STANDARDISATION OF SYSTEM OF RICE INTENSIFICATION (SRI) TECHNIQUE

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DECLARATION

I hereby declare that this thesis entitled "**Standardisation of System of Rice Intensification (SRI) technique**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **"Standardisation of System of Rice Intensification (SRI) technique"** is a record of research work done independently by **Ms. Rajani Satish, L.** (2004-11-14) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

%	–	Per cent
°C	–	Degree Celsius
@	–	At the rate of
Ad	–	Absolute density
Af	–	Absolute frequency
a.i.	–	Active ingredient
ANOVA	–	Analysis of variance
B-C Ratio	–	Benefit-cost ratio
CD	–	Critical Difference
CGR	–	Crop Growth Rate
cm	–	Centimeter
cv.	–	Cultivar
DAS	–	Days after sowing
DAT	–	Days after transplanting
DMP	–	Dry matter production
et al.	–	And others
Fig.	–	Figure
g	–	Gram
ha	–	Hectare
HDG	–	High Density Grains
HI	–	Harvest index
i.e.	–	That is
K	–	Potassium
KAU	–	Kerala Agricultural University
kg	–	Kilogram
l	–	Litre
LAD	–	Leaf Area Duration
LAI	–	Leaf area index
m	–	Metre
mg	–	Milligram
N	–	Nitrogen
NAR	–	Net Assimilation Rate
NS	–	Non significant
P	–	Phosphorus
Rd	–	Relative density
Rf	–	Relative frequency
RGR	–	Relative Growth Rate
Rs.	–	Rupees
S	–	Significant
t	–	Tonnes
viz.	–	Namely

Introduction

1. INTRODUCTION

Rice is the world's most important food crop that has been grown for more than 6000 years in South Asia. Currently, it is the staple food of almost three billion people of the world.

In India, rice provides 43 per cent of the calorie requirement for more than 70 per cent of the population. India stands first in rice area and second in production which almost tripled from 30.4 million tonnes (milled rice) in 1966 to a record production of 93.3 million tonnes in 2001-02 (Rai, 2006). However, the burgeoning population of our country may stabilize around 1.4 billions by 2025 requiring annually 380 million tonnes of food grains (Siddiq, 2000).

Accounting for 40 per cent of our food grain production, rice, unlike wheat and millets, has still sizeable under and unexploited potential to increase further its share and meet the future demand projections. With practically no scope for area increase under rice and very limited opportunities for bringing more area under irrigation, tapping of the potential opportunities has to be through better management and genetic intervention mediated vertical yield growth in all the major rice ecologies.

In Kerala, rice area has drastically declined to 2.87 lakh ha with a production of 5.70 lakh tonnes (FIB, 2006). Over 60 per cent of the states' food requirement is met by rice imports from neighbouring states

A comparatively higher cost of cultivation and quantum of effort required with relatively low profit obtained by the farmers has made rice cultivation in Kerala an unattractive proposition. This has resulted in large scale conversion of paddy lands for growing remunerative crops like coconut, banana, cassava and vegetables threatening the very sustainability of the farming system. Over the past 30 years, 5.4 lakh ha of rice lands have been irrecoverably converted and the rate of conversion was on an average 52 ha day^{-1} (Expert Committee Report, 1998).

The existing rice holdings are too small for introducing modern cultivation techniques and comprehensive development activities such as land development, irrigation, introduction of modern implements, soil conservation, flood control etc. A system integrating all the available technological innovations aimed to help the farmers and simultaneously bring down the cost of production and enhance productivity has emerged as a felt need to revive rice cultivation.

The System of Rice Intensification (SRI) is an unconventional management system developed by Fr. Henri de Laulanie in Madagascar, where it was reported to increase rice yields substantially. Such increases could be obtained simply by managing the rice crop according to a set of principles known as the System of Rice Intensification (SRI) (Stoop *et al.*, 2002 and Uphoff, 2002). This is based on the premise that the rice plant has significant untapped growth potential which the conventional management systems failed to exploit.

The system of rice cultivation in the SRI has its own methodologies. Transplanting of young seedlings (8 to 15 days old and having just two leaves) is done in a very careful manner with minimum trauma to the young plants. Seedlings are placed one to two cm deep into the soil that is muddy but not flooded. They are planted singly rather than in clumps of two or three or more, in a square pattern with plenty of space between them in all directions. Transplanting with wider spacing enables the use of a rotary weeder that churns up the surface soil and provides additional soil aeration. In SRI method, soil is kept moist but not flooded during the vegetative period, ensuring that more oxygen is available in the soil for the roots. After the panicle initiation stage, a thin layer of water (one to two cm) is maintained in the field until 10 to 15 days before harvest, when the field is drained. The requirement of water in this system is only one third to half of the quantity in a continuous flooding system. Stoop *et al.* (2002) reported that SRI is used to increase yield of rice and to save water, based on the synergistic effects of applying various cultivation practices simultaneously, *viz.*, the use of young and single seedling per hill, limited irrigation and frequent loosening of the top soil to stimulate aerobic soil conditions.

Keeping the above factors in view, the present study was undertaken with the following objectives

1. To compare the performance of rice under SRI and normal system of cultivation.
2. To standardize the seedling age, spacing and weed management for rice under SRI system of cultivation.
3. To work out the economics of the system as influenced by treatments.

Review of Literature

2. REVIEW OF LITERATURE

An experiment was undertaken to standardize the seedling age, spacing and weed management for rice under SRI system of cultivation and to compare the performance of rice under SRI and normal system of cultivation. The works related to these aspects are reviewed hereunder.

The System of Rice Intensification (SRI) was developed in Madagascar in the early 1980s by Fr. Henri de Laulanie, a Jesuit priest and hence also called the 'Madagascar method'. It was not known outside Madagascar till about 1997. The potential benefits of SRI are being tested now in all the predominant rice growing countries like China, India, Thailand, Indonesia etc.

SRI is a new revolutionary system of rice cultivation for increasing rice productivity. SRI is literally a system or a methodology rather than a technology as it is not based on fixed set of practices. This system permits resource limited farmers to realize yields up to 15 t ha^{-1} on relatively poor soils, with greatly reduced rates of irrigation and without external inputs. Inspite of the poor soil fertility, small farmers using the SRI methods on plots that range from 100 to 500 m^2 have obtained average rice yields of 8 to 9 t ha^{-1}. (Hirsch, 2000)

Uphoff (2002) described SRI as a system of rice production through synergistic interactions for the production of much higher grain yield than usually achieved by conventional practices with new varieties and external inputs. Further, that the combination of plant, soil, water and nutrient management practices that are used in SRI promote measurably greater root growth, correspondingly observable increase in tillering resulting in greater grain filling and higher grain weight.

2.1 EFFECT OF SEEDLING AGE

2.1.1 Effect of Seedling age on Growth Components

Transplanting older seedlings reduced plant height and dry matter production as compared to younger seedlings (Theetharappan and Palaniappan, 1984). Rao and Raju (1987) reported that planting 25 day old seedlings increased dry matter production as compared to 35 and 45 day old seedlings. The experiments in SRI revealed that the full production potential of individual plants could only be realized when the growth and development condition during the early phases have been optimal, with minimal negative affects from early setbacks (Laulanie, 1993). Nayak *et al.* (1994) noticed an increase in field duration of rice by 14 to 15 days due to planting of aged seedlings during wet season.

Kim *et al.* (1999) found that the crop growth rate (CGR) was lower in 10 day old seedlings up to 40 DAT, but in later growth stages, these seedlings recorded greater CGR. The relative growth rate (RGR) was the highest in 10 day old seedlings up to 40 DAT, while after 50 DAT, RGR was higher for seedlings transplanted after 35 or 40 days.

In SRI, transplanting very young seedlings of eight to ten days old and not more than 15 days old registered better tillering and rooting and this was reduced when transplanting was done after the fourth phyllochron usually about 15 days after emergence (Uphoff, 2002; Kumar and Shivay, 2004 and Shanmuganathan and Sharmila, 2005).

Mahender (2006) reported that rice seedlings lose much of their growth potential when transplanted beyond 15 days of age and this potential is preserved by early transplanting in SRI.

2.1.2 Effect of Seedling age on Yield Attributes and Yield

Migo and De Datta (1982) reported that ten day old young seedlings produced higher productive tillers and grain yield than 21 and 45 day old seedlings. Ramasamy *et al.* (1987) observed that when aged rice seedlings were transplanted, the primary tillers produced panicles within 21 DAT, but these panicles shattered before harvest. Datt and Gautam (1988) observed that the filled grain percentage and thousand grain weight were significantly higher with 30 and 40 day old seedlings than with 50 day old ones. They also found that the grain yield was gradually decreased from 6.7 t ha^{-1} to 5.7 t ha^{-1} with increasing seedling age from 30 to 50 days.

According to Joseph (1991), the days to 50 per cent flowering was found to increase with increase in seedling age. Reddy and Reddy (1991) recorded significant reduction in number of productive tillers m^{-2} with increase in seedling age for transplanting. Kurmi *et al.* (1993) noticed increased panicle weight by planting 25 day old seedlings when compared to 35 and 45 day old seedlings.

In experiments using long duration rice varieties, Patel and Thakur (1997) observed that 55 day old seedlings recorded higher grain yield (6.2 t ha^{-1}) than 65 day old seedlings (3.3 t ha^{-1}). Patel (1999) found that 30 day old seedlings produced more tillers (492 m^{-2}) than 40 and 50 day old seedlings. Transplanting 30 and 45 day old seedlings recorded 13 to 15 per cent higher grain yield than 60 days old seedlings (Singh *et al.*, 1999)

Singh and Singh (1999) found that grain yields of 4.92, 4.64 and 4.22 t ha^{-1} could be realized by transplanting of 25, 35 and 45 day old seedlings respectively. Krishna (2000) observed significantly higher yield attributes like panicle length (14.6 cm), productive tillers (385 m^{-2}) and test weight (15.5 g) in a crop planted with 30 day old seedlings as compared to 51 day old seedlings and direct seeding of sprouted seeds.

As per the recommendations of KAU, 18 day old seedlings in short duration varieties, 20 to 25 day old seedlings in medium duration varieties and 30 to 35 day old seedlings in long duration varieties are transplanted for enhancing the yield (KAU, 2002).

In SRI, transplanting very young seedlings of 8 to 15 days old and having just two leaves contributed to yield improvement (Uphoff, 2002). McHugh *et al.* (2002) reported that planting 10 day old seedlings @ one seedling $hill^{-1}$ produced an average yield of 6.4 t ha^{-1}compared to conventional planting of 33 day old seedlings @ three seedlings $hill^{-1}$. Evaluation of the suitability of SRI technique indicated that transplanting of 14 day old seedlings recorded higher yield than normal planting with aged seedlings of 25 days (Nirmala, 2006)

Rao and Raju (1987) noticed that the days to 50 per cent flowering significantly increased with age of seedling, while the yield attributes except panicle length were significantly reduced. Nayak *et al.* (1994) and Shashikumar *et al.* (1995) reported higher grain yield with aged seedlings of photo-insensitive rice variety

Venugopal and Singh (1985) observed that seedling age had no influence on grain yield but a trend of higher straw yield and lower harvest index was noticed with younger seedlings. Krishnan and Nayak (1997) showed that age of seedlings at transplanting had not much influence on the grain yield of photosensitive rice variety.

2.1.3 Effect of Seedling age on Nutrient Uptake

Manoharan (1981) found that uptake of nitrogen by rice planted with 45 day old seedlings were lesser than that planted with 25 and 35 day old seedlings. He also noticed higher uptake of phosphorous with younger seedlings while potassium uptake was not influenced by seedling age. Reddy and Reddy (1991) observed a negative correlation between age of seedlings at transplanting and nitrogen uptake.

2.2 EFFECT OF NUMBER OF SEEDLINGS PER HILL

2.2.1 Effect of Number of Seedlings per Hill on Growth Components

Savant *et al.* (1994) suggested that increased number of seedlings per hill affected the early growth and tiller formation. Transplanting single seedling hill^{-1} at a spacing of 20 x 15 cm has been suggested as the general practice but it is location specific (Siddiq, 1995). Ramasamy and Babu (1997) stated that planting less number of seedlings hill^{-1} enabled the plant to produce new tillers which undergoes normal physiological growth resulting in more healthy panicles.

Sanico *et al.* (1998) reported that splitting the tiller bearing plant into a single tiller and transplanting one tiller hill^{-1} helped to reduce seedling requirement. Barkelaar (2001) opined that transplanting of single seedling rather than in clumps reduced competition with other rice plants for space, for light, or for nutrients in the soil. Appropriate aged seedlings are transplanted @ two to three seedlings hill^{-1} in rows (KAU, 2002).

Obulamma and Reddy (2002) found that the rice hybrid cv.APRH2 planted with one seedling hill^{-1} registered higher dry matter production. Based on experiments in SRI, Uphoff (2002) reported that planting three or more seedlings hill^{-1} retarded growth due to plant competition below and above ground. Planting of single seedling rather than in clumps helped to avoid root competition that promoted vigorous root growth (Uphoff and Randriamiharisoa, 2002).

2.2.2 Effect of Number of Seedlings per Hill on Yield Attributes and Yield

According to Ramasamy *et al.* (1987), increasing the number of seedlings hill^{-1} had an adverse affect and all yield parameters were reduced with more than two seedlings hill^{-1}. Govindarasu *et al.* (1997) recommended one seedling hill^{-1} for hybrid rice for enhanced productivity. Planting of one seedling hill^{-1} gave comparable grain yield with two seedlings hill^{-1} in case of hybrids, whereas, two seedlings hill^{-1} of conventional rice cv. Chaitanya gave significantly higher yield than one seedling hill^{-1} (Srinivasulu *et al.*, 1999).

Rice hybrid cv. APRH 2 planted with one seedling $hill^{-1}$ recorded higher grain yield but it was on par with that of two seedlings $hill^{-1}$ as reported by Dongarwar *et al.*(2002). Similar result was also reported by Obulamma and Reddy (2002) in a hybrid rice.

Wang *et al.*(2002) noticed that the percentage of filled grains and thousand grain weight with one seedling $hill^{-1}$ tended to be higher than with two seedlings $hill^{-1}$. Singh and Singh (2005) reported that planting of single seedling $hill^{-1}$ performed better in respect of length of panicle, number of grains per panicle, test weight and grain yield as compared to two or three seedlings $hill^{-1}$.

Padhi (1999) and Shrirame *et al.* (2000) reported that transplanting two seedlings $hill^{-1}$ produced significantly higher number of total tillers $hill^{-1}$ over one seedling but the harvest index was highest with single seedling $hill^{-1}$. Nayak *et al.* (2003) reported that planting of two seedlings $hill^{-1}$ was beneficial with a yield advantage of 8.2 per cent over one seedling $hill^{-1}$.

Rajarathinam and Balasubramaniyan (1998) observed zero impact of seedling number on yield attributes.

2.3 EFFECT OF SPACING

2.3.1 Effect of Spacing on Growth Components

Murty and Murty (1980) reported that LAI and dry matter production were higher at a spacing of 10 x 10 cm and reduced progressively with increased spacing. Balasubramaniyan and Vaithialingam (1983) observed that the plant height was not influenced by spacing. Savant *et al.* (1994) suggested that the number of hills m^{-2} affected the early growth and tiller formation.

Shukla *et al.* (1995) reported that square planting (15 x 15 cm) provided better ecosystem for improving the morpho-physiological growth parameters namely plant height, tiller number $hill^{-1}$, dry matter production, CGR, RGR, LAI and net assimilation rate (NAR) during the entire growth period. Fu *et al.* (2000) observed a reduction in plant height with decreasing plant spacing. He also opined that with a reduction in plant density, the number of tillers and leaves increased and the growth period was extended.

Shrirame *et al.* (2000) noticed that the plant height was not affected due to spacing in rice, but reducing the plant density resulted in increase in number of functional leaves and maximum leaf area. Jacob (2002) reported that spacing of 20 x 10 cm recorded the highest value in terms of plant height, number of tillers hill^{-1}, LAI at panicle initiation stage and dry matter production.

The usual recommended spacing of medium duration rice variety is 20 x 10 cm with 50 hills m^{-2} (KAU, 2002). Uphoff (2002) opined that providing a spacing of 25 x 25 cm (16 plants m^{-2}) or 50 x 50 cm (4 plants m^{-2}) in SRI could ensure optimum care to each seedling, resulting in enhanced tillering. Iqbal (2004) reported that a spacing of at least 22.5 x 22.5 cm helped more root growth and better tillering. Islam *et al.* (2005) noticed an increase in tiller number hill^{-1} with increase in spacing, but tiller number per unit area decreased. The plants' full potential for tillering could be captured by early transplanting and spacing of at least 25 x 25 cm (Uprety, 2005)

2.3.2 Effect of Spacing on Yield Attributes and Yield

The number of productive tillers m^{-2} significantly increased with closer spacing, whereas, the other yield attributes, namely, number of spikelets per panicle, number of filled grains per panicle and thousand grain weight improved with wider spacing (Venkateswarlu and Singh, 1980). Balasubramanian and Vaithialingam (1983) found that spacing in rice significantly influenced the number of productive tillers hill^{-1}. Rao and Raju (1987) reported that the closer spacing of 15 x 10 cm reduced the number of days to 50 per cent flowering, decreased grains panicle^{-1}and increased straw yield but grain yield remained unaffected.

Wider spacing increased the extent of root system and resulted in higher grain yield per plant compared to closer spacing (Kujira, 1990). From their studies on varying plant density, Xian and Young (1990) did not observe major changes in rate of seed set, thousand seed weight, panicle length and harvest index. However, seed yield plant^{-1}, number of panicles plant^{-1} and quality attributes were found to be varying under different levels of plant density in rice.

Azad *et al.* (1995) reported that when seedlings were transplanted at 20 x 10 cm, 25 x 15 cm or 30 x 20 cm spacings, the maximum grain yield was recorded in 25 x 15 cm spacing. Padmajarao (1995) stated that in rice cv. Basmati 370 and IET 8580, the grain yield and grains panicle^{-1} were the highest at a plant spacing of 20 x 10 cm. Vimala (1997) reported that the spacing of 15 x 15 cm expressed better plant growth characteristics associated with best quality seeds, whereas, closer spacing (10 x 15 cm) recorded maximum seed yield with marginal seed quality in hybrid rice.

Saha (1998) reported that the number of high density grains (HDG) in the upper portion of rice panicle decreased with increased plant population. He also pointed out that the number of HDG and grain yield were significantly correlated and that wider spacing gave better grain filling due to lesser competition among the plants for light, space, water and nutrition.

Zadseh and Mirlohi (1998) noticed that closer spacing resulted in increased number of tillers and panicles per unit area but tillers plant^{-1} and number of grains panicle^{-1} decreased. They opined that the number of panicles per unit area was the most important component determining grain yield.

Kyeong *et al.* (1999) suggested that in transplanted rice, eventhough the number of panicles m^{-2} increased with increasing plant density, the number of grains per panicle decreased. Lourduraj (1999) reported that planting geometry had pronounced effect on tillering and interception and utilization of light in rice. He also opined that for low tillering rice cultivars, yield declined as plant spacing increased from 15 x 15 cm to 25 x 25 cm, while high tillering cultivars showed the opposite trend. He further stated that for medium duration rice cultivars, the optimum plant population for achieving maximum yield is 50 hills m^{-2} (20 x 10 cm). Increasing the population to 80 hills m^{-2} reduced the grain yield significantly.

Patel (1999) observed a reduction in grain yield when spacing was increased from 20 x 10 cm to 20 x 20 cm. Rajarathinam and Balasubramaniyan (1998) compared different plant population of 50, 33 and 25 hills m^{-2} using rice hybrid CORH 2 and concluded that yield parameters namely panicles m^{-2}, panicle weight and length, grains $panicle^{-1}$, filled grains $panicle^{-1}$, harvest index, thousand grain weight and grain yield were highest with the population of 50 hills m^{-2}. They also found that dry matter production and nitrogen uptake increased with increasing hill number from 25 to 50 hills m^{-2}. Regression analysis studies indicated that seedlings m^{-2} was an important factor contributing much to grain yield in transplanted rice (Sharma and Ghosh, 1999).

According to Bindra and Kalia (2000), increasing the normal plant stand of 20 x 10 cm by 33 per cent could not exhibit positive effect on grain yield. Crusciol *et al.* (2000) obtained more number of stalks and panicles per unit area with decreasing row spacing resulting in higher yield.

Geethadevi *et al.* (2000) reported that higher grain yield of hybrid rice was obtained with wider spacing of 20 x 10 cm, than with 15 x 10 cm. They also reported significant positive correlations between grain yield and spikelet number per panicle, panicle length, thousand grain weight and weight of panicle. Shrirame *et al.* (2000) observed that the grain and straw yields were not affected due to spacing in rice. In humid tropic environment, high plant density of rice resulted in excessive vegetative growth. The resulting inter and intra plant competition and low radiation during anthesis and grain filling caused high rate (40-70%) of tiller abortion, delay in flowering of late tillers, low percentage of filled spikelets and low yield, despite a high biomass production (Tuong *et al.*,. 2000).

Patra and Nayak (2001) explained that the superior grain yield under closer spacing is mainly due to the higher number of panicles m^{-2}. They also observed that effective tillers $hill^{-1}$ increased significantly with wider spacing while closer spacing of 10 x 10 cm significantly lowered number of grains $panicle^{-1}$. Satyavathi *et al.* (2001) reported positive and significant correlation between yield $plant^{-1}$ and the number of productive tillers $plant^{-1}$ at 20 x 10 cm spacing. The same spacing resulted in increased number of productive tillers $hill^{-1}$, number of spikelets $panicle^{-1}$, number of filled grains $panicle^{-1}$, thousand grain weight, grain yield, straw yield and harvest index compared to 15 x 10 cm spacing.

Subbaiah *et al.* (2001) reported that the variety, ADT-38 raised in clay loam soil of Tamil Nadu responded well at an optimum spacing of 20 x 10 cm registering a maximum grain yield of 6.78 t ha^{-1} and 6.92 t ha^{-1} respectively during 1996 and 1997. Kewat *et al.* (2002) obtained significantly higher grain (63 q ha^{-1}) and straw (162 q ha^{-1}) yields and B:C ratio (2.8) with 20 x 10 cm spacing compared to wider spacing of 20 x 20 cm and 20 x 15 cm. Uphoff and Randriamiharisoa (2002) observed that planting seedlings with a spacing of 25 x 25 cm was ideal, but in highly fertile soils, wider spacing of 30 x 30 cm or even more gave higher yield than closer spacing. Rajesh and Thanunathan (2003) found that wider spacing of 20 x 15 cm was better than 20 x 10 cm and 15 x 15 cm spacings in increasing the yield.

Vijayakumar (2003) reported that the yield attributes namely, panicle length, number of panicles $hill^{-1}$ and total number of grains per panicle were higher when planted at a spacing of 25 x 25 cm in SRI. Yield increase was observed in traditional rice varieties of Kerala when planted at a wider spacing of 20 x 20 cm and 30 x 30 cm (Girijan, 2004). Kumar *et al.* (2005) noticed that, following a wider spacing of 25 x 25 cm in SRI resulted in yield improvement from the traditional method of rice cultivation in Andhra Pradesh.

2.3.3 Effect of Spacing on Weed Flora

In recent years, attempts have been made to introduce weed-competitive cultivars of rice. In transplanted rice, use of competitive cultivars in conjunction with higher seed rates and shallow submergence has reduced weed competition.

Ghosh and Sarkar (1975) had shown that as the distance between hills of transplanted rice was reduced, the crop became more competitive and weed population was reduced. The yield of semi-dwarf cultivars could be increased and weed competing ability improved by decreasing the spacing from 25 x 25 cm to 15 x 15 cm (IRRI,1976).

Estornios and Moody (1983) found that under identical management practices, weed dry weight was the lowest at closer spacing. Transplanting of seedlings at 44.4 hills m^{-2} significantly reduced the density and dry weight of weeds and significantly increased the paddy yield compared to 26.66 hills m^{-2} (Verma *et al.*, 1988).

Ghosh and Singh (1996) proved that reduction of plant density enhanced weed infestation. Relative weed density of each species increased with increase in spacing from 20 x 10 cm to 30 x 20 cm (Khondaker and Sato, 1996). They further pointed out that weed growth increased significantly with increase in spacing and weed growth rate was higher at 25 DAT than at 45 DAT. In lowland transplanted rice, closer spacing resulted in fewer weeds (Gogoi, 1998).

Singh *et al.* (1999) reported that among the three spacings tried (10 x 10 cm, 15 x 10 cm and 20 x 10 cm), the weed population increased significantly with increase in spacing. They also opined that weed control efficiency increased from 61.60 per cent in 20 x 10 cm spacing to 66.40 % in 10 x 10 cm spacing. Lourduraj *et al.* (2000) found that weed count and weed dry weight were higher under wider planting of 33 hills m^{-2} (20 x 15 cm) compared to closer planting of 50 hills m^{-2} (20 x 10 cm).

Yong and Seiji (2000) indicated that high planting density of rice was favourable for competing with barnyard grass in paddy fields. Barnyard grass produced more tillers at lower rice density (Guo and Yong, 2001). They also reported that when the rice density was increased, the growth rate and LAI of barnyard grass decreased. Jacob (2002) reported that a spacing of 20 x 10 cm registered the lowest value of total absolute density of weed compared to 15 x 15 cm and 15 x 10 cm spacings.

2.4 EFFECT OF WEED MANAGEMENT

Lowland transplanted rice is grown under the condition which is favourable for growth and multiplication of weed species. Selection of an appropriate method of weed control technology should be based not on the degree of weed control or the cost of weed control alone. Both these factors should be considered in deciding the weed control method.

2.4.1 Weed Flora Infesting Rice

Weed flora infesting rice crop varies widely with respect to prevailing soil and climatic condition. Rice fields are colonized by terrestrial, semiaquatic or aquatic plants depending on the type of rice culture and season (Moody and Drost, 1983).

A brief review of weed flora in transplanted rice in Kerala (Table 1) suggested that among grassy weeds, *Echinochloa* spp. is the foremost. *Cyperus* spp. and *Fimbristylis* spp. were predominant among the sedges, and *Monochoria vaginalis* and *Marsilea quadrifoliata* constituted the common broad leaved group.

