EVALUATION OF WEED MANAGEMENT PRACTICES IN THE SYSTEM OF RICE INTENSIFICATION (SRI)

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The thesis attached hereto, entitled **"EVALUATION OF WEED MANAGEMENT PRACTICES IN THE SYSTEM OF RICE INTENSIFICATION (SRI)"** was prepared under the direction of the chairman of the candidate supervisory committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **MASTER OF AGRICULTURAL SCIENCE (AGRONOMY).**

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DECLARATION OF ORIGINALITY

This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

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DEDICATED TO MY BELOVED PARENTS,

U HLA THEIN & DAW KHIN MAR KYU

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ABSTRACT

To evaluate the effectiveness of different weed control methods in the System of Rice Intensification (SRI), two experiments were conducted at the Department of Agronomy, Yezin Agricultural University, during dry and wet seasons, 2009. Randomized Complete Block Design (RCBD) with three and four replications was used in dry and wet seasons, respectively. There were six different weed control treatments in both experiments. viz, two hand weeding at 21 and 35 days after transplanting (DAT), rotary weeding at 15 DAT + hand weeding at 35 DAT, two rotary weeding at 15 and 30 DAT, herbicide application at 20 DAT+ hand weeding at 40 DAT, herbicide application at 20 DAT+ rotary weeding at 40 DAT and unweeded (no weeding). The tested cultivar in both experiments was Shwe Thwe Yin (IR-50).

The results of both experiments indicated that the highest grain yield was observed in rotary weeding at 15 DAT + hand weeding at 35 DAT where unweeded produced the lowest grain yield in both seasons. Weed density, weed dry weight and weed control efficiency were significantly influenced by different weed control treatments. In both experiments, two hand weedings at 21 and 35 DAT showed good performance with minimum weed dry weight and the highest weed control efficiency at harvest. The significant negative correlations were found between weed dry weights and yield and yield components of rice. The number of spikelets per panicle, filled grain percent and panicle length were found to be reduced in unweeded check as a result of weed competition.

Yield loss percent due to weed competition were found to be ranged from 59.5 % to 74.06 % in dry season and 49.97 % to 73.4 % in wet season respectively. In terms of economic analysis, rotary weeding followed by hand weeding had the highest net benefits among weeding treatments. Therefore, rotary weeding at 15 DAT+ hand weeding at 35 DAT was recommended as the cost-effective weeding method in SRI.

CONTENTS

CHAPTER I
INTRODUCTION

Rice is the staple food for more than half of the world's population. In Asia, more than 80 % of the people live on rice, and their primary food security is entirely dependent on the volume of rice produced in this part of the world (Kabir 2006). World rice production nearly doubled from the 1960s to the 1980, mainly due to the technological advances referred to as the Green Revolution. The Green Revolution comprised the replacement of traditional cultivars with modern cultivars and the increased use of external inputs that included mineral fertilizer, irrigation water and pesticides. The expansion of this technological package was facilitated by the political incentives to construct irrigation infrastructure and to subsidize chemical inputs. After the wide spread of the green revolution throughout irrigated paddy fields in Asia, however, the rice yield increase has slackened, reflected by the decline in the annual rate of rice yield increase from 2.7 % in the 1980s to 1.1% in the 1990s. As the population in rice growing areas is still expanding rapidly, the resumption of yield increases is vital. It is estimated that 40 % of more rice production will be required by 2030 to satisfy growing demand with no increases in cropping areas (Khush 2005).

The existing system of paddy production, particularly green revolution technology is input intensive and favors cash rich farmers. Increasing prices of agricultural inputs prevent poor farmers from completely adopting modern production technologies (Stoop et al. 2002).

In order to improve resource use efficiency, it will be necessary to address the growing concerns regarding water scarcity, higher fertilizer costs, and negative environmental impacts due to the increasing use of agrochemicals for rice production. Some possible solutions include breeding superior genotypes under water-saving rice cultivation methods (Atlin et al. 2006), improving water management(Shi et al. 2002; Yang et al. 2004) and fertilizer use efficiency via more frequent split applications (Deberman et al. 2000) and the use of controlled-release fertilizers (Shoji and Kanno 1994). An additional benefit from cultivating rice in unflooded paddies, as done with the system of rice intensification (SRI) during most of the growing season, would be some reduction in greenhouse gas emissions (Roger and Ladha 1992).

In such a situation, the system of rice intensification was recently promoted as an alternative technology and resource management strategy for rice cultivation that may offer the opportunity to boost rice yields with less external inputs (Stoop et al. 2002; Uphoff and Randriamiharisoa 2002). The system of rice intensification consists of a set of management practices that were mainly developed through participatory on farm experiments in the central highland of Madagascar in the 1980s (Stoop et al. 2002). The main elements of SRI are: (1) early transplanting of young seedlings, 8-12 days old, (2) transplanting single seedlings with wide spacing, 25 cm x 25 cm or more depending upon soil fertility status, (3) mechanical weeding with a rotary push weeder that aerates the soil as well as it controls weeds, (4) water management in such a way that there is no continuously standing water during the vegetative growth phase, and (5) reliance on compost as far as possible, with supplemental or no use of chemical fertilizer (Randriamiharisoa and Uphoff 2002).

Since 2001, the system of rice intensification experience was initiated by Metta Development Foundation, a local non-governmental organization working in Myanmar, through the introduction of Farmer Field School (FFS) program in an effort to improve the basic food security status of Kachin and Shan farmers (Kabir 2008). Positive results from SRI methods have been reported from the Philippines, Cambodia, Myanmar, Laos, Sri Lanka, Bangladesh, Gambia, Sierra Leone, China, India, Indonesia, Iraq, Iran, Nepal, Vietnam and Cuba. Yield increases of 50 % to 100 % are common, with sometimes even a tripling of yield (Yamah 2002).

On the basis of field experiences from some Asian and African countries reported that the average rice yield with SRI was to be double the current average yield (Uphoff 2002; 2004). Uprety (2004) reported that the average rice yield with SRI was 8 t ha^{-1}, whereas the yield is 3 t ha^{-1} under conventional practices. Rice yields with SRI have been reported to vary significantly with the practices used (Kabir 2008).

Weeds are at present the major biotic constraint to increase rice production worldwide (Zhang 1996). Weed infestation is regarded as one of the major causes of low crop yields throughout the world and can cause 50-60 % reduction in grain yield under puddle conditions and 91% yield reduction in non puddled conditions (Ali and Sankaran 1984). Normally the loss in rice yield ranges between 15-20 % yet in severe cases the yield losses can be more than 50% depending upon the species and intensity of weeds (BRRI 2006). In Myanmar, weed infestation reduces the rice grain yield by 26 % in wet–seeded rice (Mar Mar Kyu 1993). The prevailing climatic and edaphic conditions are highly favorable for luxuriant growth of numerous species of weeds that strongly compete with rice crop (Mamun 1990).

When fields are not kept continuously flooded, weed growth becomes one of the problem, and farmers use excess water to reduce their labor requirements for weed control. Weeding can be quite labor demanding, but its timing is more flexible than in transplanting. So, weeding is a deterrent to SRI adoption (Satyanarayana et al. 2007).

Cultural changes such as these may help improve grain production; however, these very same practices have also tended to make SRI more weed-prone and thus require more laborious weeding operations (Latif et al. 2005). Although hand weeding is effective to control weeds, it demands high labor cost, labor scarcity during peak periods and sometimes unfavorable weather condition at weeding time. In most rice growing areas, increasing cost of labor and its scarcity during the critical period of crop-weed competition are the major reasons that rice farmers use hand weeding only as a supplement to mechanical weeding or to herbicides (Myint Myint Win 1999).

Herbicides have been introduced as they are efficient, practical and cost-effective particularly in areas where labor is scare or expensive. They are often the best alternatives to control weeds in least amount of time and labor where vast areas are involved. Herbicides are applied into non flooded soil or into the flood water and require appropriate equipment and calibration. Improper calibration or application could result in under dosage and inadequate control or over dosage and rice injury and adverse effects on the environments (De Detta and Baltazar 1996).

In Myanmar, there is still relatively little use of herbicides in rice production. High cost of herbicides and lack of knowledge are the major limitations on using herbicides (Myint Myint Win 1999). Weeds have a variable growth habit and life cycles so that no single method can effectively control weeds in all situations (De Datta and Herdt 1983). Integrated weed management approach is an urgent requirement for improvement of rice yield (Labrada 1996). Therefore, cost effective and consistent integrated weed management system should be carried out in the system of rice intensification. In this regard, the present study was conducted with the following objectives:

1. to evaluate the effectiveness of different weed control methods for the system of rice intensification,
2. to observe the yield loss percent due to weed infestation in the system of rice intensification, and
3. to determine the most cost-effective weed control method for the system of rice intensification.

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CHAPTER II
LITERATURE REVIEW

2.1 The Origins of System of Rice Intensification (SRI)

The SRI methodology was synthesized in the early 1980s by Fr. Henri De Laulanié, S.J., who came to Madagascar from France in 1961 and spent the next (and last) 34 years of his life working with Malagasy farmers to improve their agricultural systems particularly their rice production, since rice is the staple food in Madagascar. Rice provides more than half the daily calories consumed in Madagascar, a sign of the cultural and historic significance of rice to Malagasies, but also an indication of their poverty (CIIFAD 2009).

De Laulanié established an agricultural school in Antsirabe in 1981 to help rural youths gain an education that was relevant to their vocations and family needs. Though SRI was discovered in 1983, benefiting from some serendipity, it took some years to gain confidence that these methods could consistently raise production so substantially. In 1990, de Laulanié together with a number of Malagasy colleagues established an indigenous non-governmental organization (NGO), Association of Tefy Saina, to work with farmers, other NGOs, and agricultural professionals to improve production and livelihoods in Madagascar. In 1994, Tefy Saina began working with the Cornell International Institute for Food, Agriculture and Development (CIIFAD) in Ithaca, NY, to help farmers living around Ranomafana National Park to find alternatives to their slash-and-burn agriculture. They would need to continue growing upland rice in this manner destructive to Madagascar's precious but endangered rain forest ecosystems if they could not significantly increase their yields from rice grown in the limited irrigated lowland area, about 2 tons per hectare. Farmers using SRI averaged over 8 tons per hectare during the first five years that these methods were introduced around Ranomafana. A French project for improving small-scale irrigation systems on the high plateau also found that farmers using SRI methods averaged over 8 tons per hectare (CIIFAD 2009).

The name "Tefy Saina" means, in Malagasy, "to improve the mind," indicating that this organization is not concerned just with rice, but also with helping people to change and enrich their thinking. Before he died in June 1995, de Laulanié published one article on SRI in the journal Tropicultura. Since 1997, a number of other papers or articles have been written about SRI. While most interest came initially from NGO and university circles, evaluations are now coming also from national research programs and International Research Institutes (CIIFAD 2009).

2.2 The Basic Elements of System of Rice Intensification (SRI) Practices

Satyanarayana et al. (2007) stated the following basic elements of SRI practices.

1. The system of rice intensification methods gives highest yield when young seedlings (less than 15 days old and preferably only 8-12 days, i.e., before the start of the 4^{th} phyllochron) are transplanted.

2. Transplanting should be done carefully to avoid trauma to the plants' roots and also quickly to avoid their becoming desiccation. Seedlings are raised in an unflooded, garden-like nursery and then transplanted within 15-30 minutes after uprooting. Shallow transplanting (only 1-2 cm deep, with roots laid in the soil as horizontally as possible) is recommended.

3. Plant density is greatly reduced with SRI compared to conventional rice cultivation. Instead of replanting seedlings in clumps of three to six plants, they are transplanted singly and in a square pattern. Initially, spacing of 25cm x 25 cm is recommended, but as SRI practices improve the soil over time, wider spacing can later give even higher yields. Sparse planting avoids the inhibition of root growth that results from crowding and by exposing plants to more light and air; the system of rice intensification creates 'the edge effect' for the whole field.

4. Seedlings are transplanted into a muddy field rather than one flooded with standing water. During the vegetative growth phase, paddy soil is kept moist but never continuously saturated because flooding creates hypoxic soil conditions that cause rice roots to degenerate. The system of rice intensification recommendation has been to maintain 1-3 cm of standing water on the field after panicle initiation. However, this may be more than necessary. Some SRI farmers who practice alternate wetting and drying (AWD) throughout the crop cycle, with no continuous flooding, report good results.

5. To control weeds, use of a mechanical weeder is recommended, starting 10 days after transplanting, with additional weedings every 10-12 days until the canopy

closes. One or two weedings is usually sufficient to control most weeds; however, additional weedings are found to be boost yield by 0.5 -1 tons weeding^{-1} or more. Planting in a square pattern allows farmers to weed their fields in perpendicular directions, which achieves more and better soil aeration.

6. The system of rice intensification was originally developed using chemical fertilizer to augment soil nutrient supplies. System of rice intensificaion farmers was encouraged to apply compost. The use of compost together with other SRI practices gave even better results and was preferable for cash-poor farmers. If organic matter is not available, SRI practices can be used successfully with chemical fertilizer.

