Asian Journal of Agricultural Sciences 8(3): 10-17, 2016
DOI:10.19026/ajas.8.2988
ISSN:2041-3882; e-ISSN: 2041-3890

Submitted: September 13, 2014 Accepted: October 12, 2014 Published: September 15, 2016

Research Article

The System of Rice Intensification (SRI) Practices and Mechanization Needs

[1, 3]Suleiman Samaila, [1]Wan Ishak Bin Wan Ismail and [1, 2]Muhamad Saufi Mohd Kassim
[1]Department of Biological and Agricultural Engineering, Universiti Putra Malaysia
[2]Smart Farming Technology Research Center, Faculty of Engineering. Universiti Putra Malaysia,
[3]Department of Agricultural and Environmental Engineering, Adamawa State Polytechnic, Yola, Nigeria

Abstract: This study discusses the unique and labour intensive practice of the System of Rice Intensification (SRI) and suggests specific mechanization option/approaches for its mechanization. Despite the continuous growth in global human population, there still exist substantial labour shortages in the agricultural sector, because of outmigration of the work force. Much of the focus on agricultural research improvement efforts in recent decades has been on modifying crops' genetic potential more than on improving cropping practices, mechanization, automation and production systems. The demand for rice being a staple food for more than half of the world population will continue to increase, hence the need for increased yield. The System of Rice Intensification (SRI) has shown that by modifying crop, soil, water, intensive weeding and nutrient management, can under most of the circumstances evaluated to rise of the productivity of land, water, seeds, capital and labour used for irrigated rice production. However, SRI practices such as Paddy nursery, single seedling transplanting, single direct seeding, water management and intensive mechanical weeding requires specific mechanization approaches. This study summarizes and reflects on the cultivation practices and possible specific mechanization and automation through mechatronics and Information Technology application for the system of rice intensification (SRI).

Keywords: Cultivation practices, mechanization, system of rice intensification, transplanting, weeding

INTRODUCTION

The origin of cultivated rice (*Oriza sativa L.*), has puzzled plant biologists for decades. This is due, at least in part, to the complex evolutionary dynamics in rice cultivars and wild progenitors, particularly rapid adaptive differentiation and continuous gene flow within and between cultivated and wild rice (Sang and Ge, 2007).

Rice feeds more than half the world's population, however more than 400 million people endure chronic hunger in rice-producing areas of Asia, Africa and South America. Thus the demand for rice increases with global population which is expected to rise by a further 38% within 30 years, as forecasted the United Nations (Satyanarayana, 2005). The global rice production stands at 454.6 million ton annually; with an average yield of 4.25 ton/ha (IRRI, 2012). Average yield per hectare must therefore be increased through deliberate research policies and practice. Food habits, market price and other related factors are encouraging people to grow rice wherever water is available. This led to pressure on water and crop productivity resulting into increased investments on bore wells and agricultural inputs like seeds fertilizer and pesticides. In the past two decades, however, gains from this strategy have decelerated, with increasing economic and environmental costs of this input-dependent approach. Accordingly, there is reason to consider what can be accomplished by making optimizing changes in crops' growing environments both above ground and, especially, below ground (Kassam *et al.*, 2011).

To meet the expected increase in demand for rice, the average yield in ton/ha must be increased basically through improved cultivation practices and new techniques. However, average rice production of 4.4 tons/ha is so low that operators have not been in a position to increase wages for farm labour, hence productive rural workers are drawn to the urban areas which offer higher wages or more congenial working conditions (Sharif, 2011). The operational land holding-size is shrinking and land and water resources are being degraded. Therefore, some innovative rice production practice is needed to meet its growing demand due to population pressure. Under this scenario, the System of Rice Intensification (SRI) may be an appropriate practice to produce more food with less input Barah (2009). In such situations, System of Rice Intensification (SRI) emerged as an alternative in paddy cultivation, with core principles like using less seeds, less water and less fertilizer (Satyanarayana, 2005). This study is discusses the trends in cultivation and

Corresponding Author: Suleiman Samaila, Department of Biological and Agricultural Engineering, Faculty of Engineering. Universiti Putra Malaysia, Yola, Nigeria

mechanization options on practices of paddy cultivation with focus on System of Rice Intensification (SRI).