2.4.2 Crop- Weed Competition

Competition begins when crop and weeds grow in close proximity to one another and when the supply of an essential factor falls below their demands. (Shetty and Krishnamurthy, 1975)

Table 1. Weed species infesting transplanted rice in Kerala

Location	Grasses	Sedges	Broadleaved weeds	Reference
Pattambi, Kerala	*Echinochloa crus-galli* *Brachiaria* spp.	*Fimbristylis miliaceae*	*Cleome* spp.	Nair and Sadanandan (1975)
Onattukara, Kerala	*Echinochloa colonum* *Echinochloa crus-galli* *Sacciolepis indica*	*Cyperus iria* *Cyperus rotundus*	*Cleome viscosa* *Monochoria vaginalis*	(Lakshmi, 1983)
Vellayani, Kerala	*Echinochloa crus-galli* *Echinochloa colonum* *Panicum repens* *Brachiaria ramosa*	*Cyperus spp.* *Fimbristylis miliaceae*	*Monochoria vaginalis* *Ludwigia parviflora*	Maheswari (1987)
Onattukara, Kerala	*Brachiaria ramosa* *Cynodon dactylon* *Panicum spp.*	*Echinochloa spp.* *Cyperus iria* *C.rotundus,* *C. difformis* *Scirpus juncoides* *Fimbristylis miliaceae*	*Ammania baccifera* *Ludwigia parviflora* *Marsilea quadrifoliata* *Cleome viscosa* *Monochoria vaginalis* *Leucas aspera*	Rajan (2000)
Cropping System Research Station, Karamana, Trivandrum	*Echinochloa colona,* *Echinochloa crus-galli,* *Cynadon dactylon,* *Panicum repens*	*Cyperus iria,* *Cyperus difformis,* *Cyperus rotundus,* *Fimbrystylis miliaceae*	*Ludwigia parviflora,* *Monochoria vaginalis,* *Marsilea quadrifoliata,* *Sphenoclea zeylanica*	Seema (2004)

Crop- weed competition is complicated because various factors affect the extent to which it occurs. The total effect of the interference as reflected in crop growth and yield, resulted from competition for nutrients, moisture and sunlight (Rao, 2000)

2.4.3 Critical Period of Competition

Knowledge on the susceptible period of crop life to weed infestation decides the weed management programme to be adopted. Critical period of competition is the period at which the occurrence of weed competition greatly affects the quantity as well as the quality of the crop yield. If the crop is kept weed free during the early stages for a certain length of time, weeds that emerge and develop subsequently may not affect the yield. This intervening period is termed as "critical period" of weed competition (Hewson and Roberts, 1971)

Shetty and Gill (1974) and Bhan and Mishra(1993) reported that the most critical period of crop- weed competition was between four and six weeks (28 to 42 days) after transplanting. According to Varughese (1978) and Sukumari (1982), the critical period of crop- weed competition was between 21 and 40 DAT. Shasidhar (1983) observed that weed competition was critical during the first 40 DAT paddy and yield reduction was not significant by the presence of weeds thereafter. The weeds emerging after the first 25 to 33 per cent of the life cycle of rice plant had less effect on crop yield (Singh, 1985).

The most critical period for competition between rice and weeds is when rice is in vegetative phase and when yield components of the rice plant are being differentiated (Bayer, 1991). Chaudhary *et al.* (1995) observed that mean yield of grain was the highest in the plot kept weed free throughout crop growth period. But this was not significantly different from grain yield obtained from plots kept weed free until 60 DAT. Competition period from 15 to 45 DAS had utmost impact on yield of wet seeded rice (Sathyamoorthy and Kandasamy, 1998).

2.4.4 Effect of Crop-Weed Competition on Weed Flora Dynamics

Generally in rice fields, grass weeds occupy a major percent of total weeds followed by sedges and aquatic weeds (Kumar and Gautam, 1986 and Jayasree, 1987). Verma *et al.* (1987) reported more number of grassy weeds in association with rice. Tomer (1991) observed that, of the total weed flora, grasses, sedges and broad leaved weeds in rice accounted to 70, 25 and 5 per cent respectively.

According to Asokaraja (1994) grasses and sedges exerted severe competition during the early period, which caused broad leaved weeds to emerge subsequently coinciding with the cessation of growth of the earlier types. Balasubramanian (1996) reported that grass weed density increased up to 40 DAT, but declined at maturity while the sedges population increased with advancing growth stage of rice. The density of broad leaved weeds nearly doubled from 20 to 40 DAT and increased further at harvest.

2.4.5 Effect of Weed Infestation on Yield Attributes and Yield of Rice

Rethinam and Sankaran (1974) observed that weed control treatments had no effect on yield attributes. Ramamoorthy *et al.* (1974) found that competition of weeds with rice reduced the productive tillers in rice. The extent of yield reduction due to weeds alone was estimated to be around 15 to 20 per cent in transplanted rice, 30 to 35 per cent in direct seeded rice under puddle condition and over 50 to 60 per cent in upland rice as evident from the data collected over a number of seasons and locations in India under the multi location testing programme of the All India Co-ordinated Rice Improvement Project (Pillai, 1977 and Singh, 1985).

Varughese (1978) reported a yield reduction of 25.47 per cent in transplanted rice due to presence of weeds. As per the reports of Moody (1980) the yield reduction due to uncontrolled weed growth ranged from 20 to 25 per cent for transplanted rice and 40 to 50 per cent for broadcasted rice in puddled soil.

Weed competition in rice lowered the filled grains per panicle by 13 per cent and test weight by 4 per cent (Ghobrial, 1981). Sukumari (1982) and Lakshmi (1983) reported significant influence of weed growth on the number of filled grains per panicle.

Arya *et al.* (1991) and Varshney (1991) reported a decrease in thousand grain weight due to weed competition. Reduction in panicle length and thousand grain weight due to weed competition was reported by Mabbayad and Moody (1992).

According to Kumari and Rao (1993) and Reddy and Gautam (1993), competition stress of weeds exerted reduction in yield of transplanted rice by 50 per cent. Dhiman and Nandal (1995) noticed an yield reduction of 23.71 per cent in transplanted rice. Balasubramanian (1996) pointed out that productive tillers were only 5 to 7 $hill^{-1}$ under unweeded check as against 10.5 to 11.6 $hill^{-1}$ with two hand weedings. Muthukrishnan *et al.* (1997) observed that the number of panicles m^{-2} in hand weeded plot was significantly higher than unweeded check, (528 and 356 respectively). Rao and Singh (1997) reported negative correlation between grain yield and weed dry weight.

According to Renjan (1999), yield reduction due to weeds in transplanted rice is 44.94 per cent. He also reported that grain and straw yield were positively correlated with plant height, LAI, total dry matter production at harvest, productive tillers, panicle weight, thousand grain weight and nutrient uptake by the crop and negatively correlated with weed count, weed dry matter production and nutrient removal by weeds.

2.4.6 Methods of Weed Control

2.4.6.1 Hand Weeding

According to Crafts and Robbins (1973), hand pulling of weeds was an efficient method of eliminating annual and biennial weeds, which do not reappear again. The manual method of weed control is laborious, backbreaking and time consuming (Mani and Gautam, 1973). Ravindran (1976) reported that though hand weeding on the 20th and 40th DAT rice gave higher yield, the net profit was lower due to increased labour charges. Moody (1980) suggested that in transplanted rice, one manual weeding (at the most two) was sufficient to control weeds adequately. He also observed that manual weeding methods are most effective on young weeds. Singh and Sharma (1984) reported that hand weeding provided fairly good control of weeds because weeds from both inter and intra rows are removed, but it was laborious and expensive. The cost-benefit ratio showed a negative return from hand weeding mainly due to very high labour cost.

Chandrakar and Chandrawanshi (1985) pointed out that the hand weeded plots recorded the highest number of panicles m^{-2}, highest grain yield and the least dry weight of weeds. Preliminary evaluation of weed control practices in transplanted rice revealed that yield increase due to hand weeding in the farmer's fields ranged from 4 to 29% (Elliot *et al.*, 1985)

The reduction in weed dry weight due to hand weeding was 88 per cent (Raju and Reddy, 1986). Verma *et al.* (1987) found that hand weeding could not stop re-emergence of sedges. Hand weeding resulted in higher grain yield in rice (Azad *et al.*, 1990; Singh *et al.*, 1992 and Singh *et al.*, 1994). Hand weeding twice registered a high weed control index of 81.90 per cent (Kathiresan and Surendran, 1992)

Khare and Jain (1995) found that hand weeding gave the lowest weed biomass and highest weed control efficiency (60 kgha^{-1} and 91.6 per cent respectively). Balasubramanian (1996) pointed out that number of productive tillers in rice was enhanced by hand weeding twice. Hand weeding was effective and is the most common tool to control weeds in transplanted rice (Muthukrishnan *et al.*, 1997). Gogoi *et al.* (2000) pointed out that mechanical or manual weeding was difficult many a times due to continuous rains prevailing during rainy season and also due to scanty labour.

Thus it is seen that the traditional method of hand weeding continued to exhibit good control of weeds and record better yield. Where labour is cheap and plentiful, this method can be followed. For small holdings, use of traditional methods of weed control continues to be the most economical method.

2.4.6.2 Chemical Weed Control

Chemical weed control could be considered as a better alternative to traditional hand weeding. Rajkhowa *et al.* (2001) reported that the application of herbicides increased available nitrogen and potassium to rice due to reduction in nutrient removal by weeds. Narwal *et al.* (2002) explained that all herbicidal treatments gave significantly higher yield and better yield attributes than weedy check. Sharma *et al.* (2003) observed that all herbicidal treatments significantly reduced the density and dry weight of weeds over weedy check.

2.4.6.2.1 Butachlor

According to Rethinam and Sankaran (1974) pre emergence application of butachlor @ 2.0 kg ai ha^{-1} gave the best and economic weed control under transplanted condition. Rangiah *et al.* (1975) revealed that butachlor granules @ 2.5 kg ai ha^{-1} applied 4 DAT provided effective weed control. However, Arcco and Mercado (1981) and Diop and Moody (1989) reported that butachlor controlled weeds poorly and the crop stand reduction caused by butachlor resulted in weed growth. Butachlor applied @ 1.5 kg ai ha^{-1} as spray or sand mix gave the highest yield (Sankaran and Thiagarajan, 1982). Pillai *et al.* (1983) pointed out that the grain yield in transplanted rice with single application of butachlor was comparable to that in hand weeding check.

Chinnusamy (1985) concluded that butachlor and two hand weeding reduced the total weed population than two hand weedings. The annual grass weeds were controlled by the application of butachlor (Fajardo and Moody, 1987). Janiya and Moody (1988) found that butachlor and hand weeding resulted in significant reduction in weed dry weight. Mishra *et al.* (1992) observed that application of butachlor @ 1.5 kg ai ha^{-1} reduced dry weight of weeds.

Application of butachlor @ 1.5 kg ai ha^{-1} reduced weed population and increased the grain yield of rice (Singh *et al.*, 1992 and Patel, 1994). Sivaperumal (1995) showed that butachlor @1.5 kg ai ha^{-1} and hand weeding at 30 DAT recorded higher grain yield over two hand weedings in rabi season. While comparing different weed management practices, Muthukrishnan *et al.* (1997) observed that hand weeded plots receiving butachlor @1.5 kg ai ha^{-1} recorded maximum number of panicles m^{-2} and grain yield. They also concluded that butachlor @1.5 kg ai ha^{-1} was the most effective treatment in minimizing weed dry weight.

Butachlor @1.0 kg ai ha^{-1} and Pretilachlor @0.75 kg ai ha^{-1} were on par and resulted in significantly lower weed dry matter accumulation over weedy check at 25 DAT while at 45 DAT butachlor @1.0kg ai ha^{-1} resulted in the lowest weed dry matter accumulation (Rajkhowa *et al.*, 2001). He also observed that butachlor @ 1.0 kg ai ha^{-1} applied 30 DAT, significantly reduced the weed infestation until 45 DAT and resulted in higher rice yield over the weedy control. Butachlor @ 2 kg ai ha^{-1} and hand weeding on 40 DAT gave the highest grain yield in all the three years with an increase of 26.39, 41.58 and 51.05 % over the unweeded control respectively (Kathiresan, 2002).

Application of butachlor is recommended as a pre-emergent herbicide in paddy @1.25 kg ai ha^{-1} at 0-6 DAT (KAU, 2002). Treatment with butachlor @ 1 kg ai ha^{-1} followed by hand weeding recorded the lowest weed density (25 m^{-2}) and weed dry matter and the highest number of panicle m^{-2}, thousand grain weight and grain yield (Madhavi and Reddy,2002). Yield reduction was observed upto 16 to 18 per cent due to application of butachlor 50 EC @ 1.25 kg ai ha^{-1} as compared to pretilachlor @ 0.75 kg ai ha^{-1} (Mahapatra *et al.*, 2002). Moorthy (2002) observed that butachlor @ 1.0 kg ai ha^{-1} was only moderately effective in minimizing weed competition.

Nagappa *et al.* (2002) found out that butachlor + safener caused lowest phyto toxicity and highest yield. Nair *et al.* (2002) reported that pre emergence application of 1.25 kg butachlor ha^{-1} + hand weeding at 40 DAT resulted in the lowest weed density (126.5 m^{-2}) and weed dry weight, highest weed control efficiency, panicle m^{-2}, panicle length, grain yield and straw yield in rice.

Renjan (1999) reported that butachlor treated plots registered the highest net income of Rs. 7907.48 ha^{-1} and a benefit-cost ratio of 1.364. According to Gogoi *et al.* (2001) the highest additional net return (Rs.5135 ha^{-1}) was obtained with application of butachlor @0.5 kg ai ha^{-1} along with closer planting.

2.4.6.3 Mechanical Weed Control

Magdoff and Bouldin (1970) reported that rotary hoe churns up the surface soil to remove weeds providing additional aeration which may contribute to greater biological nitrogen fixation by mixing aerobic and anaerobic soil horizons. Mechanical weed control through the use of rotary weeder or other implements help in minimizing weed competition besides improving soil aeration (Misra and Sahoo, 1971 and Shad, 1986). Rangiah *et al.* (1975) reported that hand weeding and working rotary weeder controlled the weeds effectively and recorded maximum yield and net profit.

Dinesh and Manna (1990) studied the effect of different weed management practices in transplanted rice grown under shallow submerged condition and found that in summer crop, suppression of weeds by two hoeings with Japanese rotary weeder effectively controlled the weeds and increased the grain yield by 29.7 per cent over no hoeing. In wet season, the response to different hoeing or other weed control methods could not be observed due to continuous water stagnation.

Moody (1991) observed that push-type rotary weeders are difficult to use because they must be moved back and forth and do not work well if the soil is too dry and weeds are large sized or if the flood water is too deep. At Jabalpur, Srivastava and Solanki (1993) noticed that integration of rotary weeding and manual weeding registered a higher grain yield and nitrogen uptake in low land rice.

Manual and mechanical weeding in direct seeded rice could be used in conjunction with other cultural and chemical methods to minimise labour requirements (Ho Naikin, 1996).

An experiment by Singh *et al.* (1996) revealed that all the mechanical weeders (three line wheel hoe, double manual weeder, grubber and sweep hoe) were comparable in controlling weeds. They also found that combining herbicide application with mechanical weeders was more beneficial in raising crop productivity. Rotary weeder was effective in controlling the weeds present in inter-row space, but failed to control the weeds in intra-row space or those in the vicinity of the crop (Choubey *et al.*, 1998).

Singh and Mehta (1998) reported that use of paddy weeder at 15 DAT produced significantly higher yield than three line wheel hoe and sweep hoe and was at par with two hand weedings (20 and 40 DAT) in lowland transplanted rice in UttarPradesh, India. Paddy weeder, when operated at 25 DAT resulted in reduced weed density and weed dry weight as compared to the unweedy control (Gogoi *et al.*, 2000).

2.4.6.3.1 Mechanical weed control in SRI

Repeated use of rotating hoe with its wheels that aerate the top horizon of the soil leads to better development of the rice ecosystem (Randriamicharison, 2002). Thiyagarajan *et al.* (2002) found that mechanical weed control resulted in significantly higher yields of 10 and 3 per cent in wet and dry seasons respectively compared to manual weeding.

Uphoff (2002) emphasized that early and frequent weeding is essential in rice when fields are not covered with standing water. In his view, using a rotary hoe that churns up the surface soil, removes weeds and provides additional soil aeration compared to hand weeding or use of herbicides. He also reported that use of a simple, inexpensive mechanical hand push weeder (rotating hoe) developed at IRRI in 1960's would help to serve the purpose. The nutrients are not lost as they are returned to the soil due to decomposition of weeds. Use of a rotary hoe or cono weeder for weeding helped in better soil aeration on the soil surface that promoted vigorous growth and tillering (Uphoff and Fernandes, 2002)

An evaluation of Transformed Rice Cultivation (TRC) components revealed that, mechanical weeding+ soil stirring by cono weeder significantly increased the grain yield by 1363 and 1220 kg ha^{-1} (24 and 22%) at Tamil Nadu Rice Research Station, Aduthurai and SWMRI Research Farm, Tanjavur respectively over the traditional practice of hand weeding (no soil stirring) (Rajendran *et al.*, 2003). Sudhalakshmi *et al.* (2003) reported a relatively higher uptake of nutrients (N, P, K and Zn) and yield enhancement in rice hybrids under cono weeding.

The incorporation of weed biomass into the soil by cono weeding resulted in enrichment of carbon dioxide near the root zone, increased the biological activity of soil resulting in better nutrient availability in soil and uptake by plants (Iqbal, 2004). Anitha (2005) reported that following a wider spacing of 25 x 25cm and early and frequent weeding using a mechanical weeder encouraged the proliferation of microorganisms that symbiotically enhanced the plants' capability to produce more tillers, with vigorous and healthy root growth and a large number of panicles heavily laden with grains. Nagarajan (2005) opined that use of rotary weeder not only incorporated the weeds into the soil, but also converted it into good green manure. According to Saha *et al.* (2005) mechanical weed control by using weeder combined with one hand weeding proved to be more cost effective over hand weeding twice.

Review of the research results presented above revealed that planting young seedlings of less than 15 days old with wider spacing in a square pattern is helpful for enhancing the tillering and yield of rice. In such practice, early weed control using mechanical weeders will be helpful in incorporating the weed biomass into the soil, enhancing microbial activity and thereby increasing nutrient availability and thus improving the crop yield.

Materials and Methods

3. MATERIALS AND METHODS

The investigation entitled "Standardisation of System of Rice Intensification (SRI) technique" was taken up at College of Agriculture, Vellayani during July 2005 to April 2006, to compare the performance of rice under SRI and normal system of cultivation and to standardize the seedling age, spacing and weed management for rice under SRI system of cultivation. The investigation was programmed as two experiments. The first was a pot culture study and the second one; a field study. The materials used and methods adopted for the experiments are detailed below.

EXPERIMENT I

3.1 POT CULTURE STUDY- STANDARDISATION OF SEEDLING AGE IN SRI

3.1.1 Experimental Site

The experiment was done at the Department of Agronomy, College of Agriculture, Vellayani located at 8° 25′ N latitude and 76° 59′ E longitude, at an altitude of 29 m above MSL.

3.1.1.1 Season

The study was carried out during the period from July to November 2005. The data on various weather parameters during the cropping period are given in Appendix I and graphically presented in Fig 1.

3.1.1.2 Potting Media

The soil collected from the site allotted for field experiment was used as the media for crop growth.

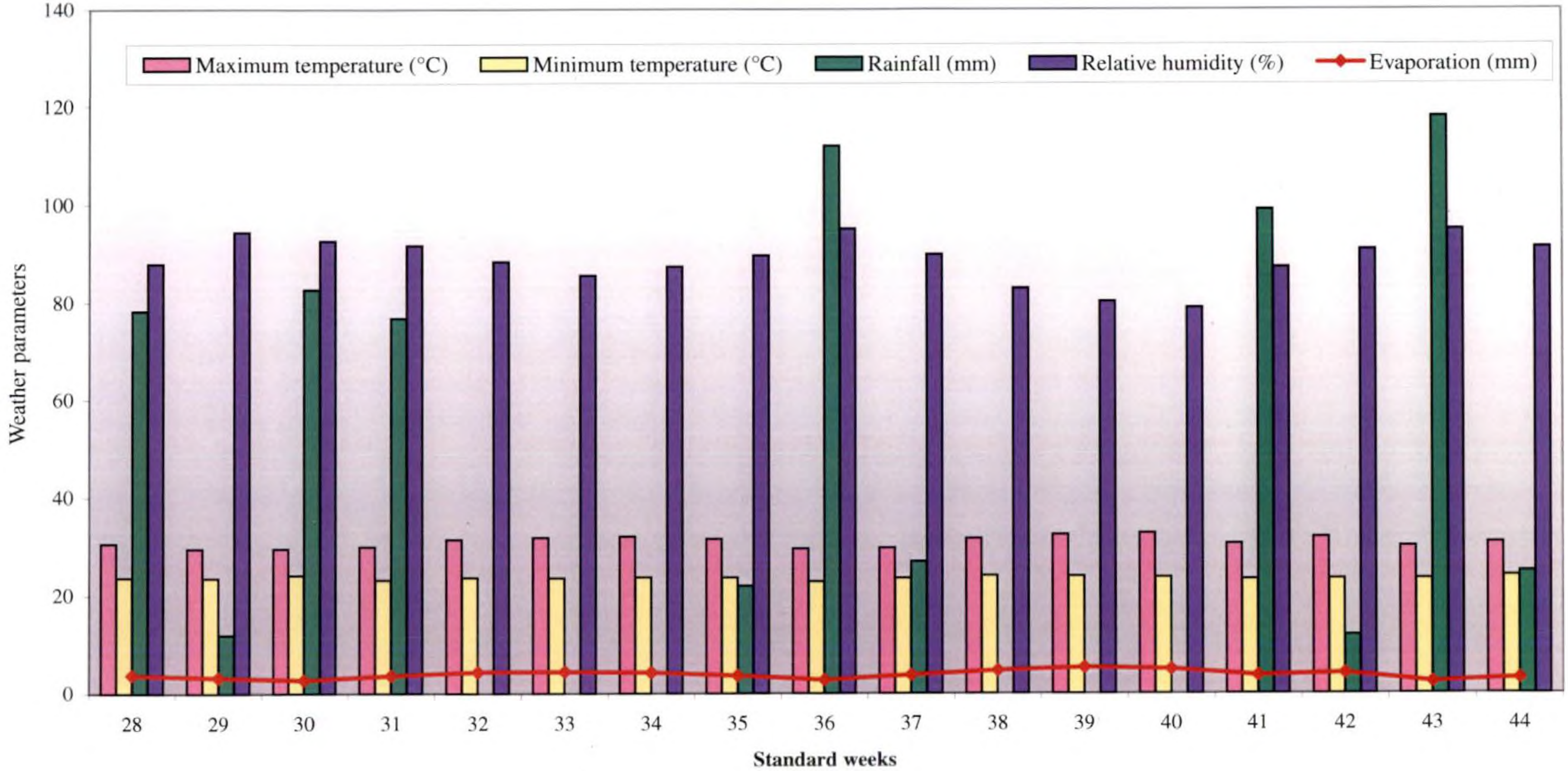


Fig. 1. Weather parameters during pot culture study (July 2005 to November 2005)

3.1.1.3 Variety

The variety used was Uma (Mo-16), which was released from Rice Research Station, Moncompu. Uma is a medium duration variety (115 to 120 days), dwarf, medium tillering, non-lodging and resistant to BPH and GM Biotype-5.

3.1.1.4 Pots

Earthern pots of 25 cm diameter and 30 cm height were used. Pots were filled with soil @ 12 kg pot^{-1} for raising the crop.

3.1.1.5 Manures and Fertilizers

Vermicompost was used as the source of organic manure for the experiment. Quantity of fertilizers required for each pot was calculated based on soil weight. The Package of Practices recommendation of Kerala Agricultural University for medium duration rice (90 : 45 : 45 kg NPK ha^{-1}) was taken. The recommended dose of chemical fertilizers were supplied as Urea, Rajphos and Muriate of Potash.

3.1.1.6 Water Management

For SRI treatments (T_1 to T_5), the pots were irrigated upto field capacity till panicle initiation stage. From panicle initiation stage onwards, a thin film of water was maintained in the pots until 15 days before harvest, when irrigation was withdrawn. For treatment T_6, the pots were kept continuously saturated throughout the growth period, until 15 days before harvest.

3.1.1.7 Plant Protection

Leaf roller attack was noticed at 17 DAS and one spray of Ekalux 25 EC (0.05 %) was given. No other pest and disease incidence was noticed in the trial.

3.1.1.8 Harvest

The crop was harvested on 2nd November 2005. The pots were harvested separately and weight of grain and straw was recorded.

3.1.2 Method

3.1.2.1 Design and Layout

The detailed lay out plan of pot culture trial is given in Fig 2.

Design	:	CRD
Treatments	:	6
Replications	:	5

Treatments

T_1	:	8 day old seedlings
T_2	:	10 day old seedlings
T_3	:	12 day old seedlings
T_4	:	14 day old seedlings
T_5	:	16 day old seedlings
T_6	:	POP recommendation (21 day old seedlings)

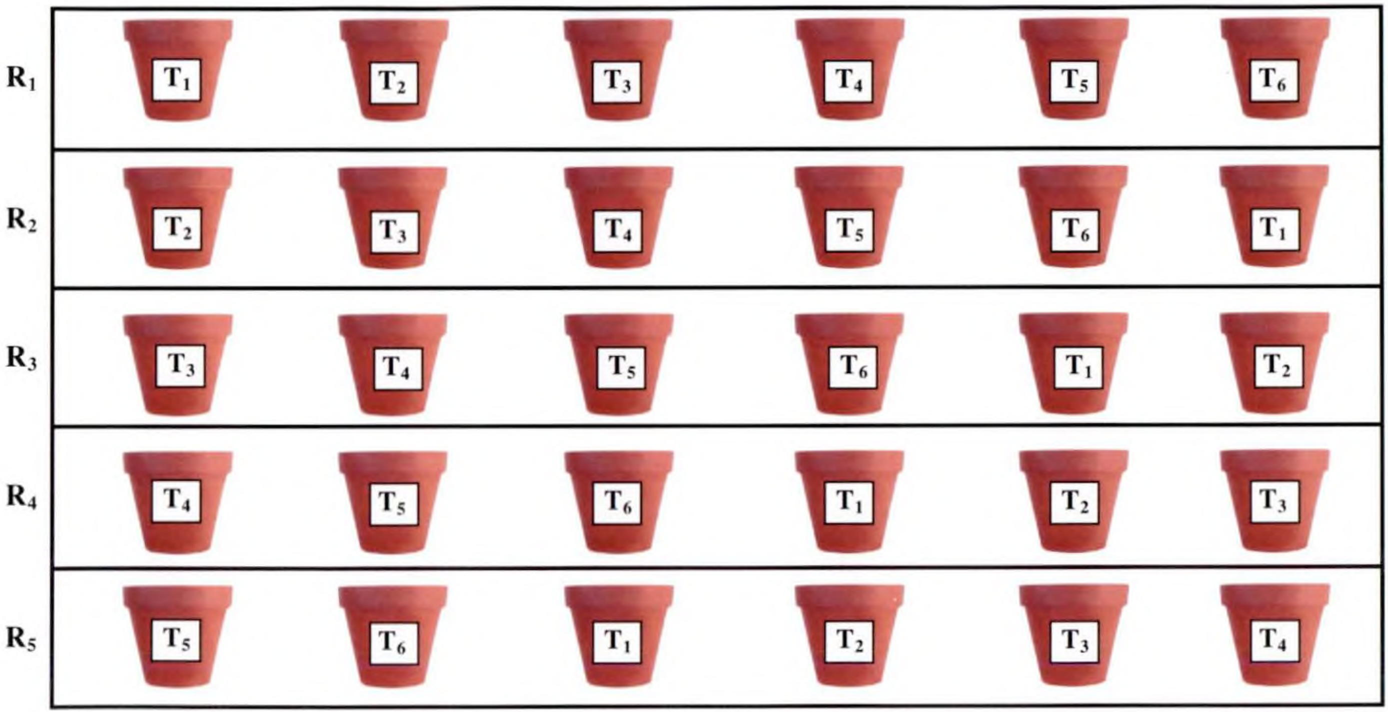
Nursery was raised in gunny bag filled with soil. Sowing was done in 11th July 2005 and transplanting was done as per the treatments. For treatments T_1 to T_5, transplanting was done @ one seedling per hill. For treatment, T_6, 21 day old seedlings were transplanted @ three seedlings per hill.