2.3. Preparation of Nursery and Age of Seedlings to be Transplanted

The following steps are recommended by CIIFAD and ATS (2004) for a modified dry bed method of nursery development for SRI seedlings.

1. Rice seeds should first be soaked in water for 24 hours. Any that are irregular or float seeds should be discarded.

2. Then, the seeds are put in a sack (burlap or other) and place it in a warm compost pile or in a hole in the ground that has been warmed by fire. The sack is covered completely with either compost or soil and leaves it for 24 hours for slow warming of the seeds.

3. The seedbed should be prepared as closely as possible to the field that will be planted, so as to minimize transport time between removal of seedlings from the seedbed and their transplanting in the field.

4. Compost should be mixed into the soil of the seedbed at a rate of 100 kg (10 m x 10 m). Prior to seeding, lay down a fine layer of well-decomposed compost or black soil in the seedbed to give the seeds good nutrient rich material to begin their growth in.

5. Farmers in Sri Lanka have found that building up the seedbed, about 10 cm, with the lengths of bamboo, putting in compost or animal manure (chicken manure is very good) along with the soil, gives the seedlings an excellent start and makes them easy to remove. Also, the organic nutrients are contained within the seedbed better this way.

6. The pre-germinated seeds are broadcasted s are onto the bed at a rate of about 200 g for every 3 square meters, and then cover the seeds with a fine layer of soil.

7. The seedbed is watered every day in the late afternoon, or as often as needed to maintain a moderate level of soil moisture. The soil should not be saturated or kept continuously wet. If there has been rain during the day, no watering may be needed. How much to add to the bed depends on whether the soil has become dry.

8. Transplanting should be done when the seedlings have just two leaves. This usually occurs between 8 and 15 days after sowing.

9. Seeds should not be sown all at the same time. Rather, appropriate batches of seeds should be sown on successive days, so that the plants when they are put into the field can be all a uniform age, all between 8 and 12 days old.

2.4 Prospects of the System of Rice Intensification in Myanmar

The System of Rice Intensification (SRI) experience began in Myanmar through the efforts of Metta Development Foundation, a pioneering national NGO in this country. Metta Development has been facilitating an ecological approach to improve crop production through the introduction of Farmer Field Schools (FFS) in collaboration with local organizations and church groups in different parts of Kachin State and Shan State in the northern part of the country (Kabir 2003).

After learning about SRI during a visit to Sri Lanka on an FAO mission in January 2002, a deputy general manager of Myanma Agriculture Service has taken an interest in getting SRI evaluated more widely in the country. In June 2002, Norman Uphoff visited Myanmar, hosted by the Ministry and Metta Development Foundation, to meet with both Ministry officials and with farmers to disseminate an understanding of SRI opportunities (Kabir 2003).

Nowadays, a number of other NGOs are also actively engaged in disseminating SRI in many parts of the country. Among them, GRET in Rakhine State bordering Bangladesh, GAA (German Agro Action) in Wa Region and Ayeyawaddy Division and World Concern in Kachin, Shan and Chin States, all have a number of ongoing projects in which SRI is a major intervention to address the food security status of the communities that these organizations have been working with. Besides this, there is a consortium of 20 NGOs, (mostly local) known as the Food Security Working Group (FSWG) in the country which has also taken an interest in SRI and many of these NGOs have been supporting communities with SRI methods , although on a limited scale (Kabir 2008).

The system of rice intensification has recently been introduced by Metta Foundation in lowland Ayeyawaddy division, in the ‘rice bowl’ of Myanmar. Rice being the main crop there, grown in both the summer and wet seasons, farmers’ response to SRI in this low-lying delta area has been observed to be much higher than in northern, more mountainous part of the country, especially Kachin, Shan and Chin States, where wet-season rice is practiced in just a single season (Kabir 2008).

In the delta area of Myanmar, where chemical fertilizers and pesticides are heavily used, constituting a major part of the cost of rice production there, farmers are desperate to try alternative methods to get out of this costly conventional system of rice cultivation. Therefore, the initial cost-saving with SRI from using no or less chemical fertilizers seem to be the immediate motivating factor for farmers to try SRI (Kabir 2008).

To disseminate SRI in Ayeyawaddy Division, Metta Development Foundation has recently started an intensive three month, season-long training on SRI near Pathein, the capital of Ayeyawaddy. Since the middle of November 2007, 24 farmers from various part of Ayeyawaddy Division have been attending the training. During the training, the participant farmers have grown around 10 acres of rice using SRI methods. After the training, they are all planning to use the methods on their own fields, and at the same time will be working as farmer-trainers to share the methods with other farmers in their areas (Kabir 2008).

Since 2001, Metta Foundation has conducted more than 600 FFS where SRI has been taught as the major strategy for rice cultivation. According to various project reports and evaluations studies conducted by Metta Foundation, more than 50,000 farmers in Kachin and Shan States who have directly participated in FFS training or have learned from these directly participating farmers are now using SRI in various degrees. While a majority of them are using the basic principles of SRI, adapting a few practices according to their capacity, at least 15% of them, or 7,500 farmers, are believed to be using the major practices of SRI. Another 5,000 farmers are believed to be using SRI in various degrees in the working areas of the other NGOs mentioned above (Kabir 2008).

In the past, the system of rice intensification is used mostly in the upper part of the country where rice is grown only in the wet season. Due to higher altitude there, these farmers do not generally have an opportunity to practice summer rice, for which SRI is most suitable. Now that SRI has been introduced into the lower part of the country where summer rice is the main crop and where farmers have greater interest in SRI due to the cost-savings attainable, it is possible that dissemination of SRI would be much wider and faster in the lowlands of lower Myanmar (Kabir 2008).

2.5 The Practices of SRI in Myanmar

Kabir (2006) reported that the practices vary from location to location and also from season to season, considering the differences of the soil in different geographical locations as well as the climatic conditions in different seasons. They also vary according to farmers' general understanding, their knowledge base to manipulate the practice to suit into their particular conditions and their overall affordability in term of costs associated with hiring labor. The SRI practices that are being introduced to farmers in Myanmar are:

1. Planting younger seedlings:

Seedlings usually 10-12 days old, but not older than 15 days are used. Usually in wet season due to comparatively higher temperatures, 10 days-old seedlings are widely used, but in winter, especially in areas with cold temperatures where very young seedlings sometimes have problems in establishment, farmers prefers to use 12-15 days old seedlings. A little older seedling is preferred in certain areas, particularly in the wet season, where standing water is a problem.

2. **Planting seedlings one by one**:

Though the majority of SRI farmers use one seedling per hill, in some cases they use up to two seedlings. This is mainly to avoid any loss of seedlings due to pests or other damages, which can happen within a few days of transplanting if they are not planted carefully.

3. Planting with wider spacing:

There has been no fixed spacing found being commonly used by SRI farmers in general, but 25 cm x 25 cm, 30 cm x 30 cm and 35 cm x 35 cm have been seen most often. Spacing also depends on the inherent quality of the soils. The better the soils, the wider the spacing is appropriate for getting higher yield.

4. Planting seedlings as immediately as possible:

Seedlings once uprooted from the seedbed are generally transplanted within half an hour with SRI practices and many farmers have even been seen to do this immediately after uprooting, as their seedbeds are already inside the main field.

5. Using compost:

Although most farmers use compost/manure, the amount varies in terms of its availability and also because there has been no fixed or recommended rate to follow. Composts are used mostly before transplanting during land preparation, but it is preferred to use this with the preceding crop.

6. Alternate irrigation:

It is practiced up to the initiation of panicles, and then the field is just kept moist. The number of irrigations needed during the entire crop period and the gap between two irrigations depend on the type of soil.

7. Intercultivation:

Soil is generally cultivated using a rotary weeder, which is primarily done to control the growth of weeds. Intercultivation is also needed to aerate the soil but the number of times for weeding varies from 2 to 5 during the entire tillering period, based on farmers' choices and affordability.

2.6 Effect of Seedlings Age on Grain Yield of Rice

Age of seedlings at transplanting is most often dependent on the availability of water, herbicides, labor and other inputs in farmers' fields. In tropical lowland rice, farmers transplant seedlings at distinct ages, most of the time from 25 to 50 days after germination (De Datta 1981; Wagh et al. 1988; Singh and Singh 1999).

Some studies indicated a positive impact on grain yield by using seedling not older than 25 days (Ashraf et al. 1999; Singh and Singh 1999; Nandini and Singh 2000;

Thanunathan and Sivasubramanian 2002). On one hand, few others reported that the use of 30 and 60 days old seedlings did not affect yield (Chandra and Manna 1988). However, Khatun et al. (2002) found that the use of 45 days old seedlings proved to be better than those aged 30, 60 and 75 days.

Some attributed the significant superiority in 1000 grain weight and grain yield of younger seedlings (25 days old versus 50 days old) to the longer heading and maturity periods (NARC 2004) while others attributed it to the longer vegetative growth (Chandra and Manna 1988). The mortality of young seedlings (14 days) right after transplanting was reported as a reason for the lower yield compared to that with older seedling (28 days) (Kewat et al. 2002). Recent studies on the system of rice intensification (SRI) showed, however, that transplanted seedlings as young as about 14 days old generated higher crop performance than transplanting 21 to 23 days old seedlings (Makarim et al. 2002; Thiyagarajan et al. 2002).

McHugh (2002) also observed in Madagascar that 8 to 15 days old seedlings transplanted at 25 hills m^{-2} produced the highest yields, whereas in Sumatra the highest yields were obtained with 10 days old transplanted seedlings. In North Sumatra, 15 days old seedling crop out-yielded a 21 days old one (Makarim et al. 2002). There were indications that the longer stay of seedlings in the nursery may have affected seedling growth pattern in response to high seedling competition (Mandal et al. 1984). Herrera and Zandstra (1980) also stated that transplanting old seedlings extended the overall crop duration.

Wiengweera (1984) reported that the grain yields of rice planted as young seedlings of IR58 and IR36 (short duration,100-110 days) were higher than those of the old seedlings because of higher panicle and spikelet numbers per unit area, higher grain filling percentage, and increased 1000 grain weight. He also stated that the yield of IR58 increased when the number of seedlings per hill increased from 3 to 6. Cada and Taleon (1963) suggested 25-30 days old seedling as optimum for early maturing varieties. Patel et al. (1978) observed that yield was the highest for 21 days old seedlings, while a yield reduction of 16 and 32 % occurred for 28 and 35 days old seedlings, respectively. Thit Thit Soe (2008) observed that grain yields of 10 and 12 days seedling age were higher than that of 20 days in wet and dry seasons.

2.7 The Relation of SRI and Increase in Grain Yield of Rice

There is evidence that cultivation of rice through SRI can increase rice yields by two to three folds compared to current yield levels (Abu 2002). Husain et al. (2004) documented a 30 % yield advantages for SRI in Bangladesh and Namara et al. (2003) showed an even larger benefit (44%) in Sri Lanka. Increased grain yield under SRI is mainly due to the synergistic effects of modification in the cultivation practices such as use of young and single seedlings per hill, limited irrigation and frequent loosening of the top soil to stimulate aerobic soil conditions (Stoop et al. 2002). Combination of plant, soil, water and nutrient management practices followed in SRI increased the root growth, along with increase in productive tillers, grain filling and higher grain weight that ultimately resulted in maximum grain yield (Uphoff 2001).

2.8 The Relation of SRI and Extensive Root System of Rice

When rice is grown under continuous submergence most of the rice plant's roots remain in the top few centimeter of soil and degenerate by the reproductive phase (Stoop et al. 2002). System of rice intensification produces vigorous plants with larger root systems (Deberman 2004; Stoop 2005). Physical and biological soil characteristics largely determine the possibilities for root development and thereby the extent to which roots can access soil nutrients (Stoop et al. 2002). In the case of SRI, deeper root systems are promoted by increased soil aeration and lack of mineral fertilizer use, which lead to greater exploitation of available indigenous soil resources (Deberman 2004).

Kar et al. (1974) observed that total root number, root dry weight, shoot dry weight of rice grown under flooded condition were much larger than under unsaturated condition. Tao et al. (2002) found that SRI plants had a much deeper root system and larger root and total plant dry matter per hill than plants grown under conventional management. Observations for the SRI system suggested that deeper and stronger root systems are developed due to intermittent irrigation practiced on soils without physical barriers to root growth, planting of young, single seedlings at wide spacing, and application of slowly-releasing nutrient sources such as compost (Stoop et al. 2002).

2.9 Differences between SRI and Traditional Practices in Rice Cultivation

Koma and Suon (2004) mentioned the differences between SRI and common traditional practices in rice cultivation as follows.