MATERIALS AND METHODS

An overview of the system of rice intensification: The system of rice intensification (SRI) originated in Madagascar for lowland/irrigated rice was first synthesized in 1993 by Father Henri de Laulaníe, a French Jesuit priest. SRI, is based on the application of the following six practices so as to achieve the best results:

- The use of very young, 8- to 12-day-old seedlings in transplantation
- Transplanting single seedlings per hill quickly, with minimal root disturbance
- Widely spaced hills, ranging from 20×20 up to 50×50 cm
- An alternate wet and dry soil moisture regime (No permanent flooding) to maintain aerobic soil conditions
- The use of organic, rather than mineral, fertilizers
- Frequent weeding, preferably performed using a surface rotary hoe, during early (40) days of crop development stages so as to control weeds and aerate the soil (Stoop, 2011; Stoop *et al*., 2002)

According to Kassam *et al*. (2011) SRI is a production system based on alternative understandings of rice agro-ecology and on alterations in the practices for crop, soil, water, nutrient and pest management. SRI presents a different vision of ‘‘intensification’’ than has been proposed by some rice scientists. SRI is a crop management system that has been depicted as a more productive and more ecologically sustainable method for cultivating rice. It is said to be particularly appropriate, accessible and beneficial for poor and marginal farmers because it can achieve substantial increases in productivity and grain yield without the need for improved seeds or chemical inputs. It has also been reported that SRI methods can produce much higher yields while consuming much less water (Berkhout and Glover, 2011). SRI is actually an amalgamation of refined and intensive management practices for rice production at farmers’ fields. The conservation of land, water, biodiversity and utilization of the hitherto ignored biological power of plant and solar energy are the novelties of SRI (Barah, 2009).

The system of rice intensification (SRI) on the other hand has generated considerable debate globally, particularly with regard to its potential to raise rice yields. Proponents of SRI have reported that the average rice yield with SRI is double the current average yield and can be increased to the level of three to four times. Opponents say the reported high yields are due to measurement error and that usual information expected in support of these fantastic yields is missing (Sinha and Talati, 2007). Sanjeewanie Ginigaddara and Ranamukhaarachchi (2009) studied the effect of conventional, SRI and modified water management on growth, yield and water productivity of direct-seeded and transplanted rice in central Thailand: They reported that, direct seeding coupled with water management of one-week irrigation for initial seedling growth and weed suppression, followed by alternating one-week irrigation and three-week non-irrigation until flowering and thereafter irrigation until dough stage of rice gives higher grain yield, water productivity and net income compared to conventional water management. Sinha and Talati (2007) evaluate the impact of adoption of SRI practices on rice yields, the economics of paddy cultivation and labour inputs based on field research conducted in Purulia, West Bengal, India. Paddy yields with SRI were higher than those under conventional paddy cultivation by 32% and net returns were higher by 67%. Research results from SRI researchers are consistent on potential of increased paddy yield per/ha. It is fairly well established that SRI cultivation methods cause changes in the physiology and morphology of rice plants, which can lead to improved productivity and grain yield under favourable conditions. Analyses of the contributions made by individual SRI practices produce a mixed picture but it seems fairly well established that transplanting younger rice seedlings with optimal spacing and the use of water-saving irrigation techniques can combine to produce a good yield and increase the productivity of seeds and water inputs (Berkhout and Glover, 2011).