EXPERIMENT II

3.2 FIELD EXPERIMENT- STANDARDISATION OF SPACING AND WEED MANGEMENT PRACTICES IN SRI

The experiment was conducted for standardization of spacing and weed management practices in SRI. Optimum seedling age obtained from pot culture trial (12 day old seedling) was used for field trial.

Fig. 2. Layout of pot culture study



3.2.1 Experimental Site

The experiment was undertaken in Block B of the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is located at 8° 25′ N latitude, 76° 59′ E longitude and at an altitude of 29 m above MSL.

3.2.1.1 Climate

The location experience a humid tropical climate. The meteorological parameters recorded during the crop growing period is presented in Appendix II and Fig 3.

3.2.1.2 Cropping Season

The experiment was conducted during third crop season from December 2005 to April 2006. Sowing in nursery was undertaken on 12th December 2005. Twelve days old seedlings were transplanted @ one seedling per hill on 23rd December 2005. The spacings were followed as per the treatments. In the control plot 21 day old seedlings were transplanted @ three seedlings per hill on second January 2006. The crop was harvested on 7-4-2006.

3.2.1.3 Soil

Prior to the experiment, composite soil samples were drawn from a depth of 0 to 15 cm layer and analysed for its mechanical composition and chemical properties. Data are presented in Table 2.

The soil of the experimental site was sandy clay loam, belonging to the taxonomical order Oxisol. It was acidic in reaction and medium in available nitrogen, phosphorus and potassium and high in organic carbon content.

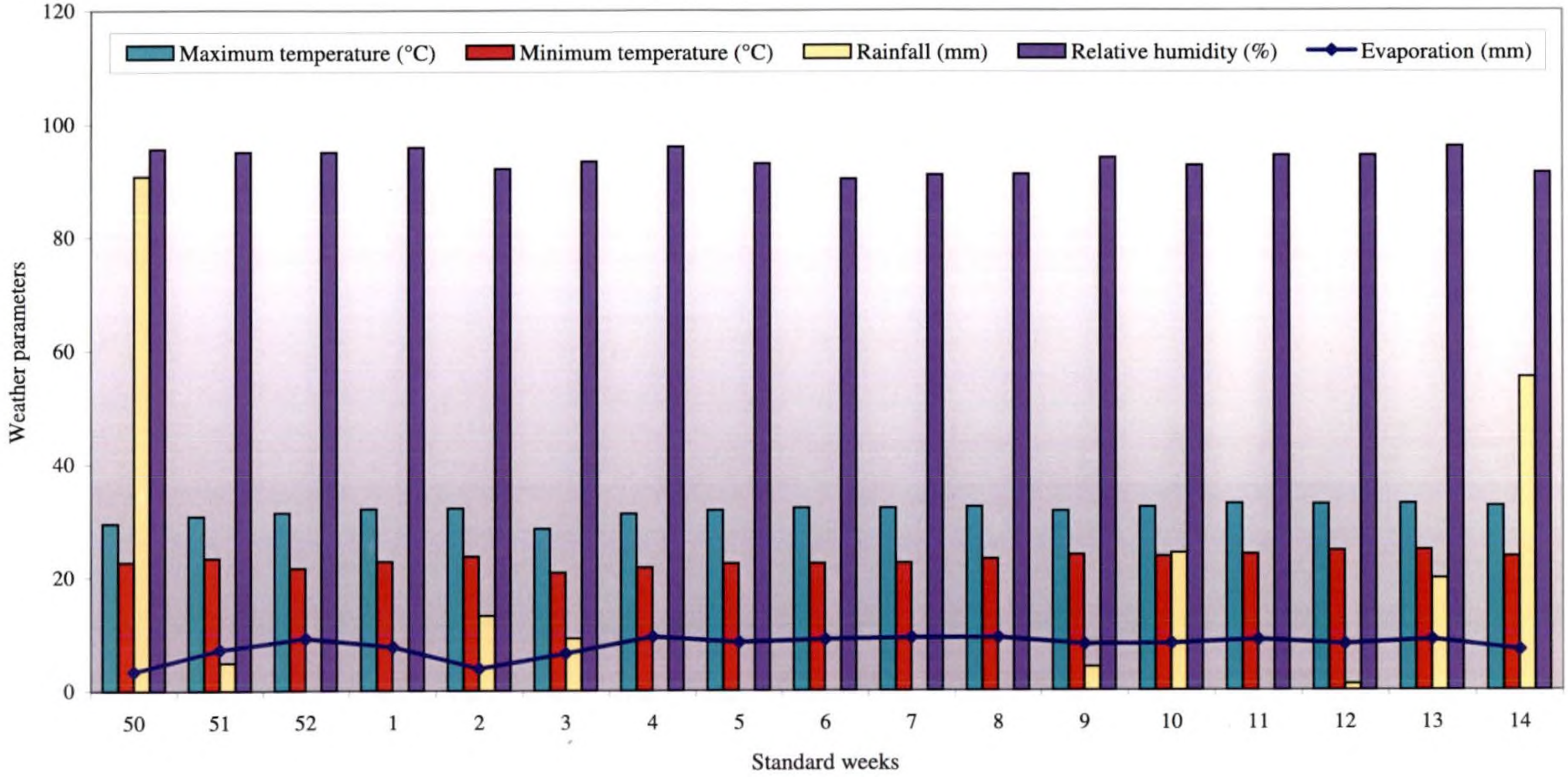


Fig. 3. Weather parameters during the cropping period (December 2005 to April 2006)

Table 2. Soil characteristics of the experimental site

A. Mechanical composition

Sl. No.	Fractions	Content in soil	Methods used
1.	Coarse sand (%)	47.78	Bouyoucos hydrometer method (Bouyoucos, 1962)
2.	Fine sand (%)	10.66	
3.	Silt (%)	8.60	
4.	Clay (%)	33.00	

B. Chemical properties

Sl. No.	Fractions	Content in soil	Methods used
1.	Available N (kg ha^{-1})	259.44 (Medium)	Alkaline Permanganate Method (Subbiah and Asija, 1956)
2.	Available P_2O_5 (kg ha^{-1})	28.52 (Medium)	Bray Colorimetric Method (Jackson, 1973)
3.	Available K_2O (kg ha^{-1})	176.40 (Medium)	Ammonium Acetate Method (Jackson, 1973)
4.	Soil reaction (pH)	5.2 (Acidic)	1 : 2.5 Soil solution ratio using pH meter with glass electrode (Jackson, 1973)
5.	Organic carbon (%)	2.37 (High)	Walkley and Black Rapid Titration Method (Jackson, 1973)

3.2.1.4 Cropping History of the Field

The area was under a bulk crop of rice (variety Aiswarya) during the previous season.

3.2.2 Materials

3.2.2.1 Crop Variety

The same variety used for pot culture experiment, Uma (Mo-16) was used for field trial.

3.2.2.2 Source of seed material

The seeds of Uma was obtained from Rice Research Station, Moncompu.

3.2.2.3 Manures and Fertilizers

FYM (0.4 % N, 0.3 % P_2O_5, 0.2 % K_2O) was used for the experiment. Urea (46 % N), Rajphos (20 % P_2O_5) and MOP (60 % K_2O) were used as source of N, P and K respectively.

3.2.2.4 Herbicides

Pre-emergent herbicide, Butachlor 50 EC [(TN – Machete 50 EC) Manufacturer – Rallis India Ltd] was applied according to treatments.

3.2.3 Methods

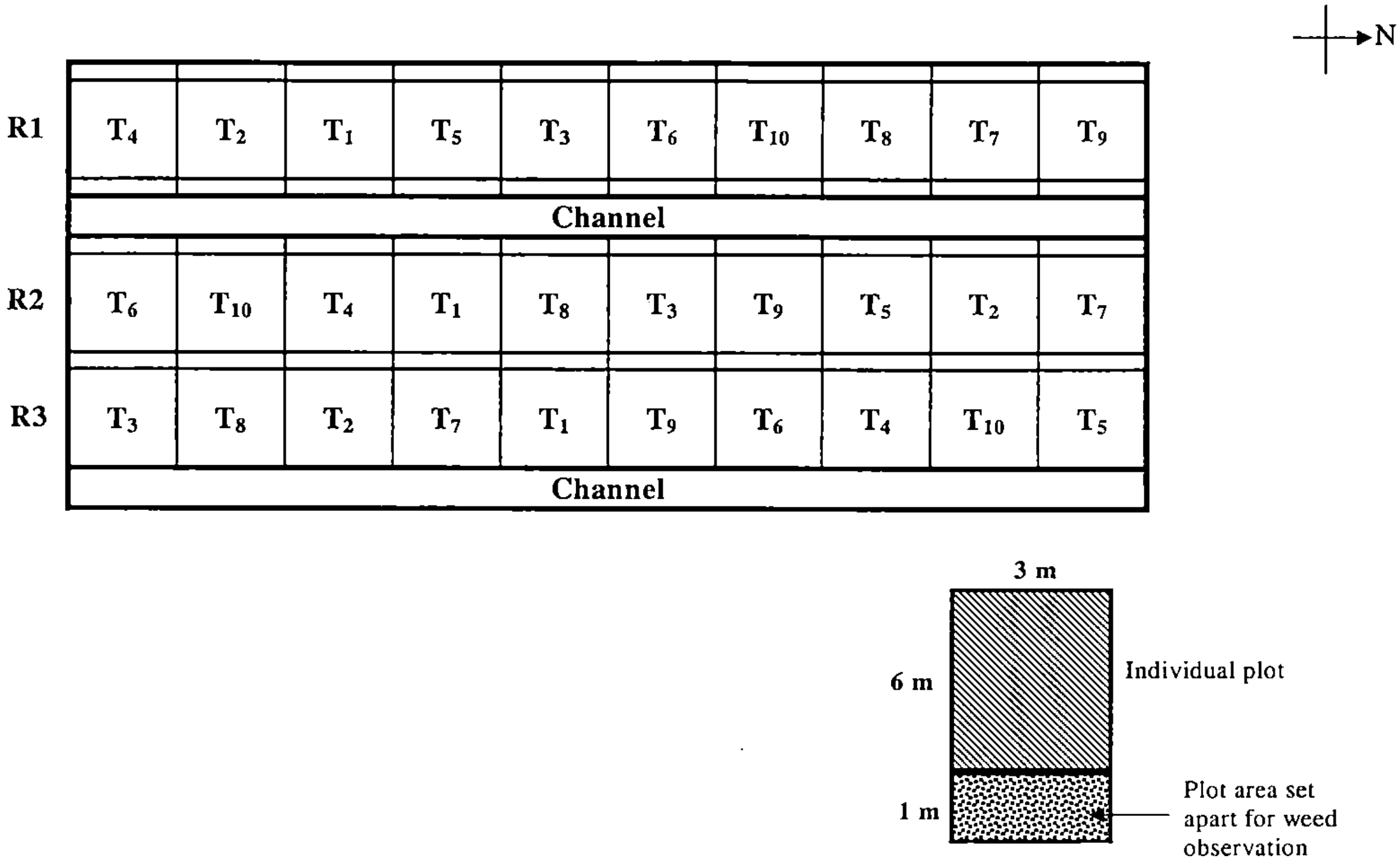
3.2.3.1 Design and Layout

The detailed lay out plan of the field experiment is given in Fig 4.

Design	:	RBD
Treatments	:	(3 x 3 + 1) = 10
Replications	:	3
Gross plot size	:	6 x 3 m
Total number of plots	:	30

The experiment was laid out in factorial RBD with 10 treatments and three replications. The gross plot size was 6 x 3 m and additional one m length was provided for recording observation on weeds.

Fig. 4. Layout of field experiment



3.2.3.2 Treatment Details

A. Spacing (S)

S_1 : 20 x 20 cm @ one seedling $hill^{-1}$

S_2 : 25 x 25 cm @ one seedling $hill^{-1}$

S_3 : 30 x 30 cm @ one seedling $hill^{-1}$

B. Weed management practices (w)

W_1 : Hand weeding twice

W_2 : A pre-emergent herbicide application (Butachlor @ 1.25 kg ai ha^{-1}) followed by one hand weeding

W_3 : Use of rotary weeder at 10 to 15 days interval

C. Control

POP recommendation (20 x 10 cm spacing, three seedlings per hill, planting at 21 DAS and hand weeding twice).

Treatment combination

Nine combinations of two factors, *viz.*, spacing and weed management practices along with control constituted the treatments.

3.2.3.3 Field Culture

3.2.3.3.1 Nursery

A raised bed having an area of 10 m^2 was prepared for nursery. Area was ploughed and weeds and stubbles were removed, 1 kg vermicompost was applied as organic source. Pre-germinated seeds @ 7 kg ha^{-1} were sown and the seeds were covered with coconut fronds for three days. Nursery was irrigated every day.

3.2.3.3.2 Main Field Preparation

The experiment area was ploughed twice, puddled, levelled and weeds and stubbles were removed. The plots were laid out into three blocks with 10 plots each. The plots and blocks were demarked with bunds of 30 cm thickness. A channel of 50 cm width was provided between blocks.

3.2.3.3.3 Manures and Fertilizers

FYM was applied uniformly to all plots @ 5 t ha^{-1}. Chemical fertilizers were applied @ 90 : 45 : 45 kg ha^{-1}, the recommendation of Kerala Agricultural University for medium duration variety. Half N, full dose of P_2O_5 + ½ dose of K_2O were applied as basal dose. ¼ N and ¼ K_2O were applied at maximum tillering stage and ¼ N and ¼ K were applied at panicle initiation stage to all treatments.

3.2.3.3.4 Transplanting

Twelve day old seedlings were gently uprooted from the nursery just before transplanting. Without much disturbance they were transplanted in the main field @ one seedling per hill. For the control plots, the seedlings were uprooted on 21st day from nursery and transplanted @ three seedlings per hill.

3.2.3.3.5 Weed Management

Weed management was done according to treatments. Hand weeding was done twice at 20 DAT and 40 DAT. Butachlor @ 1.25 kg ai ha^{-1} was applied at 5 DAT and this was followed by one hand weeding at 28 DAT.

The first rotary weeding was done at 10 DAT and three more weeding were done at 10 days interval.

3.2.3.3.6 Water Management

As far as possible, saturation was maintained in SRI treatment plots during its vegetative stage. After panicle initiation, a thin film of water was maintained in these plots until 15 days before harvest, when the field was drained. In the control plots, standing water was maintained throughout the cropping period upto 15 days before harvest when the field was drained.

Plate 1. General view of the experimental field

Plate 2. Nursery (12 days after sowing)

Plate 3. Uprooted seedlings - 12 days old

3.2.3.3.7 Plant Protection

The attack of BPH, jassid, leafroller and rice bug were observed in the field and the same were managed as per the POP recommendations of the Kerala Agricultural University.

3.2.3.3.8 Harvest

The crop was harvested on 7th April 2006. The net plot area leaving one border row on all four sides was harvested separately, threshed, winnowed and weight of grain and straw were recorded separately from individual plots.

3.1.3 Observations on Pot Culture

3.1.3.1 Crop Growth Characters

3.1.3.1.1. Plant Height

Plant height was measured at 30, 60 and 90 DAS and at harvest from the base of the plant to the tip of the longest leaf or tip of the longest ear head, whichever was longer and recorded in cms.

3.1.3.1.2 Number of Tillers per Hill

Tiller count was taken from each pot on all days upto 30 DAS and thereafter at an interval of ten days and expressed as number of tillers per hill.

3.1.3.2 Yield Attributes and Yield

3.1.3.2.1 Number of Productive Tillers per Hill

At harvest, the number of productive tillers were noted and expressed as number of productive tillers per hill.

3.1.3.2.2 Length of Panicle

Five panicles were selected at random from each pot and average panicle length was measured and expressed in cm.

3.1.3.2.3 Weight of Panicle

The five panicles selected at random from each pot was weighed and mean weight per panicle was determined and expressed in gram.

3.1.3.2.4 Number of Spikelets per Panicle

A central panicle from each pot was taken and number of spikelets per panicle was counted.

3.1.3.2.5 Yield

Harvesting was done and weight of grain and straw from individual pots were recorded separately and expressed in g pot^{-1}.

3.2.4 Observations on Field Crop

Five plants were selected at random from the net plot area of each plot and tagged. The following observations were recorded from these sample plants and the mean values worked out.

3.2.4.1 Crop Growth Characters

3.2.4.1.1 Plant Height

Plant height was recorded at 30, 60 and 90 DAS and at harvest using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest earhead, whichever was longer and the average was recorded in cm.

3.2.4.1.2 Number of Tillers per Hill

Tiller count was taken from the tagged observation hills at 30, 60 and 90 DAS and at harvest and expressed as number of tillers per hill.

3.2.4.1.3 Number of Tillers per Square Metre

Total number of tillers from unit area was recorded at 30, 60 and 90 DAS and at harvest.

3.2.4.1.4 LAI

LAI was computed at 30, 60 and 90 DAS using the method described by Gomez (1972). The maximum width 'w' and length 'l' of all the leaves of the middle most tiller of five sample hills were recorded and LAI was calculated using the relationship.

Leaf area of a single leaf = $l \times w \times k$

k – adjustment factor, taken as 0.67 at 30 and 60 DAS and 0.75 at 90 DAS

leaf area hill^{-1} = leaf area of middle most tiller x total number of tillers

3.2.4.1.5 LAD

LAD at 60 and 90 DAS was calculated using the formula suggested by Watson (1947).

$$LAD = \frac{L_i + (L_i + 1) \times (t_2 - t_1)}{2}$$

L_i – LAI at first stage

$L_i + 1$ – LAI at second stage

$(t_2 - t_1)$ – Time interval between stages

3.2.4.1.6 DMP

From each plot, two sample hills were uprooted at 30, 60 and 90 DAS and at harvest. They were washed, dried first in shade and then in a hot air oven at 80 ± 5°C till a constant weight was attained. Their dry weight was found out and DMP expressed in kg ha^{-1}.

3.2.4.2 Yield Attributes and Yield

3.2.4.2.1 Number of Productive Tillers per Hill

At harvest, the number of productive tillers were noted from observational plants and was expressed as number of productive tillers per hill.

3.2.4.2.2 Number of Productive Tillers per Square Metre

At harvest, the number of productive tillers were noted from observational hills and was expressed as number of productive tillers per square metre.

3.2.4.2.3 Length of Panicle

From the five observational plants, one panicle was selected at random and average panicle length was measured and expressed in cm.

3.2.4.2.4 Weight of Panicle

The panicle selected for recording the length was weighed and mean weight per panicle expressed in g.

3.2.4.2.5 Number of Spikelets per Panicle

The central panicle from each observational plant was threshed separately and number of spikelets per panicle was counted.

3.2.4.2.6 Number of Filled Grains per Panicle

The central panicle from each sample hill was threshed separately and the number of filled and unfilled grains was recorded.

3.2.4.2.7 Sterility Percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility per cent} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.2.4.2.8 Thousand Grain Weight

Thousand grain weight was calculated and adjusted to 13 per cent moisture using the formula suggested by Gomez (1972) and expressed in g.

$$\text{Thousand grain weight} = \frac{100 - M}{86} \quad \frac{w}{f} \quad \times\ 1000$$

where M – moisture content of filled grain

w – weight of unfilled grains in grams

f – number of filled grains

3.2.4.2.9 Grain Yield

The net plot area was harvested individually, threshed, dried, winnowed and dry weight was expressed as kg ha^{-1} after adjusting to 14 per cent moisture.

3.2.4.2.10 Straw Yield

Straw harvested from each net plot was dried under sun to a constant weight and the weight expressed as kg ha^{-1}.

3.2.4.2.11 Harvest Index (HI)

From grain yield and straw yield values, the harvest index was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.2.4.3 Observations on Weeds

Quadrant of size 50 × 50 cm was placed at random at four sites in the net plot area provided for recording weed observations. The following observations were recorded from weeds in this area and average values worked out.

3.2.4.3.1 Weed flora

Major weed species that infested the experimental site during the period of experimentation were identified and grouped into grasses, sedges and broad leaved weeds.

3.2.4.3.2 Weed Dry Matter

Weed samples were pulled out along with roots from the additional one m^2 area provided for observation on weeds. The sample were washed, dried under shade and later oven dried at 80 ± 5°C to constant weight. The dry weight of weeds was recorded and expressed as g m^{-2}.

3.2.4.3.3 Absolute Density (Ad)

Absolute density of grasses, sedges and broad leaved weeds was computed using the equation suggested by Philips (1959).

Ad = total number of plants of a given species per m^2.

3.2.4.3.4 Absolute Frequency (Af)

Absolute frequency of each species was computed using the equation given by Philips (1959).

$$Af = \frac{\text{Number of quadrants in which a given species occurred}}{\text{Total number of quadrants used}} \times 100$$

3.2.4.3.5 Relative Density (Rd)

Relative density of each species was computed using the equation given by Philips (1959).

$$Rd = \frac{\text{Ad of a species}}{\text{Total Ad of all species}} \times 100$$

3.2.4.3.6 Relative Frequency (Rf)

Relative frequency of each species was computed using the equation given by Philips (1959).

$$Rf = \frac{\text{Af of a species}}{\text{Total Af of all species}} \times 100$$

3.2.4.4 Chemical Analysis

Composite soil samples were collected before the start of the experiment and analysed to determine organic carbon, available N, P_2O_5 and K_2O. pH was also determined. After the harvest of the crop, soil samples were taken from each plot separately and analysed for available N, P_2O_5 and K_2O.

3.2.4.4.1 Organic Carbon (%)

Organic carbon content of soil was estimated by Walkley and Black rapid titration method (Jackson, 1973) and expressed in percentage.

3.2.4.4.2 Available Nitrogen (kg ha^{-1})

Available N content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956) and presented as kg ha^{-1}.

3.2.4.4.3 Available Phosphorus (kg ha^{-1})

Available P (kg ha^{-1}) was determined by Dickman and Bray's molybdenum blue method in a Klett Summerson photoelectric colorimeter. The soil was extracted with Bray's reagent No. 1 (0.03 N NH_4F in 0.025 N HCl) (Jackson, 1973).

3.2.4.4.4 Available Potassium (kg ha^{-1})

Available K was determined in the neutral normal ammonium acetate extract and estimated using EEL flame photometer (Jackson, 1973) and expressed as kg ha^{-1}.

3.2.4.5 Plant Analysis

Nutrient Content of Crops and Weeds

The crop and weed samples collected for dry matter studies at 30, 60, 90 DAS and at harvest were dried to a constant weight in an electric hot air oven at 80 ± 5°C, ground into fine powder using blender and used for chemical analysis. After harvest, the grains were analysed separately for N, P and K content.

3.2.4.5.1 Total Nitrogen Content (%)

Total N (%) was estimated by modified microkjeldhl method (Jackson, 1973).

3.2.4.5.2 Total Phosphorus Content (%)

Total P content in percentage was estimated by Vanado molybdo phosphate yellow colour method. The intensity of yellow colour developed was read in a Klett Summerson Photoelectric Colorimeter at 470 nm (Jackson, 1973).

3.2.4.5.3 Total Potassium Content (%)

The same extract used for P estimation was used for the estimation of total K using EEL flame photometer method (Jackson, 1973) and content was expressed as percentage.

3.2.4.6 Uptake of Nutrients

The uptake of N, P and K by crops and weeds at 30, 60 and 90 DAS and at harvest were calculated as the product of content of these nutrients and the respective plant dry weight and expressed as kg ha^{-1}.

3.2.4.7 Protein Content of Rice Grains

The protein content of grains was computed by multiplying the percentage nitrogen content of grains by 6.25 (Simpson *et al.*, 1965).

3.2.4.8 Economics of Cultivation

The economics of cultivation was worked out based on the cost of cultivation and prevailing price of the crop produce.

3.2.4.8.1 Net Income

Net income was computed using the formula

Net income (Rs ha^{-1}) = Gross income – Total expenditure

3.2.4.8.2 Benefit – Cost Ratio (B-C Ratio)

Benefit – cost ratio was computed using the formula,

$$BCR = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.2.5 Statistical Analysis

The data from pot culture study was subjected to statistical analysis applicable to Completely Randomised Design. The data generated from field trial was subjected to analysis of variance (ANOVA) as applied to factorial randomized block design (Panse and Sukhatme, 1985). The significance of the control treatment with the other treatment combinations was also tested. The data that do not satisfy the basic assumption of ANOVA were appropriately transformed and the transformed values were used for analysis of variance. Important correlation coefficients were estimated and tested for their significance (Snedecor and Cochran, 1967).

Results

4. RESULTS

The experiment entitled 'Standardisation of System of Rice Intensification (SRI) Technique' was taken up at College of Agriculture, Vellayani during July 2005 to April 2006. The experiment was programmed as two experiments, a pot culture trial followed by a field study to achieve the objectives envisaged. The experimental data were subjected to statistical analysis and the results obtained are presented here.

4.1 POT CULTURE STUDY

4.1.1 Crop Growth Characters

4.1.1.1 Plant Height

The perusal of the data presented in Table 3 indicated that age of seedling had significant impact on height of plant only on the planting date. The plant height increased significantly with increase in age of seedling recording the maximum by the control treatment which was of 21 day old seedling. Among the SRI treatments, T_5 (16 day old seedling) recorded maximum plant height of 18.12 cm.