Plant Management

SRI	Traditional
- Producing vigorous seedlings for transplanting, raising seedlings under garden-like conditions, and using low density of seed.	- Raising seedlings in fields with saturated soil conditions and high seed density.
- Transplanting young seedlings, at the age of 8 to 15 days old.	- Transplanting mature seedlings, generally between 1-2 months old.
- Selecting only vigorous seedlings for transplanting.	- Using mixture of weak and strong seedlings used in transplanting.
- Transplanting quickly and carefully with single plant.	- Transplanting many seedlings per hill, generally more than 5.
- Placing roots into the soil horizontally with a shallow depth of 1-2 cm when transplanting.	- Placing roots very deep into the soil.
- Transplanting in a square pattern with wide spacing (25 cm x 25 cm is recommended).	- Transplanting with close spacing.
- Punctual and frequent weeding to improve soil aeration and to remove weeds by using a rotary weeder, the weeds remain in the soil to decompose.	- Non regular weeding only when necessary; weeding is considered as the removal of a rice competitor.

Water Management

SRI	Traditional
- Transplanting when there is no flooded water standing in the rice field; the soil should be only moist and muddy. - Improving soil aeration by draining water from the rice field or by keeping the rice field from being continuously flooded and saturated during the vegetative growth phase.	- Being flooded or saturated, the field is considered good for transplanting and for growing the rice crop. - Keeping the rice plants inundated permanently during the entire growth cycle.

2.10 Rice -Weed Competition

Weeds are nourished by the same nutrients and environmental elements needed by the crop. Weeds interfere with rice growing by competing for one or more growth limiting resources, such as light, nutrients and water. Because of the limited supply of these vital elements, their association, therefore, leads to competition for these elements of survival. During the cropping period, there is a particular duration, the critical period of competition, the presence of weeds above a certain density, critical threshold level, will cause a significant reduction in yield (Mercado 1979).

Weed species differ in their ability to compete with rice (Smith 1968). The degree of rice-weed competition depends on rainfall, rice variety, soil factors, weed density, duration of rice, weed growth and crop age when weeds started to compete, and nutrient resources, among other variables (Ampong-Nyarko and De Datta 1991).

The relative competitive ability between annual and perennial weeds largely depends on the weed species and the growing conditions. In area where perennial weeds such as *Scirpus maritimus* predominate, annual weeds are not as competitive as perennials. However, the yield reduction was most severe when both annuals and perennials were present (De Datta 1974). Even though red rice was a more serious competitor, early season control was more important for barnyard grass or sprangletop than for red rice (Smith 1988).

2.10.1 Competition for light

Competition for light can occur throughout rice growth whenever plants are growing closely together. Weeds compete with rice by growing faster and by shading rice with large, horizontal leaves. Shading occurs with a high leaf area index (LAI) reducing the light available to the vegetation below the canopy as expressed in a low light transmission ratio (LTR) below the canopy (Mercado 1979).

Most weeds and rice have maximum photosynthesis and growth in full sunlight (Ampong-Nyarko and De Detta 1991).The ability to compete for light depends largely on the comparative growth stature of the competitors. Thus plants which are tall or have an erect habit will a competitive advantage over short or prostrate plants. Rice suffers little competition for light from *Monochoria vaginalis* (Burm.F.) Presl., a short-statured plant whereas competition from *Echinochloa cruss-galli* (L.) Beauv., a tall weed which eventually overtops the rice plant can be quite severe particularly in the later stages of growth (Moody 1995).

2.10.2 Competition for water

Water is one of the critical factors in crop production. The amount and distribution of rainfall determines the kind of crops grown throughout the year in an area, particularly under unirrigated condition. In tropical areas where there is a distinct dry season, crop-weed competition for water becomes a serious problem (Mercado 1979).

Competition for water and nutrients usually begins before competition for light and is thought to be more important. Competition is greatest when plant roots are closely intermingled, and crops and weeds are obtaining their water from the same volume of soil. Less competition occurs if the roots and weeds are concentrated in different areas of the soil profile. The more competitive plant has a factor growing and larger root system so that it is able to exploit a larger volume of soil quickly (Moody 1995). If plants have similar root length, those with more widely spreading and less branched root systems will have a comparative advantage in competition for water (Zimdahl 1999).

The overall competitive ability of a plant is partly controlled by its root system. Those with extensive root systems that ramify within the plow depth of the soil will benefit more from additional supply of nutrients and water. Those with the tap root system that goes deeper into the ground can compete better for water under conditions of very limited water supply (Mercado 1979).

2.10.3 Competition for nutrient

If soil nutrients are abundant, weed competition is less important. However, in many tropical and subtropical areas, soils are nutrient-poor and thus competition is critical (Doll 1994). The three most common yield limiting nutrients are N, P and K. Competition, however, may occur for any nutrient required for plant growth. Weeds also have a large requirement for nutrients (Ampong-Nyarko and De Detta 1991).

Weeds will absorb as much or more than the crop plant. Usually nitrogen is the first nutrient to become limiting factor as a result of crop-weed competition. In a study of competition for nutrients between rice and *Echinochloa cruss-galli*, the total amount of nitrogen taken up by plants growing in any combination of rice weed association is approximately the same (Borema 1963).

Generally nitrogen affects plant development, competition and community structure. Modern rice varieties require more nitrogen than the traditional varieties. In tropical areas, nitrogen fertilizer accounts for about 67 % of the total amount of fertilizers applied to the rice crop (De Datta and Natasomsaran 1991). In that case, nitrogen responsive crop species are more competitive under high N fertilization, but if the associated weed is also responsive to N it utilizes more of the applied N and no advantage in crop yield may be obtained (Ehsanullah et al. 2001).

Weeds infestation affects on modern rice cultivars especially nitrogen competition. Nitrogen responses of IR-20 were greater with weed control than without it (De Datta and Malabuyoc 1976). Thus, to favour nitrogen uptake by the crop, weeds should be eliminated. Kleing and Noble (1969) reported that the addition of phosphorus to dry seeded wetland rice increased the number of rice tillers and panicles when rice was grown alone. In the presence of *E. cruss-galli*, the number of tillers and panicles of rice were depressed when phosphorus was added. Smith (1967) also reported that phosphorus increased rice yield substantially when rice grown alone but a significant decrease occurred when the rice was competing with *E.cruss-galli*. The addition of phosphorus greatly increased dry matter yield of *E.cruss-galli* both when grown alone and in competition with rice. He also stated that potassium applied directly to rice has little or no effect on weed growth.

2.10.4 Crop-weed allelopathy

Allelopathy is the influence of one plant upon another plant growing in its vicinity by the release of certain metabolic toxic products in the environment. Ahn and Chang (2000) mentioned that the term allelopathy was introduced by Molisoh since 1937. It covers biochemical interactions, both beneficial and harmful between plant species including fungi and bacteria.

Allelopathy plays an important role in agro-ecosystems leading to a wide array of interactions between crop-crop, crop-weed and tree crops (Singh et al. 2001). Some weed species inhibit other weed species. They represent an excellent strategic source of natural chemicals that may be involved in developing natural herbicides (Qasem and Foy 2001). Although allelochemicals are present in all plant parts and tissues including stems, leaves, flowers, bark, pollen grains, seeds, fruits, roots and rhizomes (Kohli et al. 1998), their concentration varies from one part to another (Qasem and Foy 2001).

Allelopathy can be used in weed management in two ways. The first is by selecting an appropriate crop variety or incorporating an allelopathic character into a desired crop variety. The second way is by applying residues and straw as mulches or growing an allelopathic variety in a rotational sequence that allows residues to remain in the field (Rice 1995).

The allelopathic effect of rice on paddy weeds had a higher growth inhibition on the root than the shoot (He 2000). Allelopathic accessions had six to nine times heavier root dry weights than non-allelopathic accessions (Dilday et al. 1989; 1991). In addition; the japonica type had higher allelopathic activity than the javanica type (Fujii 1993). Chou and Lin (1976), and Chou et al. (1981) reported that rice productivity was decreased when grown rice after rice. They believed that it was due mainly to the allelopathic effects of decaying rice residues. Barley releases the largest amount of allelopathic alkaloids after germination in hydroponic culture (Liu and Lovett 1993).

Allelopathic rice cultivars could supplement the use of herbicides in direct seeding (Olofsdotter and Navarez 1996). Some allelopathic cultivars strongly inhibit root elongation of barnyardgrass [*Echinochloa cruss-gulli* (L.) P. Beauv.], but weakly affect the shoot (Navarez and Olofsdotter 1996). Hassan et al. (1995) identified rice cultivars that expressed allelopathic effects after plants reached the 3-leaf stage, and such varieties inhibited root development and emergence of the first or second leaf of *E. cruss-gulli*.

2.11 Rice Yield Losses Due to Weed Infestation

Yield losses caused by weeds in transplanted rice fields depend upon the time of weed infestation, soil fertility, rice cultivar and planting methods. In transplanted rice fields, about 60% of the weeds emerge in the period between one week and one month after transplanting. These emerging weeds are the major populations competing with rice in maximum tillering stage and reducing the number of panicles causing the yield reduction. About 15-20 % of the weed population emerges in the period between one month and two months after transplanting and 20-25% of weeds emerge later and are not important in yield reduction (Zhang 1996).

Weed competition and corresponding yield losses are usually greater in upland rice than in other rice production systems (Moody 1983). Elliot and Moody (1987) reported that an additional weeding within 8 weeks after crop emergence resulted in yield increase of 43-80 %. Yield losses due to uncontrolled weed growth were on average 9% higher in wet seeded rice than in transplanted rice in trial conducted at IRRI (Ho 1996). As yield losses by weed competition involves many factors such as varieties, spacing, crop vigor, population density, timing of crop emergence, soil fertility, climate and duration of competition, a quantitative approach to reach on yield loss caused by weed competition can be helpful to integrate weed control practices (Chisaka 1977).

Weeds cause greater yield losses in direct seeded rice than in transplanted rice and in dry seeded soil than in puddle seeded soil (Moody 1977). The selection of shorter statured rice cultivars has led to reduced ability to compete with weeds and poorer adaptation to weedy situations. As a result, yield losses due to weeds are greater in the modern cultivars and more time is spent in removing them than in traditional cultivars (Moody 1979). In manually transplanted rice, the yield loss was minimum (46 %) when compared with 90% losses with direct seeded rice (Hassan and Rao 1993). Yield reductions due to weeds were 26 to 46 % in Manawthukha, 49 to 62% in Shwethweyin in

2002 and 38 to 47 % in Shwethweyin in 2003 trial. More weed dry weight in Shwethweyin than Manawthukha showed that Manawthukha was more competitive against weed than Shwethweyin (Than Than Soe 2003). Ecophysiological model showed that the relative leaf area of weeds is more closely related to yield loss than is density count (Kropff and Spitters 1991).

2.12 The Effect of Manual Weeding on Yield of Rice

The first weeding operation is done 3-4 weeks after transplanting and needs 25-34 labors ha^{-1} depending on the weed density. The second weeding is generally done 15-30 days after first weeding and usually required 12-15 labors ha^{-1}. The second weeding operation is needed to pull out the weeds, which escaped the first weeding (Moody 1998). The hand removal of early emerged grassy weeds and sedges along with the broad leaved species allowed lower accumulation of dry matter and these resulted in better crop growth which in turn smothered the weed growth in comparison to other treatments. These resulted in maximum weed control efficiency under other treatments (Gogoi 1998). Increasing the frequency of hand weeding from one to two doubled the yield and also reported weed free period between 0 to 49 days after transplanting resulted in highest yield for transplanted rice (Ahmed 1982).

Hand weeding is the most common and effective methods of weed control in rice but it is being difficult and uneconomical day by day due to high wages and non availability of labors at the peak of farm operation (Singh et al. 1999). A large portion of the total labor is required for hand weeding, however, hand weeding is common in areas where labor is easily available and costs are low. Otherwise, chemical weed control is recommended (Silveira Filho and De Aquino 1983). Hand weeding is generally not a very efficient method. Probably 10-20 % or more of the plants with 10 cm or more growth is left in the field after weeding. On an average the efficiency of this method is not more than 70% (Moody 1998).

2.13 The Effect of Mechanical Weed Control on Yield of Rice

With SRI, weeding is done manually using a mechanical hand weeder (rotating hoe or cono -weeder) with no herbicide use. This returns the weeds to the soil as green manure. Moreover, weeding for SRI becomes less hard in successive years as skill is gained in the methods and as better implements is developed. Giving up herbicides has a health benefit for all concerned persons like the farm worker and the consumer, and there is no pollution of the environment and ground water. The pronounced effect of the increased number of rotary weeding indicates that weed control is the key factor and it should also increase the aeration in the field (Fernandes and Uphoff 2002).

Senthilkumar (2003) compared the use of rotary weeder (five times with ten day intervals from 20 days after transplanting until booting stage) with the conventional hand weeding (three times) for wet season, and chemical weeding and two times hand weeding for dry season. In both seasons, mechanical weed control significantly increased grain yields. Weeder use alone increased the plant height and enhanced the grain yield by 10.9 % as compared to manual weeding. Vijayakumar et al. (2006) found significant yield increase of 9.7% (20 cm x 20 cm plant density) and 11.1 % (25 cm x 25 cm plant density) due to weeder use when compared to conventional weeding (herbicide + hand weeding) with 14 days old seedlings and limited irrigations. In one Madagascar community, farmers who did not do mechanical weeding got 6 t ha^{-1}, farmers who did one or two weedings got 7.5 t ha^{-1}, but the farmers who weeded three times averaged 9.2 t ha^{-1}, and the farmers who were weeding four times got 11.8 t ha^{-1} (Uphoff 2003).