SRI mechanization: Much of the focus of agricultural improvement efforts in recent decades has been on modifying crop's genetic potential more than on improving cropping practices and production systems. These efforts have resulted in increased yield through varietal improvements and the increased use of inputs, such as energy, agrochemicals and more water to crops through irrigation technology (Kassam *et al*., 2011). According to Vidhan *et al*. (2012) increase in rice production is achieved mainly due to the improvement of irrigation facilities, introduction of high yielding varieties and judicious use of critical inputs. Agricultural mechanization is one critical input which not only facilitates timely completion of operations and thereby increases the production, labour saving, energy efficiency, productivity and profitability. Agricultural mechanization refers to introduction and application of improved tools, implements and machines between farm workers and materials handled by them. Kassam *et al*. (2011) reported that the need for mechanisation in rice cultivation arises when seeking solutions to problems such as drudgery, high cost of production, low cropping intensity and most importantly labour scarcity. Assorted tools in appropriate forms have been used in history of rice cultivation. The need for the development of new machineries to address new cultivation practices especially in rice production, with the view to lower cost, increase yield and solve the problem of labour is very crucial. SRI (System of Rice Intensification) method/practices stimulated the creativity of several farmers wherein several efforts were made to improvise the system. Inspired farmers innovated in developing appropriate implements for SRI. The wider and equal spacing between the plants allow easy operation of inter-row and intra-row mechanical weeders with high ground clearance specifically developed for SRI. This process incorporates the weeds into the soil as green manure crops (Thiyagarajan *et al*., 2005). The steady drift of agricultural labour to industrial sector is adding more to the woes of the rice/SRI farmer with its labour intensive practices. Because of drudgery and notion that the farm operations are below the dignity, labour availability in general, has decreased considerably to farm operations. To offset these problems stress on mechanization is the need of the hour (Vidhan *et al*., 2012).

The System of Rice Intensification (SRI) is not necessarily more labour-intensive once the methods have been learned, but the initial labour requirements can be a barrier to adoption and farmers with large land areas cannot find the labour needed to use these more productive methods. In view of this problem, a set of agricultural implements have been designed, while research is ongoing for mechanizing the operations of SRI. This is aimed at reducing water requirements as well as labour requirement. More scientific research on varietal selection, wide spacing and ideal crop geometry, transplanting of tender seedlings, single direct seeding, subjunctive use of water, akin to the concept of aerobic rice, zero tillage and intensive weed management will help effective adoption and reduction in high labour demand. The specific practices linked to the system of rice intensification (SRI), such as land preparation/puddling, nursery development, transplanting single seedling, intensive mechanical weeding, water saving and compost manure requires the synergy of scientists and engineers to explore the application of mechatronics in developing low cost machines, with focus on automation and Information Technology to reduce labour demand, timeliness and save cost.

SRI cultivation practices: The ideas or cultivation practices specific to SRI mentioned earlier are:

- Transplanting young seedlings raised in an un-flooded nursery.
- Transplant them carefully and shallow.
- Transplant single seedling at wider spacing of 25 cm×25 cm.
- Apply a minimum amount of water, no continuous flooding.
- Control weeds at (10) days interval up to (40) DAT through intensive mechanical weeding/active soil aeration.

Table 1: Operation wise labour requirement in rice cultivation

S. No.	Operations	Percentage of total labour requirement
1.	Puddling	11%
2.	Transplanting	38%
3.	Weeding	19%
4.	Harvesting	20%
5.	Threshing	12%

Vidhan Singh *et al*. (2012)