At 30, 60 and 90 DAS and at harvest, seedling age failed to show any significant impact on plant height.

4.1.1.2 Tiller Number Per Hill

The results on tiller number per hill furnished in Table 4 revealed that seedling age significantly influenced the tiller number from 50 DAS till harvest.

In treatments T_1 to T_4, first tiller appeared on 20 DAS whereas, for T_5, it was on 24 DAS. Then there was progressive increase in tiller number. At 20 DAS, the seedling age had no significant influence in tiller number. At 24 DAS to 40 DAS, T_6 (control) varied significantly from the treatments though there was no significant variation among SRI

Table 3. Effect of seedling age on plant height (cm)

Treatments	Date of transplanting	30 DAS	60 DAS	90 DAS	Harvest
T_1	10.36	34.98	72.66	101.98	104.46
T_2	12.26	31.78	66.60	99.00	104.10
T_3	13.64	36.28	68.72	94.40	105.44
T_4	17.56	35.34	66.68	99.54	109.58
T_5	18.12	34.18	71.30	95.24	101.02
Control	18.74	32.12	67.90	94.52	102.44
SE	0.590	2.121	3.007	2.672	2.068
CD (0.05)	1.743	NS	NS	NS	NS
Control Vs treatments	S	NS	NS	NS	NS

Table 4. Effect of seedling age on number of tillers per hill

Treatments	20 DAS	24 DAS	27 DAS	29 DAS	30 DAS	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS	90 DAS	100 DAS	Harvest
T_1	0.40	1.40	3.00	3.80	4.60	15.60	23.20	27.20	30.20	30.20	30.20	27.60	27.60
T_2	0.40	1.00	1.60	2.80	3.20	14.40	23.60	30.60	32.80	32.80	32.80	30.40	30.40
T_3	0.60	1.40	2.40	3.40	5.60	19.40	30.20	36.40	39.20	39.20	39.20	37.20	37.20
T_4	0.60	1.20	2.40	3.40	4.60	19.00	28.60	33.60	36.20	36.20	36.20	33.80	33.80
T_5	0.00	0.40	1.40	3.00	4.00	13.40	22.00	30.30	32.80	32.80	32.80	30.00	30.00
Control	0.00	0.00	0.00	0.60	1.60	11.40	17.80	22.80	24.20	24.20	24.20	21.20	21.20
SE	0.219	0.322	0.456	0.583	0.681	1.94	1.581	1.063	1.039	1.039	1.039	1.095	1.095
CD (0.05)	NS	NS	NS	NS	NS	NS	4.665	3.139	3.066	3.066	3.066	3.232	3.232
Control Vs treatments	NS	S	S	S	S	S	S	S	S	S	S	S	S

treatments. At all the stages, the control recorded the lowest number of tillers and was significantly inferior to all other SRI treatments.

From 50 DAS to 90 DAS, T_3 recorded the highest number of tillers and was on par with T_4 (14 day old seedling). At 100 DAS and at harvest, treatment T_3 was significantly superior to all other treatments.

4.1.2 Yield Attributing Characters

4.1.2.1 Number of Productive Tillers

Data presented in Table 5 indicated that, the number of productive tillers were the highest for 12 day old seedling (T_3), recording a tiller number of 37.2 and was significantly superior to other treatments. Control was significantly inferior and registered a productive tiller number of 21.2.

4.1.2.2 Panicle Length

Among the treatments, the seedling age had no significant impact on panicle length. T_6 (control) recorded a panicle length of 23.6 and was significantly inferior to other treatments. (Table 5)

4.1.2.3 Panicle Weight

Data furnished in Table 5 indicated no significant variation between control and various treatments on panicle weight.

4.1.2.4 Number of Spikelets Per Panicle

The various treatments and control failed to show any significant variation in number of spikelets per panicle (Table 6)

4.1.2.5 Number of Filled Grains Per Panicle

There was no significant variation between control and treatments as far as the number of filled grains per panicle was concerned (Table 6)

4.1.2.6 Grain Yield

The results of grain yield furnished in Table 7 indicated that, T_3 recorded the highest grain yield of 64.29 g pot^{-1} and was on par with T_4 and T_5. Among the treatments, T_1 recorded the lowest yield of 53.89 g pot^{-1}.

Table 5. Effect of seedling age on the number of productive tillers per hill, panicle length (cm) and panicle weight (g)

Treatments	Number of productive tillers per hill	Panicle length (cm)	Panicle weight (g)
T_1	27.60	24.66	2.01
T_2	30.40	24.68	2.02
T_3	37.20	25.08	1.99
T_4	33.80	24.94	2.04
T_5	30.00	24.94	2.02
Control	21.20	23.60	2.03
SE	1.095	0.337	0.521
CD (0.05)	3.232	NS	NS
Control Vs treatments	S	S	NS

Table 6. Effect of seedling age on number of spikelets per panicle and number of filled grains per panicle

Treatments	Number of spikelets per panicle	Number of filled grains per panicle
T_1	104.00	91.62
T_2	101.61	91.86
T_3	105.10	93.82
T_4	104.68	93.85
T_5	102.62	91.25
Control	103.21	91.21
SE	3.416	3.273
CD (0.05)	NS	NS
Control Vs treatments	NS	NS

Table 7. Effect of seedling age on grain yield (g pot^{-1}) and straw yield (g pot^{-1})

Treatments	Grain yield (g pot^{-1})	Straw yield (g pot^{-1})
T_1	53.89	25.79
T_2	56.67	25.94
T_3	64.29	30.87
T_4	61.52	24.51
T_5	61.27	26.83
Control	43.39	23.29
SE	2.119	1.459
CD (0.05)	6.186	NS
Control Vs treatments	S	S

The control pot recorded a yield of 43.39 g pot^{-1} and was significantly inferior to all treatments.

4.1.2.7 Straw Yield

From the data on straw yield furnished in Table 7, it was observed that the various treatments failed to have a significant influence on straw yield. Control was significantly inferior and registered a straw yield of 23.29 g pot^{-1}.

4.2 FIELD EXPERIMENT

4.2.1 Crop Growth Characters

Observations on crop growth characters like plant height, tiller number per hill, leaf area index, leaf area duration and crop dry matter production were recorded from five randomly selected hills from the net plot area.

4.2.1.1 Plant Height

The data summarized in Table 8 showed that spacing significantly influenced plant height only at 90 DAS when S_1 was found superior. At all stages of observations, the closer spacing of 20 x 20 cm registered comparatively higher plant height than other spacings tried though variation was not significant.

Weed management practices and its interaction with spacing had no significant influence on plant height at the different growth stages.

Comparing treatments with control, all treatment combinations had significant influence on plant height during the early stages of growth, *i.e.*, at 30 and 60 DAS. During these two stages, the control plot recorded the maximum plant height of 30.96 and 66.92 cms respectively and was significantly superior to other treatment combinations. But at 90 DAS and at harvest, the effect was found to be non-significant and control plot recorded a height which was on par with other treatment combinations.

Table 8. Effect of spacing, weed management practices and their interaction on plant height (cm)

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	26.00	59.72	101.51	108.28
S_2	26.07	57.98	99.80	106.30
S_3	24.29	55.79	95.89	105.36
Weed management practices				
W_1	25.39	55.61	98.16	106.52
W_2	25.46	59.46	100.69	107.14
W_3	25.51	58.43	98.35	106.28
Interaction effect treatment combination				
s_1w_1	27.07	60.97	101.43	109.63
s_1w_2	25.35	58.59	103.05	109.29
s_1w_3	25.59	59.61	100.05	105.93
s_2w_1	26.07	53.84	98.99	106.25
s_2w_2	26.63	61.49	99.83	104.41
s_2w_3	25.53	58.61	100.59	108.24
s_3w_1	23.05	52.01	94.05	103.67
s_3w_2	24.41	58.29	99.21	107.73
s_3w_3	25.41	57.08	94.41	104.67
Control	30.96	66.92	96.74	104.01
SE : S/W	0.767	1.210	1.182	1.154
: SW	1.330	2.096	2.047	1.999
CD : S	NS	NS	3.545	NS
: W	NS	NS	NS	NS
: SW	NS	NS	NS	NS
Control Vs treatments	S	S	NS	NS

4.2.1.2 Number of Tillers Per Hill

Number of tillers hill^{-1} was recorded at 30, 60 and 90 DAS and at harvest and the results are presented in Table 9. Spacing, weed management practices and their interaction had no significant influence on number of tillers hill^{-1} at any growth stages.

Compared to control, the different treatments showed significant variation. At 30 DAS, though the control plot recorded highest number of tillers (5.73) which was significantly superior to all other treatment combinations, a reverse trend was observed during other stages. At 60 and 90 DAS and at harvest, the control plot recorded the lowest number of tillers and was significantly inferior to other treatment combinations.

4.2.1.3 Number of Tillers Per Square Metre

The data on number of tillers m^{-2} are presented in Table 10. The data revealed that spacing had significant impact on number of tillers m^{-2}. At all stages of observations, the closer spacing of 20 x 20 cm (S_1) recorded significantly higher value than other spacings tried. The wider spacing of 30 x 30 cm (S_3) registered the lowest value at all stages.

The various weed management practices had no significant impact on tiller number. There was no significant interaction between spacing and weed management practices as far as this parameter was concerned.

The control plot with closest spacing, 20 x 10 cm and two hand weedings recorded the highest value at all stages and was significantly superior to all other treatment combinations.

4.2.1.4 Leaf Area Index

Perusal of the data presented in Table 11 showed that LAI varied significantly due to spacings. At 30, 60 and 90 DAS, LAI was highest (0.13, 4.35 and 4.06 respectively) for closer spacing of 20 x 20 cm (S_1) which was significantly superior to other spacings tried. LAI was the lowest for the widest spacing of 30 x 30 cm (S_3), the values being 0.05, 1.87 and 2.26 respectively at 30, 60 and 90 DAS.

Table 9. Effect of spacing, weed management practices and their interaction on number of tillers hill^{-1}

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	3.64	29.71	31.80	29.40
S_2	3.31	29.47	31.60	28.73
S_3	3.47	29.47	31.22	28.64
Weed management practices				
W_1	3.49	28.58	30.73	28.42
W_2	3.49	30.89	32.80	30.22
W_3	3.44	29.18	31.09	28.13
Interaction effect treatment combination				
s_1w_1	3.67	28.33	30.67	28.40
s_1w_2	3.47	32.07	33.93	31.47
s_1w_3	3.80	28.73	30.80	28.33
s_2w_1	3.40	27.20	30.00	27.13
s_2w_2	3.27	30.07	32.20	29.67
s_2w_3	3.27	31.13	32.60	29.40
s_3w_1	3.40	30.20	31.53	29.73
s_3w_2	3.73	30.53	32.27	29.53
s_3w_3	3.27	27.67	29.87	26.67
Control	5.73	17.73	19.60	18.53
SE : S/W	0.158	1.813	1.466	1.407
: SW	0.275	3.141	2.539	2.438
CD : S	NS	NS	NS	NS
:W	NS	NS	NS	NS
: SW	NS	NS	NS	NS
Control Vs treatments	S	S	S	S

Table 10. Effect of spacing, weed management practices and their interaction on number of tillers m^{-2}

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	91.11	742.78	795.00	735.00
S_2	52.98	471.47	505.60	459.73
S_3	38.13	324.13	343.44	315.09
Weed management practices				
W_1	61.16	491.91	531.18	490.40
W_2	60.00	539.53	572.82	528.73
W_3	61.07	506.93	540.04	490.69
Interaction effect treatment combination				
s_1w_1	91.67	708.33	766.67	710.00
s_1w_2	86.67	801.67	848.33	786.67
s_1w_3	95.00	718.33	770.00	708.33
s_2w_1	54.40	435.20	480.00	434.13
s_2w_2	52.27	481.07	515.20	474.67
s_2w_3	52.27	498.13	521.60	470.40
s_3w_1	37.40	332.20	346.87	327.07
s_3w_2	41.07	335.87	354.93	324.87
s_3w_3	35.93	304.33	328.53	293.33
Control	286.67	886.67	980.00	926.67
SE : S/W : SW	5.269 9.126	32.464 56.230	26.179 45.343	24.839 43.022
CD : S :W : SW	15.798 NS NS	97.333 NS NS	78.488 NS NS	74.471 NS NS
Control Vs treatments	S	S	S	S

Table 11. Effect of spacing, weed management practices and their interaction on leaf area index

Treatments	30 DAS	60 DAS	90 DAS
Spacing			
S_1	0.13	4.35	4.06
S_2	0.08	2.73	3.06
S_3	0.05	1.87	2.26
Weed management practices			
W_1	0.08	2.91	3.24
W_2	0.09	3.04	2.92
W_3	0.09	2.99	3.23
Interaction Effect Treatment combination			
s_1w_1	0.14	4.25	4.26
s_1w_2	0.12	4.12	3.45
s_1w_3	0.14	4.69	4.46
s_2w_1	0.07	2.69	3.17
s_2w_2	0.08	2.97	2.97
s_2w_3	0.08	2.52	3.04
s_3w_1	0.04	1.79	2.28
s_3w_2	0.06	2.04	2.33
s_3w_3	0.05	1.78	2.17
Control	0.56	5.04	4.81
SE : S/W : SW	8.205 14.212	1.865 3.23	0.190 0.329
CD : S :W : SW	0.032 NS NS	0.898 NS NS	0.571 NS NS
Control Vs treatments	S	S	NS

Weed management practices and S x W interaction did not have any significant influence on LAI. Significant effect was observed on LAI at 30 and 60 DAS between control and the various treatment combinations. At 30 and 60 DAS, the control plot recorded the highest LAI of 0.56 and 6.04 respectively which was significantly superior to other treatment combinations. At 90 DAS, LAI of control plot was on par with other treatment combination.

4.2.1.5 Leaf Area Duration

The data on LAD presented in Table 12 revealed that spacing significantly influenced LAD, both at 60 and 90 DAS. At both the stages, the closer spacing of 20 x 20 cm recorded the highest value of LAD and the widest spacing of 30 x 30 cm, the least value (28.78 and 61.90 at 60 and 90 DAS respectively)

Weed management practices did not exert any significant influence on LAD. The interaction effect of spacing and weed management practices also failed to have a significant impact on this parameter.

Compared to other treatment combinations, control plot recorded a significantly superior value of LAD at both the stages, values being 99.05 and 140.85 at 60 and 90 DAS respectively.

4.2.1.6 Dry Matter Production

Perusal of the data presented in Table 13 indicated that spacing had significant influence on dry matter production of rice at 30 and 90 DAS and at harvest. At all the stages, 30 x 30 cm spacing recorded the lowest dry matter production. At harvest the closest spacing of 20 x 20 cm registered the dry matter production of 7900.35 kg ha^{-1} which was on par with 25 x 25 cm spacing.

Weed management practices influenced dry matter production only at 60 DAS, when rotary weeding was observed to be superior to other weed management aspects.

Table 12. Effect of spacing, weed management practices and their interaction on leaf area duration

Treatments	60 DAS	90 DAS
Spacing		
S_1	67.30	126.20
S_2	42.03	86.80
S_3	28.78	61.90
Weed management practices		
W_1	44.87	92.15
W_2	46.92	89.38
W_3	46.33	93.37
Interaction Effect Treatment combination		
s_1w_1	65.81	127.70
s_1w_2	63.55	113.55
s_1w_3	72.55	137.35
s_2w_1	41.35	87.80
s_2w_2	45.70	89.10
s_2w_3	39.05	83.50
s_3w_1	27.45	60.95
s_3w_2	31.50	65.50
s_3w_3	27.40	59.25
Control	99.05	140.85
SE : S/W : SW	4.506 7.805	4.906 8.498
CD : S :W : SW	13.512 NS NS	14.711 NS NS
Control Vs treatments	S	S

Table 13. Effect of spacing, weed management practices and their interaction on dry matter production of crop (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	47.64	602.53	6541.33	7900.35
S_2	41.29	612.80	3345.60	7198.55
S_3	32.78	541.98	2207.41	5902.99
Weed management practices				
W_1	39.91	411.60	4446.86	7081.39
W_2	45.54	597.33	3963.24	7390.94
W_3	36.26	748.37	3684.24	6529.56
Interaction effect treatment combination				
s_1w_1	44.58	354.25	6617.50	8087.39
s_1w_2	54.58	687.92	6984.09	8132.36
s_1w_3	43.75	765.42	6022.39	7481.30
s_2w_1	42.93	353.33	4199.73	7756.78
s_2w_2	44.80	690.93	3198.40	7429.62
s_2w_3	36.13	794.13	2638.67	6409.25
s_3w_1	32.22	527.22	2523.33	5399.99
s_3w_2	37.22	413.15	1707.22	6610.84
s_3w_3	28.89	685.55	2391.67	5698.14
Control	343.333	3507.50	5054.35	6959.07
SE : S/W : SW	3.272 5.668	46.614 80.738	203.816 353.019	287.717 498.341
CD : S :W : SW	9.812 NS NS	NS 139.766 NS	611.113 NS NS	862.680 NS NS
Control Vs treatments	S	S	S	NS

The control plot recorded a significantly higher dry matter production. at 30 and 60 DAS and was superior to other treatment combinations. At 90 DAS, treatment combinations involving lower spacing of 20 x 20 cm with various weed management practices were found superior to control plot. The control and treatment combinations had no variation at harvest stage.

4.2.2 Yield Attributes and Yield

4.2.2.1 Number of Productive Tillers Per Hill

The data indicated in Table 14 revealed that the various spacings, weed management practices and their interaction failed to have a significant impact on this parameter. However, compared to control all the treatment combinations were found superior. Control registered the lowest value of 18.13

4.2.2.2 Number of Productive Tillers Per Square Metre

The data pertaining to number of productive tillers m^{-2} is furnished in Table 14.

The results revealed that the closer spacing, 20 x 20 cm (S_1) recorded a higher value of 697.78 which was significantly superior to other two spacings tried. Weed management practices and its interaction with spacing did not exert any significant impact on this yield parameter.

Control plot, where a closer spacing of 20 x 10 cm was followed recorded the highest number of productive tillers m^{-2} of 906.67 and was significantly superior to other treatment combinations.

4.2.2.3 Length of Panicle

Data presented in Table 15 showed that there was no variation due to spacing, weed management and their interaction on this yield attribute.

All the treatment combinations were significantly superior to control plot as far as the panicle length was concerned.

Table 14. Effect of spacing, weed management practices and their interaction on number of productive tillers

Treatments	Number per hill	Number m^{-2}
Spacing		
S_1	27.91	697.78
S_2	26.40	422.40
S_3	25.40	279.40
Weed management practices		
W_1	26.00	452.64
W_2	27.82	489.13
W_3	25.89	447.80
Interaction Effect Treatment combination		
s_1w_1	26.73	668.33
s_1w_2	29.40	735.00
s_1w_3	27.60	690.00
s_2w_1	25.13	402.13
s_2w_2	27.53	440.53
s_2w_3	26.53	424.53
s_3w_1	26.13	287.47
s_3w_2	26.53	291.87
s_3w_3	23.53	258.87
Control	18.13	906.67
SE : S/W : SW	1.260 2.183	22.883 39.635
CD : S :W : SW	NS NS NS	68.607 NS NS
Control Vs treatments	S	S

Table 15. Effect of spacing, weed management practices and their interaction on length of panicle (cm) and weight of panicle (g)

Treatments	Length of panicle (cm)	Weight of panicle (g)
Spacing		
S_1	25.44	2.58
S_2	26.57	3.08
S_3	26.20	2.93
Weed management practices		
W_1	26.22	2.81
W_2	25.97	2.87
W_3	26.02	2.91
Interaction Effect Treatment combination		
s_1w_1	25.40	2.34
s_1w_2	25.82	2.68
s_1w_3	25.09	2.74
s_2w_1	27.00	3.19
s_2w_2	26.65	3.04
s_2w_3	26.06	3.01
s_3w_1	26.25	2.91
s_3w_2	25.44	2.91
s_3w_3	26.91	2.98
Control	23.57	2.02
SE : S/W : SW	0.375 0.650	0.117 0.203
CD : S :W : SW	NS NS NS	0.351 NS NS
Control Vs treatments	S	S

4.2.2.4 Weight of Panicle

The data indicated in Table 15 revealed that medium spacing, S_2 recorded the maximum panicle weight of 3.08 g, which was on par with widest spacing, S_3. The weed management practices and its interaction with spacing had no significant influence on this parameter.

Compared to treatment combinations, control plot recorded the lowest panicle weight of 2.02 g which was significantly inferior to other treatment combinations.

4.2.2.5 Number of Spikelets Per Panicle

The data on number of spikelets per panicle presented in Table 16 revealed that spacing significantly influenced this attribute. The spacing of 25 x 25 cm (S_2) recorded the highest number of 145.09 and was on par with S_3. The closer spacing of 20 x 20 cm (S_1) recorded the lowest number of 125.36

The weed management practices and its interaction with spacing failed to have any significant effect on this yield attribute. The control plot recorded a value of 104.53 which was significantly inferior to other treatment combinations.

4.2.2.6 Number of Filled grains Per Panicle

The results are presented in Table 16. The various spacings, weed management practices and their interaction had no significant influence on the number of filled grains.

Comparing treatment combination with control it was observed that the number of filled grains per panicle was significantly superior in all treatment combinations and the lowest value of 93.00 was registered by the control plot.

4.2.2.7 Sterility Percentage

Of the different spacings tried, S_3 recorded the maximum sterility percentage and was on par with S_2. The percentage of sterility was the

Table 16. Effect of spacing, weed management practices and their interaction on number of spikelets per panicle, number of filled grains per panicle, sterility percentage and thousand grain weight (g)

Treatments	Number of spikelets per panicle	Number of filled grains per panicle	Sterility percentage	Thousand grain weight (g)
Spacing				
S_1	125.36	116.91	6.69	25.74
S_2	145.09	133.13	8.29	26.68
S_3	139.62	128.02	8.42	24.56
Weed management practices				
W_1	131.71	121.96	7.30	24.99
W_2	137.29	126.31	8.05	25.52
W_3	141.07	129.80	8.05	26.47
Interaction effect treatment combination				
s_1w_1	110.87	104.40	5.87	26.07
s_1w_2	128.20	119.53	6.79	24.87
s_1w_3	137.00	126.80	7.41	26.30
s_2w_1	144.93	133.27	8.03	25.47
s_2w_2	145.20	133.60	7.99	26.37
s_2w_3	145.13	132.53	8.87	28.20
s_3w_1	139.33	128.20	8.01	23.43
s_3w_2	138.47	125.80	9.36	25.33
s_3w_3	141.07	130.07	7.88	24.90
Control	104.53	93.00	11.17	26.67
SE : S/W : SW	5.111 8.852	5.089 8.815	0.481 0.833	0.732 1.268
CD : S :W : SW	15.324 NS NS	NS NS NS	1.429 NS NS	NS NS NS
Control Vs treatments	S	S	S	NS

lowest in S_1. The various weed management practices and their interaction with spacing did not have any significant impact on sterility percentage (Table 16).

Compared to treatment combinations, control plot had a sterility percentage of 11.17 which was significantly higher than other treatment combinations.

4.2.2.8 Thousand Grain Weight

Data presented in Table 16 revealed that thousand grain weight was not influenced by spacing, weed management practices and their interaction. The control plot was also observed to be on par with the treatment combinations.

4.2.2.9 Grain Yield

The effect of spacing on grain yield (Table 17) was insignificant. The different weed management practices tried had a significant impact on grain yield. Among the weed management practices, use of butachlor followed by hand weeding (W_2), recorded the highest grain yield of 3335.61 kg ha^{-1} and this was on par with W_1 (hand weeding twice). The lowest yield of 2986.35 kg ha^{-1} was registered in rotary weeded plots. The spacing-weed management interaction effect had no influence on grain yield. However, control plot recorded a significantly lower yield of 2660.73 kg ha^{-1} than other treatment combinations.

4.2.2.10 Straw Yield

It could be observed from data summarized in Table 17 that spacing had significant influence on straw yield. The 20 x 20 cm spacing (S_1) recorded the highest straw yield of 4670.31 kg ha^{-1} which was significantly superior to other two spacings. The lowest yield was recorded with the widest spacing of 30 x 30 cm. The effect of weed management practices and its interaction with spacing was found insignificant.

Table 17. Effect of spacing, weed management practices and their interaction on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}) and harvest index

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
Spacing			
S_1	3218.93	4670.31	0.41
S_2	3214.80	3983.75	0.46
S_3	3039.33	2863.67	0.52
Weed management practices			
W_1	3151.10	3930.29	0.47
W_2	3335.61	4055.33	0.46
W_3	2986.35	3532.09	0.46
Interaction effect treatment combination			
s_1w_1	3142.21	4945.18	0.39
s_1w_2	3375.88	4756.48	0.42
s_1w_3	3138.71	4309.26	0.42
s_2w_1	3231.47	4525.31	0.43
s_2w_2	3342.58	4087.04	0.45
s_2w_3	3070.36	3338.89	0.49
s_3w_1	3079.63	2320.37	0.58
s_3w_2	3288.36	3322.48	0.50
s_3w_3	2749.99	2948.15	0.48
Control	2660.73	4298.33	0.39
SE : S/W : SW	89.151 154.414	219.482 380.153	0.014 0.025
CD : S :W : SW	NS 267.287 NS	658.085 NS NS	0.043 NS 0.074
Control Vs treatments	S	NS	NS

No significant variation was observed between control plot and other treatment combinations as far as straw yield was concerned.

4.2.2.11 Harvest Index

The results presented in Table 17 revealed that the different spacings tried had significant effect on harvest index. The wider spacing (S_3) recorded significantly higher value of 0.52, while the closer spacing (S_1) recorded the lowest value (0.41)

The different weed management practices had no influence on harvest index of crop. Among the interactions, s_3w_1 recorded a significantly higher value of 0.58 followed by s_3w_2 which was on par with s_3w_3.

Comparing the treatment combinations with control, no significant variation was observed as far as harvest index was concerned.

4.3 PROTEIN CONTENT OF GRAINS

The results presented in Table 18 indicated that the various treatments and their interactions failed to have a significant influence on protein content of grains.

There was no significant variation between control plot and treatment combinations as far as protein content of grains were concerned.

4.4 OBSERVATION ON WEEDS

Observations on weeds were gathered from the area set apart for that purpose. The data were statistically analysed after appropriate transformation.