2.14 The Effect of Herbicide Application on Yield of Rice

In rice, the conventional method of weed control i.e hand weeding is very laborious, expensive and inefficient. Chemical weed control can be considered as a better alternative (Singh and Singh 1993). Use of chemical to control weed has been found effective and economical (Pilai 1977; Singh and Mani 1981). Chemical weeding is easier, time-saving and economical as compared to hand weeding alone (Brar and Mishra 1989). Herbicidal weed control methods offer an advantage to save labor and money, as a result, regarded as cost effective method of weed control (Ahmed et al. 2000).

Herbicides gave significant control of weeds when applied one day after transplanting (Sharma et al. 1994). In South Korea and China, rice is treated with herbicides by 70% and 90% respectively. Moreover, 90% rice herbicides being applied are pre-emergence and farmers prefer granular herbicides at 4-6 days after transplanting

(Moody 1982). Herbicide use move the agro-ecosystem to low species diversity with new problem weeds appearing, so that there is a need for an ecological approach to weed control instead of replying totally on chemical control methods (Moody 1992).

CHAPTER III
MATERIALS AND METHODS

3.1 Experiment I (Dry season, 2009)

This experiment was conducted at the lowland field of Department of Agronomy, Yezin Agricultural University during the dry season (February to June), 2009. The soil was sandy loam with the pH value of 5 to 6.5. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and each subplot size was 12.8 m^2 (4 m x 3.2 m). Twelve days old seedlings of rice plants were transplanted with a spacing of 20 cm x 20 cm between rows and within rows since the tested variety was short duration. There were 16 rows per plot and 20 hills per row in this experiment. ShweThweYin (IR50) variety which has life period of 105-110 days was used as the tested rice cultivar. The treatments are as follows:

1. Two hand weedings [at 21 and 35 days after transplanting (DAT)] (2 HW)
2. Rotary weeding followed by (fb) hand weeding at 15 and 35 DAT (RW fb HW)
3. Two rotary weedings at 15 and 30 DAT (2 RW)
4. Herbicide application fb hand weeding at 20 and 40 DAT (HA fb HW)
5. Herbicide application fb rotary weeding at 20 and 40 DAT (HA fb RW)
6. No weeding (Unweeded check)

Post emergence herbicide (Fenoxyprop-ethyl + Ethoxysulfuron) were applied by knapsack sprayer with fan type nozzle. It was applied at the rate of 395 ml ha^{-1} at 20 DAT. The plots were completely drained out before herbicide application so as to achieve thorough contact of herbicide with weeds. Water was reintroduced at 3 days after herbicide application, and follow-up hand weeding and rotary weeding were undertaken at 40 DAT.

3.1.1 Seedbed preparation for raising seedlings

Seedbed preparation was done in February 2009. The size of each seedbed was 4 m x 1 m and raised about 7 cm above the original soil level. Seedbed was covered with plastic sheet and then placed wooden frame and put a mixture of cow dung manure, compost, decomposed straw and soil. Pre-germinated seeds were broadcasted on each seedbed. Seeds were then covered by rice husk ash to prevent from birds and moisture losses. Irrigation was done whenever necessary. The photo of nursery bed is shown in Figure 3. 1.

3.1.2 Procedure of transplanting

The twelve days old seedlings of rice were uprooted gently from seedbed and then immediately transplanted into the field. The ropes were knotted at intervals of 20 cm and seedlings were then transplanted with the rate of three seedlings hill^{-1}.The rice seedlings corresponded to two-leaf stage at transplanting. Ten sample seedlings were randomly taken and measured the shoot and root length just before transplanting. The average shoot and root length were found to be 14 cm and 5 cm respectively (Figure 3.2).

3.1.3 Field operations

The land was prepared by ploughing and harrowing. At final land preparation, fertilizers were applied at the rate of 61.8 Kg P_2O_5 ha^{-1}, 30.9 Kg K_2O ha^{-1} and 18 Kg gypsum ha^{-1} as basal application and 125 Kg Urea ha^{-1}were top dressed at active tillering stage, panicle initiation and booting stage. The water management was done by alternative wetting and drying according to the system of rice intensification.

3.1.4 Data collection

The visual assessment of herbicide phytotoxicity on rice plant and weeds were observed at 7, 14 and 21 days after spraying by using phytotoxicity score.

Data regarding weeds were collected two times at 50 DAT and harvest from two sampling units (0.5 m^2 quadrates) from each plot to measure the weed density. The weed samples were cleaned and discarded the roots. The collected weeds were identified into three groups: grasses, sedges and broadleaf weeds and counted the number of each group. The weeds were dried in electric oven for three days at 70 HC and then recorded the weed dry weight. Rice plant was harvested at 110 DAT and grain yield was determined by harvested area of 5.76 m^2 of each plot. The harvested plants were threshed, dried and weighed.

Figure 3.1 Seedbed preparation in the system of rice intensification

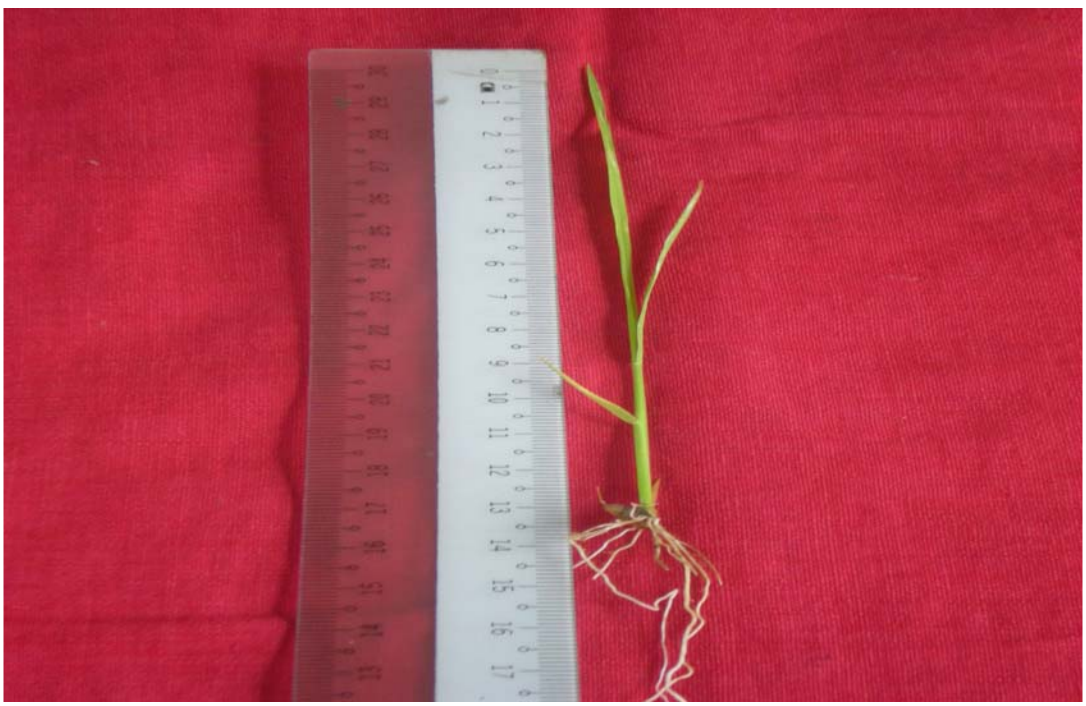

Figure 3.2 Twelve days old seedling of rice at transplanting

Grain yield of each plot was converted to ton per hectare. Yield components and agronomic characters such as number of panicles hill^{-1}, number of spikelets hill^{-1}, filled grain percentage, panicle length and 1000 grain weight were collected from five sample hills of each sampling area plot^{-1}. These samples were taken just before harvest time.

The moisture percentage of rice grain for each treatment was measured by moisture meter. Grain yields were calculated with adjusted grain weight at 14 % moisture level by using the following formula:

Adjusted grain weight at 14% moisture level = A x W

where,

A = Adjustment coefficient

W = Weight of harvested grains

$$A = \frac{100 - \text{Moisture }\%}{86}$$

Economic analysis was also calculated to find out the weed control method which generates the highest net benefit. Partial budget method was used for economic analysis which was calculated as follows.

Step-1 Calculation of the grain yield

Step-2 Calculation of the adjusted yield which was adjusted downwards by 10% losses from harvesting and threshing

Step-3 Calculation of the gross yield benefits = adjusted yield x field price of rice

Step-4 Calculation of the total costs that varied

Step-5 Calculation of the net benefit = Gross field benefits – total costs that varied

In evaluating the economics of weed control treatments, Marginal Benefit Cost Ratio (MBCR) was used.

The MBCR of the existing practice (E) and of any potential replacement (P) can be calculated as follows:

$$\text{MBCR} = \frac{\text{Gross benefit (P)} - \text{Gross benefit (E)}}{\text{Total variable cost (P)} - \text{Total variable cost (E)}} = \frac{\text{Marginal benefit}}{\text{Marginal cost}}$$

(Moody 1995)

Yield losses due to weeds and yield increase due to weeding treatments were determined using the following equations.

Yield losses due to weeds

$$\text{Yield loss \%} = \frac{\text{Yield of weeded plots} - \text{Yield of unweeded plot}}{\text{Yield of weeded plot}} \times 100$$

(Moody 1995)

Yield increase due to weeding treatments

$$\text{Yield increase \%} = \frac{\text{Yield of weeded plot} - \text{Yield of unweeded plot}}{\text{Yield of unweeded plot}} \times 100$$

(Moody 1995)

Weed control efficiency was calculated with the following formula:

$$\text{Weed control efficiency (WCE)} = \frac{\text{DWC} - \text{DWT}}{\text{DWC}} \text{ X } 100$$

Where,
DWC = Dry weight of weeds in unweeded plot
DWT = Dry weight of weeds in treated plot

(Sawant and Jadhav 1985)

3.1.5 Data analysis

Experimental data were subjected to analysis of variance by using CROPSTAT software (version 7.2) and treatment means were computed and compared using Least Significant Difference (LSD) test at 5 % level. Excel program was utilized for correlation analyses.

3.2 Experiment II (Wet Season, 2009)

This experiment was conducted from July to October 2009 at the farm of Department of Agronomy, Yezin Agricultural University. A Randomized Complete Block Design (RCBD) with four replications was used in this experiment. Seedbed preparation for raising seedling, other cultural practices and data collection were the same as Experiment I.

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Experiment I (Dry Season, 2009)

4.1.1 Plant height

The plant heights of rice at harvest and weekly interval are shown in Table 4.1 and Figure 4.1, respectively. It was not significantly different among the treatments at $P < 0.05$ level. The result of present study was not similar to the finding of De Datta (1981) who stated that weed has a significant effect on crop height. However, Lubigan and Vega (1971) reported that the height of the rice plant was diminished in a heavy competition with *E. cruss-gulli*. The results from present study are similar to those the observations of Islam and Molla (2001) who stated that plant heights did not differ significantly among the treatments.

4.1.2 Number of tillers per hill

Figure 4.2 illustrates the number of tillers per hill at weekly interval. There were no significant differences between other tested weeding methods and unweeded until 21 days after transplanting and it was observed considerably to be differed at 28 days after transplanting. Among the treatments, the maximum tiller numbers were achieved at 35 days after transplanting and then declined after maximum tillering stage. As a result, treatments with poor weed control were generally associated with minimum tiller numbers. The less the number of tillers, the less the panicles per unit area due to weed competition with rice.

4.1.3 Panicle length

The mean values of panicle length are mentioned in Table 4.1. The treatment of RW fb HW treatment produced the longest length of panicle (21.62 cm) which was not statistically different from the other treatments except unweeded check. These results corroborated with the results of Than Than Soe (2003) who stated that longer panicle length was observed in weed free plot than unweeded check. The findings are similar to those the observations of Myint Myint Win (1999) who reported that panicle length did not differ significantly among weeding treatments in dry season.

4.1.4 Number of panicles per hill

Number of panicles per hill is presented in Table 4.1. There were not significantly different among the treatments; however, all the weeding treatments gave higher number of panicles per hill when compared with those of unweeded check. The results of present study were consistent with the findings of Than Than Soe (2003) who found that number of panicles per hill were higher in weeding treatments and the lowest number was found in unweeded plot. Mamun et al. (1986) stated the similar reduction in number of panicles per plant due to competition from weeds.

4.1.5 Number of spikelets per panicle

The numbers of spikelets panicle^{-1} are shown in Table 4.1. The treatment of RW fb HW produced the maximum number of spikelets per panicle (76.67) which was statistically similar to the other weeding treatments except unweeded plot. Unweeded plot produced the lowest number of spikelets per panicle. The results of present study were similar to the results of Than Than Soe (2003) who reported that number of spikelets per panicle was higher in weed free plot than in unweeded. Moody (1985) stated that the overall effect of rice-weed competition were reduced in the biomass of rice and reproductive potential of the competitor.

