperse spacing, no frequent irrigation, applying of chemical fertilizer and occasional used of organic matter to develop the soil structure. Secondly, is the preferable and perfect SRI-: organic SRI which is similar to the basic SRI, But without applying chemical fertilizer, instead, organic fertilizer is being applied in order to increase the soil fertility at the same time enhancing the biological activities. Thirdly, is partial SRI due to the influence of farmers' choice (e.g. transplanting older seedlings instead of younger once) and Local climate condition (e.g. in rain fed SRI, moist environment is difficult to manage).

1.2 Problem Statements

One of the most important problems of SRI is weed infestation due to the AWD, wider planting spacing of one seedling (at least 25 × 25 cm) and aerobic or unsaturated environment. Competition of weeds in SRI practice has an important influence in affecting the final yield. Similar research revealed that SRI yield failure due to competition of weed is up to 69.15% and 10 to 88% in unweeded plots if there is no weed control attempted. Water productivity which is among the advantages of SRI was significantly decreased up to 38% compare to weed free treatment plot. This may possibly occur due to the effects of transpiration from the weeds in the unweeded treatment plots.

Water, nutrients, sunlight and carbon dioxide are the main factors for which rice crops and weeds compete. For instance, if weeds were not control, it depletes 35 N, 45 K_2O and 15 P_2O_5 kg/ha from the plots whereas 60 N, 26 K_2O and 80 P_2O_5 kg/ha are being absorbed by rice plants under weed free condition at maturity stage (Singh et al., 1999).

Generally, SRI farming uses different methods of weed management such as herbicide application, competitive rice cultivars, hand weeding, flooding, mechanical weeding, mulching and integrated weed management (IWM), with dissimilar degree of achievement. Currently, hand row weeder can be able to suppress the infested weeds up to 40 days after transplanting (DAT), although is labour intensive. motorized weeding machine resolved the problem of the intensive labour, however it can be able to operate in SRI farm up to 30 DAT (10, 20 and 30 DAT) because of the height and horizontal vegetative part of the rice plants, which is being injured by the motorized weeding machine. Again, due to the design of the motorized weeder, it cannot be able to suppress all the weeds within the rows, leading to hurtful competition to the rice plants. After the weeding operations using manual weeder or motorized weeder some of the infested weeds can be able to grow again from the roots, mostly, rhizomatous weeds.

1.3 Scope of the Study

This research focused on developing a SRImat involved rice straw, plastic net, lemon grass extract (LGE) and binder, which can be used in the SRI farm for weed control and moisture conservation. The study is only to control the weeds and soil moisture up to 40 DAT; because the SRI field is being flooded permanently from 40 DAT, until two weeks to harvesting, hence, the field is kept under drain (non-flooded) condition. Also, LGE served as natural insecticide which is environmentally friendly, less hazardous and sustaining of the natural enemies of the insects.

The effect of permanent flooding and shading effect of the rice crops vegetative part will prevent sun light radiation to reach the soil surface. Thus, the weeds and moisture control will be overtaken by the permanent flooding and shading effect of the rice crops vegetative part.

1.4 Objective of the Study

The main objective of this research is to develop a bio-engineering material to serve as organic mulch which enables to suppress weeds in order to reduce the loss of water from the weeds through transpiration; conserve soil moisture in order to reduce the loss of water from the bare soil through evaporation; and repel insects in SRI farming practice. The objectives of the study are clearly stated as follows:

1. To develop a bio-mulching material for weed control, soil moisture conservation and insect repellent in SRI farming.
2. To determine the performance of SRImat on weed control and soil moisture content.
3. To determine the performance of UMAR-SRImat on weed control, soil moisture conservation and insect repellent.

1.5 Hypothesis of the study

The hypothesis in the present study is that, rice straw when processed into mat will provide effective weed control and moisture conservation as well as insect repellent.

1.6 Significance of the Study

New method of organic weeds control in SRI farming which can prevent soil loss and degradation, recycling of rice straw nutrients and preventing environmental pollution due to burning of the rice straw is developed. Most of the farmers in Malaysia, that are practicing SRI farming are eager to overcome the inability to control the weed infestation up to 40 days after transplanting (DAT) with motorized mechanical weeder (CIIFAD, 2014d; Yahaya, 2013) without destructing the sideways vegetative part of the rice plant (Haden et al., 2007).