- Use of organic matter for soil fertilization. These Important features of SRI are further elaborated on by WASSAN and Network (2006) as follows:
  - **Low seed requirement:** Since a single seedling is transplanted per hill at wider spacing, seed requirement is drastically reduced.
  - **Low water requirement:** As there is no need to maintain standing water.
  - **Transplantation of tender/young seedlings (8-12days):** Transplantation of young seedlings at shallow depth results in quick recovery, establishment and production of more tillers
  - **Transplanting at wider spacing (10×10 inches or 25×25 cm):** Wider spacing allows enough sunlight to reach the leaves of each rice plant thus reducing competition for water, space and nutrients resulting in the spread of roots and healthy growth of plants (the distance can be increased depending on soil fertility)
  - **Incorporating weeds into the soil while weeding:** Weeding with a simple hoe helps in replenishing the nutrients in the form of green manure. Working with a hoe or weeder helps to aerate soil which in turn helps in vigorous root growth. First weeding is 10 days after transplating and a minimum 3 weedings at 10-12 day interval.
  - **Organic manures in place of chemical fertilizers:** Organic manures improve soil aeration and also microbial activity, thus helps in decomposing organic matter into nutrients, essential for plant growth.

These practices are labour intensive against the phenomenal global labour shortage. To sustain the gains of SRI to meet up with the increasing food demand need to be shifted to the mechanization of these SRI practices. The rice cultivation practices that takes most of the labour demand are transplanting and weeding as reported by Vidhan *et al*. (2012).

The cummulative labour demad for transplanting and weeding of 57% under conventional practice in Table 1 may be higher under SRI with single seedling transplanting and intensive weeding needs. Hence, the need for specific mechanisation needs under SRI.

RESULTS AND DISCUSSION

Land preparation: Puddling is the most important operation in the preparation of soil bed for transplanting rice. The soil physical properties like soil structure, viscosity, bulk density etc changes due to puddling. Puddling creates an impervious layer and this assists in reducing the deep percolation losses. Prerequisite for puddling is preparatory dry tillage (Vidhan *et al*., 2012). Undulation in the plot causes water to stagnate in some parts of the land. So land should be properlly levelled before transplantation to enable water to spread uniformly over the field. There should also be a provision to remove excess water i.e., drainage facility (WASSAN and Network, 2006). Land preparation in terms of mechanization for paddy cultivation has attained significant level. There are several land preparation and puddling implements available, among these are:

Cono puddler: It operates in the soil in a horizontal back and forth movement. It can be operated in all types of soils since this is a lightweight and modular implement.

Power tiller: It is a self propelled machine specifically useful for rice fields and orchards as it can take short turns. It comes with a package of implements like rotavator for puddling, cultivator for land preparation and weed control.

Tractor: Tractors are available in various power ranges. Small power range tractor with 18 HP is meant for rice cultivation. It is a lightweight tractor with four wheel drive with rotavator used for puddling. It has a small turning radius. Traffic ability problem can be avoided with this tractor due to its light weight. It can puddle one hectare in 2.5-3 h (Vidhan *et al*., 2012).

Water management: Innovations in water saving technologies are the foremost needs in today's rice production as water has become the most limiting resource in agriculture (Sanjeewanie Ginigaddara and Ranamukhaarachchi, 2009). The availability of fresh water is one of the major constrains for increasing rice production in Asia (Lampayan *et al*., 2003). About 80% of the available water resources world-wide are used by the agricultural sector (Sujono, 2007).

Future predictions indicate that two million ha of fully irrigated and thirteen million ha of partially irrigated lands in Asia during wet season would experience a "physical water scarcity" and 22 million ha of irrigated lands in the dry season would face "economic water scarcity" by 2025 (Tuong and Bouman, 2003).

Irrigated rice makes the highest water demand. Currently, on-farm availability of fresh water is reducing due to many reasons (Uphoff, 2006). Increase in rice production is achieved mainly due to the improvement of irrigation facilities, introduction of high yielding varieties and judicious use of critical inputs (Vidhan *et al*., 2012). With irrigation waters getting scarce and costly their efficient application has become essential. As a result the pressurised irrigation systems-sprinklers, micro sprinklers and drip systems have come in use that save about 35-50% of irrigation water with 25-35% increase in the yield. In rice wheat cropping zero-till drill and raised bed planting are found to reduce water require about 35-50% with about 5-10% yield advantage (Alam, 2012). Farm All Technology Pvt. Ltd. Pakistan had a series of trials/evaluations since 2009, first on irrigated rice following System of Rice Intensification (SRI) principles with almost full mechanization, to reduce labour requirements and economize on water and other inputs. FarmAll Technology also introduced laser-leveling of fields in 1984 as a technology for saving water by making precise minimal applications of water that can keep root zones moist enough to support plant growth (Sharif, 2011). This will necessitate and encourage research on alternative measures for reducing water use and increasing the efficiency of water use in order to ensure food security (Sanjeewanie Ginigaddara and Ranamukhaarachchi, 2009).