4.1.6 Filled grain percentage

The filled grain percent is presented in Table 4.1. The results were significantly different from the other tested treatments at $P < 0.01$ level. The highest filled grain percent (83.66 %) was obtained from two hand weedings treatment which was not significantly different from the other tested weeding treatments and the lowest value (59.91 %) was observed in unweeded check. Therefore, it can be assumed that filled grain percent, one of the important yield components of rice, can be reduced as a result of rice-weed competition.

4.1.7 1000 grain weight

The mean values of 1000 grain weight are shown in Table 4.1. Among the treatments, 1000 grain weights were not statistically different. This finding coincides with Razia (2000) who found the similar non-significant effects of weed competition on 1000 grain weight. The present findings are in conformity with the results of Iqbal et al. (2008) who reported that 1000 grain weight is a genetic character widely used in yield estimation and varietal selection in rice, and environmental factors have minimum influence on it.

4.1.8 Grain yield

Grain yield, percent of yield increase over unweeded check and yield loss due to weeds as affected by different weed control methods are shown in Table 4.2. Grain yield in weeding treatments were significantly higher than that of unweeded check. These results agreed on the findings of IRRI (1990) which reported that yields of weeded plots were consistently higher than those of unweeded. In this study, the highest yield (5.86 t ha^{-1}) was obtained from RW fb HW and the lowest yield (1.52 t ha^{-1}) from unweeded check. Two hand weedings treatment gave good yield as in RW fb HW treatment. IRRI (1985) reported that yield of rice increases due to the application of herbicides followed by hand weeding. Gogoi et al. (1995) found that two hand weedings during the critical period are necessary to increase rice grain yield significantly.

Estorninos and Moody (1979) found that superior weed control and higher yields were obtained when herbicides were supplemented with hand weedings. Lubigan and Moody (1982) reported that manual weeding has proven to be effective but demands high labor and is expensive, labor may be scarce during peak periods and sometimes the weather is unfavorable at weeding time. In this study, the yield of two times rotary weeding was higher than that of HA fb RW treatment, but no significant difference was found. This result conformed to those of Shad (1986) who reported that the combination of limited irrigation and mechanical weeding increased the yield which might be due to the reason that this minimizes weeds besides improving soil aeration and root pruning. Uprety (2005) stated that by using a rotary hoe, this does not only control weeds but it aerates the top horizon of the soil, which stimulates the growth of aerobic bacteria and fungi in the soil. With SRI, weeds are controlled by the use of mechanical weeding with a rotary pushed weeder. The system relies on early and frequent weeding which varies from 3 to 4 times throughout the cultivation period (A T S 1992).

4.1.9 Yield loss percentage due to weeds

The yield loss percentage due to weed competition is presented in Table 4.2. The yield losses due to weeds ranged from 59.47 to 74.06 % in dry season. Deberman and Fairhurst (2000) reported that estimation of yield losses caused by competition from weeds ranges from 30-100 %.This indicates that heavy weed infestation has caused a substantial reduction in the yield of rice. Yield losses from weeds in rice varies with the type of culture, method of planting, time of weed infestation, soil fertility and cultivar (De Datta et al. 1969). Moody (1977) suggested that the taller the rice plant, the less the grain yield reduction. Ramzan (2003) reported yield reduction up to 48, 53 and 74% in transplanted, direct seeded in flooded conditions and direct seeded in dry soil respectively. Moody (1990) stated that yield reduction caused by uncontrolled weed growth in wet seeding could be as high as 64 % in Philippines. Yield increase over unweeded check was found to be in the range from 146.71 to 285.53 percent in dry season, 2009 (Table 4.2). Two times rotary weeding (2 RW) may give more in percent of yield increase than HA fb RW. The highest yield increase percentage was observed by practicing RW fb HW among the weeding treatments.

Table 4.1 Mean values of agronomic characters and yield components of rice as affected by different weed control methods in the system of rice intensification during dry season, 2009

Treatments	Plant height at harvest (cm)	Panicle length (cm)	Number of panicles hill^{-1}	Number of spikelets panicle^{-1}	Filled grain (%)	1000 grain weight (g)
2 HW	83.76	21.36 a	15.53	75. 94 a	83.66 a	19.83
RW fb HW	83.33	21.62 a	16.53	76.67 a	80.09 a	20.00
2 RW	85.82	20.52 a	17.80	58.96 ab	76.43 a	19.43
HA fb HW	83.99	20.67 a	15.67	64.31 a	76.31 a	20.17
HA fb RW	82.56	20.97 a	13.33	67.30 a	74.79 a	19.97
Unweeded	78.03	18.58 b	12.13	50.46 b	59.91 b	20.03
LSD $_{(0.05)}$	5.72	1.74	4	12.15	11.5	0.55
CV(%)	3.8	4.7	14.5	10.2	8.4	1.5
Pr>F	0.1507	0.0351	0.0858	0.0054	0.0153	0.1537

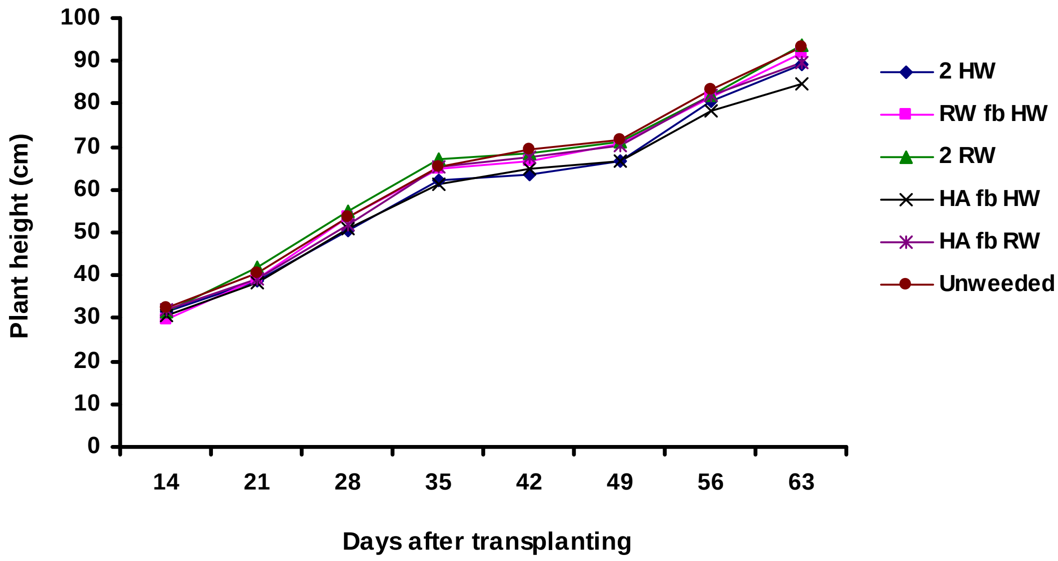

Figure 4.1 Plant height of rice plant at weekly interval in SRI, dry season, 2009

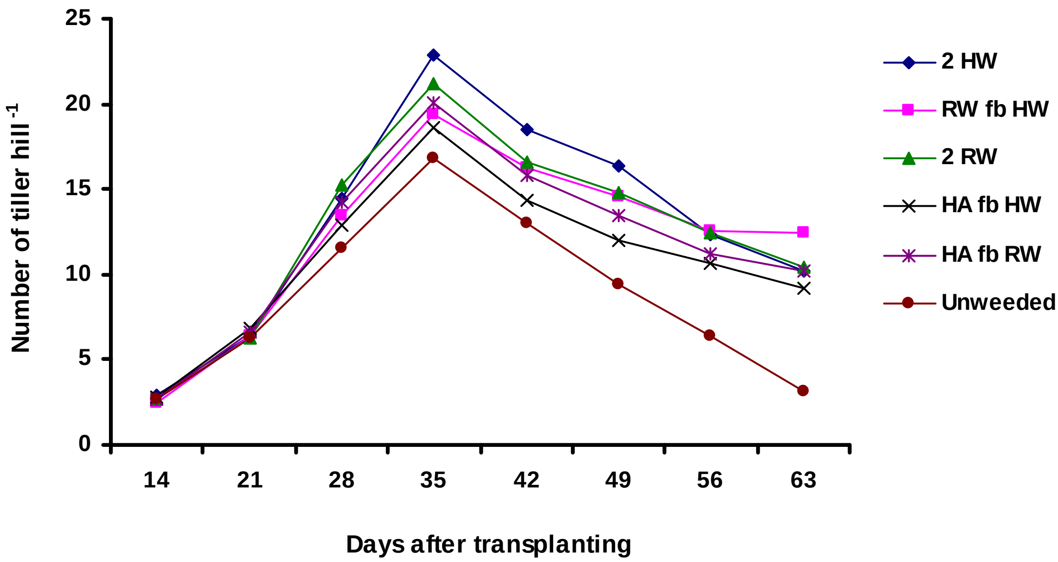

Figure 4.2 Number of tiller hill^{-1} of rice plant at weekly interval in SRI, dry season, 2009

Table 4.2 Grain yield, percent of yield increase over unweeded check and yield losses due to weeds as affected by different weed control methods in the system of rice intensification during dry season, 2009

Treatment	Grain yield ($t\ ha^{-1}$)	Yield increase over unweeded (%)	Yield losses due due to weeds (%)
2 HW	5.59 ab	267.76	
RW fb* HW	5.86 a	285.53	
2 RW	4.23 cd	178.29	
HA fb HW	5.00 bc	228.95	
HA fb RW	3.75 d	146.71	
Unweeded	1.52 e	-	59.47-74.06
LSD 0.05	0.83		
CV (%)	10.5		
Pr>F	0.00001		

*fb = followed by HW = hand weeding

RW = rotary weeding HA = herbicide application

4.1.10 Weed density, weed dry weight and weed control efficiency

The weed density was significantly influenced by different weed control methods at harvest while it did not differ at 50 DAT. The weed density was significantly greater in the unweeded plots than other weeding treatments at both 50 DAT and harvest (Table 4.3). Similar results were observed by Singh and Bhandari (1986).

Among the weeding treatments, the highest weed density was observed in HA fb HW treatment at 50 DAT. The lowest weed density was observed in the treatment of RW fb HW at 50 DAT. The weed density of HA fb HW and unweeded check were the same at harvest. The lowest weed density was obtained from the treatment of 2 RW and RW fb HW. This result pointed out that rotary weeding follow-up hand weeding gave the lowest weed density at both 50 DAT and harvest.

The weed dry weight in unweeded plots was 57.80 and 179.90 g 0.25 m^{-2} at 50 DAT and harvest time, respectively. These greatest weed dry weights could be attributed to the greater density of weed species. The lowest dry weights were observed in rotary weeding supplemented by one hand weeding at 50 DAT and two hand weedings. Among the weeding treatments, the highest weed dry weight at 50 DAT and harvest was found in 2 RW, which was not significantly different from the other weeding treatments.

The highest weed control efficiency was found in rotary weeding accompanied by one hand weeding treatment at 50 DAT and two hand weedings at harvest. Among the weed control treatments, weed control efficiency was the lowest in two times rotary weeding at both 50 DAT and harvest.

Table 4.3 Weed density, weed dry weight and weed control efficiency as affected by different weed control methods in the system of rice intensification during dry season, 2009

Treatment	Weed density (no. 0.25 m^{-2})		Weed dry weight (g 0.25 m^{-2})		Weed control efficiency (%)	
	50 DAT	Harvest	50 DAT	Harvest	50 DAT	Harvest
2 HW	76.16	63.16 ab	1.76 b	5.83 b	96.65	96.76
RW fb* HW	38.00	29.00 b	1.03 b	8.08 b	98.22	95.51
2 RW	40.50	28.83 b	13.63 b	57.73 b	76.42	67.90
HA fb HW	92.00	80.73 a	1.46 b	16.88 b	97.4	90.62
HA fb RW	59.66	43.16 ab	12.18 b	44.38 b	78.92	75.33
Unweeded	284.0	80.83 a	57.80 a	179.9 a	-	-
LSD 0.05	174.44	38.43	25.95	57.51		
CV (%)	97.5	38.9	97.4	60.6		
Pr>F	0.0753	0.0322	0.0048	0.0005		

*fb = followed by HW = hand weeding

RW = rotary weeding HA = herbicide application

4.1.11 Number of grasses, sedges and broadleaf weeds in SRI during dry season,

2009

(a) At 50 DAT

Figure 4.3 shows the number of weeds at 50 DAT as affected by different weed control methods in SRI during dry season, 2009.The highest weeds population of grasses, sedges and broadleaf at 50 DAT were observed in unweeded check among the treatments. The HA fb HW treatment gave the lowest number of grasses. The HA fb RW treatment observed the lowest number of sedges among the treatments; however, 2 RW gave the lowest number of broadleaf weeds at 50 DAT. The field dries up and as a consequence of alternate dry and wetting, an aggressive flush of both terrestrial and aquatic weeds come up in the early stage of crop growth (Sharma and Bhunnia 1999).