Furthermore, due to population growth and water crises, there is need for water conservation for the sustainability of irrigation water and food security, which influences various locations in the world (Satyanarayana et al., 2007). These will improve the potential of water and land productivity of SRI farming, which in turn, contributed to food security.

1.7 Thesis Layout

Five chapters are reported in this thesis. Chapter one highlighted the background on food security in Malaysia, water crises, conventional modern agricultural practices, and SRI farming system; problem statements; scope of the study; objectives of the study; hypothesis as well as significance of the study. In chapter two, literature review is explained on the SRI background, different between conventional and SRI system of farming, weeds found in SRI fields, weed and rice crop competition, various method of weed control, mulching effects, water saving and irrigation requirement for SRI, rice straw in SRI farm, and insects diversity in SRI farm. In chapter three, methodology of the research work is presented on SRImat fabrication, experimental field work I, Improved SRImat known as UMAR-SRImat and experimental field work II. In chapter four, the results obtained from the research work are presented and discussed accordingly. Finally, summary and conclusion derived from this study, as well as the recommendations for further studies are presented in chapter five.

REFERENCES

Albertsson, A., Andersson, S. O., & Karlsson, S. (1987). The mechanism of biodegradation of polyethylene. *Polymer Degradation and Stability, 18*(1), 73-87.

Ali, M., Hasan, M., Sikder, S., Islam, M., & Hafiz, M. (2013).Effect of seedling age and water management on the performance of boro rice (*oryza sativa L.*) variety BRRI Dhan28. *The Agriculturists, 11*(2), 28-37.

Babar, S. R., & Velayutham, A. (2012a). Weed management practices on nutrient uptake, yield attributes and yield of rice under system of rice intensification. *Madras Agricultural Journal, 99*(1/3), 51-54.

Babar, S., & Velayutham, A. (2012b). Weed management practices on weed characters, plant growth and yield of rice under system of rice intensification. *Madras Agricultural Journal, 99*(1/3), 46-50.

Barison, J., & Uphoff, N. (2011). Rice yield and its relation to root growth and nutrient-use efficiency under SRI and conventional cultivation: An evaluation in madagascar. *Paddy and Water Environment, 9*(1), 65-78.

Bhella, H. (1988). Tomato response to trickle irrigation and black polyethylene mulch. *Journal of the American Society for Horticultural Science (USA). http://agris.fao.org/agris-search/search.do?recordID=US8853637*. Retrieved 2 October 2014.

Bioflora.(2013). Definition of soil microbe groups. http://www.bioflora.com/soil-microbes. Retrieved 21 November 2013.

Bird, J., Eagle, A., Horwath, W., Hair, M., Zilbert, E., & van Kessel, C. (2002). Long-term studies find benefits, challenges in alternative rice straw management. *California Agriculture, 56*(2), 69-75.

Carnell, D. (1978). Photodegradable plastic mulch in agriculture. *Proc Nat Agr Plastics Congr, 14*, 143-148.

Chaboussou, F. (2004).*Healthy crops: A new agricultural revolution.* Jon Carpenter Publishing.http://www.cabdirect.org/abstracts/20053039457.html;jsessionid=403C9DE2382DFFAB9853B5B9779F503F. Retrieved 21 November 2013.

Chauhan, B., & Johnson, D. (2009). Ludwigia hyssopifolia emergence and growth as affected by light, burial depth and water management. *Crop Protection, 28*(10), 887-890.

Chen, Z. (1985). Polythene mulched groundnut development in guanzhou city. *Peanut Sci. Technol, 3*, 34-37.

Cherati, F. E., Bahrami, H., & Asakereh, A. (2011).Evaluation of traditional, mechanical and chemical weed control methods in rice fields. *Australian Journal of Crop Science, 5*(8), 1007.

Chung, I., Ahn, J., & Yun, S. (2001). Identification of allelopathic compounds from rice (oryza sativa L.) straw and their biological activity. *Canadian Journal of Plant Science, 81*(4), 815-819.

Chung, I., Kim, K., Ahn, J., Lee, S., Kim, S., & Hahn, S. (2003). Comparison of allelopathic potential of rice leaves, straw, and hull extracts on barnyardgrass. *Agronomy Journal, 95*(4), 1063-1070.

CIIFAD.(2013). SRI international network and resource center. Retrieved from http:// sri.ciifad.cornell.edu/

CIIFAD.(2014a). Guideline on SRI practice for tropical countries. http://sri.ciifad.cornell.edu/countries/japan/extmats/JSRI_Guideline0312.pdf. Retrieved 25 April 2014.