The reported savings in water management under SRI practices need to be enhanced and more productive use of excess water be channelled to other uses, such as Aquaculture, Horticulture and domestic to form and integrated water management system.

Seed nursery development: Rice seedlings can maintain greater potential for tiller and root growth if:

- Transplanted while still very young
- If transplanted very quickly and carefully to avoid desiccation and traumatization of the plant, particularly protecting the roots (Uphoff, 2006). Nursery preparation in SRI is raised using available inputs and specific methods. Pre-soaking seeds in water for 24 h and incubating in a rag for 24 h before sowing in a well-drained, garden-like nursery helps seeds to germinate faster. SRI nursery bed is prepared with application of Farm Yard Manure (FYM) and soil alternately in 4 layers.

1st layer: 1 inch (2.54 cm) thick well decomposed FYM
2nd layer: 1 ½ inch (3.78 cm) soil
3rd layer: 1 inch (2.54 cm) thick well decomposed FYM
4th layer: 2 ½ inch (6.3 cm) soil

All these layers should be mixed well, as the FYM helps in easy penetration of roots. To prevent soil erosion, the bed on all sides should be made secure with wooden reapers/planks or paddy straw rope or anything of that sort. To drain excess water appropriate channels should be provided on all sides (WASSAN and Network, 2006). The success of a single seedling SRI transplanting starts from the nursery, hence the need for research into mechanised seed nursery and seed trays that will facilitate single seedling transplanting.

SRI transplanting: If the crop is not established by single direct-seeding, an SRI option being developed by farmers, it is best to transplant seedlings while still at the 2-3 leaf stage. This is usually between 8 and 12 days after sowing in the nursery. Such young seedlings, although they look more vulnerable and unpromising than older, larger ones, have a far greater vigour and potential for root and canopy development and consequently they mature into more productive plants (Stoop, 2011). Hussain *et al*. (2013) reported eight rice planting methods namely; drilling of soaked seed in water condition, drilling on beds and furrow, drilling on beds, Planting on beds and furrow, transplanting on beds, line transplanting in a well puddled soil, conventional transplanting and parachute transplanting. In contrast to the existing or conventional method of mechanical transplanting rice of (5) to (8) seedlings per stand the SRI practices in paddy seedling transplanting involves (1) young paddy seeding of (8-14) days old per hill at 25 cm by 25 cm row and intra-row spacing, at 1-2 cm depth. According to Kassam *et al*. (2011) spacing hills farther apart, in a square pattern with single seedlings per hill, having only about 12-20 plants per square meter results in minimizing plant competition below and above ground, thereby encouraging greater root and canopy growth and distribution. SRI has been characterized as labor-intensive, indeed so labour-intensive that this constitutes a barrier to adoption or a cause for dis-adoption (Moser and Barrett, 2003).

Berkhout and Glover (2011) reported that the agricultural sector in Tamil Nadu is characterised by a transition towards mechanisation, as a result of scarcity and a relatively high price of labour. The latter is a result of urbanisation and a government scheme to combat rural unemployment, both of which appear to decrease the supply of labour to agriculture. In the case of transplanting, mechanised transplanting machines do exist; however they are not able to carefully transplant a single young seedling per hill. Bala and Wan Ishak (2013) reported that a specialized implement fitted to transplant rice seedling in paddy field have been under development for years by different researchers improving performance, components functions, simplifying the mechanism and handling, but until today there is no single machine fully automated transplanting machine for SRI. According to Dhananchezhiyan *et al*. (2013) the main component in the development of SRI transplanter is suitable nursery raising method. The SRI transplanter will be successful only when the nursery raising method is modified to suit the SRI transplanter. Standard planting or transplanting methods as described by Hussain *et al*. (2013) in Table 2 be explored for possible mechanisation to suit SRI practice.