4.4.1 Major Weed Flora in Experimental Field

The different weed species observed in the experimental field were identified and categorized into grasses, sedges and broad leaved weeds. The detailed list of all weed species observed were summarized in Table 19. *Isachne miliacea* Roth ex Roem. et Schult and *Echinochloa colona* (L.) Link were the most important grassy weeds present. Among sedges,

Table 18. Effect of spacing, weed management practices and their interaction on protein content of grains (%)

Treatments	Protein content (%)
Spacing	
S_1	5.75
S_2	5.73
S_3	5.64
Weed management practices	
W_1	5.75
W_2	5.66
W_3	5.71
Interaction effect treatment combination	
s_1w_1	5.83
s_1w_2	5.71
s_1w_3	5.71
s_2w_1	5.81
s_2w_2	5.68
s_2w_3	5.71
s_3w_1	5.60
s_3w_2	5.60
s_3w_3	5.73
Control	5.73
SE : S/W : SW	0.059 0.103
CD : S : W : SW	NS NS NS
Control Vs treatments	NS

Table 19. Major weed flora observed in experimental field

Scientific name	Common name	Family
Grasses		
Isachne miliacea Roth ex Roem. et Schult.	Blood grass (Changalipullu*)	Poaceae
Echinochloa colona (L.) Link	Jungle rice (Kavada*)	Poaceae
Sedges		
Cyperus iria L.	Yellow nut sedge (Manjakora*)	Cyperaceae
Cyperus difformis L.	Umbrella sedge (Thalekkettan*)	Cyperaceae
Fimbristylis miliacea (L.) Vahl.	Globe fingerush (Mung*)	Cyperaceae
Broadleaved weeds		
Ludwigia parviflora Roxb.	Water primrose (Neergrambu*)	Onagraceae
Monochoria vaginalis (Burm. F.) Kunth.	Monochoria (Karimkoovalam*)	Pontenderiaceae
Marsilea quadrifolia Linn	Airy Pepper wort (Nalila kodiyan*)	Marsileaceae

* Vernacular name

Cyperus iria L., *Cyperus difformis* L. and *Fimbristylis miliacea* (L.) Vahl were the predominant ones. *Ludwigia parviflora* Roxb., *Monochoria vaginalis* (Burm. F.) Kunth. and *Marsilea quadrifoliata* were the predominant broad leaved weeds.

4.4.2 Absolute Density

4.4.2.1 Total Absolute Weed Density

Data on absolute density of all types of weeds are presented in Table 20.

The various spacings and weed management practices and their interactions did not have any significant impact on total absolute weed density.

The control plot recorded a significantly lower value of absolute density compared to treatment combinations at 30 and 90 DAS. No significant variation in total absolute density between control plot and treatment plot was noticed at 60 DAS and at harvest.

4.4.2.2 Absolute Density of Grasses

The same trend as in total absolute density of weeds could be noticed in absolute density of grasses (Table 21), with spacing, weed management practices and their interaction failing to have any significant impact on this parameter. At 30 and 90 DAS, the absolute density of grasses in control plot was the lowest compared to other treatment combinations. At 60 DAS and at harvest, control plot and various treatment combinations did not show any significant variation.

4.4.2.3 Absolute Density of Sedges

As depicted in Table 22, absolute density of sedges was not significantly influenced by spacing, weed management practices and their interaction at any stage of growth.

However, in the early stages of observations, at 30 and 60 DAS, the control plot registered significant reduction in the absolute density of

Table 20. Effect of spacing, weed management practices and their interaction on total absolute weed density (number m^{-2})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	33.57 (5.88)	114.70 (10.71)	221.71 (14.89)	359.86 (18.97)
S_2	38.31 (6.27)	80.46 (8.97)	230.43 (15.18)	390.85 (19.77)
S_3	51.27 (7.23)	91.97 (9.59)	337.09 (18.36)	499.52 (22.35)
Weed management practices				
W_1	36.45 (6.12)	122.99 (11.09)	355.32 (18.85)	455.39 (21.34)
W_2	51.13 (7.22)	72.93 (8.54)	200.51 (14.16)	357.21 (18.90)
W_3	35.48 (6.04)	92.93 (9.64)	237.78 (15.42)	434.31 (20.84)
Interaction effect treatment combination				
s_1w_1	37.94 (6.24)	185.23 (13.61)	322.20 (17.95)	482.68 (21.97)
s_1w_2	34.40 (5.95)	72.25 (8.50)	141.37 (11.89)	205.92 (14.35)
s_1w_3	28.59 (5.44)	100.40 (10.02)	220.23 (14.84)	423.95 (20.59)
s_2w_1	14.13 (3.89)	105.88 (10.29)	296.18 (17.21)	340.03 (18.44)
s_2w_2	73.82 (8.65)	56.55 (7.52)	166.67 (12.91)	368.26 (19.19)
s_2w_3	38.44 (6.28)	82.63 (9.09)	237.47 (15.41)	469.16 (21.66)
s_3w_1	66.73 (8.24)	87.79 (9.37)	457.10 (21.38)	557.43 (23.61)
s_3w_2	48.56 (7.04)	92.35 (9.61)	312.58 (17.68)	536.39 (23.16)
s_3w_3	39.83 (6.39)	96.24 (9.81)	256.32 (16.01)	410.87 (20.27)
Control	0.77 (1.33)	40.19 (6.34)	64.16 (8.01)	390.06 (19.75)
SE : S/W : SW	0.846 1.466	1.043 1.806	1.320 2.287	1.369 2.372
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	NS	S	NS

transformed values are given in parenthesis

Table 21. Effect of spacing, weed management practices and their interaction on absolute density of grasses (number m^{-2})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	20.81 (4.67)	97.22 (9.86)	214.33 (14.64)	357.97 (18.92)
S_2	22.14 (4.81)	62.73 (7.92)	214.62 (14.65)	384.55 (19.61)
S_3	29.69 (5.54)	76.21 (8.73)	315.77 (17.77)	493.28 (22.21)
Weed management practices				
W_1	20.81 (4.67)	99.40 (9.97)	339.29 (18.42)	451.14 (21.24)
W_2	31.60 (5.71)	57.61 (7.59)	186.87 (13.67)	353.82 (18.81)
W_3	20.53 (4.64)	80.10 (8.95)	223.80 (14.96)	428.08 (20.69)
Interaction effect treatment combination				
s_1w_1	24.20 (5.02)	151.78 (12.32)	308.70 (17.57)	481.36 (21.94)
s_1w_2	22.43 (4.84)	57.91 (7.61)	137.12 (11.71)	203.06 (14.25)
s_1w_3	16.31 (4.16)	93.12 (9.65)	213.74 (14.62)	423.12 (20.57)
s_2w_1	8.67 (3.11)	88.55 (9.41)	282.91 (16.82)	336.36 (18.34)
s_2w_2	39.45 (6.36)	38.94 (6.24)	147.38 (12.14)	363.66 (19.07)
s_2w_3	23.60 (4.96)	65.93 (8.12)	224.40 (14.98)	459.67 (21.44)
s_3w_1	33.57 (5.88)	66.91 (8.18)	435.14 (20.86)	549.43 (23.44)
s_3w_2	34.28 (5.94)	79.74 (8.93)	294.81 (17.17)	534.07 (23.11)
s_3w_3	22.14 (4.81)	82.26 (9.07)	233.78 (15.29)	403.61 (20.09)
Control	0.54 (1.24)	37.58 (6.13)	61.78 (7.86)	387.69 (19.69)
SE : S/W : SW	0.645 1.117	1.024 1.774	1.362 2.359	1.409 2.441
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	NS	S	NS

transformed values are given in parenthesis

Table 22. Effect of spacing, weed management practices and their interaction on absolute density of sedges (number m^{-2})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	9.82 (3.29)	11.89 (3.59)	4.71 (2.39)	0.29 (1.14)
S_2	10.49 (3.39)	13.29 (3.78)	5.40 (2.53)	0.74 (1.32)
S_3	16.31 (4.16)	10.63 (3.41)	10.63 (3.41)	0.99 (1.41)
Weed management practices				
W_1	12.18 (3.63)	17.32 (4.28)	9.30 (3.21)	0.59 (1.26)
W_2	15.32 (4.04)	10.36 (3.37)	4.71 (2.39)	0.72 (1.31)
W_3	9.05 (3.17)	8.86 (3.14)	6.45 (2.73)	0.69 (1.30)
Interaction effect treatment combination				
s_1w_1	10.69 (3.42)	27.41 (5.33)	8.61 (3.10)	0.29 (1.14)
s_1w_2	9.82 (3.29)	9.82 (3.29)	2.20 (1.79)	0.00 (1.00)
s_1w_3	8.99 (3.16)	3.62 (2.15)	4.15 (2.27)	0.64 (1.28)
s_2w_1	3.84 (2.20)	12.99 (3.74)	5.97 (2.64)	0.54 (1.24)
s_2w_2	27.62 (5.35)	12.76 (3.71)	6.56 (2.75)	1.16 (1.47)
s_2w_3	5.81 (2.61)	14.29 (3.91)	3.88 (2.21)	0.54 (1.24)
s_3w_1	26.67 (5.26)	13.14 (3.76)	14.05 (3.88)	0.90 (1.38)
s_3w_2	11.11 (3.48)	8.55 (3.09)	5.97 (2.64)	1.16 (1.47)
s_3w_3	12.91 (3.73)	10.36 (3.37)	12.76 (3.71)	0.90 (1.38)
Control	0.00 (1.00)	0.90 (1.38)	0.29 (1.14)	0.29 (1.14)
SE : S/W : SW	0.605 1.049	0.449 0.777	0.475 0.824	0.116 0.201
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	NS	NS

transformed values are given in parenthesis

sedges in comparison to other combinations. But at the later stages the variation was found insignificant.

4.4.2.4 Absolute Density of Broad Leaved Weeds

Both the treatments and their interactions had no influence on absolute density of broad leaved weeds (Table 23). There was also no significant variation between control and various treatment combinations.

4.4.3 Relative Density

4.4.3.1 Relative Density of Grasses

The treatments and their interactions failed to have any significant influence on the relative density of grasses (Table 24).

The control plot showed a significant variation from the treatment combinations during the early stages (30 and 60 DAS). At 30 DAS, control plot registered the lowest relative density of 10.63 and at 60 DAS; an opposite trend was noticed with control plot recording significantly higher relative density of 94.22 than the treatments. At 90 DAS and at harvest, treatment combinations and control did not differ significantly.

4.4.3.2 Relative Density of Sedges

The results depicted in Table 25 revealed that the relative density of sedges did not show any significant variations due to treatments and their interactions.

However, significant variation was observed between treatment and control during the early stages (30 and 60 DAS). Control plot recorded the lowest relative density values. At 90 DAS and at harvest, the variation between control plot and various treatment combinations became non-significant.

4.4.3.3 Relative Density of Broad Leaved Weeds

Neither the treatments nor their interaction showed any significant influence on relative density of broad leaved weeds (Table 26). Variation between control and treatment combinations remained insignificant.

Table 23. Effect of spacing, weed management practices and their interaction on absolute density of broad leaved weeds (number m^{-2})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	2.72 (1.93)	3.33 (2.08)	2.03 (1.74)	0.85 (1.36)
S_2	1.99 (1.73)	2.49 (1.87)	6.62 (2.76)	3.33 (2.08)
S_3	3.24 (2.06)	3.41 (2.10)	5.50 (2.55)	3.58 (2.14)
Weed management practices				
W_1	2.76 (1.94)	4.11 (2.26)	4.62 (2.37)	2.88 (1.97)
W_2	2.57 (1.89)	3.33 (2.08)	5.15 (2.48)	1.79 (1.67)
W_3	2.53 (1.88)	1.96 (1.72)	3.84 (2.20)	2.76 (1.94)
Interaction effect treatment combination				
s_1w_1	2.65 (1.91)	4.81 (2.41)	3.97 (2.23)	0.90 (1.38)
s_1w_2	2.46 (1.86)	3.00 (2.00)	1.31 (1.52)	1.40 (1.55)
s_1w_3	3.00 (2.00)	2.31 (1.82)	1.16 (1.47)	0.29 (1.14)
s_2w_1	0.64 (1.28)	1.40 (1.55)	6.08 (2.66)	2.31 (1.82)
s_2w_2	4.95 (2.44)	4.02 (2.24)	8.67 (3.11)	3.33 (2.08)
s_2w_3	1.19 (1.48)	2.28 (1.81)	5.25 (2.50)	4.43 (2.33)
s_3w_1	5.92 (2.63)	6.84 (2.80)	3.84 (2.20)	6.24 (2.69)
s_3w_2	0.90 (1.38)	2.96 (1.99)	6.89 (2.81)	0.90 (1.38)
s_3w_3	3.67 (2.16)	1.31 (1.52)	5.92 (2.63)	4.43 (2.33)
Control	0.29 (1.14)	1.62 (1.62)	1.66 (1.63)	1.40 (1.55)
SE : S/W : SW	0.269 0.466	0.270 0.468	0.392 0.680	0.309 0.535
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	NS	NS	NS	NS

transformed values are given in parenthesis

Table 24. Effect of spacing, weed management practices and their interaction on relative density of grasses

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	69.73 (8.41)	85.48	96.39	99.16
S_2	67.56 (8.28)	77.65	92.42	98.09
S_3	59.68 (7.79)	81.23	93.02	98.71
Weed management practices				
W_1	63.80 (8.05)	81.00	95.58	98.99
W_2	68.72 (8.35)	79.01	92.80	98.70
W_3	64.12 (8.07)	84.35	93.45	98.27
Interaction effect treatment combination				
s_1w_1	71.08 (8.49)	84.42	95.79	99.71
s_1w_2	71.93 (8.54)	81.85	96.44	98.02
s_1w_3	66.08 (8.19)	92.17	96.93	99.75
s_2w_1	67.06 (8.25)	83.71	95.82	98.67
s_2w_2	59.68 (7.79)	69.81	88.23	98.62
s_2w_3	76.09 (8.78)	79.42	93.21	96.97
s_3w_1	53.91 (7.41)	76.87	95.13	98.58
s_3w_2	74.86 (8.71)	85.38	93.73	99.47
s_3w_3	51.42 (7.24)	81.44	90.19	98.08
Control	10.63 (3.41)	94.22	94.81	99.54
SE : S/W : SW	0.295 0.512	2.915 5.049	1.862 3.225	0.744 1.288
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	NS	NS

transformed values are given in parenthesis

Table 25. Effect of spacing, weed management practices and their interaction on relative density of sedges

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	18.62 (4.43)	8.86 (3.14)	2.20 (1.79)	0.06 (1.03)
S_2	22.72 (4.87)	17.06 (4.25)	2.46 (1.86)	0.25 (1.12)
S_3	27.30 (5.32)	13.14 (3.76)	2.96 (1.99)	0.25 (1.12)
Weed management practices				
W_1	22.14 (4.81)	13.89 (3.86)	2.53 (1.88)	0.17 (1.08)
W_2	24.10 (5.01)	13.75 (3.84)	2.69 (1.92)	0.23 (1.11)
W_3	21.94 (4.79)	10.83 (3.44)	2.39 (1.84)	0.19 (1.09)
Interaction effect treatment combination				
s_1w_1	15.56 (4.07)	14.13 (3.89)	2.72 (1.93)	0.06 (1.03)
s_1w_2	22.43 (4.84)	10.42 (3.38)	1.72 (1.65)	0.00 (1.00)
s_1w_3	18.27 (4.39)	3.58 (2.14)	2.17 (1.78)	0.14 (1.07)
s_2w_1	18.00 (4.36)	12.25 (3.64)	1.86 (1.69)	0.25 (1.12)
s_2w_2	32.41 (5.78)	21.94 (4.79)	4.11 (2.26)	0.42 (1.19)
s_2w_3	19.07 (4.48)	17.40 (4.29)	1.66 (1.63)	0.10 (1.05)
s_3w_1	35.24 (6.02)	15.40 (4.05)	3.04 (2.01)	0.19 (1.09)
s_3w_2	18.62 (4.43)	10.22 (3.35)	2.46 (1.86)	0.29 (1.14)
s_3w_3	29.25 (5.50)	14.05 (3.88)	3.37 (2.09)	0.29 (1.14)
Control	0.00 (1.00)	1.99 (1.73)	0.25 (1.12)	0.10 (1.05)
SE : S/W : SW	0.556 0.963	0.445 0.770	0.276 0.478	0.041 0.071
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	NS	NS

transformed values are given in parenthesis

Table 26. Effect of spacing, weed management practices and their interaction on relative density of broad leaved weeds

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	4.90 (2.43)	3.08 (2.02)	1.07 (1.44)	0.51 (1.23)
S_2	3.33 (2.08)	3.28 (2.07)	3.58 (2.14)	1.28 (1.51)
S_3	7.29 (2.88)	3.79 (2.19)	2.53 (1.88)	0.88 (1.37)
Weed management practices				
W_1	5.35 (2.52)	2.92 (1.98)	1.53 (1.59)	0.74 (1.32)
W_2	2.96 (1.99)	4.90 (2.43)	3.12 (2.03)	0.79 (1.34)
W_3	7.29 (2.88)	2.53 (1.88)	2.35 (1.83)	1.13 (1.46)
Interaction effect treatment combination				
s_1w_1	4.34 (2.31)	2.31 (1.82)	1.34 (1.53)	0.23 (1.11)
s_1w_2	3.71 (2.17)	4.57 (2.36)	1.40 (1.55)	1.40 (1.55)
s_1w_3	6.89 (2.81)	2.49 (1.87)	0.51 (1.23)	0.08 (1.04)
s_2w_1	3.49 (2.12)	1.16 (1.47)	1.99 (1.73)	0.93 (1.39)
s_2w_2	3.93 (2.22)	6.67 (2.77)	5.55 (2.56)	0.93 (1.39)
s_2w_3	2.57 (1.89)	2.88 (1.97)	3.49 (2.12)	2.06 (1.75)
s_3w_1	8.86 (3.14)	6.08 (2.66)	1.25 (1.50)	1.13 (1.46)
s_3w_2	1.46 (1.57)	3.62 (2.15)	2.96 (1.99)	0.19 (1.09)
s_3w_3	14.44 (3.93)	2.20 (1.79)	3.67 (2.16)	1.46 (1.57)
Control	5.86 (2.62)	2.88 (1.97)	4.02 (2.24)	0.35 (1.16)
SE : S/W : SW	0.456 0.789	0.270 0.468	0.285 0.494	0.194 0.335
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	NS	NS	NS	NS

transformed values are given in parenthesis

4.4.4 Absolute Frequency

4.4.4.1 Total Absolute Weed Frequency

Results presented in Table 27 revealed that spacing had no influence on total absolute weed frequency. Weed management practices had significant influence on this parameter only at 60 DAS. Rotary weeding (W_3) recorded the least value of 172.22 and was significantly superior to other weed management practices at this stage. Hand weeding twice (W_1) recorded the highest value of 222.22

Control plot was significantly superior to treatment combinations at 30, 60 and 90 DAS and recorded the lowest value of total absolute weed frequency. However, at harvest, the variation between control and treatment combinations was observed to be insignificant.

4.4.4.2 Absolute frequency of Grasses

The direct effect of spacing and weed management and their interactions were not significant in absolute frequency of grasses as depicted in Table 28. The grass weed frequency was cent percent in all treatments and control during the entire growth stages except at 30 DAS. At this stage, control plot registered the lowest value.

4.4.4.3 Absolute Frequency of Sedges

Perusal of data presented in Table 29 showed that the treatments and their interaction failed to show any significant impact on absolute frequency of sedges. Control plot was significantly superior to other treatment combinations recording the lowest value of absolute frequency during the three stages (30, 60 and 90 DAS). At harvest, no variation was observed between treatments and control.

4.4.4.4 Absolute Frequency of Broad Leaved Weeds

Data summarized in Table 30 showed that the treatments and their interactions had no significant influence on absolute frequency of broad leaved weeds.

Table 27. Effect of spacing, weed management practices and their interaction on total absolute weed frequency

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	137.29 (11.76)	200.00	166.67	127.78
S_2	167.22 (12.97)	200.00	211.11	155.56
S_3	195.84 (14.03)	211.11	216.67	158.33
Weed management practices				
W_1	164.64 (12.87)	222.22	202.78	147.22
W_2	176.96 (13.34)	216.67	200.00	147.22
W_3	156.50 (12.55)	172.22	191.67	147.22
Interaction effect treatment combination				
s_1w_1	149.06 (12.25)	233.33	175.00	125.00
s_1w_2	141.32 (11.93)	208.33	166.67	133.33
s_1w_3	121.99 (11.09)	158.33	158.33	125.00
s_2w_1	110.09 (10.54)	191.67	225.00	141.67
s_2w_2	228.83 (15.16)	233.33	216.67	166.67
s_2w_3	172.98 (13.19)	175.00	191.67	158.33
s_3w_1	248.64 (15.80)	241.67	208.33	175.00
s_3w_2	165.93 (12.92)	208.33	216.67	141.67
s_3w_3	177.76 (13.37)	183.33	225.00	158.33
Control	4.62 (2.37)	125.00	133.33	133.33
SE : S/W : SW	0.950 1.645	11.689 20.246	15.549 26.932	14.096 24.414
CD : S : W : SW	NS NS NS	NS 35.049 NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	S	NS

transformed values are given in parenthesis

Table 28. Effect of spacing , weed management practices and their interaction on absolute frequency of grasses

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	69.22 (8.38)	100.00	100.00	100.00
S_2	85.12 (9.28)	100.00	100.00	100.00
S_3	93.67 (9.73)	100.00	100.00	100.00
Weed management practices				
W_1	77.85 (8.88)	100.00	100.00	100.00
W_2	90.78 (9.58)	100.00	100.00	100.00
W_3	78.74 (8.93)	100.00	100.00	100.00
Interaction effect treatment combination				
s_1w_1	69.56 (8.40)	100.00	100.00	100.00
s_1w_2	73.65 (8.64)	100.00	100.00	100.00
s_1w_3	64.77 (8.11)	100.00	100.00	100.00
s_2w_1	66.08 (8.19)	100.00	100.00	100.00
s_2w_2	100.00 (10.05)	100.00	100.00	100.00
s_2w_3	91.35 (9.61)	100.00	100.00	100.00
s_3w_1	100.00 (10.05)	100.00	100.00	100.00
s_3w_2	100.00 (10.05)	100.00	100.00	100.00
s_3w_3	81.45 (9.08)	100.00	100.00	100.00
Control	4.62 (2.37)	100.00	100.00	100.00
SE : S/W : SW	0.443 0.767	-	-	-
CD : S : W : SW	NS NS NS	-	-	-
Control Vs treatments	S	-	-	-

transformed values are given in parenthesis

Table 29. Effect of spacing, weed management practices and their interaction on absolute frequency of sedges

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	36.09 (9.06)	49.27 (7.09)	29.14 (5.49)	4.62 (2.37)
S_2	53.46 (7.38)	65.91 (8.18)	37.81 (6.23)	8.30 (3.05)
S_3	63.16 (8.01)	71.08 (8.49)	62.36 (7.96)	16.56 (4.19)
Weed management practices				
W_1	48.28 (7.02)	83.64 (9.20)	43.62 (6.68)	8.30 (3.05)
W_2	54.65 (7.46)	59.99 (7.81)	41.90 (6.55)	9.76 (3.28)
W_3	48.14 (7.01)	44.69 (6.76)	40.60 (6.45)	9.76 (3.28)
Interaction effect treatment combination				
s_1w_1	48.42 (7.03)	91.35 (9.61)	40.73 (6.46)	4.62 (2.37)
s_1w_2	38.82 (6.31)	42.43 (6.59)	23.40 (4.94)	0.00 (1.00)
s_1w_3	23.40 (4.94)	24.91 (5.09)	24.91 (5.09)	12.91 (3.73)
s_2w_1	23.40 (4.94)	69.56 (8.40)	30.58 (5.62)	4.62 (2.37)
s_2w_2	81.45 (9.08)	82.91 (9.16)	44.56 (6.75)	18.45 (4.41)
s_2w_3	64.77 (8.11)	47.86 (6.99)	38.82 (6.31)	4.62 (2.37)
s_3w_1	81.45 (9.08)	91.35 (9.61)	62.36 (7.96)	18.45 (4.41)
s_3w_2	47.86 (6.99)	57.83 (7.67)	62.36 (7.96)	18.45 (4.41)
s_3w_3	62.36 (7.96)	66.08 (8.19)	62.36 (7.96)	12.91 (3.73)
Control	0.00 (1.00)	12.91 (3.73)	4.62 (2.37)	4.62 (2.37)
SE : S/W : SW	0.866 1.501	0.751 1.301	1.030 1.784	0.799 1.385
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	S	NS

transformed values are given in parenthesis

Table 30. Effect of spacing, weed management practices and their interaction on absolute frequency of broad leaved weeds

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	23.40 (4.94)	33.81 (5.90)	27.30 (5.32)	10.36 (3.37)
S_2	17.32 (4.28)	26.77 (5.27)	63.16 (8.01)	33.46 (5.87)
S_3	35.97 (6.08)	36.21 (6.10)	39.58 (6.37)	28.70 (5.45)
Weed management practices				
W_1	30.58 (5.62)	27.19 (5.31)	45.65 (6.83)	26.77 (5.27)
W_2	23.11 (4.91)	49.27 (7.09)	43.62 (6.68)	21.47 (4.74)
W_3	21.66 (4.76)	22.72 (4.87)	37.32 (6.19)	20.90 (4.68)
Interaction effect treatment combination				
s_1w_1	23.40 (4.94)	36.82 (6.15)	32.41 (5.78)	12.91 (3.73)
s_1w_2	23.40 (4.94)	49.98 (7.14)	32.41 (5.78)	15.16 (4.02)
s_1w_3	23.40 (4.94)	18.45 (4.41)	18.45 (4.41)	4.62 (2.37)
s_2w_1	23.40 (4.94)	12.91 (3.73)	81.45 (9.08)	24.91 (5.09)
s_2w_2	81.45 (9.08)	47.86 (6.99)	66.08 (8.19)	40.73 (6.46)
s_2w_3	64.77 (8.11)	24.91 (5.09)	44.56 (6.75)	35.72 (6.06)
s_3w_1	81.45 (9.08)	35.72 (6.06)	30.58 (5.62)	47.86 (6.99)
s_3w_2	47.86 (6.99)	49.98 (7.14)	35.72 (6.06)	12.91 (3.73)
s_3w_3	62.36 (7.96)	24.91 (5.09)	54.20 (7.43)	30.58 (5.62)
Control	0.00 (1.00)	18.45 (4.41)	32.41 (5.78)	18.45 (4.41)
SE : S/W	0.945	0.834	0.973	1.142
: SW	1.636	1.445	1.685	1.978
CD : S	NS	NS	NS	NS
: W	NS	NS	NS	NS
: SW	NS	NS	NS	NS
Control Vs treatments	S	NS	NS	NS

transformed values are given in parenthesis

Control plot recorded the lowest value at 30 DAS and was significantly superior to other treatment combinations. No significant difference between control and treatment combinations were observed during other stages of growth.