(b) At harvest

Figure 4.4 illustrates the influence of weeding at harvest on the number of weeds. The highest weed population of grasses and sedges were found in unweeded check among the treatments. In HA fb HW treatment, the lowest number of grasses and sedges weeds was obtained at harvest while the number of broadleaf weeds was the highest. The lowest number of broadleaf weeds was found in 2 RW at harvest.

In dry season, broadleaf weeds dominated weed population considerably in SRI and provided severe competition for rice. Ahmed (1982) stated that the process of puddling results in fewer weed species, fewer weeds and a higher proportion of broadleaf weeds in the weed flora than under dryland conditions.

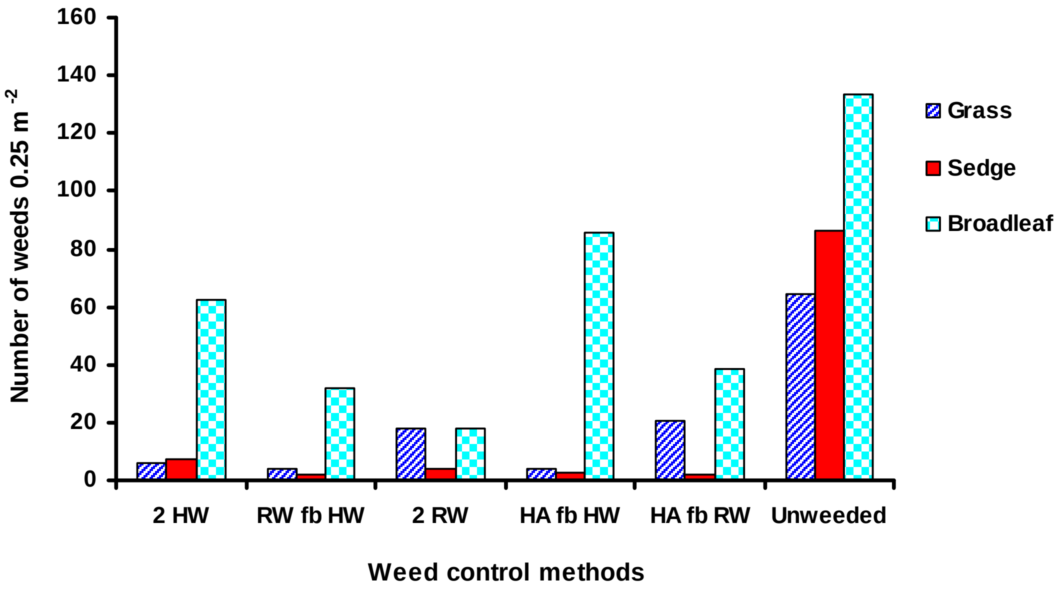

Figure 4.3 Number of grasses, sedges and broadleaf weeds at 50 DAT as affected by different weed control methods in SRI, dry season, 2009

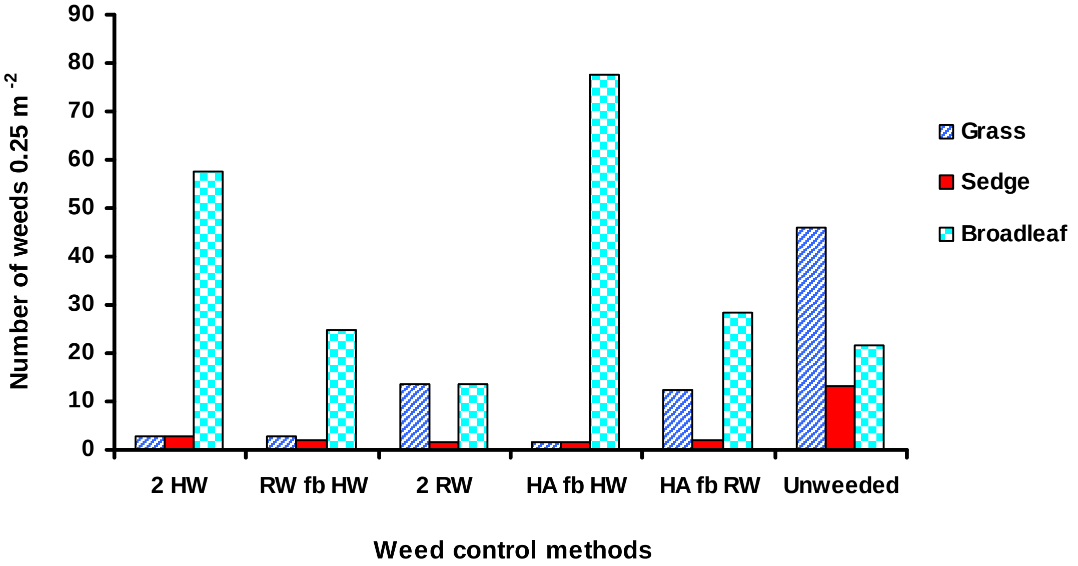

Figure 4.3 Number of grasses, sedges and broadleaf weeds at harvest as affected by different weed control methods in SRI, dry season, 2009

4.1.12 Phytotoxicity of herbicide on rice plants and weeds

Table 4.4 presents the phytotoxicity of herbicide on rice and weeds in system of rice intensification during dry season, 2009.The used herbicide (Fenoxyprop-ethyl + ethoxysulfuron) caused slight damage on rice plants until 21 DAS and gradually disappeared at later growing stage. It shows the selectivity of (Fenoxyprop-ethyl + ethoxysulfuron) on rice plants. The herbicide treatments were found to have satisfactory level of controlling weeds. The severe damage on weeds was found at 21 DAS. Uphoff (2002) stated that there was no adverse effect of herbicides on young seedlings in SRI practices and herbicide use would significantly reduce the labor cost, as opposed to manual or mechanical weed control encouraged for SRI.

Early weed control is more important to the achievement of high yields than late weeding (De Datta et al. 1969). Uprety (2005) reported that weeding is another important operation to increase yields with SRI methods. With a single weeding, the majority of farmers produced at least 6 tons of yields per hectare and with three weedings, most of the farmers produced more than 9 tons per hectare. If weeding is begun late, then the number of weedings may not be so beneficial. If we keep our crop weed-free for the first month after transplanting, weeding will have a positive influence on rice yield.

4.1.13 Correlation between weed dry weight, agronomic characters, grain yield and yield components

The correlation coefficient for eight parameters of rice is shown in Table 4.5. It was found that weed dry weight was significantly and negatively correlated with grain yield, panicle length, filled grain percent and number of spikelets at 1% level while there was no significant association between weed dry weights with number of panicles, plant height and 1000 grain weight.

There was highly and positively correlation between grain yield with panicle length, filled grain percent and number of spikelets. However, there were no correlation between number of panicles, plant height and 1000 grain weight.

Panicle length was significantly and positively correlated with filled grain percent and number of spikelets at 1% level (r = 0.95 and r = 0.93) but there was no correlation between panicle length with number of panicles, plant height and 1000 grain weight. The correlation between filled grain percent and number of spikelets was positive and highly significant at 1% level (r = 0.88).

4.1.14 Economic analysis

Table 4.6 shows the economic analysis of different weed control practices. Dry season trial indicated that HA fb HW had the highest total costs that vary while the lowest was observed in two times rotary weeding treatment among the weeding treatments. Although HA fb HW showed higher gross field benefits compared to two hand weedings, its higher variable cost brought about a bit lower in net benefit than two hand weedings. Two times rotary weeding from the system of rice intensification was found to be higher in gross field benefits and net benefits than HA fb RW. The treatment combination of RW fb HW appeared to be an economical treatment giving 9.24 marginal benefit cost ratio, while all other treatments were dominated due to higher cost that vary and hence were uneconomical. Moody (1995) reported that in evaluating the economic feasibility of a treatment, a MBCR of 2 is acceptable. If more than one treatment has an MBCR greater than 2, then the one that has the highest net benefit must be used. The finding of present study suggests that RW fb HW was considered to be the most cost-effective weeding method in the system of rice intensification in dry season.

Table 4.4 Phytotoxicity of herbicide on rice and weeds in the system of rice intensification during dry season, 2009

Treatment	Mean value of phytotoxicity rating scale					
	Rice			Weeds		
	7 DAS	14 DAS*	21 DAS	7 DAS	14 DAS	21 DAS
2 HW	-	-	-	-	-	-
RW fb* HW	-	-	-	-	-	-
2 RW	-	-	-	-	-	-
HA fb HW	1	2	2	3.3	3.45	5.0
HA fb RW	2	1	1	3.5	3.67	5.0
Unweeded	-	-	-	-	-	-

* DAS = days after spraying
HW = hand weeding
RW = rotary weeding
HA = herbicide application
* fb = followed by

1. No apparent effect
2. Slight damage or chlorosis
3. Moderate damage
4. Severe damage
5. Plant dead

Table 4.5 Correlation between weed dry weight, agronomic characters, grain yield and yield components during dry season, 2009

	Weed dry weight	Grain yield	Panicle length	Filled grain %	Number of spikelets	Number of Panicle	Plant height	1000 grain weight
Weed dry weight	1							
Grain yield	-0.963**	1						
Panicle length	-0.965**	0.935**	1					
Filled grain %	-0.963**	0.957**	0.956**	1				
Number of spikelets	-0.874**	0.891**	0.932**	0.883**	1			
Number of panicle	-0.658	0.736	0.615	0.714	0.414	1		
Plant height	-0.313	-0.225	-0.128	-0.084	-0.125	0.126	1	
1000 grain weight	0.032	-0.055	-0.095	-0.229	0.100	-0.565	0.67	1

Table 4.6 Economic analysis of different weed control methods in the system of rice intensification during dry season, 2009

Treatment	Gross field benefits (Kyats ha^{-1})	Total costs that vary (Kyats ha^{-1})	Net benefits (Kyats ha^{-1})	MBCR*
2 HW	693409	74100	619309	-
RW fb* HW	727158	54340	672818	9.24
2 RW	524838	34580	490258	-
HA fb HW	682213	85715	596498	-
HA fb RW	464982	65955	399027	-
Unweeded	188656	-	188656	-

* MBCR = Marginal Benefits Cost Ratio HW = hand weeding

RW = rotary weeding HA=herbicide application

* fb = followed by

4.2 Experiment II (Wet season, 2009)

4.2.1 Plant height

The plant heights of rice at harvest and weekly interval are shown in Table 4.7 and Figure 4.5. Two times rotary weeding produced the longest plants (75.63 cm) but it did not differ from other weeding treatments and unweeded check. Islam et al. (2003) stated that the tallest rice plants were produced in weed free condition and the height was reduced due to weed competition. Moody (1995) mentioned that the ability to compete for light depends largely on the comparative growth stature of the competitors. Moody and De Datta (1983) stated that plant height is highly correlated with competitive ability, the taller the rice plant, the lower the yield reduction due to weeds. Hasanuzzaman et al. (2009) reported that lower plant height was associated with poor weed management or unweeded control and it might be due to inter plant competition for longer period which inhibited the plants to become taller.

4.2.2 Number of tillers per hill

Figure 4.6 shows the number of tillers per hill at weekly interval. The maximum tiller production reached at 35 DAT and gradually declined at later growth stages. The treatment of RW fb HW produced maximum tiller numbers. Weed competition with rice was serious at younger seedlings of rice. Uprety (2005) stated that early weeding enhances production of more primary tillers, which ultimately produces larger panicles having more grains and higher yield.

4.2.3 Panicle length

The panicle length of rice in all treatments was significantly different at $P < 0.01$ level (Table 4.7). Among the treatments, the longest panicle length (20.42 cm) was observed from RW fb HW treatment which was not statistically different from two hand weedings. It was followed by two times rotary weeding, HA fb HW and HA fb RW. Greater weed infestation in unweeded check resulted the shortest panicle length (11.45 cm) among the treatments.

4.2.4 Number of panicles per hill

The number of panicles per hill was significantly different in all treatments at $P < 0.01$ level (Table 4.7). Two times rotary weeding gave the highest number of panicles per hill (14.77) which was significantly different from other weeding treatments except RW fb HW treatment. The lower production of panicles were observed in HA fb RW and unweeded check. Fazlul et al. (2003) found significantly highest number of total tillers produced in weed free treatments. Proper control of weeds reduced the weed density which facilitates the crop plants to have sufficient space, light, nutrient and moisture, and thus the effective tillers increased (Hasanuzzaman et al. 2009).

4.2.5 Number of spikelets per panicle

The mean values of the spikelets per panicle are presented in Table 4.7. There were highly significant differences among the treatments at $P < 0.01$ level. The highest number of spikelets per panicle (79.58) was observed in RW fb HW treatment which was not statistically different from two hand weedings and HA fb RW treatments while the lowest number of spikelets per panicle was obtained from unweeded check. The result indicated that greater weed infestation in the unweeded plots resulted in the lowest number of spikelets per panicle. Sultana (2000) found that there were 40 % reduction of grains per panicle due to competition of *E. crussgalli* and 28.7 % reduction due to competition of *E. colonum* at a density of 200 weeds m^{-2}.