CIIFAD. (2014b). REPORT ON S.R.I. VISIT TO MALAYSIA, july 1 - 9, 2011. http://sri.ciifad.cornell.edu/countries/malaysia/Malaysia_UphoffTripRept0711.pdf. Retrieved 2 April 2014.

CIIFAD. (2014c). SRI in Madagascar. http://sri.ciifad.cornell.edu/countries/madagascar/index.html. Retrieved 2 April 2014.

CIIFAD. (2014d). SRI in Malaysia. http://sri.ciifad.cornell.edu/countries/malaysia/index.html. Retrieved 2 April 2014.

CIIFAD. (2014e). SRI in Malaysia. http://sri.ciifad.cornell.edu/countries/malaysia/MalaysiaArchives.html. Retrieved 2 April 2014.

CIIFAD. (2014f). SRI origin. http://sri.ciifad.cornell.edu/aboutsri/origin/index.html. Retrieved 2 April 2014.

Dahal, K. R., & Khadka, R. B. (2013). Performance of rice with varied age of seedlings and planting geometry under system of rice intensification (SRI) in Farmer's field in western terai, nepal. *Nepal Journal of Science and Technology, 13*(2), 1-6.

De Prisco, N., Immirzi, B., Malinconico, M., Mormile, P., Petti, L., & Gatta, G. (2002).Preparation, physico-chemical characterization, and optical analysis of polyvinyl alcohol-based films suitable for protected cultivation. *Journal of Applied Polymer Science, 86*(3), 622-632.

Deb, D., Lässig, J., & Kloft, M. (2012).A critical assessment of the importance of seedling age in the system of rice intensification (SRI) in eastern India. *Experimental Agriculture, 48*(03), 326-346. doi:10.1017/S001447971200004X

Debeaufort, F., Quezada-Gallo, J., & Voilley, A. (1998). Edible films and coatings: Tomorrow's packagings: A review. *Critical Reviews in Food Science, 38*(4), 299-313.

Devasinghe, D., Premarathne, K., & Sangakkara, U. (2011). Weed management by rice straw mulching in direct seeded lowland rice (oryza sativa L.). *Tropical Agricultural Research, 22*(3), 263-272.

Dewi, P. P. (2009). Climate change impacts on tropical agriculture and the potential of organic agriculture to overcome these impacts.*Asian Journal of Food and Agro-Industry, 2*(Special Issue), S10-S17.

Di Franco, C., Cyras, V., Busalmen, J., Ruseckaite, R., & Vázquez, A. (2004). Degradation of polycaprolactone/starch blends and composites with sisal fibre. *Polymer Degradation and Stability, 86*(1), 95-103.

Dobermann, A. (2004). A critical assessment of the system of rice intensification (SRI). *Agricultural Systems, 79*(3), 261-281.

Doran, J. (1980). Microbial changes associated with residue management with reduced tillage. *Soil Science Society of America Journal, 44*(3), 518-524.

Ebana, K., Yan, W., Dilday, R. H., Namai, H., & Okuno, K. (2001). Variation in the allelopathic effect of rice with water soluble extracts. *Agronomy Journal, 93*(1), 12-16.

El-Shahawy, T. A., & Zydenbos, S. (2010). Rice straw as an allelopathic agent for controlling weeds.*17th Australasian Weeds Conference. New Frontiers in New Zealand: Together we can Beat the Weeds. Christchurch, New Zealand, 26-30 September, 2010.* 143-146.

Garnaud, J. (1974). The intensification of horticultural crop production in the mediterranean basin by protected cultivation. http://agris.fao.org/agris-search/search.do? record ID=XF19750015629. Retrieved 2 October 2014.

Geethalakshmi, V., Ramesh, T., Palamuthirsolai, A., & Lakshmanan.(2011). Agronomic evaluation of rice cultivation systems for water and grain productivity. *Archives of Agronomy and Soil Science, 57*(2), 159-166.

Gibson, K., & Fischer, A. (2001).Relative growth and photosynthetic response of water-seeded rice and echinochloa oryzoides (ard.) fritsch to shade. *International Journal of Pest Management, 47*(4), 305-309.

Ginigaddara, S., & Ranamukhaarachchi, S. (2011).Study of age of seedlings at transplanting on growth dynamics and yield of rice under alternating flooding and suspension of irrigation of water management. *Recent Research Science and Technology, 3*(3), 76-88.