4.4.5 Relative Frequency

4.4.5.1 Relative Frequency of Grasses

Results presented in Table 31 showed that different spacings had no influence on the relative frequency of grasses. The various weed management practices showed a significant influence on relative frequency of grasses at 60 DAS, where rotary weeding recorded the highest value. Application of butachlor followed by hand weeding and two hand weedings were on par and registered lower relative frequency of grasses than rotary weeding.

Control significantly reduced the relative frequency of grasses at 30 DAS. The relative frequency values were the highest in control plot at 60 DAS. At later stages, no significant variation was observed between control and treatments.

4.4.5.2 Relative Frequency of Sedges

The results depicted in Table 32 revealed that the treatments and their interaction had no influence on relative frequency of sedges. At all three stages (30, 60 and 90 DAS), control plot recorded the least value and was significantly superior to other treatment combinations. At harvest this variation was found insignificant.

4.4.5.3 Relative Frequency of Broad Leaved Weeds

The treatments and their interaction (Table 33) did not impart any influence on the relative frequency of broad leaved weeds. Control plot recorded a relative frequency value of zero at 30 DAS, which was significantly superior to other treatments. At other stages, the variation between the control and other treatment combinations remained insignificant.

Table 31. Effect of spacing, weed management practices and their interaction on relative frequency of grasses

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	56.46 (7.58)	53.18	61.27	81.85
S_2	54.50 (7.45)	52.61	49.35	68.68
S_3	48.42 (7.03)	46.10	48.52	67.64
Weed management practices				
W_1	54.06 (7.42)	47.79	51.25	71.29
W_2	53.61 (7.39)	46.26	53.88	73.44
W_3	51.56 (7.25)	57.83	54.00	73.44
Interaction effect treatment combination				
s_1w_1	57.22 (7.63)	43.60	57.94	80.00
s_1w_2	54.95 (7.48)	50.37	62.38	83.33
s_1w_3	57.06 (7.62)	65.56	63.49	82.22
s_2w_1	65.59 (8.16)	56.29	47.68	74.60
s_2w_2	45.65 (6.83)	43.60	46.67	62.38
s_2w_3	53.17 (7.36)	57.94	53.70	69.05
s_3w_1	40.73 (6.46)	43.49	48.15	59.26
s_3w_2	60.78 (7.86)	44.81	52.59	74.60
s_3w_3	44.69 (6.76)	50.00	44.81	69.05
Control	15.16 (4.02)	68.33	68.89	75.56
SE : S/W : SW	0.324 0.561	3.253 5.635	4.413 7.644	7.037 12.188
CD : S : W : SW	NS NS NS	NS 9.755 NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	NS	NS

transformed values are given in parenthesis

Table 32. Effect of spacing , weed management practices and their interaction on relative frequency of sedges

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	21.94 (4.79)	23.30 (4.93)	16.98 (4.24)	36.23 (2.15)
S_2	31.49 (5.70)	32.52 (5.79)	17.32 (4.28)	4.90 (2.43)
S_3	31.15 (5.67)	33.93 (5.91)	28.70 (5.45)	9.56 (3.25)
Weed management practices				
W_1	22.23 (4.82)	37.81 (6.23)	21.09 (4.70)	5.25 (2.50)
W_2	34.52 (5.96)	26.88 (5.28)	19.88 (4.57)	5.92 (2.63)
W_3	28.05 (5.39)	25.21 (5.12)	20.99 (4.69)	6.24 (2.69)
Interaction effect treatment combination				
s_1w_1	20.34 (4.62)	39.58 (6.37)	23.11 (4.91)	3.79 (2.19)
s_1w_2	30.58 (5.62)	18.54 (4.42)	12.76 (3.71)	0.00 (1.00)
s_1w_3	16.14 (4.14)	14.92 (3.99)	15.73 (4.09)	9.63 (3.26)
s_2w_1	15.56 (4.07)	35.24 (6.02)	12.18 (3.63)	2.88 (1.97)
s_2w_2	45.65 (6.83)	35.72 (6.06)	19.98 (4.58)	10.16 (3.34)
s_2w_3	37.69 (6.22)	26.88 (5.28)	20.44 (4.63)	2.88 (1.97)
s_3w_1	32.41 (5.78)	38.56 (6.29)	29.91 (5.56)	10.16 (3.34)
s_3w_2	28.38 (5.42)	27.62 (5.35)	28.48 (5.43)	11.60 (3.55)
s_3w_3	32.64 (5.80)	36.09 (6.09)	27.73 (5.36)	7.18 (2.86)
Control	0.00 (1.00)	9.63 (3.26)	3.28 (2.07)	3.71 (2.19)
SE : S/W : SW	0.620 1.075	0.493 0.854	0.648 1.123	0.585 1.014
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	S	S	NS

transformed values are given in parenthesis

Table 33. Effect of spacing, weed management practices and their interaction on relative frequency of broad leaved weeds

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	12.76 (3.71)	16.98 (4.24)	16.56 (4.19)	7.01 (2.83)
S_2	8.73 (3.12)	12.91 (3.73)	29.80 (5.55)	19.79 (4.56)
S_3	17.85 (4.31)	16.81 (4.22)	17.49 (4.30)	16.56 (4.19)
Weed management practices				
W_1	14.13 (3.89)	11.32 (3.51)	22.52 (4.85)	17.23 (4.27)
W_2	11.18 (3.49)	22.91 (4.89)	21.18 (4.71)	12.76 (3.71)
W_3	12.99 (3.74)	13.21 (3.77)	19.16 (4.49)	11.96 (3.60)
Interaction effect treatment combination				
s_1w_1	9.69 (3.27)	15.48 (4.06)	18.36 (4.40)	10.49 (3.39)
s_1w_2	12.76 (3.72)	24.91 (5.09)	19.88 (4.57)	8.30 (3.05)
s_1w_3	16.14 (4.14)	11.67 (3.56)	11.89 (3.59)	3.28 (2.07)
s_2w_1	8.99 (3.16)	6.02 (2.65)	36.58 (6.13)	15.73 (4.09)
s_2w_2	13.52 (3.81)	20.16 (4.60)	31.04 (5.66)	24.40 (5.04)
s_2w_3	4.62 (2.37)	14.44 (3.93)	22.72 (4.87)	19.52 (4.53)
s_3w_1	26.46 (5.24)	13.52 (3.81)	15.08 (4.01)	27.19 (5.31)
s_3w_2	7.76 (2.96)	24.10 (5.01)	14.13 (3.89)	8.24 (3.04)
s_3w_3	21.28 (4.72)	13.67 (3.83)	23.90 (4.99)	16.72 (4.21)
Control	0.00 (1.00)	14.92 (3.99)	24.60 (5.06)	13.52 (3.81)
SE : S/W : SW	0.656 1.136	0.517 0.895	0.612 1.059	0.805 1.395
CD : S : W : SW	NS NS NS	NS NS NS	NS NS NS	NS NS NS
Control Vs treatments	S	NS	NS	NS

transformed values are given in parenthesis

4.4.6 Dry Weight of Weeds

The different spacings tried had no significant influence on the dry weight of weeds at 30 and 60 DAS (Table 34). At 90 DAS and at harvest, S_2 and S_3 were on par and recorded significantly higher dry weight than the closer spacing of 20 x 20 cm.

At all growth stages, hand weeding twice, W_1 recorded significantly lowest weed dry weight. At 30 and 60 DAS, W_2 was on par with W_3. At 90 DAS and at harvest, significantly higher weed dry weight was recorded in W_3 (1676.97 g m^{-2})

Spacing and weed management interaction was significant only at 90 DAS. Lowest weed dry weight of 293.93 g m^{-2} was recorded in s_1w_1 which was significantly superior to other treatment combinations and was on par with s_1w_2. The highest weed dry weight of 911.09 g m^{-2} was recorded in s_2w_3 which was on par with s_2w_2.

The control plot recorded a significantly lower weed dry weight at all stages and was significantly superior to other treatment combinations at 30 and 90 DAS and at harvest.

4.5 CHEMICAL ANALYSIS

4.5.1 Nutrient Uptake of Crop

4.5.1.1 Nitrogen Uptake of Crop

The data presented in Table 35 revealed that the nitrogen uptake of 20 x 20 cm spacing (S_1) was significantly higher than other treatments at all stages of observations except at 60 DAS. At 30 DAS and at harvest, S_1 recorded a value which was on par with S_2. The widest spacing (S_3) recorded significantly lower values than the other spacings.

The various weed management practices had significant impact on nitrogen uptake of crop at 30 and 60 DAS. At 30 DAS, weed management practice, W_2 recorded highest nitrogen uptake of 0.27 kg ha^{-1} and was on par with W_1. At 60 DAS, rotary weeding, W_3 recorded significantly higher value of 6.62 kg ha^{-1}.

Table 34. Effect of spacing, weed management practices and their interaction on dry weight of weeds (g m^{-2})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	118.49	141.59	493.84	1231.24
S_2	102.18	152.03	748.57	1479.55
S_3	121.19	145.16	726.04	1523.29
Weed management practices				
W_1	82.19	121.22	429.42	1109.16
W_2	137.10	151.78	675.38	1447.95
W_3	122.58	165.78	863.64	1676.97
Interaction effect treatment combination				
s_1w_1	65.38	116.78	293.93	966.70
s_1w_2	140.05	136.59	347.02	1153.65
s_1w_3	150.07	171.39	840.56	1573.37
s_2w_1	93.26	122.71	475.49	1135.39
s_2w_2	136.83	149.49	859.11	1678.43
s_2w_3	76.45	183.88	911.09	1624.83
s_3w_1	87.92	124.16	518.84	1225.39
s_3w_2	134.42	169.26	820.03	1511.78
s_3w_3	141.24	142.07	839.25	1832.70
Control	41.83	111.51	383.51	825.51
SE : S/W : SW	9.918 17.178	10.453 18.105	26.254 45.474	59.892 103.736
CD : S : W : SW	NS 29.736 NS	NS 31.342 NS	78.720 78.720 136.346	179.578 179.578 NS
Control Vs treatments	S	NS	S	S

Table 35. Effect of spacing, weed management practices and their interaction on nitrogen uptake of crop (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	0.28	5.47	80.79	100.08
S_2	0.23	5.49	39.74	93.63
S_3	0.19	4.76	23.88	78.39
Weed management practices				
W_1	0.23	3.65	51.63	105.04
W_2	0.27	5.45	49.19	99.29
W_3	0.19	6.62	43.59	95.91
Interaction effect treatment combination				
s_1w_1	0.27	3.26	79.41	105.04
s_1w_2	0.35	6.19	90.09	99.29
s_1w_3	0.22	6.96	72.87	95.91
s_2w_1	0.24	3.15	49.98	100.41
s_2w_2	0.26	6.65	38.38	95.54
s_2w_3	0.19	6.67	30.87	84.95
s_3w_1	0.18	4.54	25.49	72.33
s_3w_2	0.21	3.51	19.12	86.92
s_3w_3	0.17	6.24	27.03	75.90
Control	1.99	31.57	58.12	89.727
SE : S/W	0.018	0.381	2.447	3.755
: SW	0.032	0.659	4.239	6.503
CD : S	0.055	NS	7.338	11.258
: W	0.055	1.142	NS	NS
: SW	NS	1.977	12.710	NS
Control Vs treatments	S	S	NS	NS

The S x W interaction was significant only at 60 and 90 DAS. The interaction s_1w_3 recorded the highest value of 6.96 kg ha-1 which was on par with s_2w_2 and s_2w_3 at 60 DAS. The lowest nitrogen uptake was recorded in treatment combination s_2w_1. At 90 DAS, s_1w_2 recorded the highest uptake of 90.09 kg ha^{-1} which was on par with s_1w_1. The lowest nitrogen uptake was recorded in treatment combination s_3w_2.

Control plot recorded a significantly higher nitrogen uptake than all other treatment combinations at 30 and 60 DAS but towards later stages the effect was found non-significant.

4.5.1.2 Phosphorus Uptake of Crop

The data presented in Table 36 showed that spacing influenced phosphorus uptake only at later stages (90 DAS and at harvest). Closer spacing, S_1 recorded significantly higher values at these stages. The widest spacing (S_3) recorded the least phosphorus uptake at all stages of observation.

The effect of weed management practices on phosphorus uptake was significant at all stages of observations except at harvest. At 30 DAS, W_2 recorded a maximum uptake of 0.40 kg ha^{-1} which was on par with W_1. At 60 DAS, W_3 recorded a significantly higher phosphorus uptake of 4.69 kg ha^{-1}. At 90 DAS, W_1 recorded the highest value of 32.45 kg ha^{-1} which was on par with W_2.

The interaction effect was significant only at 60 DAS where s_1w_3 recorded the highest uptake of 6.01 kg ha^{-1}. The lowest phosphorus uptake was noticed in treatment combination s_2w_1 which was on par with s_1w_1 and s_3w_2.

The control plot recorded a significantly higher phosphorus uptake than other treatments at 30 and 60 DAS. At 90 DAS, the phosphorus uptake by s_1w_1, s_1w_2 and s_1w_3 was superior to control. At harvest, the effect was noticed insignificant.

Table 36. Effect of spacing, weed management practices and their interaction on phosphorus uptake of crop (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	0.36	4.04	47.09	53.65
S_2	0.32	3.24	22.77	50.90
S_3	0.32	3.06	15.29	41.85
Weed management practices				
W_1	0.32	2.19	32.45	51.20
W_2	0.40	3.45	28.20	50.75
W_3	0.27	4.69	24.51	44.45
Interaction effect treatment combination				
s_1w_1	0.37	2.07	49.33	57.91
s_1w_2	0.47	4.05	51.19	52.06
s_1w_3	0.28	6.01	40.77	50.99
s_2w_1	0.24	1.68	28.67	55.06
s_2w_2	0.39	3.89	21.77	52.17
s_2w_3	0.34	4.13	17.86	45.47
s_3w_1	0.35	2.85	19.35	40.64
s_3w_2	0.35	2.39	11.65	48.03
s_3w_3	0.24	3.94	14.89	36.87
Control	2.14	19.79	36.91	43.94
SE : S/W : SW	0.033 0.058	0.297 0.514	1.463 2.533	2.174 3.766
CD : S : W : SW	NS 0.100 NS	NS 0.890 1.541	4.386 4.386 NS	6.519 NS NS
Control Vs treatments	S	S	S	NS

4.5.1.3 Potassium Uptake of Crop

Table 37 revealed that, the closer spacing (S_1) recorded significantly higher potassium uptake compared to S_2 and S_3 at all stages except at 60 DAS when S_1 and S_2 were on par and superior to S_3.

The different weed management practices had a significant effect on potassium uptake of crop at all stages of observation except at harvest. W_2 recorded the highest uptake at 30 DAS and was on par with W_1. At 60 DAS, W_3 recorded the highest potassium uptake and at 90 DAS, hand weeding twice (W_1) recorded the highest potassium uptake and was significantly superior to other weed management practices.

The S x W interaction was significant at 60 DAS and at harvest. At 60 DAS, s_2w_3 registered the highest potassium uptake and was significantly superior to other treatment combinations. The highest potassium uptake at harvest was recorded by s_1w_1 which was on par with s_1w_2, s_1w_3 and s_2w_1. The lowest potassium uptake was noticed by s_3w_1 which was on par with s_2w_3 and s_3w_3.

Control plot recorded significantly higher potassium uptake than other treatments at 30 and 60 DAS. At 90 DAS, interaction involving closer spacing (S_1) along with various weed management practices recorded significantly higher values compared to control. The variation was not significant at harvest stage.

4.5.2 Nutrient Uptake of Weeds

4.5.2.1 Nitrogen Uptake of Weeds

The data presented in Table 38 showed that the different spacings tried had no significant influence on nitrogen uptake of weeds except at 90 DAS. The highest nitrogen uptake was recorded for S_2 at 90 DAS which was significantly higher than the other two spacings.

The different weed management practices adopted influenced nitrogen uptake of weeds at all stages of observation, with W_3 recording a value which was on par with W_2 at 30 and 60 DAS. At 90 DAS and at

Table 37. Effect of spacing, weed management practices and their interaction on potassium uptake of crop (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	0.53	14.54	127.79	157.95
S_2	0.44	14.76	65.50	127.65
S_3	0.32	9.97	40.79	94.98
Weed management practices				
W_1	0.47	8.22	89.64	134.93
W_2	0.50	11.79	74.44	126.87
W_3	0.33	19.26	70.02	118.77
Interaction effect treatment combination				
s_1w_1	0.53	9.45	133.61	175.75
s_1w_2	0.65	14.94	133.61	149.71
s_1w_3	0.41	19.23	116.16	148.39
s_2w_1	0.54	5.88	87.86	155.40
s_2w_2	0.47	11.57	58.10	121.79
s_2w_3	0.31	26.84	50.54	105.75
s_3w_1	0.33	9.33	47.43	73.65
s_3w_2	0.38	8.88	31.60	109.11
s_3w_3	0.26	11.71	43.36	102.18
Control	4.30	89.44	105.98	118.72
SE : S/W : SW	0.043 0.074	1.131 1.960	3.876 6.714	6.227 10.785
CD : S : W : SW	0.128 0.128 NS	3.392 3.392 5.876	11.623 11.623 NS	18.671 NS 32.339
Control Vs treatments	S	S	S	NS

Table 38. Effect of spacing, weed management practices and their interaction on nitrogen uptake of weeds (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	1.28	1.89	7.66	20.67
S_2	0.65	2.09	11.09	22.69
S_3	1.24	2.02	10.69	22.54
Weed management practices				
W_1	0.66	1.64	6.36	17.26
W_2	1.14	2.09	10.11	22.53
W_3	1.06	2.27	12.98	26.11
Interaction effect treatment combination				
s_1w_1	0.53	1.50	4.49	16.24
s_1w_2	1.25	1.89	5.38	19.03
s_1w_3	1.28	2.29	13.11	26.75
s_2w_1	0.76	1.67	6.89	17.03
s_2w_2	1.12	2.08	12.72	26.02
s_2w_3	0.65	2.54	13.66	25.02
s_3w_1	0.68	1.75	7.68	18.50
s_3w_2	1.06	2.33	12.22	22.53
s_3w_3	1.24	1.99	12.16	26.58
Control	0.34	1.43	5.18	11.39
SE : S/W : SW	0.083 0.145	0.143 0.248	0.396 0.687	0.931 1.612
CD : S : W : SW	NS 0.250 NS	NS 0.429 NS	1.189 1.189 2.059	NS 2.791 NS
Control Vs treatments	S	S	S	S

harvest, rotary weeding, W_3 recorded a significantly higher value compared to other two practices. W_1 recorded a significantly lower nitrogen uptake and was superior to other treatments.

S x W interaction was significant at 90 DAS with s_2w_3 recording higher uptake which was on par with s_1w_3, s_2w_2, s_2w_3, s_3w_2 and s_3w_3. The lowest value was recorded in s_1w_1 which was on par with s_1w_2.

Control plot recorded a significantly lower value of nitrogen uptake by weeds compared to other treatment combinations at all stages.

4.5.2.2 Phosphorus Uptake of Weeds

The data presented in Table 39 revealed that phosphorus uptake was not influenced by spacing except at 90 DAS, where S_2 recorded a higher phosphorus uptake and was on par with S_3.

Weed management practices influenced phosphorus uptake during different growth stages except at 60 DAS. At 30 DAS, the highest phosphorus uptake was recorded in w_2 which was on par with W_3. At 90 DAS and at harvest, a significantly higher phosphorus uptake was recorded in W_3.

S x W interaction was significant at 90 DAS and at harvest. At 90 DAS, the highest phosphorus uptake was recorded in treatment combination s_2w_3 which was on par with s_1w_3. Lowest phosphorus uptake was recorded in s_1w_1 which was on par with s_1w_2 and s_2w_1. At harvest, a significantly higher phosphorus uptake was recorded in s_3w_3. The lowest phosphorus uptake was recorded in s_1w_1 which was on par with s_3w_1 and s_3w_2.

The control plot was significantly superior to all other treatments recording a lower phosphorus uptake value at all stages of observations.

4.5.2.3 Potassium Uptake of Weeds

The results are presented in Table 40.

Table 39. Effect of spacing, weed management practices and their interaction on phosphorus uptake of weeds (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	0.75	0.92	3.64	8.10
S_2	0.68	0.94	5.11	9.14
S_3	0.78	0.88	4.83	9.44
Weed management practices				
W_1	0.59	0.79	3.03	7.22
W_2	0.87	0.93	4.45	8.89
W_3	0.75	1.03	6.10	10.56
Interaction effect treatment combination				
s_1w_1	0.44	0.75	2.19	6.20
s_1w_2	0.86	1.03	2.58	9.08
s_1w_3	0.94	0.98	6.16	9.02
s_2w_1	0.74	0.89	3.03	8.27
s_2w_2	0.84	0.87	5.51	9.75
s_2w_3	0.47	1.06	6.78	9.39
s_3w_1	0.59	0.73	3.87	7.20
s_3w_2	0.91	0.88	5.25	7.83
s_3w_3	0.83	1.03	5.36	13.28
Control	0.26	0.63	2.95	4.67
SE : S/W : SW	0.068 0.119	0.070 0.121	0.194 0.336	0.395 0.684
CD : S : W : SW	NS 0.205 NS	NS NS NS	0.581 0.581 1.006	NS 1.185 2.052
Control Vs treatments	S	S	S	S

Of the different spacings tried, S_2 recorded a significantly higher potassium uptake of 2.85 kg ha^{-1} at 60 DAS which was on par with S_1. At 90 DAS and at harvest, S_2 was found significantly superior to other spacings. The lowest potassium uptake was recorded in S_3 both at 60 DAS and at harvest, whereas potassium uptake was the lowest for S_1 at 90 DAS.

Both at 60 DAS and at harvest, the potassium uptake was the highest in W_2 which was on par with W_3. At 90 DAS, W_3 recorded a significantly higher value compared to other two weed management practices. Lowest potassium uptake was recorded in W_1 at 60 and 90 DAS and at harvest.

S x W interaction had a significant impact on potassium uptake of weeds, with interaction s_2w_3 recording a significantly higher potassium uptake at 60 and 90 DAS and at harvest. At 60 DAS, s_2w_3 was on par with s_1w_3 and s_3w_2 and at 90 DAS it was on par with s_1w_3 and s_2w_2. At harvest, s_2w_3 and s_2w_2 were on par. At 90 DAS and at harvest, the treatment combination, s_1w_1 recorded a significantly lower potassium uptake.

In general, control plot recorded significantly lower potassium uptake and was significantly superior to other treatment combinations at all stages of observations. At 60 DAS, s_1w_1 and at 90 DAS, s_1w_1 and s_1w_2 registered lower potassium uptake values than control.

4.5.4 Nutrient Status of Soil after Experiment

A perusal of the data on available nitrogen, available phosphorus and available potassium (Table 41) reveal that the various spacings and weed management practices had no significant impact on available nitrogen content of soil after experiment. Among the treatment combinations, the available nitrogen was the highest in treatment combination s_3w_2 which was on par with s_1w_1, s_1w_3, s_2w_2 and s_3w_3. The lowest phosphorus status was recorded in treatment combination s_1w_2.

The different spacings and its interaction with weed management practices did not show a significant influence on phosphorus status of soil

Table 40. Effect of spacing, weed management practices and their interaction on potassium uptake of weeds (kg ha^{-1})

Treatments	30 DAS	60 DAS	90 DAS	Harvest
Spacing				
S_1	0.82	2.47	9.46	21.42
S_2	0.72	2.85	14.60	27.60
S_3	0.97	2.06	12.34	20.67
Weed management practices				
W_1	0.88	1.95	7.29	17.54
W_2	0.90	2.76	12.43	26.32
W_3	0.73	2.68	16.66	25.83
Interaction effect treatment combination				
s_1w_1	0.68	1.98	5.39	16.37
s_1w_2	0.80	2.57	5.60	21.59
s_1w_3	0.98	2.86	17.37	26.28
s_2w_1	0.78	2.04	8.07	18.73
s_2w_2	0.89	2.72	17.51	30.59
s_2w_3	0.48	3.79	18.22	33.49
s_3w_1	1.17	1.83	8.43	17.51
s_3w_2	1.02	2.99	14.19	26.78
s_3w_3	1.73	1.37	14.39	17.71
Control	0.31	1.53	6.61	11.12
SE : S/W : SW	0.079 0.136	0.193 0.334	0.457 0.791	1.144 1.981
CD : S : W : SW	NS NS NS	0.579 0.579 1.002	1.369 1.369 2.371	3.429 3.429 5.940
Control Vs treatments	S	S	S	S

Table 41 Effect of spacing, weed management practices and their interaction on nutrient status of soil after experiment

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Spacing			
S_1	241.69	23.87	144.15
S_2	240.91	23.68	143.75
S_3	243.68	23.71	143.99
Weed management practices			
W_1	242.11	24.24	143.99
W_2	241.74	22.82	145.10
W_3	242.44	24.20	142.79
Interaction effect treatment combination			
s_1w_1	247.47	24.14	145.06
s_1w_2	233.39	22.93	145.55
s_1w_3	244.23	24.53	141.82
s_2w_1	240.35	24.22	143.54
s_2w_2	242.55	22.17	145.32
s_2w_3	239.82	24.66	142.39
s_3w_1	238.50	24.36	143.39
s_3w_2	249.27	23.35	144.43
s_3w_3	243.27	23.41	144.18
Control	243.49	23.51	143.95
SE : S/W	1.458	0.244	0.746
: SW	2.525	0.423	1.291
CD : S	NS	NS	NS
: W	NS	0.733	NS
: SW	7.572	NS	NS
Control Vs treatments	NS	NS	NS

after experiment. Among the weed management practices, hand weeding twice (W_1) recorded higher phosphorus status which was on par with rotary weeding (W_3).

The two treatments and their interaction failed to have any significant impact on potassium status of soil after experiment.

There was no significant variation between control plot and various treatment combinations as far as nutrient status of soil after experiment was concerned.

When compared with the initial nutrient status of soil, N and P content of soil showed slight decrease after the experiment while the depletion of K was more.

4.6 ECONOMICS OF CULTIVATION

The data summarized in Table 42 revealed that the treatment combination involving closer spacing of 20 x 20 cm along with the use of butachlor followed by hand weeding was most renumerative as it recorded the highest net income and benefit-cost ratio compared to other treatment combinations. The combination of various spacings along with hand weeding twice (W_1) recorded lower net income. Rotary weeding (W_3) along with various spacing combinations, though recorded comparatively lower cost of cultivation, the net income was low. Control plot in which a closer spacing of 20 x 10 cm along with hand weeding twice was followed recorded the lowest net income and benefit-cost ratio compared to other treatment combinations.