4.2.6 Filled grain percentage

The percentage of filled grains were highly significant different among the treatments at $P < 0.001$ level. Among the weed control methods, the highest number of filled grains (81.09 %) was observed in two hand weedings which was not statistically different from the other weeding treatments (Table 4.7). In this study, greater weed infestation in the unweeded plots resulted in the lowest number of filled grains. Yoshida (1981) reported that factors such as weather, soil, fertilizer application and incidence of pests affect filled spikelets or sterility percentage.

4.2.7 1,000 grain weight

The 1,000 grain weights of all treatments are shown in Table 4.7. Those were not significantly affected by weeding treatments. These results corroborated with the results of Islam et al. (2003) and they reported that no significant difference in 1,000 grain weight was found between weed free and weed competition levels. The result of present study was similar to the finding of Yoshida (1981) who stated that 1,000 grain weight is a stable varietal character because the grain size is rigidly controlled by the size of the hull. The findings are supported by the observations of Matsushima (1980) who stated that the weight of 1,000 grains always shows the least variation under any cultural season and practices, compared to other components. Rao and Moody (1992) mentioned that weed competition did not affect seed weight of the rice.

4.2.8 Grain yield

Grain yield, percent of yield increase over unweeded check and yield losses due to weeds as affected by different weed control methods are shown in Table 4.8. The grain yield was found to be ranged from 1.27 to 4.85 t ha^{-1}, depending upon the combination of different weed control methods. Grain yields in weeding treatments were significantly higher than that of unweeded check. The highest grain yield (4.85 t ha^{-1}) was observed in rotary weeding followed by one hand weeding which was not significantly different from two hand weedings treatment while the lowest grain yield (1.27 t ha^{-1}) was produced by untreated plot which was due to increased crop-weed competition. This indicates that heavy weed infestation has caused a substantial reduction in the yield of rice. The present findings are in conformity with the results of Rekha et al. (2002) who reported that two hand weedings resulted in lower weed density compared to weedicides and untreated control. Mukhopadhyay (1983) stated that hand weeding is the most common method and two weedings are sufficient to adequately control weeds in transplanted rice. The grain yield of two hand weedings was higher than that of HA fb HW treatment, but no significant difference was found. IRRI (1985) reported that yield of rice increased due to application of herbicide followed by hand weeding. Two times rotary weeding gave lower grain yield than that of two hand weedings. These results conformed to those of Dinesh and Manna (1990) and they pointed out that the mechanical weeding with a rotary weeder increased the yield in dry season but not in wet season.

4.2.9 Yield loss percentage due to weeds

The yield loss percentage owing to weed competition is shown in Table 4.8. The yield losses percent due to weeds were found to be ranged from 49.6 to 73.40 %. Salim (2002) reported that 20 to 63 % yield losses in uncontrolled weed growth. According to the report of Moody (1983), yield losses due to uncontrolled weed growth in different types of lowland rice culture were 60 % in transplanted, 69 % in wet-seeded and 83 % in dry-seeded methods. He also reported that to assess losses due to weeds is notoriously difficult because how weeds interfere with human affair is very subjective and the extent and value of damage varies greatly from year to year depending upon weed species, soil conditions and climate. Bhar et al. (1995) reported that the loss in grain yield caused by weeds varies from 30-50 %. Yield increase over unweeded check was found to be in the range from 98.45 to 275.97 % during wet season, 2009. The highest yield increase was observed in treatment combination of RW fb HW among the weeding treatments.

Table 4.7 Mean values of agronomic characters and yield components of rice as affected by different weed control methods in the system of rice intensification during wet season, 2009

Treatments	Plant height at harvest (cm)	Panicle length (cm)	Number of panicles hill^{-1}	Number of spikelets panicle^{-1}	Filled grain (%)	1000 grain weight (g)
2 HW	73.44	18.21 c	12.14 bc	75.49 c	81.09 a	19.55
RW fb HW	73.54	20.42 c	13.61 cd	79.58 c	80.62 a	19.60
2 RW	75.63	14.05 b	14.77 d	57.01 ab	74.66 a	19
HA fb HW	73.63	15.30 b	12.39 bc	64.56 b	75.26 a	19.87
HA fb RW	72.79	14.92 b	10.24 a	67.63 ac	73.74 a	19.60
Unweeded	75.29	11.45 a	10.92 ab	51.07 a	59.96 b	19.45
LSD (0.05)	4.16	2.2	1.66	9.5	8.50	0.97
CV(%)	3.7	9.5	8.9	9.6	7.6	3.3
Pr>F	0.66	0.00001	0.0004	0.0001	0.0012	0.5763

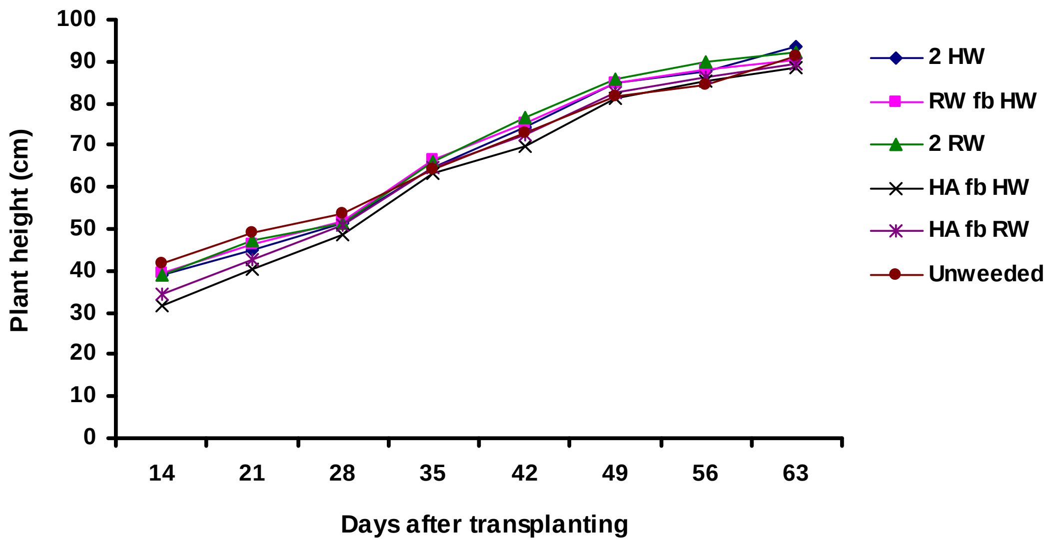

Figure 4.5 Plant height of rice plant at weekly interval in SRI, wet season, 2009

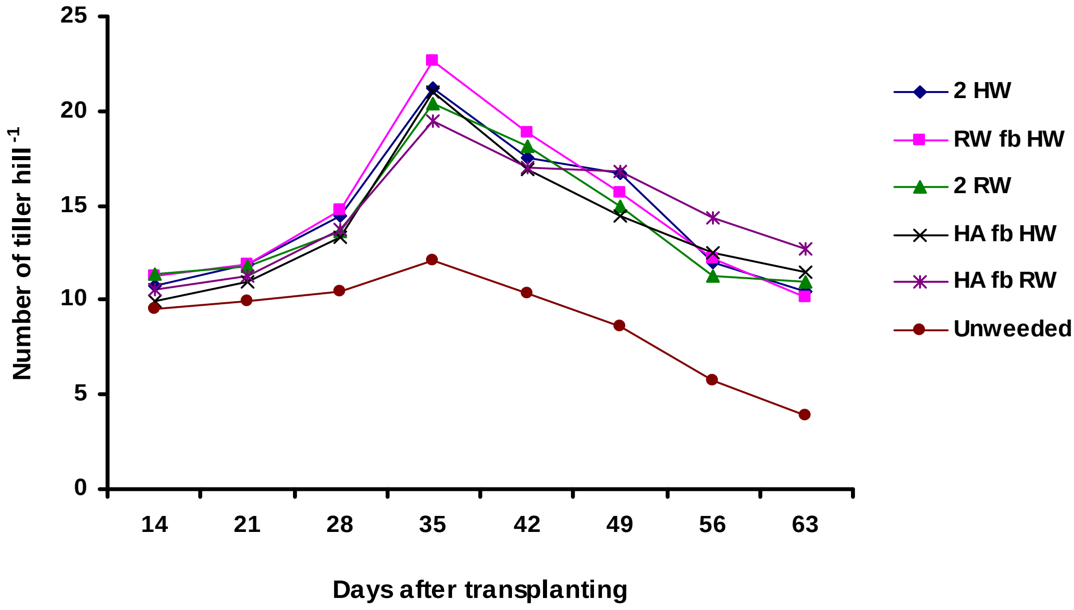

Figure 4.6 Number of tiller hill^{-1} of rice plant at weekly interval in SRI, wet season, 2009

Table 4.8 Grain yield, percent of yield increase over unweeded check and yield losses due to weeds as affected by different weed control methods in the system of rice intensification during wet season, 2009

Treatment	Grain yield (t ha^{-1})	Yield increase over unweeded (%)	Yield losses due to weeds (%)
2 HW	4.62 ab	258.14	
RW fb* HW	4.85 a	275.97	
2 RW	3.19 d	147.29	
HA fb HW	4.07 bc	215.50	
HA fb RW	2.56 e	98.45	
Unweeded	1.27 f	-	49.6-73.40
LSD 0.05	0.57		
CV (%)	11.1		
Pr>F	0.00001		

*fb = followed by HW = hand weeding

RW = rotary weeding HA = herbicide application

4.2.10 Weed density, weed dry weight and weed control efficiency

Table 4.9 shows weed density, weed dry matter and weed control efficiency as affected by different weed control methods in the system of rice intensification during wet season, 2009. The weed density was significantly influenced by different weed control methods. The weed density of unweeded plot was significantly greater than that of other weeding treatments at both 50 DAT and harvest.

The treatment of 2 RW produced the highest weed density among the weeding treatments which was not significantly different from the treatment of 2 HW at 50 DAT. The lowest weed density was obtained in the treatment receiving HA fb HW at both 50 DAT and harvest. The highest weed density (59.37) was obtained from unweeded check, but it significantly differed from weeding treatments at the time of harvest.

The highest weed dry weight were recorded at unweeded check treatment, 37.72 and 102.32 g 0.25 m^{-2} at 50 DAT and harvest, respectively. At 50 DAT, the minimum number of weed dry weight was observed from HA fb HW treatment, which did not differ from 2 HW, RW fb HW and HA fb RW treatments and 2 HW gave the minimum number of weed dry weight at harvest. Similar trend was noticed in case of weed density since weed dry weight is positively related to weed density.

Weed control efficiency was the highest with HA fb HW treatment and two hand weedings at 50 DAT and harvest, respectively. Among weed control treatments, weed control efficiency was the lowest in 2 RW at both 50 DAT and harvest.

Table 4.9 Weed density, weed dry weight and weed control efficiency as affected by different weed control methods in the system of rice intensification during wet season, 2009

Treatment	Weed density (no. 0.25 m^{-2})		Weed dry weight (g 0.25 m^{-2})		Weed control efficiency (%)	
	50 DAT	Harvest	50 DAT	Harvest	50 DAT	Harvest
2 HW	67.25 b	26.87 b	1.79 c	11.22 c	95.25	89.03
RW fb* HW	30.00 c	24.62 b	2.29 c	13.78 c	93.95	86.52
2 RW	71.25 b	33.75 b	15.56 b	68.76 ab	58.74	32.79
HA fb HW	16.62 c	19.12 b	0.46 c	12.57 c	98.78	87.71
HA fb RW	25.12 c	27.75 b	2.97 c	29.91 bc	92.12	70.77
Unweeded	153 a	59.37 a	37.72 a	102.32 a	-	-
LSD 0.05	31.46	22.43	8.42	40.42		
CV (%)	34.50	46.60	55.10	67.40		
Pr>F	0.00001	0.0228	0.00001	0.0009		

*fb = followed by HW = hand weeding

RW = rotary weeding HA = herbicide application

4.2.11 Numbers of grasses, sedges and broadleaf weeds in SRI during wet season, 2009

(a) At 50 DAT

The unweeded check showed the highest grasses population among the treatments (Figure 4.7). Sharma et al. (1995) stated that frequent aerobic condition of soil and high temperature favor the growth of grassy weeds. The treatment of 2 HW gave the lowest number of grasses and the highest number of sedges, respectively.
The treatment of 2 RW produced the lowest weed population of broadleaf among the treatments. HA fb HW and HA fb RW treatments were obtained very negligible number of sedges among the treatments at harvest.

(b) At harvest

The highest number of grasses, sedges and broadleaf weeds were observed in unweeded check among the treatments (Figure 4.8). Sedges and grasses were less dominating weed species in HA fb HW and HA fb RW treatments. Al-Kothayri and Hasan (1990) reported that the treatments of all herbicide reduced weed population significantly as compared with weedy check. HA fb HW treatment gave the lowest number of broadleaf weeds.