Haden, V. R., Duxbury, J. M., DiTommaso, A., & Losey, J. E. (2007). Weed community dynamics in the system of rice intensification (SRI) and the efficacy of mechanical cultivation and competitive rice cultivars for weed control in indonesia. *Journal of Sustainable Agriculture, 30*(4), 5-26.

Halley, P., Rutgers, R., Coombs, S., Kettels, J., Gralton, J., Christie, G., . . . Jayasekara, R. (2001). Developing biodegradable mulch films from starch-based polymers. *Starch‐Stärke, 53*(8), 362-367.

Hameed, K. A., Mosa, A. J., & Jaber, F. A. (2011). Irrigation water reduction using system of rice intensification compared with conventional cultivation methods in iraq. *Paddy and Water Environment, 9*(1), 121-127.

Hanafi, E. M., El Khadrawy, H., Ahmed, W., & Zaabal, M. (2012).Some observations on rice straw with emphasis on updates of its management. *World Applied Sciences Journal, 16*(3), 354-361.

Hanumanthappa, M., Dalavai, B., & Malleshappa, C. (2009). Influence of age of seedlings and use of conoweeder on growth and yield of SRI method paddy. *Mysore Journal of Agricultural Sciences, 43*(1), 173-175.

Hasanuzzaman, M., Ali, M., Alam, M., Akther, M., & Alam, K. F. (2009).Evaluation of preemergence herbicide and hand weeding on the weed control efficiency and performance of transplanted aus rice. *American–Eurasian J.Agron, 2*, 138-143.

Hassan, S., Aidy, I., Bastawisi, A., & Draz, A. (1998a). Weed management using allelopathic rice varieties in egypt. *Allelopathy in Rice, International Rice Research Institute, Manila,* , 27-37.

Hassan, S., Aidy, I., Bastawisi, A., & Draz, A. (1998b). Weed management using allelopathic rice varieties in egypt. *Allelopathy in Rice, International Rice Research Institute, Manila,* , 27-37.

Hong, Y. C., Lee, J. T., Kim, H., Ha, E. H., Schwartz, J., & Christiani, D. C. (2002).Effects of air pollutants on acute stroke mortality. *Environmental Health Perspectives, 110*(2), 187-191. doi:sc271_5_1835 [pii]

Horie, T., Shiraiwa, T., Homma, K., Katsura, K., Maeda, S., & Yoshida, H. (2005). Can yields of lowland rice resume the increases that they showed in the 1980s? *Plant Production Science-Tokyo-, 8*(3), 259.

Hu, W., Duan, S., & Sui, Q. (1995). *High-yield technology for groundnut*. International arachis newsletter volume 15 ICRISAT.

Hutchison, C. E., & Kieber, J. J. (2002).Cytokinin signaling in arabidopsis.*The Plant Cell, 14 Suppl*, S47-59.

Ibarra-Jimenez, L., Quezada-Martin, R., Cedeno-Rubalcava, B., Lozano-del Rio, A., & de la Rosa-Ibarra, M. (2006). Watermelon response to plastic mulch and row covers. *European Journal of Horticultural Science, 71*(6), 262-266.

IRRI.(2014). Weed control. http://www.knowledgebank.irri.org/ericeproduction/PDF_&_Docs/Weed_control.pdf. Retrieved 2 May 2014.

Jacob, D., & Syriac, E. K. (2005).Performance of transplanted scented rice (oryza sativa L.) under different spacing and weed management regimes in southern kerala. *J.Tropical Agric, 43*(1/2), 71-73.

Jaishy, S. (2000). Current fertility status of nepal and IPNS. *Component of Integrated Plant Nutrient Management for Nepal. Proceedings of a Workshop at the Department of Agriculture, Harihar Bhawan, Lalitpur, Nepal*, 23-29.

Japanese Standards Association (JSA).(2003). Particleboards.japanese industrial standard (JIS) A 5908-2003.

Jayasekara, R., Harding, I., Bowater, I., & Lonergan, G. (2005).Biodegradability of a selected range of polymers and polymer blends and standard methods for assessment of biodegradation. *Journal of Polymers and the Environment, 13*(3), 231-251.

Jung, W., Kim, K., Ahn, J., Hahn, S., & Chung, I. (2004). Allelopathic potential of rice (Oryza sativa L.) residues against echinochloa crus-galli. *Crop Protection, 23*(3), 211-218.