4.7 CORRELATION STUDIES

Simple correlations of crop and weed characters with grain and straw yield of rice were worked out and the results are presented in Table 43. The grain and straw yield was found significantly and positively correlated with dry matter production at harvest and number of productive tillers per hill. LAI at 30, 60 and 90 DAS showed significant positive

Table 42. Interaction effect of spacing and weed management practices on economics of cultivation

Treatments	Total cost of cultivation (Rs. ha^{-1})	Total income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B : C ratio
s_1w_1	22900.00	36831.01	13931.01	1.61
s_1w_2	15655.00	37900.60	22245.60	2.42
s_1w_3	16030.00	34898.75	18868.75	2.18
s_2w_1	22990.00	36196.22	13206.22	1.57
s_2w_2	15615.00	35659.18	20044.18	2.28
s_2w_3	15990.00	31509.19	15519.19	1.97
s_3w_1	22960.00	28518.52	5558.52	1.24
s_3w_2	15585.00	32985.96	17400.96	2.12
s_3w_3	15960.00	28094.38	12134.38	1.76
Control	23600.00	31520.10	7920.10	1.34

Price of grain - Rs. 7.00 kg^{-1}
Price of straw - Rs. 3.00 kg^{-1}

Table 43. Simple correlation coefficients of important parameters with grain and straw yield

Sl. No.	Parameters	Grain yield	Straw yield
1.	Crop growth characters		
1.1	Plant height at harvest	0.0280	-0.1440
1.2	Number of tillers per hill at harvest	0.3499	0.2567
1.3	Leaf area index		
1.3.1	Leaf area index at 30 DAS	0.1573	0.4102*
1.3.2	Leaf area index at 60 DAS	0.2882	0.6360*
1.3.3	Leaf area index at 90 DAS	0.2923	0.6698*
1.4	Dry matter production at harvest	0.7213*	0.09830*
2	Crop yield attributes		
2.1	Number of productive tillers per hill	0.3911*	0.3947*
2.2	Length of panicle	-0.1658	-0.0766
2.3	Weight of panicle	0.0394	0.0437
2.4	Number of spikelets per panicle	-0.0044	-0.0242
2.5	Number of filled grains per panicle	-0.0105	0.0196
2.6	Sterility percentage	0.0254	-0.03808*
2.7	Thousand grain weight	0.0047	0.1773
2.8	Harvest index	-0.2646	-0.9163*
3	Observation on weeds		
3.1	Weed dry weight		
3.1.1	Weed dry weight at 30 DAS	0.0447	-0.0138
3.1.2	Weed dry weight at 60 DAS	-0.03655	-0.3715
3.1.3	Weed dry weight at 90 DAS	-0.2737	-0.4142*
3.1.4	Weed dry weight at harvest	-0.2644	-0.3128
3.2	Absolute density		
3.2.1	Absolute density of all types of weeds at 30 DAS	-0.0304	-0.3243
3.2.2	Absolute density of all types of weeds at 60 DAS	-0.3144	-0.0269
3.2.3	Absolute density of all types of weeds at 90 DAS	-0.3686	-0.4759*
3.2.4	Absolute density of all types of weeds at harvest	-0.3486	-0.5707*
4.	Chemical analysis		
4.1	Nutrient uptake of crop		
4.1.1	Nitrogen uptake of crop at harvest	0.7360*	0.9662*
4.1.2	Phosphorus uptake of crop at harvest	0.7629*	0.9225*
4.1.3	Potassium uptake of crop at harvest	0.5193*	0.9591*
4.2	Nutrient uptake of weeds		
4.2.1	Nitrogen uptake of weeds at harvest	-0.2038	-0.1982
4.2.2	Phosphorus uptake of weeds at harvest	-0.3397	-0.2101
4.2.3	Potassium uptake of weeds at harvest	0.1504	0.0036

*Significant at 0.05 level

correlation with straw yield. Nutrient (nitrogen, phosphorus and potassium) uptake by crop also showed significant positive correlation with grain and straw yield.

Significant negative correlation was observed with harvest index and sterility percentage on straw yield. Among the weed characters, absolute density of all types of weeds at 90 DAS and at harvest showed a significant negative correlation with straw yield. Weed dry weight also showed a negative correlation with grain and straw yield of rice.

Discussion

5. DISCUSSION

The results of the experiment conducted to standardise the seedling age, spacing and weed management practices for SRI system of cultivation and its comparison with the already recommended practices are discussed.

5.1 EFFECT OF SEEDLING AGE

The results of the pot culture study to standardise the seedling age under SRI system of cultivation revealed that transplanting young seedlings of 12 days old registered higher yield than the recommended practice of transplanting 21 day old seedlings for medium duration rice variety.

Under SRI system, when seedlings are transplanted very early and very carefully with no trauma to the root and no malpositioning thereof and with favourable soil condition, the plants go through a very rapid exponential growth of tillers and roots (Uphoff, 2002).

In the present study also, the improvement in growth parameters as evident from the plant height and tiller number might have stimulated better photosynthetic efficiency of the crop leading to higher production. Moreover, transplanting single, young seedlings stimulated early tiller production starting from 20 DAS (Table 4). This ensured better resource utilization leading to higher grain production compared to conventional method. From 24 DAS up to harvest, these young seedlings performed better in tiller production. The enhanced tiller production could be explained by 'Katayama-de Laulanie's tillering model'. According to this model, tillers emerge in a sequence, defined in terms of regular time intervals known as "phyllochrons" separating the onset of two successive leaves on the same tiller. For rice, the duration of "phyllochron" varies from 5 to 8 days. When seedlings are transplanted at younger age, it usually coincides with the second or atleast third phyllochron enabling the rice to recover more quickly from the transplanting shock and to resume its growth quickly and produce more number of tillers (Uphoff, 2002). He also noticed that transplanting young seedling preserves plant potential for massive tillering and root growth that is lost by later transplanting.

Though yield attributes like number of spikelets per panicle and number of filled grains per panicle, showed no variation among treatments and control, the younger seedlings out yielded the present recommended seedling age. The enhancement in yield by planting young seedlings could be attributed to the increased productive tiller count. Improvement in grain yield due to increase in productive tiller count was also reported by Iqbal (2004).

Among the different seedling ages tried, the highest grain yield was registered by transplanting 12 day old seedlings (64.29 g pot^{-1}) and this was on par with 14 and 16 day old seedlings. Here also the improvement in the number of productive tillers $hill^{-1}$ contributed to higher grain yield though other yield parameters did not show any significant variation among treatments. Kumar and Shivay (2004) reported that transplanting the seedlings while still young, of less than 15 days old, that is, prior to the start of the fourth phyllochron of growth stimulated tiller production and hence grain yield. The enhancement in rice yield by transplanting 12 day old seedlings was also observed by Mahender (2006). Evaluation of the suitability of SRI technique indicated that square planting with young seedlings of 14 days recorded higher yield than normal planting with aged seedlings of 25 days (Nirmala, 2006).

Under SRI system of cultivation, the advice to start by using 8 to 12 day old seedlings remains sound, but decision about seedling age need to match varietal and climatic differences (Uphoff and Fernandes, 2002). Hence, considering the highest yield realised in the present pot culture study and based on available literature, the seedling age of 12 days could be considered as the ideal age for medium duration rice variety under SRI system of cultivation.

5.2 COMPARISON OF SRI WITH CONVENTIONAL METHOD

Perusal of the results obtained from the field experiment indicated that the different treatment combinations imparted a significant positive influence on the growth and yield of rice over the conventional system. All the treatment combinations under SRI registered significantly higher yield than the recommended practice of transplanting 21 day old seedlings @ 2 to 3 seedlings hill^{-1} with two hand weedings.

In SRI, soil is kept moist and aerated during the vegetative period enabling better root production. Under continuous flooding, rice roots degenerate earlier and as many as 75 % become dysfunctional by panicle initiation. Moreover, transplanting older seedlings, usually take 7 to 14 days to recover from the transplanting shock which could be effectively utilized for growth when seedlings are transplanted young (Uphoff and Randriamiharisoa, 2002).

Similar improvement in growth by transplanting young seedlings was observed in the present study.

Though the control registered more plant height and tiller count at 30 DAS, the young seedlings acquired more vigour and the difference was nullified during the later stages. As per the SRI practice, in the first month, SRI paddy fields seem empty as the tillers are preparing themselves for growth and from second month onwards tillering enhances. The result of the present study is in agreement with the observations of Kirk and Solivas (1997). Regarding other growth attributes like number of tillers m^{-2}, LAI and LAD the control recorded higher values. Though the growth parameters for individual hill was lower in control plot, the enhanced plant population at closer spacing (20 x 10 cm) in control contributed to improvement in tiller number m^{-2}, LAI and LAD.

However, the enhancement in LAI, LAD and tiller number m^{-2} in the control plot could not contribute to yield improvement and all yield attributes registered lower value in the control plot. Moreover, a critical examination of observations on weed parameters also indicated that weed population as estimated by total absolute density, relative density of different species, total absolute frequency and relative frequency of different species registered lower values in the control. This could be attributed to the closer spacing of 20 x 10 cm resulting in smothering of weed population to a greater extend than the wider spacings tried in treatment plots. This might have resulted in reduced weed dry matter production of 825.51 g m^{-2} in control at harvest. However, all favourable aspects have not reflected in the productivity of the crop and this could be attributed to the reason that while crop-weed competition is more in SRI plot, the crop to crop competition might be severe in control due to closer spacing adopted. The enhancement in vegetative growth characters thus could not contribute to the sink.

The SRI treatment plots registered a higher productivity and this could be attributed to the higher number of productive tillers $hill^{-1}$ (ranging from 23.53 to 29.40) compared to 18.13 in control. Here also the 'Katayama-de Laulanie's tillering model' holds good. Transplanting of seedlings before the fourth phyllochron enhanced tiller production. Kumar and Shivay (2004) observed that early transplanting enhanced the number of tillers with corresponding increase in the percentage of productive tillers. The positive correlation value for productive tillers per hill with grain yield also supports the observation. Moreover, the treatment plots registered a higher value for yield attributes like number of spikelets per panicle, number of filled grains per panicle, length and weight of panicle and low sterility percentage. The cumulative effect of all these contributed to enhanced grain yield in SRI treatment plots. Vijayakumar (2003) also obtained similar results in SRI.

The maximum improvement in grain yield in SRI treatment (s_1w_2) was 715.15 kg ha^{-1} accounting to 27 % increase over control. Mc Hugh *et al.* (2002) indicated a large difference between grain yield in SRI and conventional plots and reported that grain yield of SRI were 70 to 90 %

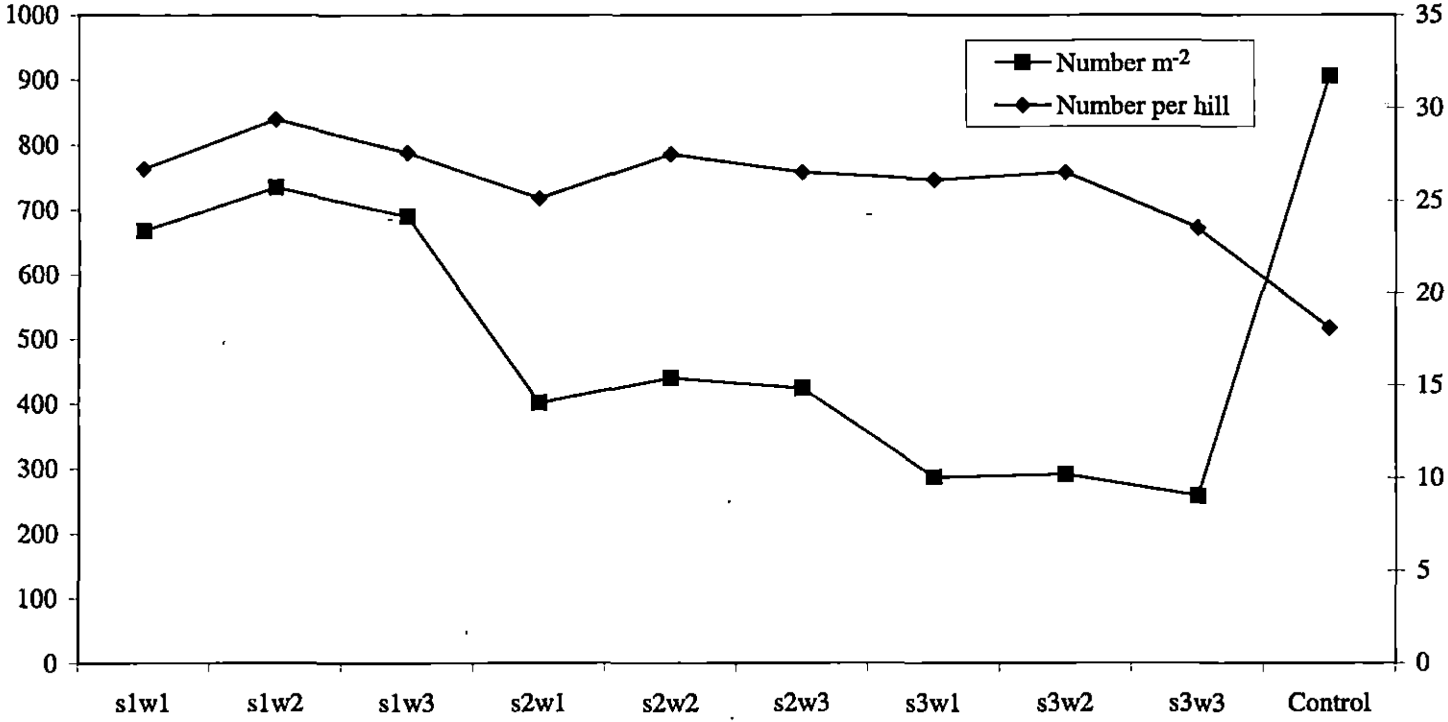


Fig. 5. Interaction effect of spacing and weed management practices on number of productive tillers per hill and productive tillers m^{-2}

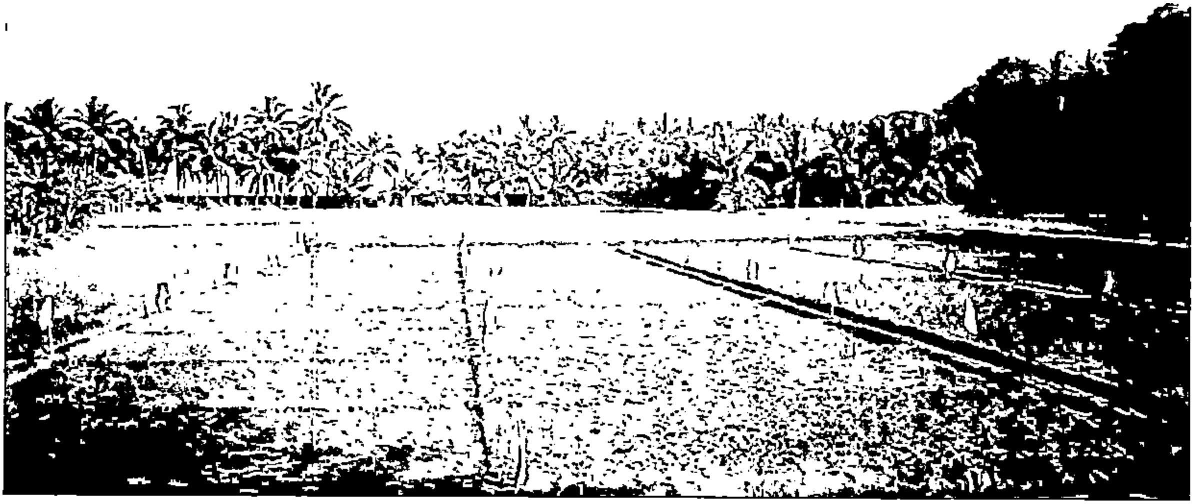


Plate 4. General view of the experimental field after transplanting 12 day old seedlings

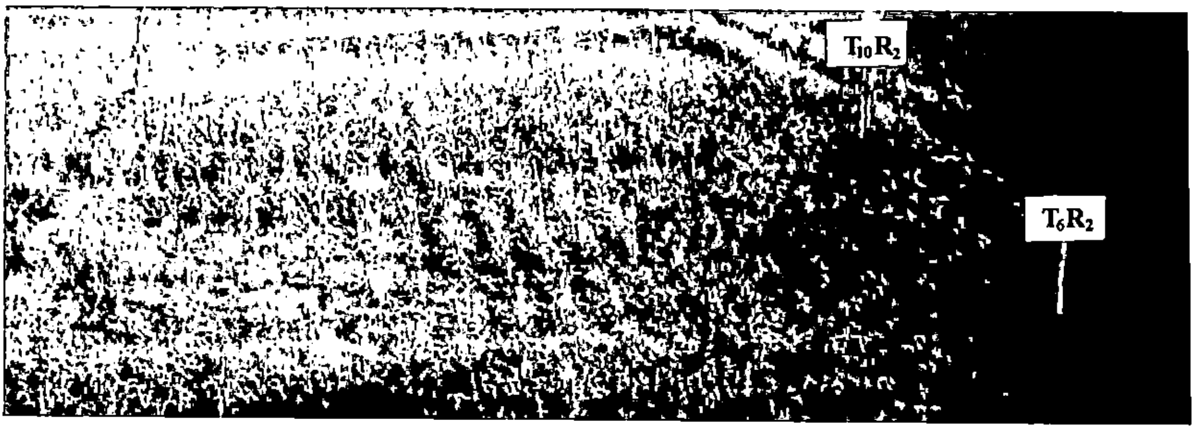


Plate 5. Control and SRI plots (30 days after sowing)

higher than the conventional system. Similar yield enhancement could not be registered in the present study owing to the predominance of grass weeds and their high competitive ability with rice plants in the experimental area.

Though the straw yield did not show any variation between treatments and control, the combination of 20 x 20 cm spacing with hand weeding registered 647 kg ha^{-1} improvement over control.

The harvest index values registered under SRI treatment was more than that of control (0.39). Translocation of assimilates from leaf, stem and sheath and conversion percentage of stored assimilates before heading were higher under SRI system leading to improvement in harvest index (Wang *et al.*, 2002). They also observed that slight moisture stress improved population quality especially grain number per unit leaf area at heading stage; thus the sink became larger and the source became smaller. The single plants also became stronger and more effective in translocation of assimilates leading to better yield attributes and higher reserve yield.

Summarising the whole thing, it could be inferred that compared to the conventional rice cultivation practice, SRI perform better with regard to yield of rice.

5.3 EFFECT OF SPACING

According to the practices followed in SRI, single seedlings are planted in square pattern with comparatively wider spacing. The results of the present study revealed that the different spacings tried did not impart any substantial variation in the grain yield of rice. However, the closer spacing of 20 x 20 cm produced comparatively higher yield than the other spacings of 25 x 25 cm and 30 x 30 cm.

An analysis of vegetative growth parameters at 20 x 20 cm spacing revealed that the different characters like number of tillers per hill, number of tillers per unit area, LAI, LAD and dry matter production were more for this spacing. The closer spacing produced taller plants which could be attributed to the initial competition with rice plants for better utilization of resources. The rice plants raised under wider spacing of 30 x 30 cm registered lower values for vegetative growth characters. The wide interspaces enabled luxuriant weed growth, which interfered with the growth of rice plant for utilization of resources. This is evident from the increased total absolute density of weeds in this spacing (Table 20). Moreover, the weed dry matter production at 30 x 30 cm spacing was 1523.29 g m^{-2} at harvest which was significantly higher than closer spacing. The high weed density, starting from the early crop growth stages might have resulted in severe competition with rice plants thereby reducing the vegetative growth of the plant. That is why, a low tiller production was observed under widely spaced plants. Ali and Sankaran (1975) reported that severe weed infestation suppressed the height of rice plants. Similar to the results of the present study, reduction in number of tillers per unit area due to wider spacing in SRI was also noticed by Islam *et al.* (2005).

The highest grain yield, though not significant was obtained with closer spacing of 20 x 20 cm due to the cumulative effect of enhancement in vegetative growth characters and consequent improvement in yield attributes. Among the vegetative growth characters, the improvement in LAI and LAD at closer spacing helped in better interception and utilization of sunlight contributing to higher photosynthetic efficiency and resultant yield. LAI as an important measure of the potential photosynthetic area and thus of the growth capability was earlier pointed out by Potter and Jones (1997).

Yield attributes like number of productive tillers $hill^{-1}$ and its number per unit area were superior in closer spacing to wider spacing resulting in higher grain yield. Several studies in SRI have pointed out that wider spacing result in improved yield. Contrary to this, in the present study, wider spacing did not cause any improvement in the number of productive tillers $hill^{-1}$. Competition due to weeds and the predominance of grass species in the field might have limited the productive tillers in the hill resulting in low number of panicles per unit area. The negative correlation values observed between yield and weed dry weight substantiate this yield reduction. Though the yield attributes were less at wider spacing of 30 x 30 cm, a higher harvest index of 0.52 was recorded due to reduced straw yield.

In addition, quantity of nitrogen, phosphorus and potassium uptake at closer spacing of 20 x 20 cm was significantly higher especially during the early growth stages, which stimulated better growth and formation of more productive tillers. Higher potassium uptake at closer spacing also favoured reduced sterility percentage enhancing total yield. The significant positive correlation between N, P and K uptake and yield also supports the result.

Though SRI advice wider spacing, starting from 20 x 20 cm to 50 x 50 cm, it has to be optimized so as to produce maximum number of grain bearing tillers m^{-2} and the wider spacings are usually followed when soil quality is excellent (Uphoff and Fernandes, 2002). In the present study also, increasing the spacing to 30 x 30 cm did not result in a corresponding increase in tiller production and number of grain bearing tillers m^{-2}. In a medium fertile soil, having predominant grass weed population, enhancing spacing above 25 x 25 cm is not advantageous for yield improvement. The feasibility of adopting 20 x 20 cm or 25 x 25 cm for yield improvement of traditional rice varieties of Kerala like Chennellu and Gandhakasala under SRI was also reported by Girijan (2004). Vijayakumar (2003) and Kumar and Shivay (2004) also reported yield improvement at a spacing of 25 x 25 cm.

5.4 EFFECT OF WEED MANAGEMENT

Weed management is an important aspect in SRI owing to the wider spacing adopted. In the present study, the three weed management practices adopted, namely, two hand weedings at 20 and 40 DAS (W_1), use of a pre-emergent herbicide, butachlor @ 1.25 kg ai ha^{-1} followed by hand weeding (W_2) and use of rotary weeder at 10 days interval (W_3) were evaluated for their efficiency in enhancing rice yield under SRI. Critical review of the results revealed that W_2 (use of butachlor followed by hand weeding) registered the highest yield of 3335.61 kg ha^{-1} and was on par with the practice of hand weeding twice (3138.71 kg ha^{-1}). However, these treatments were significantly superior to w_3 which registered a yield of 2986.35 kg ha^{-1}.

Ghosh (2005) opined that chemical weeding in rice particularly with Machete was fairly comparable with manual weeding. The different growth attributes registered in herbicide treatment and hand weeding, namely, plant height, tiller number and dry matter production were comparatively higher than rotary weeding, though not significant. Herbicide treatment at 5 DAT helped to suppress the weed growth at early stages of crop growth thereby providing better environment for the early establishment and better growth.

An analysis of nutrient uptake by crop revealed that nitrogen uptake in herbicide treated plots and hand weeding practice registered significantly higher values than rotary weeding. Similarly, nitrogen uptake by weeds was also lower for hand weeded plots followed by herbicide treated plots. This could be the reason for enhanced growth attributes of rice in these treatments.

Nutrient uptake by the crop was highest in herbicide treated plots at 30 DAS. Hence the plots treated with herbicide were able to compete with the high weed competition at later growth stages. Analysis of results on weed observation revealed that the total absolute density, relative density and absolute frequency of weeds of different species were comparatively lower in herbicide applied plots though no significant variation was observed. Rao *et al.* (1993) opined that butachlor @ 1.25 kg ai ha^{-1} followed by hand weeding recorded the lowest weed population. Similar result was observed by scheduling hand weeding after herbicide application in controlling weeds (Kandasamy, 1999).