Most of grasses population was observed at both 50 DAT and harvest in SRI during wet season. Weaver (1994) mentioned that dramatic changes in practices such as a switch from manual to chemical weed control, from conventional to direct seeded rice, can lead to weed species to replacement.

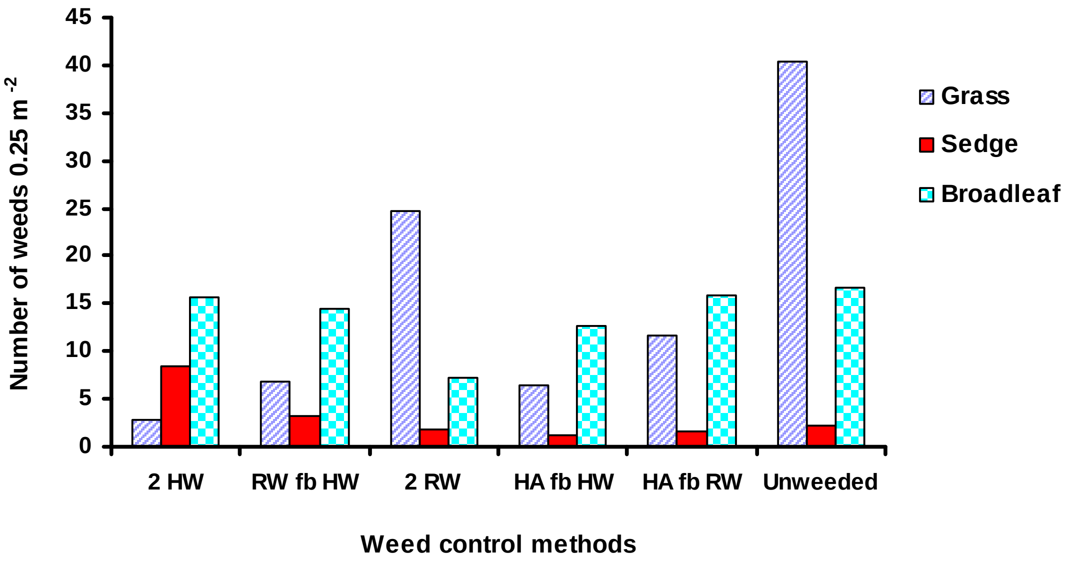

Figure 4.7 Number of grasses, sedges and broadleaf weeds at 50 DAT as affected by different weed control methods in SRI, wet season, 2009

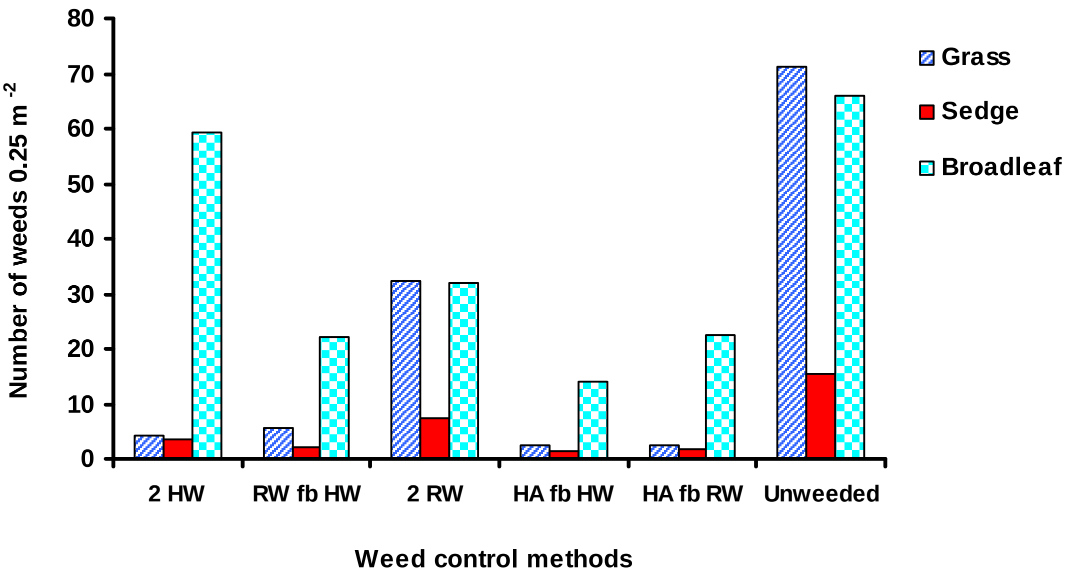

Figure 4.8 Number of grasses, sedges and broadleaf weeds at harvest as affected by different weed control methods in SRI, wet season, 2009

4.2.12 Phytotoxicity of herbicide on rice plants and weeds

The phytotoxicity of herbicide application on rice was observed in herbicide treated plots during wet season, 2009. Initial rice toxicity was manifested by slight damage or chlorosis in both herbicide treatments. However, rice plants were found to recover from the initial injury caused by herbicide at three weeks after spraying. The phototoxic effects on weeds were observed in both herbicide treatments (Table 4.10). Weeds were severely affected by herbicide treatments at two weeks after spraying. Continuous rain and cloudy weather conditions were probably the main reason of lower herbicidal activity and less suppression of weeds. It can be pointed out that the favorable weather conditions and application at the right time are very important to achieve full effectiveness of herbicide. Application of herbicide (Fenoxyprop-ethyl + Ethoxysulfuron) effectively controlled weeds in wet season.

4.2.13 Correlation between weed dry weight, agronomic characters, grain yield and yield components

Relationship between weed dry weight, agronomic characters, grain yield and yield components are presented in Table 4.11. In this investigation, the correlation between weed dry weight with grain yield and panicle length was negative and significant at 5 % level (r = -0.86 and -0.82). It can be assumed that the more increasing the weed dry weight, the less the grain yield and the shorter the panicle length. The weed dry weight was negatively and significantly correlated with filled grain percent and number of spikelets at 1 % level (r = -0.87 and -0.88). It means that when weed dry weight increases, the number of spikelets and filled grain percent decreases. Although there were positively and significantly correlation between grain yields and panicle length, filled grain percent at 1 % level, the significant and positive relationship between grain yield and number of spikelets was observed at 5 % level. It can be assumed that the grain yield is increased when filled grain percent and number of spikelets are increased. Moreover, the maximum grain yield of rice can be obtained when panicle length is not affected by competition of weeds. Panicle length was significantly and positively correlated with filled grain percent and number of spikelets. It means that the longer the panicle length, the increasing filled grain percent and the number of spikelets.

Table 4.10 Phytotoxicity of herbicide on rice and weeds in the system of rice intensification during wet season, 2009

Treatment	Mean value of phytotoxicity rating scale					
	Rice			Weeds		
	7 DAS	14 DAS*	21 DAS	7 DAS	14 DAS	21 DAS
2 HW	-	-	-	-	-	-
RW fb* HW	-	-	-	-	-	-
2 RW	-	-	-	-	-	-
HA fb HW	2.8	2	1	3	3.8	5.0
HA fb RW	2	2.3	1.2	3.2	3.6	5.0
Unweeded	-	-	-	-	-	-

* DAS = days after spraying	1. No apparent effect
HW = hand weeding	2. Slight damage or chlorosis
RW = rotary weeding	3. Moderate damage
HA = herbicide application	4. Severe damage
* fb = followed by	5. Plant dead

Table 4.11 Correlation between weed dry weight, agronomic characters, grain yield and yield components in wet season, 2009

	Weed dry weight	Grain yield	Panicle length	Filled grain %	Number of spikelets	Number of Panicle	Plant height	1000 grain weight
Weed dry weight	1							
Grain yield	-0.863*	1						
Panicle length	-0.821*	0.911**	1					
Filled grain %	-0.878**	0.936**	0.885**	1				
Number of spikelets	-0.883**	0.850**	0.968**	0.868*	1			
Number of panicle	-0.083	0.515	0.345	0.455	0.124	1		
Plant height	0.619	-0.378	-0.168	-0.268	-0.237	0.155	1	
1000 grain weight	-0.606	0.299	0.310	0.165	0.433	-0.508	0.76	1

4.2.14 Economic Analysis

The economic analysis of different treatments under study was worked out in the Table 4.12 to evaluate the most beneficial and economical weeding treatment for rice cultivation with SRI practices. The highest total costs that vary were found from herbicide application supplemented by hand weeding among the weeding treatments whereas two times rotary weeding treatment showed the lowest. Two hand weedings gave lower gross field benefits as well as net benefits than RW fb HW treatment. The gross field benefits and net benefits were higher in two times rotary weeding treatment than herbicide application followed by rotary weeder treatment. Rotary weeding followed by hand weeding appeared to be an economical treatment giving 9.17 marginal benefit cost ratio (MBCR), while all other treatments were dominated due to higher cost that vary and hence were uneconomical. Therefore, according to the rule of MBCR, the treatment combination of rotary weeding followed by hand weeding was recommended as the most cost effective weeding method of SRI in wet season. De Datta and Barker (1977) stated that farmers' resources such as land, labor and capital are important considerations in making the final choice of weeding method.

Table 4.12 Economic analysis of different weed control methods in the system of rice intensification during wet season, 2009

Treatment	Gross field benefits (Kyats ha^{-1})	Total cost that vary (Kyats ha^{-1})	Net benefits (Kyats ha^{-1})	MBCR*
2 HW	561337	74100	487237	-
RW fb* HW	588325	54340	533985	9.17
2 RW	387269	34580	352689	-
HA fb HW	493869	85715	408154	-
HA fb RW	310355	65955	244400	-
Unweeded	156526	-	15626	-

* MBCR = Marginal Benefits Cost Ratio HW = hand weeding

RW = rotary weeding HA = herbicide application

* fb = followed by

CHAPTER V
CONCLUSION

Not only do moisture regimes and methods of crop establishment affect the severity of weed communities but also water scarcity is likely to become a more significant problem around the world. So adopting rice cultivation practices that use less water can become more important. One of the characteristics of rice farmers in Asia is small holding, and SRI methods are well suited to those resource limited farmers. Weed growth becomes one of the problems because the fields are not kept continuously flooded and young seedlings are used. The weeding requirement in the SRI practices might pose an adoption constraint for farmers who usually leave their farm often transplanting to seek additional income opportunities. Weed control is very important in SRI practices because young seedlings seem to be less competitive for light, water and nutrient against weeds. The present study evaluated the different weed control methods in order to determine the cost-effective one during dry and wet seasons, 2009.

Based on the results of two experiments, the following points can be highlighted. Rotary weeding followed by hand weeding gave superior yield and high weed control efficiency. Rotary weeding makes soil aeration to stimulate the growth of aerobic bacteria and fungi and associated organisms in the soil food web. Planting in a square pattern allows farmers to weed their fields in perpendicular direction, which achieves more and better soil aeration. Its effectiveness on weeds was obvious and weeds were effectively controlled during the critical period of rice-weed competition. Using rotary weeding in rice fields is only feasible when rice seedlings are planted in rows. Rotary weeding is efficient to use with moving back and forth. It does not work well if the soil is too dry or too much water and weeds are too vigorous. The slightly lower yield with two rotary weedings was due to the lack of weed control within rows and close to rice plants. In such a situation, rotary weeding should be combined with hand weeding because hand weeding enable removal of weeds close to, or along rice hills which are not removed by rotary weeder as well as removal of escapes, especially deep-rooted perennials.

The other weeding methods proved to be effective in controlling weeds and their yields were greater than that of unweeded check. Two hand weedings contributed good yield performance and weed control efficiency. Hand weeding is the most common, effective and widely used control measure, but it is highly labor intensive. Otherwise, the use of herbicide may be an easily way in controlling weeds when there is a labor scarcity. The number of spikelets per panicle, filled grain percent and panicle length were found to be reduced in unweeded check as a result of weed competition. These results pointed out that weed control is very important in the system of rice intensification.

When left undisturbed in SRI field, the weed populations of broadleaf were dominating in dry season and grasses appeared to be the most prolific weed class by virtue of their high-biomass in wet season. It can be observed that higher populations of one weed group can suppress other weed groups. Seasonal variation in rainfall and flooding both during crop establishment and early growth selectively influences weed recruitment, whereas early drought may reduce not only rice yield but also weed seed production. Yield losses percent due to weed competition were found to be ranging from 59.47 % to 74.06 % in dry season and 49.6 % to 73.4 % in wet season. These results indicated that to achieve higher rice yields, weeds must be controlled effectively during early growth stage.

In terms of economic analysis, rotary weeding followed by hand weeding had the highest net benefits in both seasons among the treatments. This method of weeding gave 9.24 and 9.17 MBCR in dry and wet seasons, respectively. The other tested weeding methods were dominated due to higher costs that vary and hence were uneconomical. Therefore, rotary weeding followed by hand weeding was recommended as the cost-effective weeding method in the system of rice intensification. The system of rice intensification methods are particularly accessible to and beneficial for the poor, who need to get the maximum benefit from their limited resources such as land, labor, water and capital. However, the system of rice intensification concepts and practices can be adapted and used with any scale of production, from small-scale to large scale.

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