Kalita, H., & Gogoi, A. (1994).Effect of calcium peroxide and butachlor on growth and yield of rice (oryza sativa). *Indian Journal of Agronomy, 39*(2), 297-298.

Karki, K. (2009). Productivity and economic viability of rice under different planting pattern and age of seedlings through system of rice intensification (SRI). Master of Science thesis.

Karthikeyan, K., Sosamma, J., & Purushothaman, S. M. (2010).Incidence of insect pests and natural enembies under SRI method of rice cultivation. *ORYZA-an International Journal on Rice, 47*(2), 154-157.

Kasirajan, S., & Ngouajio, M. (2012). Polyethylene and biodegradable mulches for agricultural applications: A review. *Agronomy for Sustainable Development, 32*(2), 501-529.

Kassam, A., Stoop, W., & Uphoff, N. (2011). Review of SRI modifications in rice crop and water management and research issues for making further improvements in agricultural and water productivity. *Paddy and Water Environment, 9*(1), 163-180.

Khatri-Chhetri, T. (1991).Introduction to soils and soil fertility. *Rampur, Chitwan, Nepal: Institute of Agriculture and Animal Sciences,* , 28-42.

Krishna, A., & Biradar Patil, N. (2010). Influence of seedling age and spacing on seed yield and quality of short duration rice under system of rice intensification cultivation. *Karnataka Journal of Agricultural Sciences, 22*(1)

Krupnik, T. J., Rodenburg, J., Haden, V. R., Mbaye, D., & Shennan, C. (2012). Genotypic trade-offs between water productivity and weed competition under the system of rice intensification in the sahel. *Agricultural Water Management*, *115*, 156-166.

Krupnik, T. J., Shennan, C., Settle, W. H., Demont, M., Ndiaye, A. B., & Rodenburg, J. (2012). Improving irrigated rice production in the senegal river valley through experiential learning and innovation. *Agricultural Systems*, *109*, 101-112.

Kumar, R. M., Padmavathi, C., Surekha, K., Latha, P. C., Krishnamurthy, P., & Singh, S. P. (2007). Influence of organic nutrient sources on insect pests and economics of rice production in india. *Indian Journal of Plant Protection*, *35*(2), 264-267.

Kwabiah, A. (2004). Growth and yield of sweet corn (zea mays L.) cultivars in response to planting date and plastic mulch in a short-season environment. *Scientia Horticulturae*, *102*(2), 147-166.

Lamont, W. J. (2005). Plastics: Modifying the microclimate for the production of vegetable crops. *HortTechnology*, *15*(3), 477-481.

Latif, M., Ali, M., Islam, M., Badshah, M., & Hasan, M. (2009). Evaluation of management principles and performance of the system of rice intensification (SRI) in bangladesh. *Field Crops Research*, *114*(2), 255-262.

Latif, M. A., Islam, M. R., Ali, M. Y., & Saleque, M. A. (2005). Validation of the system of rice intensification (SRI) in Bangladesh. *Field Crops Research, 93*(2-3), 281-292.

Lawrence, M. J. (2007). *A Novel Machine to Produce Fuel Nuggets from Non-Recyclable Plastics* (Doctoral dissertation), the Pennsylvania State University.

Li, F., Song, Q., Jjemba, P. K., & Shi, Y. (2004). Dynamics of soil microbial biomass C and soil fertility in cropland mulched with plastic film in a semiarid agro-ecosystem. *Soil Biology and Biochemistry*, *36*(11), 1893-1902.

Li, Y., Hagen, G., & Guilfoyle, T. J. (1992).Altered morphology in transgenic tobacco plants that overproduce cytokinins in specific tissues and organs. *Developmental Biology, 153*(2), 386-395.

Lin, X., Zhou, W., Zhu, D., Zhang, Y., & Yang, G. (2005). The photosynthetic rate and water use efficiency of leaves at different position at panicle initiation stage under the system of rice intensification (SRI). *Chinese Journal of Rice Science, 19*, 200-206.

Lippert, L., Takatori, F., & Whiting, F. (1964).Soil moisture under bands of petroleum and polyethylene mulches. *Journal of the American Society for Horticultural Science, 67*, 541-546.

Liu, J., Jia, C., & He, C. (2012).Flexural properties of rice straw and starch composites. *AASRI Procedia, 3*, 89-94.