Table 2: Planting methods tested in rice growing areas of Punjab

S/No.	Treatments
1	Direct seeding on well prepared soil in water condition
2	Drilling on beds and furrow
3	Drilling on beds
4	Planting on beds and furrow
5	Transplanting on beds
6	Line transplanting
7	Conventional transplanting
8	Parachute transplanting

Hussain *et al*. (2013)

Fig. 1: SRI-drum seeder; Vidhan *et al*. (2012)

Fig. 2: Chinese model of transplanter; Vidhan *et al*. (2012)

Some recent desings of rice transplanters that are specific to SRI transplanting are discussed in Fig. 1 and 2.

Direct row seeder with wider spacing (25 cm×25 cm) SRI drum-seeder: A row seeder Fig. 1 (with a spacing of 25 cm row to row) sows the pregerminated paddy seeds in rows at spacing of 25 cm in puddle soil. The other principles of SRI can be well adopted with this seeder to enhance the productivity. The drum seeder is under testing at DRR to save seed and enhance profitability.

Eight-row paddy transplanter (chinese design): This is a self-propelled machine driven by 3-4 hp diesel engines Fig. 2. The machine transplants at a row spacing of 23 cm with a provision to vary the plant to plant distance of 10-12 cm and vary the depth of planting and number of plants per hill requires mat type nursery. The machine is more suitable for light textured soils. Presently, the mechanical transplanters can plant 2 seedlings per hill at a spacing of 24 cm (row to row) and 12-24 cm (plant to plant) for adoption of other SRI principles. This will be a very good development in promoting SRI in large scale (Vidhan *et al*., 2012). However, further research is needed to develop a single seedling transplanting machine to match the exact requirement for SRI.

Fig. 3: Locally developed low clearance rotavator by SRI farmers in Tanjun Karang, Malaysia

Crop protection/weed management under SRI: The principle that suppressing weeds is important for preventing yield losses is uncontroversial, regardless of the cultivation system being applied. With SRI management, the necessity of weeding is made more acute by lower density planting patterns, the use of very young seedlings which are more vulnerable to competition from weeds and non-flooded irrigation (Berkhout and Glover, 2011). Weeds are serious menace to crops as they reduce the yields and farmers income since they affect crop growth and development in many ways. Experiments carried out in Senegal indicated that weeds were a greater threat to rice under SRI management than rice under conventional Basic Management Practices, so that effective weed management was vital in order to attain the potential advantages of the other SRI practices (Krupnik *et al*., 2010). In SRI, first weeding is done after 10-12days after transplanting; subsequently weeding is done every 10 days, until crop permits operation. The field is irrigated one day before weeding at least half inch water is retained for easy operation (Vidhan *et al*., 2012). Square planting method helps in operating weeders in check-rowed geometry to obtain maximum weeding efficiency and better soil aeration (Hameed and Jaber, 2007). Proper use of cono weeders incorporate weeds into the soil, whereby the decomposed biomass enriches the organic contents in soil. The four compulsory weedings in SRI improve soil aeration, invigorate microbial activities and promote a healthy root system. A form of mechanisation that starts becoming more common is the use of motorised weeders. While many farmers appear to use the cono-and rotary weeder, some others are using motorized weeders. Many of these weeders are adapted to a specific spacing as used in the countries of origin and as such are likely to dictate the actual distance between rows, which in some cases differs from the present recommendations (Berkhout and Glover, 2011). Ahmad (2012) further reported that, the efficacy of the weeding operation often depends on factors such as pant height, rooting depth and forward speed. More aggressive operations, generally result in higher weed control efficiency, but often increase the risk of damaging crop plant. The intensive weeding requirement in SRI at interval of ten days with minimum of three mechanical weeding, up to forty days after transplanting is limited by paddy height. Most of the available motorised mechanical weeder especially in Malaysia is limited by clearance height, as seen in Fig. 3. To meet the weeding requirement of up 40DAT under SRI means that a weeder with enough ground clearance need to be developed specific to SRI to address this unique weeding need.