Liu, X., Wang, J., Lu, S., Zhang, F., Zeng, X., Ai, Y., . . . Christie, P. (2003). Effects of non-flooded mulching cultivation on crop yield, nutrient uptake and nutrient balance in rice–wheat cropping systems. *Field Crops Research, 83*(3), 297-311.

Lu, Z., Yu, X., Heong, K., & Hu, C. (2007).Effect of nitrogen fertilizer on herbivores and its stimulation to major insect pests in rice. *Rice Science, 14*(1), 56-66.

McCabe, M. S., Garratt, L. C., Schepers, F., Jordi, W. J. R. M., Stoopen, G. M., Davelaar, E., . . . Davey, M. R. (2001). Effects of PSAG12-IPT gene expression on development and senescence in transgenic lettuce. *Plant Physiology, 127*(2), 505-516. doi:10.1104/pp.010244

Meyyappan, M., Ganapathy, M., Sriramachandrasekharan, M., & Sujatha, S. (2013). Effect of age of seedlings and weed management practices on certain growth parameters of rice under system of rice intensification (SRI).*Journal of Rice Research, 6*(1), 53.

Mishra, A., & Salokhe, V. (2010). Flooding stress: The effects of planting pattern and water regime on root morphology, physiology and grain yield of rice. *Journal of Agronomy and Crop Science, 196*(5), 368-378.

Mishra, A., & Uphoff, N. (2011). System of rice intensification:'less can be more'with climate-friendly technology. *SATSA Mukhaptra Annual Technical Issue, 15*, 28-39.

Miyazato, T., Mohammed, R. A., & Lazaro, R. (2010a). Irrigation management transfer (IMT) and system of rice intensification (SRI) practice in the philippines. *Paddy and Water Environment, 8*(1), 91-97.

Miyazato, T., Mohammed, R. A., & Lazaro, R. C. (2010b). Irrigation management transfer (IMT) and system of rice intensification (SRI) practice in the philippines. *Paddy and Water Environment, 8*(1), 91-97.

Nader, G. A., & Robinsons, P. H. (2010). *Rice producers' guide to marketing rice straw*. UCANR Publications.

Nawaz, A., & Raqib, A. (2006).Appraisal of weight losses in stored grains by oryzaephilus surinamensis (1.)(coleoptera: Cucujidae) and its mortality by plant extracts. *Sarhad Journal of Agriculture*, *22*(4), 651.

Ngo, T. (2007). SRI application in rice production in northern ecological areas of vietnam. *Report from the National IPM Program to Council of Science and Technology, Ministry of Agriculture and Rural Development, Hanoi,*

Norela, S., Anizan, I., Ismail, B. S. & Maimon, A. (2013). Diversity of pest and non-pest insects in an organic paddy field cultivated under theSystem of rice intensification (SRI): A case study in lubok china, melaka, malaysia. *Journal of Food, Agriculture & Environment, 11*(3&4), 2861-2865.

Padmavathi, C., Kumar, R. M., Rao, L. V. S., Surekha, K., Prasad, M. S., Babu, V. R., & Pasalu I. C. (2009). Influence of SRI method of rice cultivation on insect pest incidence and arthropod diversity. *Oryza- an International Journal on Rice, 46*(3), 227-230.

Pandey, S. (2009). *Effect of weed control methods on rice cultivars under the system of rice intensification (SRI)* (Unpublished Master of science thesis), Tribhuvan University.

Pasuquin, E., Lafarge, T., & Tubana, B. (2008). Transplanting young seedlings in irrigated rice fields: Early and high tiller production enhanced grain yield. *Field Crops Research, 105*(1), 141-155.

Pinheiro, F., Diniz, I., Coelho, D., & Bandeira, M. (2002). Seasonal pattern of insect abundance in the brazilian cerrado. *Austral Ecology, 27*(2), 132-136.

Prabha, A. S., Thiyagarajan, T., & Senthivelu, M. (2011). System of rice intensification principles on growth parameters, yield attributes and yields of rice (oryza sativa L.). *Journal of Agronomy, 10*

Ramakrishna, A., Tam, H. M., Wani, S. P., & Long, T. D. (2006).Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern vietnam. *Field Crops Research, 95*(2), 115-125.

Ramana, A., Naidu, G., & Murthy, K. (2007). Integrated weed management in rainfed upland rice (oryza sativa). *Indian Journal of Agronomy, 52*(4), 311-314.

Randriamiharisoa, R., & Uphoff, N. (2002).Factorial trials evaluating the separate and combined effects of SRI practices. *N.Uphoff Et Al*, , 1-4.