Agricultural mechanization is one critical input which not only facilitates timely completion of operations and thereby increases the production, labour saving, energy efficiency, productivity and profitability. According to Vidhan *et al*. (2012) transplanting, weeding and harvesting operations consume most of the labour requirement in rice cultivation and hence thrust should be given for mechanizing these operations in order to reduce the labour requirement in rice cultivation. An expert committee on the agricultural mechanization observed that the productivity is influenced by mechanization as follows:

- 5-10% improvement in yield by proper and timely seed bed.
- 5-30% improvement in yield by efficient control of weeds.
- Reduces losses by 4-5% through efficient harvesting and threshing.
- 8-10% losses reduction by proper post harvest process and storage.
- Up to 2.5% increase in head rice recovery by efficient milling (Vidhan *et al*., 2012)
  Berkhout and Glover (2011) reported that in Tamil Nadu, SRI farmers respond by mechanising part of their paddy production. Both the public and private sector address this increased demand for mechanisation. The former by research on mechanical weeders and transplanters specifically suited for SRI, the latter through local production and imports of such machinery. The System of Rice Intensification with its potential of increased yield, water savings and high labour demand, when complimented with mechanization will boost rice production and global food security.

CONCLUSION

The critical importance of mechanization in carrying out timely operation and reducing cost of cultivation is the prerequisite for enhancing the production and productivity of rice through SRI, as well as to make rice cultivation commercially viable and profitable enterprise for the farmers. Full mechanization of SRI practices can help attain much needed reduction in manual labour, increased yield and self-sufficiency. The need to develop suitable machines and implements such as single seedling transplanters, single direct seeders and motorised high clearance weeders for (SRI cultivation) will help for large scale adoption. The application of Mechatronics should be explored to make future SRI equipment compact, accurate and affordable. Reduction or saving in water with SRI and the adoption of compost manure releases the scarce water resources for other uses. This can be channelled to other productive agricultures like aquaculture or domestic needs.

REFERENCES

Ahmad, M.T.B., 2012. Development of an automated mechanical inter-row weeder for vegetable crop. M.Sc. Thesis, Iowa State University, Iowa, pp: 12278.

Alam, A., 2012. Future requirements of agricultural machines for mechanizing agriculture. Indian Council of Agricultural Research, New Delhi, India, pp: 5-7.

Bala, I. and W.B.I. Wan Ishak, 2013. Development of System of Rice Intensification (SRI) paddy transplanter. Asian J. Agric. Sci., 1: 1-6.

Barah, B.C., 2009. Economic and ecological benefits of System of Rice Intensification (SRI) in Tamil Nadu. Agric. Econ. Res. Rev., 22: 209-214.

Berkhout, E. and D. Glover, 2011. The evolution of the system of rice intensification as a socio-technical phenomenon: A report to the bill and melinda gates foundation. In: Ezra Berkhout (Ed.), Wageningen University and Research Centre.

Dhananchezhiyan, P., C.D. Durairaj and S. Parveen, 2013. Development of nursery raising technique for “system of rice intensification” machine transplanting. Afr. J. Agric. Res., 8(29): 3873-3882.

Hameed, K.A. and F.A. Jaber, 2007. System of rice intensification in Iraq during 2007. Al-Mishkhab Rice Research Station (MRRS), Najaf, Iraq.