Randriamiharisoa, R. (2002). Research results on biological nitrogen fixation with the system of rice intensification. *Assessments of the System for Rice Intensification (SRI). Proceedings of an International Conference, Sanya, China,*

Richmond, A. E., & Lang, A. (1957).Effect of kinetin on protein content and survival of detached xanthium leaves. *Science, 125*(3249), 650-651.

Rodenburg, J., & Johnson, D. (2009). Weed management in Rice-Based cropping systems in africa. *Advances in Agronomy, 103*, 149-218.

Saad, M. J., & Kamal, I. (2012). Mechanical and physical properties of low density kenaf core particleboards bonded with different resins. *Journal of Science and Technology, 4*(1)

Saleh, R., Jadooa, K., Hameed, K., & Tawfeek, G. (2007).The influence of sprinkler irrigation on growth and productivity of three varieties of rice. *Iraqi J Agric, 12*(3)

San-oh, Y., Sugiyama, T., Yoshita, D., Ookawa, T., & Hirasawa, T. (2006).The effect of planting pattern on the rate of photosynthesis and related processes during ripening in rice plants. *Field Crops Research, 96*(1), 113-124.

Sathiya, K., & Moorthi, K. S. (2009).System of rice intensification-A review. *Agricultural Reviews, 30*(3), 184-191.

Sato, S., & Uphoff, N. (2007). A review of on-farm evaluations of system of rice intensification methods in eastern indonesia. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources, 2*, 54.

Satyanarayana, A., Thiyagarajan, T., & Uphoff, N. (2007).Opportunities for water saving with higher yield from the system of rice intensification. *Irrigation Science, 25*(2), 99-115.

Schonbeck, M. (1995). Mulching practices and innovations for warm season vegetables in virginia and neighboring states. 1. *An Informal Survey of Growers.VA Assoc.Biol.Farming, Blackburn, VA,*

Shad, R. (1986).Improving weed management in wetland rice. *Progressive Farming, 6*(1), 49-53.

Shaik, M. (2009). Modern concepts of agricultural research: Ripples and options for conservation agriculture and resource use efficiency. *Indian Journal of Agronomy, 54*(2), 149-158.

Shu-Qing, C., Rong-Xian, Z., Wei, L., Zhi-Rui, D., & Qi-Ming, Z. (2004).The involvement of cytokinin and abscisic acid levels in roots in the regulation of photosynthesis function in flag leaves during grain filling in super High-yielding rice (oryza sativa). *Journal of Agronomy and Crop Science, 190*(1), 73-80.

Singh, G., Singh, R., Singh, V., Singh, B., & Nayak, R. (1999). Effect of cropweed competition on yield and nutrient uptake by direct-seeded rice (oryza sativa) in rainfed, lowland situation. *Indian Journal of Agronomy, 44*(4), 722-727.

Singh, H., AL-Samararrai, G. F., Jaffar, M. H., Chemat, M. H., & Islam, A. (2013). Performance of five plant extract on-leaf-cuttingbeetle hypomeces squamosus on harumanis variety of mango in perlis, malaysia. *International Journal of Agricultural Science and Research (IJASR), 3*(1), 89-98.

Singh, H., Batish, D. R., & Kohli, R. (2001). Allelopathy in agroecosystems: An overview. *Journal of Crop Production, 4*(2), 1-41.

Singh, N., Kumar, D., Thenua, O. V. S., & Tyagi, V. K. (2012). Influence of spacing and weed management on rice (oryza sativa) varieties under system of rice intensification. *Indian Journal of Agronomy, 57*(2), 138-142.

Sinha, S. K., & Talati, J. (2007). Productivity impacts of the system of rice intensification (SRI): A case study in west bengal, india. *Agricultural Water Management, 87*(1), 55-60.

Stoop, W. (2005). The ‘‘system of rice intensification’’(SRI); results from exploratory field research in ivory coast: Research needs and prospects for adaptation to diverse production systems of resource-poor farmers. *West African Rice Development Association (WARDA), Bouaké, Ivory Coast,*

Stoop, W. A., Uphoff, N., & Kassam, A. (2002). A review of agricultural research issues raised by the system of rice intensification (SRI) from madagascar: Opportunities for improving farming systems for resource-poor farmers. *Agricultural Systems, 71*(3), 249-274.

Styger, E. (2012). Increasing rice yields and saving water: Lessons for policy and practice-the system of rice intensification (SRI). *Knowledge for development.* http://knowledge.cta.int/Dossiers/Commodities/Rethinking-the-rice-value chain/Feature-articles/Increasing-rice-yields-and-saving-water-Lessons-for-Policy-and-Practice-The-System-of-Rice-Intensification-SRI. Retrieved 2 October 2014.

Subrahmaniyan, K., & Zhou, W. (2008). Soil temperature associated with degradable, non-degradable plastic and organic mulches and their effect on biomass production, enzyme activities and seed yield of winter rapeseed (brassica napus L.). *Journal of Sustainable Agriculture, 32*(4), 611-627.

Tann, H., Makhonpas, C., Utthajadee, A., & Soytong, K. (2012). Effect of good agricultural practice and organic methods on rice cultivation under the system of rice intensification in cambodia. *International Journal of Agricultural Technology, 8*(1), 289-303.

Tarara, J. M. (2000). Microclimate modification with plastic mulch. *HortScience, 35*(2), 169-180.

Tech, C. (2004).Ecological system of rice intensification (SRI) impact assessment (2001–2003). *Center for Study and Development of Cambodian Agriculture, Phnom Penh, may http://ciifad.Cornell.edu/sri/countries/cambodia/camcedacimpact03.Pdf)*. Retrieved 2 April 2014.

Thakur, A., Rath, S., Roychowdhury, S., & Uphoff, N. (2010).Comparative performance of rice with system of rice intensification (SRI) and conventional management using different plant spacings. *Journal of Agronomy and Crop Science*, *196*(2), 146-159.

Thura, S. (2010). Evaluation of weed management practices in the system of rice intensification (SRI) (Unpublished Master of science thesis), Yezin Agricultural University.

Tindall, J. A., Beverly, R., & Radcliffe, D. (1991).Mulch effect on soil properties and tomato growth using micro-irrigation. *Agronomy Journal*, *83*(6), 1028-1034.

UC IPM.(2014). Weeds photo gallery. http://www.ipm.ucdavis.edu/PMG/weeds_intro.html. Retrieved 2 May 2014.

Uphoff, N. (1999). How to help rice plants grow better and produce more: Teach yourself and others. *Ithaca, NY: CIIFAD, Cornell University,*

Uphoff, N. (2001). Scientific issues raised by the system of rice intensification: A less-water rice cultivation system. *Water-Saving Rice Production Systems.Proceedings of an International Workshop on Water-Saving Rice Production Systems at Nanjing University.p*, 69-82.

Uphoff, N. (2003). Higher yields with fewer external inputs? The system of rice intensification and potential contributions to agricultural sustainability. *International Journal of Agricultural Sustainability, 1*(1), 38-50.

Usman Z. B. (2013). *Design and development of seedling tray in system of rice intensification (SRI)* (Unpublished Master of science thesis), Universiti Putra Malaysia.

Visalaksmi, V., Rao, P., & Satyanaranya, N. (2014).Impact of paddy cultivation systems on insect pest incidence. *Journal of Crop and Weed, 10*(1), 139-142.

Visarto, P., Zalucki, M. P., Nesbitt, H. J., & Jahn, G. C. (2001). Effect of fertilizer, pesticide treatment, and plant variety on the realized fecundity and survival rates of brown planthopper, nilaparvata lugens (stål)(homoptera: Delphacidae)—Generating outbreaks in Cambodia. *Journal of Asia-Pacific Entomology*, *4*(1), 75-84.

Weber, C. (2003). Biodegradable mulch films for weed suppression in the establishment year of matted-row strawberries. *HortTechnology*, *13*(4), 665-668.

Yahaya, S. (2013). Implication of SRI-inspired innovation on the rice industry in Malaysia. *System of Rice Intensification (SRI) Workshop*. Universiti Putra Malaysia 10 March, 2013. Unpublished manuscript.

Yaji, M. (2003). In Professor O. A. Folorunson (Ed.), *Soil science for engineers laboratory techniques* (First ed.). Ibadan, Oyo State, Nigeria: Stirling Horden publishers (Nig) Ltd.

Zhao, D., Atlin, G., Bastiaans, L., & Spiertz, 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.

Zhao, L., Wu, L., Li, Y., Lu, X., Zhu, D., & Uphoff, N. (2009). Influence of the system of rice intensification on rice yield and nitrogen and water use efficiency with different N application rates. *Experimental Agriculture, 45*(03), 275-286.