Hussain, S., M. Ramzan, M.A. Rana, R.A. Mann and M. Akhter, 2013. Effect of various planting techniques on yield and yield components of rice. J. Anim. Plant Sci., 23(2): 672-674.

IRRI, 2012. Hand Book of Weed Control. IRRI, Phillipines.

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

Krupnik, T.J., J. Rodenburg, C. Shennan, D. Mbaye and V.R. Haden, 2010. Risky trade-offs: Comparing yield, water productivity and weed competition under the system of rice intensification and best management practices in the sahel. Proceeding of the Africa Rice Congress, Bamako, Mali.

Lampayan, R.M., B.A.M. Bouman, J.L. De Dios, A.T. Lactaoen, A.J. Espiritu and T.M. Norte, 2003. Adoption of water saving technologies in rice production in the Philippines. Proceeding of the International Workshop on “Transitions in Agriculture for Enhancing Water Productivity", Tamil Nadu, India.

Moser, C.M. and C.B. Barrett, 2003. The disappointing adoption dynamics of a yield-increasing, low external-input technology: The case of SRI in Madagascar. Agr. Syst., 76: 1085-1100.

Sang, T. and S. Ge, 2007. The puzzle of rice domestication. J. Integr. Plant Biol., 49(6): 760-768.

Sanjeewanie Ginigaddara, G.A. and S.L. Ranamukhaarachchi, 2009. Effect of conventional, SRI and modified water management on growth, yield and water productivity of direct-seeded and transplanted rice in central Thailand. Aust. J. Crop Sci., 3(5): 278-286.

Satyanarayana, A., 2005. System of rice intensification: An innovative method to produce more with less water and inputs. Proceeding of the 4th IWMI-Tata Annual Partners’ Meet, IRMA, Anand, India.

Sharif, A., 2011. Technical adaptations for mechanized SRI production to achieve water saving and increased profitability in Punjab, Pakistan. Paddy Water Environ., 9(1): 111-119.

Sinha, S.K. and J. Talati, 2007. Productivity impacts of the system of rice intensification (SRI): A case study in West Bengal, India. Agr. Water Manage., 87(1): 55-60.

Stoop, W.A., 2011. The scientific case for the system of rice intensification and its relevance for sustainable crop intensification. Int. J. Sustain. Agric., 9(3): 443-455.

Stoop, W.A., N. Uphoff and A. Kassam, 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. Agr. Syst., 71(3): 249-274.

Sujono, J., 2007. Water saving irrigation on paddy fields for increasing productivity and for flood reduction. Proceeding of the IASTED International Conference on Water Resources Management (WRM).

Thiyagarajan, T.M., K. Senthikumar, R. Priyadarshini, J. Sundarsingh, A. Muthusankaranarayanan and H. Hengsdijk, 2005. Evaluation of water-saving irrigation and weeder use on the growth and yield of rice. In: Thiyagarajan T.M. *et al*. (Eds.), Proceeding of the International Symposium on Transitions in Agriculture for Enhancing Water Productivity, Tamil Nadu, India, pp: 3-18.

Tuong, T.P. and B.A.M. Bouman, 2003. Rice Production in Water-Scarce Environments. In: Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI Publication, Oxon, Cambridge, MA, 1: 53-67.

Uphoff, N., 2006. The system of rice intensification (SRI) as a methodology for reducing water requirements in irrigated rice production. Proceeding of the International Dialogue on Rice and Water: Exploring Options for Food Security and Sustainable Environment, pp: 7-8.

Vidhan, S.T., K.R. Mahender and B.C. Viraktamath, 2012. Selective mechanization in rice cultivation for energy saving and enhancing the profitability. Rice Knowledge Management Portal (RKMP). Directorate of Rice Research, Rajendranagar, Hyderabad.

WASSAN and Network, 2006. Watershed Support Services and Activities. In: Kishan Rao (Ed.), SRI-System of Rice Intensification: An emerging alternative. SRI, Centre for Sustainable Agriculture, India, pp: 8-20.