The two weed management practices, namely hand weeding twice and application of butachlor reduced weed dry weight except at 30 DAS where butachlor treated plots registered highest value. In hand weeded plots, first hand weeding was given 20 DAT and by the observation time, weed population was comparatively lower, whereas in herbicide treated plots,

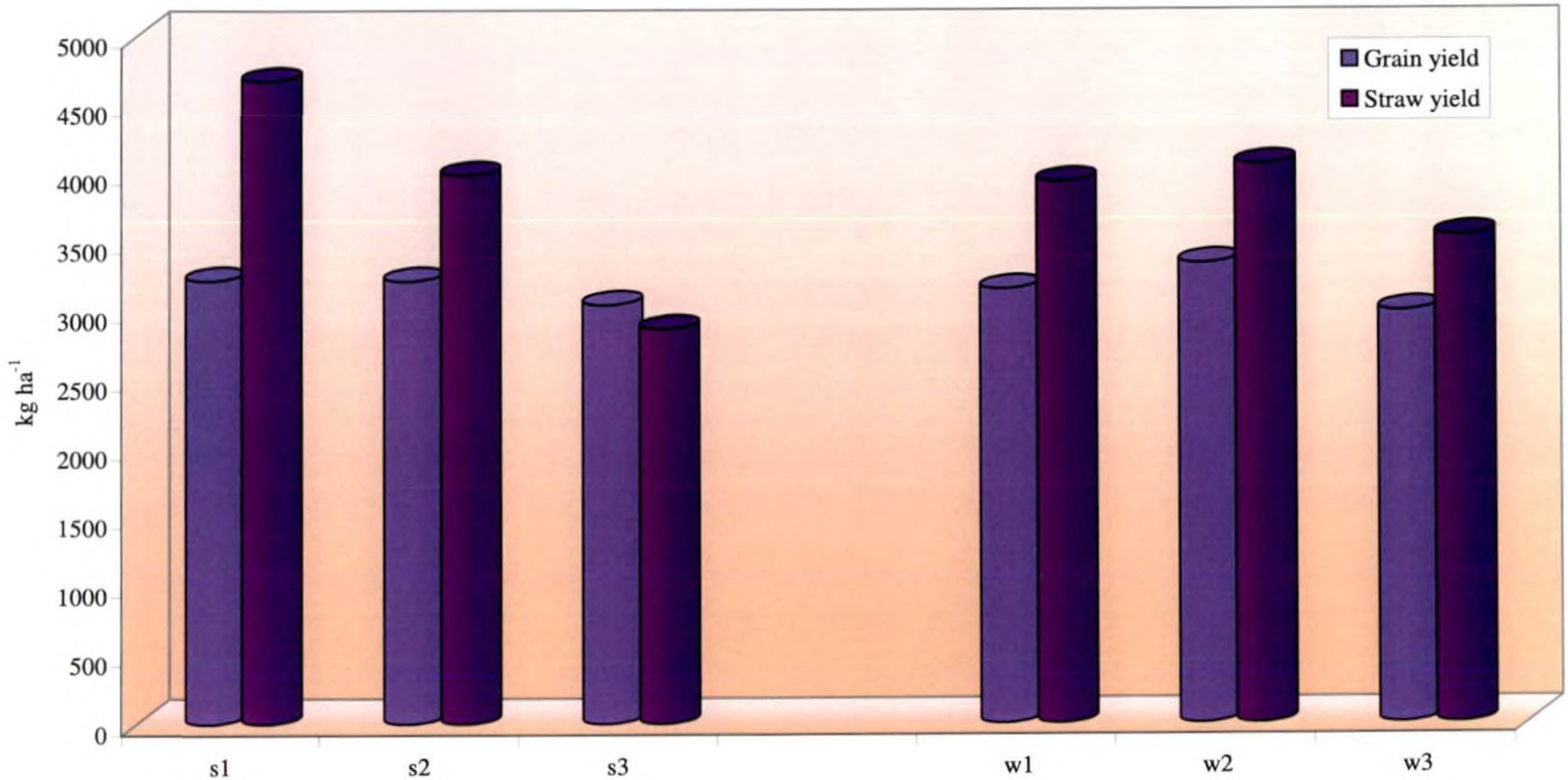


Fig. 6. Effect of spacing and weed management practices on grain yield and straw yield of rice (kg ha^{-1})

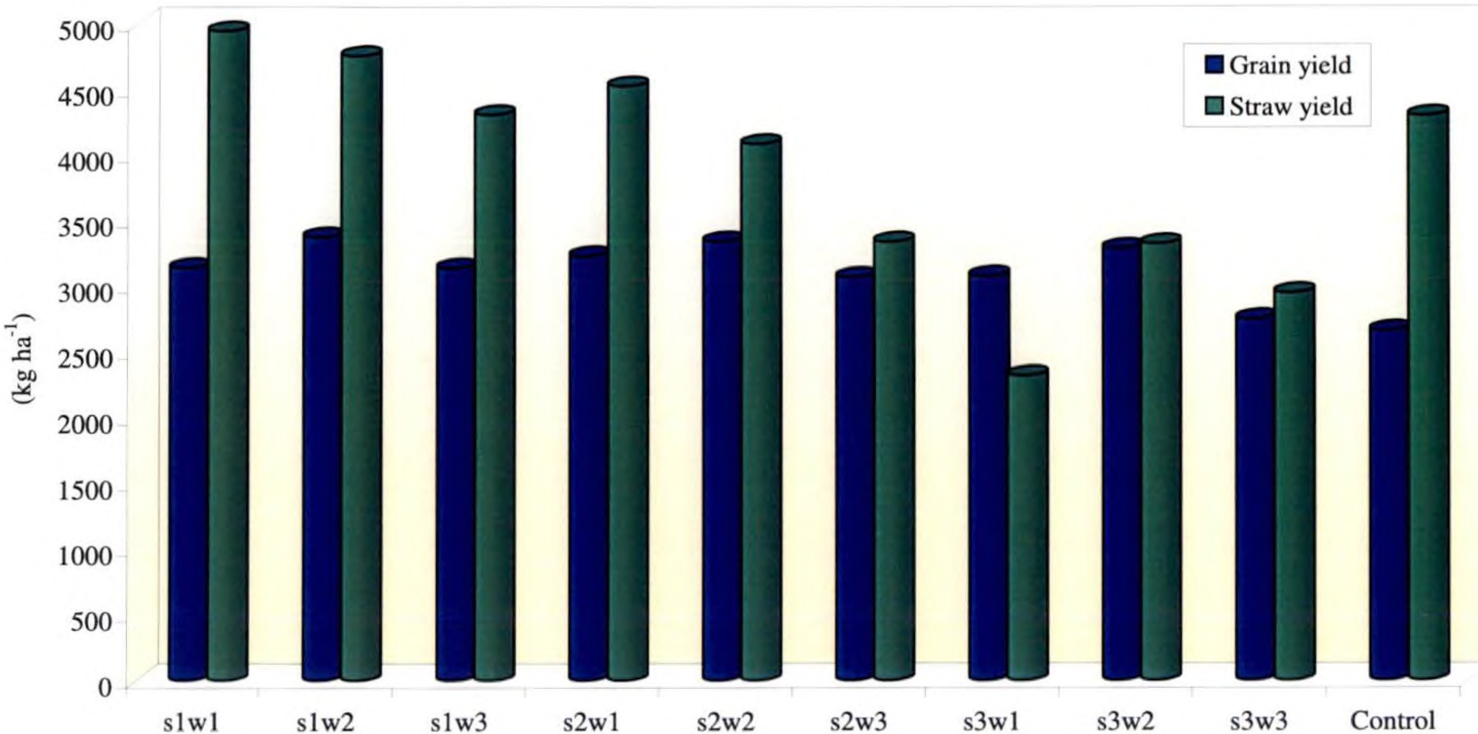


Fig. 7. Interaction effect of spacing and weed management practices on the grain yield and straw yield of rice (kg ha^{-1})

weeding was given 30 DAS, thus contributing to higher weed dry weight. The efficiency of hand weeding in complete uprooting of the weed species might have contributed to reduced weed dry weight in this treatment. Similar reduction in weed dry weight by hand weeding due to removal of weeds from intra and inter rows was reported by Singh (1985).

At panicle initiation stage of crop (60 DAS), the dry weight of weeds in hand weeded plots and herbicide treated plots were found to be the lowest owing to better tillering and consequent suppression of weeds. This might have contributed to better nutrient absorption and mobilization to the developing sink at this critical growth stage of the crop.

Improvement in growth characters and consequent reduction in weed population and dry weight in hand weeded plots and herbicide applied plots enhanced productive tiller count per hill contributing to higher grain yield in these treatments which was on par and superior to mechanical weeding. Choubey *et al.* (1998) could also obtain comparable yield in hand weeding and butachlor applied plots by effective reduction in weed population and weed dry weight. The superiority of these treatments over mechanical weeding was also observed from their studies.

Several research studies on SRI revealed that use of cono weeder at 10 to 15 days interval starting from 10 DAT was ideal because it helps to churn up soil, incorporate weeds, improve soil structure, enhances aeration thereby improving biological activities in soil resulting in better nutrient uptake and yield (Thiyagarajan *et al.*, 2002; Iqbal, 2004).

Contrary to this, rotary weeding was found inferior to manual weeding and herbicide application in the present study. In the field where experiment was conducted, grass weeds predominated, especially perennial grass like *Isachne miliacea.* Under this condition, use of rotary weeder was difficult mainly due to the abundance of this grass and its entangling with the crop due to its spreading habit. At times weeding with the rotary weeder caused disturbance to the crop and in rare cases, even a tendency for uprooting of the

Plate 6. Rotary weeded plots - weeds near the crop are not removed

Plate 7. Rotary weeding

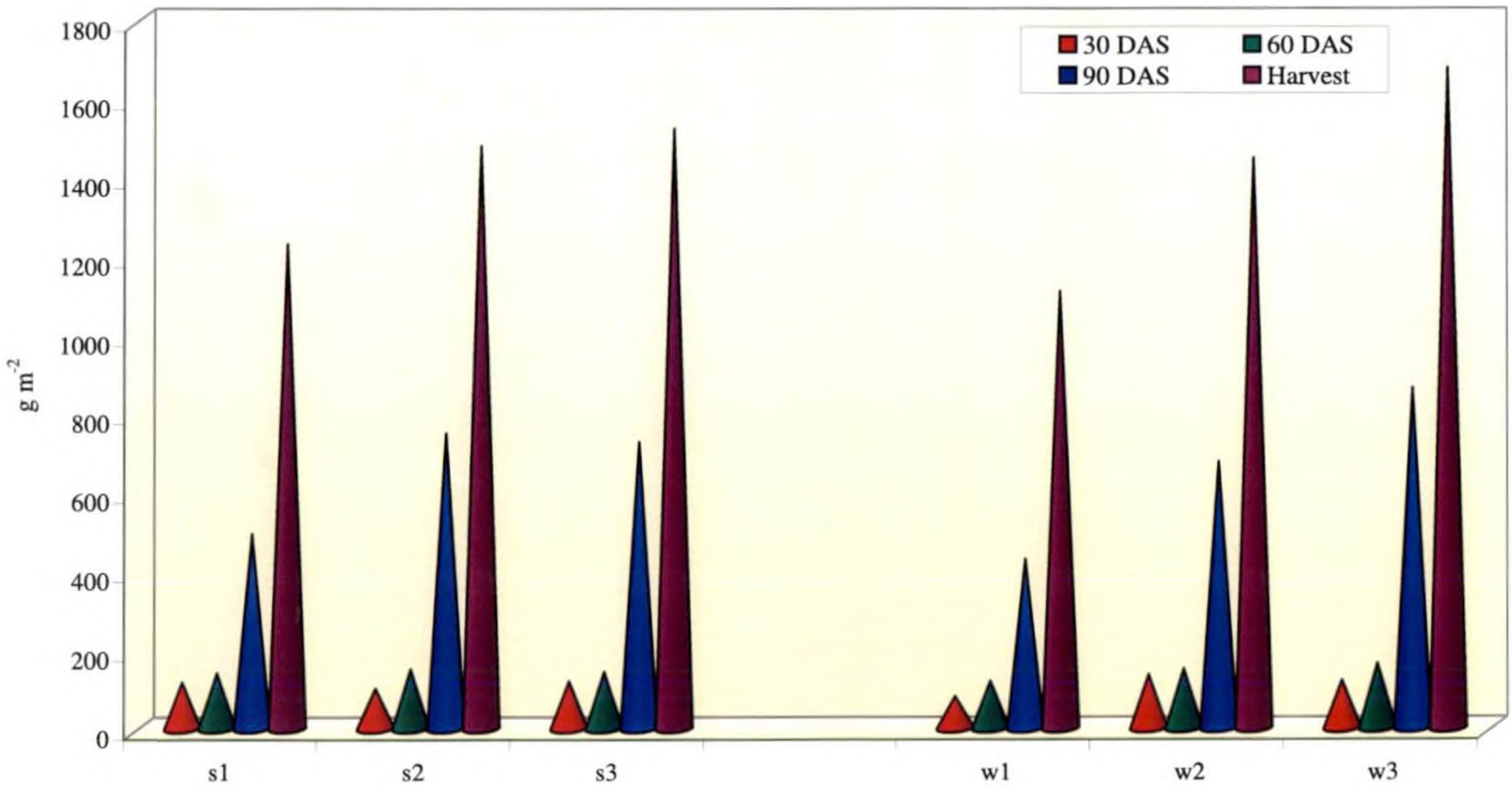


Fig. 8. Effect of spacing and weed management practices on dry weight of weeds (g m^{-2}) at different intervals

rice plant was noticed. Hence extra care had to be bestowed for weeding operation. Moreover, the weeds very near to the crop plant could not be controlled by this operation and frequent weeding at 10 days interval resulted in the weakening of the plant during early stages, though the associated benefits of aeration and root growth might have been obtained. The total biomass production was also the lowest in this treatment. All these contributed to higher weed dry weight during the different growth stages of crop resulting in reduced nutrient uptake by the crop and reduced yield.

5.5 ECONOMICS OF CULTIVATION

The results of the present investigation indicated that all SRI treatments registered higher net income and benefit-cost ratio than the control plot. The cost of cultivation in control (Rs 23600) was higher than SRI treatments owing to the high seed rate and high labour cost incurred for manual weeding. Moreover, the enhanced productivity in SRI treatments contributed to better returns. Among the treatments, the highest net income (Rs 22245.60) and benefit-cost ratio (2.42) were registered by the combination of closer spacing of 20 x 20 cm (S_1) along with the application of butachlor followed by one hand weeding (W_2) accounting to 180 % increase in net income over control. This could be attributed to the higher grain and straw yield obtained from this combination along with reduced cost involved for herbicide application. Prasad *et al.* (1992) and Renjan (1999) also obtained similar results, with herbicide treated plots recording the highest net income and benefit-cost ratio. The combination of butachlor application along with the three spacings (s_1w_2, s_2w_2 and s_3w_2) registered higher net income than other combinations due to low weed management expenses.

In this study, the cost of cultivation in rotary weeded plots was comparable to herbicide application. But the combination involving rotary weeding with different spacings registered comparatively lower net income and benefit-cost ratio than herbicide treated plots. This could be attributed to

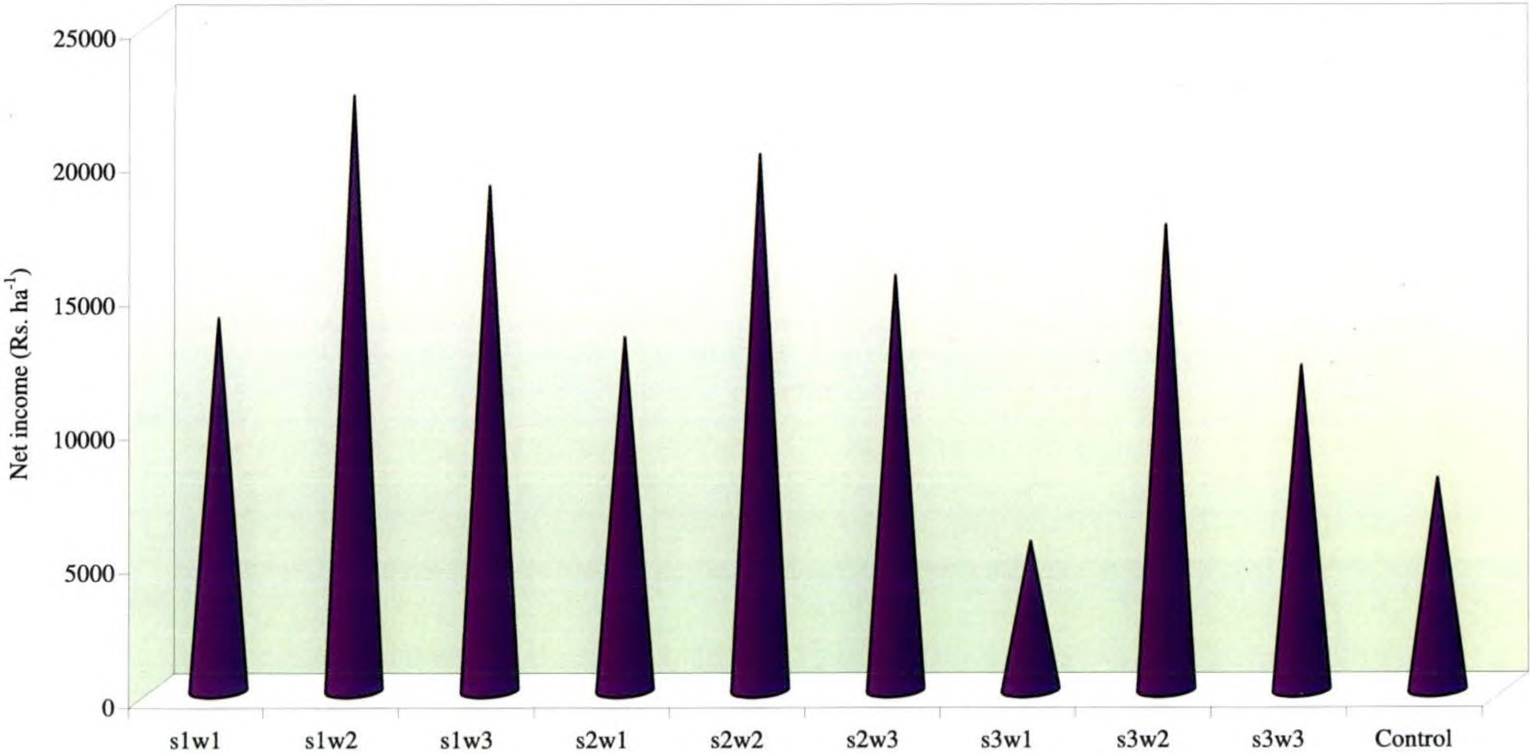


Fig. 9. Interaction effect of spacing and weed management practices on net income (Rs. ha^{-1})

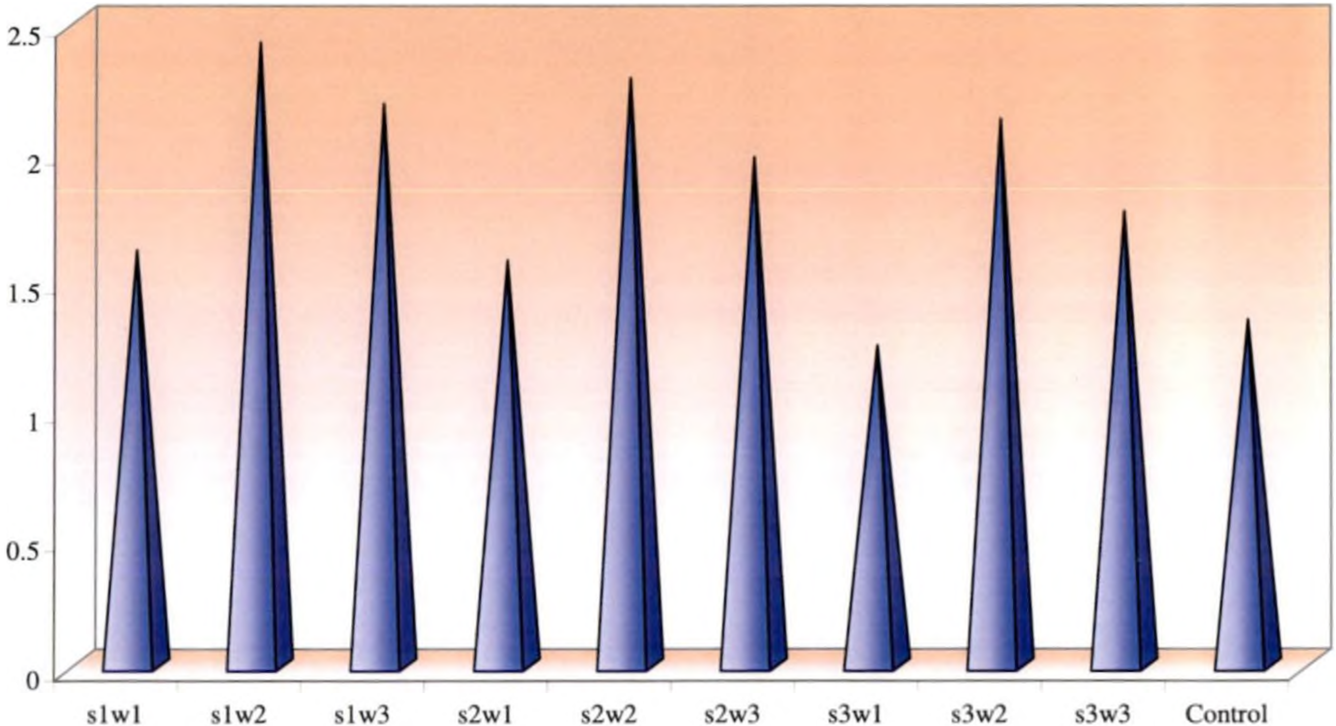


Fig. 10. Interaction effect of spacing and weed management practices on B:C ratio

the reduced yield realised in this treatment. Compared to hand weeding, the combinations of rotary weeding with different spacings were found to be superior as far as the net income was concerned. Though the yield from rotary weeding was lower than hand weeding practice, the low cost for rotary weeding compensated the yield reduction registering higher net income. The cost effectiveness of using finger weeder and pre-emergent application of butachlor combined with one hand weeding over hand weeding twice was also reported by Saha *et al.* (2005)

Since hand weeding is a labour intensive operation, it enhanced the cost involved for weeding operation resulting in low net income and benefit-cost ratio. Similar reports on reduced net profit due to increased labour charges were also reported by Ravindran (1976) and Rao *et al.* (1993). Singh (1985) obtained a negative cost-benefit ratio from hand weeded plots due to high labour cost.

From an analysis of the results of the present study, the following conclusions could be drawn.

1. Rice productivity can be improved by practicing SRI in areas where water can be managed.
2. For SRI practice, planting 12 day old seedlings in a square pattern with 20 x 20 cm or 25 x 25 cm spacing is ideal.
3. Use of pre-emergent herbicide followed by one hand weeding entails economic management of weeds in this system.

Summary

6. SUMMARY

The present study entitled 'Standardisation of System of Rice Intensification (SRI) technique' was taken up at College of Agriculture, Vellayani during July 2005 to April 2006. The investigation was undertaken as two experiments, a pot culture trial followed by a field study, to compare the performance of rice under SRI and normal system of cultivation and to standardize the seedling age, spacing and weed management for rice under SRI system of cultivation.

To standardize the seedling age under SRI, a pot culture study was laid out in CRD with six treatments and five replications. The treatments included transplanting single seedling of 8, 10, 12, 14 and 16 days old. Transplanting 21 day old seedling @ three seedlings hill^{-1} formed the control.

Seedling age significantly influenced the growth characters like tiller number hill^{-1} and yield attributes like number of productive tillers hill^{-1}. Among the treatments, 12 day old seedling recorded the maximum number of tillers and productive tillers. The highest grain yield was recorded by 12 day old seedling which was on par with 14 and 16 day old seedling. All the treatments were significantly superior to control in grain and straw yield.

Based on pot culture study, 12 day old seedlings were selected for field experiment.

The field experiment was laid out in factorial RBD with two factors, in nine treatment combinations and a control in three replications. The factors included three spacings, namely, 20 x 20 cm (S_1), 25 x 25 cm (S_2)and 30 x 30 cm (S_3) and three weed management practices, namely, hand weeding twice at 20 and 40 DAT (W_1), use of pre-emergent herbicide, butachlor @ 1.25 kg ai ha^{-1} followed by hand weeding (W_2), rotary weeding at 10 days interval starting from 10 DAT (W_3) and a control (transplanting 21 day old

seedlings at a spacing of 20 x 10 cm and hand weeded twice at 20 and 40 DAT).

The different spacings followed had no significant influence on growth attributes like plant height and tiller number. The closer spacing of 20 x 20 cm (S_1) recorded significantly higher LAI and LAD and also produced higher dry matter production at 30 and 90 DAS and at harvest. The number of productive tillers hill^{-1} and m^{-2} were also the highest for 20 x 20 cm. Other yield attributes like weight of panicle and number of spikelets per panicle were significantly superior in 25 x 25 cm spacing. Regarding yield, no significant variation was observed among the spacings tried. The SRI plots registered higher value for yield attributes and the yield was significantly superior to control.

The growth attributes like plant height, tiller number hill^{-1} and dry matter production and the yield attributes were not influenced by weed management practices. Use of pre-emergent herbicide followed by hand weeding significantly enhanced the grain yield which was on par with hand weeding twice (W_1). However, the straw yield was not influenced by weed management practices.

The interaction effect of spacing and weed management practices failed to show any significant impact on either the growth characters or the yield attributes.

The most important grassy weeds observed in the experimental area were *Isachne miliacea* Roth ex Roem. et Schult and *Echinochloa colona* (L.) Link. Among sedges, *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliacea* (L.) Vahl were the predominant ones. *Ludwigia parviflora* Roxb., *Monochoria vaginalis* (Burm. F.) Kunth and *Marsilea quadrifoliata* were the common broad leaved weeds observed.

With respect to absolute density of all types of weeds, the control plot recorded a significantly lower value compared to treatment combinations at 30 and 90 DAS. After that the variation between treatments and control was not significant. The same trend could be noticed in absolute density of grasses.

Though the control plot recorded a significantly lower value for weed parameters like absolute density of each species, relative density of grasses and sedges and total absolute frequency during the early stages of observation (30 and 60 DAS), at later stages the variation between control and treatments was found insignificant.

Regarding dry weight of weeds, spacings of 25 x 25 cm and 30 x 30 cm were on par and recorded significantly higher values than closer spacing of 20 x 20 cm. Hand weeding twice recorded significantly the lowest weed dry weight at all growth stages. At 90 DAS and at harvest, significantly higher weed dry weight was recorded in rotary weeded plots. At 90 DAS, the treatment combination of closer spacing along with hand weeding recorded a significantly lower weed dry weight which was on par with closer spacing with herbicide application. The control plot recorded a significantly lower weed dry weight at 30 and 90 DAS and at harvest and was superior to other treatment combinations.

The nutrient uptake by rice was the highest in closer spacing of 20 x 20 cm. Among the weed management practices, W_2 recorded significantly higher nutrient uptake at 30 DAS whereas, at 60 DAS, rotary weeding recorded significantly higher nutrient uptake. The control plot recorded significantly higher nutrient uptake by crop compared to treatment combinations at early growth stages but towards later stages, the effect was found non-significant.

In case of nutrient uptake by weeds, medium spacing of 25 x 25 cm (S_2) recorded significantly higher values. Among the weed management practices, hand weeding twice (W_1) recorded significantly lower nutrient uptake by weeds. The control plot recorded significantly lower nutrient uptake by weeds and was significantly superior to all other treatment combinations.

Among the treatment combinations, closer spacing of 20 x 20 cm (S_1) along with the use of herbicide followed by hand weeding recorded the highest net income and benefit-cost ratio. The treatment combinations involving various spacings along with hand weeding twice (W_1) recorded lower net income and benefit-cost ratio. Though rotary weeding (W_3) along with different spacings recorded comparatively lower cost of cultivation, the net income was low. The net income and benefit-cost ratio in SRI treatments were higher than the control.

The present investigation revealed the superiority of SRI practice of rice cultivation over conventional method on yield and economics of rice.

FUTURE LINE OF WORK

For enhancing the productivity of rice in SRI, location specific research on the following lines can be initiated.

- Standardisation of integrated crop management for rice in SRI with more thrust to organic farming
- Developing farmer friendly low cost implements for easy transplanting and weed management in SRI
- Assessing the effect of SRI on the productivity of rice in different seasons.

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*Original not seen

Appendices

APPENDIX-I

Weather parameters during pot culture study
(July 2005-November 2005)

Standard weeks	Relative humidity (%)	Maximum temperature (°C)	Minimum temperature (°C)	Evaporation (mm)	Rainfall (mm)
28	88.0	30.7	23.7	3.8	78.3
29	94.4	29.6	23.6	3.3	12.0
30	92.7	29.6	24.2	2.8	82.7
31	91.7	30.0	23.2	3.7	76.8
32	88.4	31.5	23.7	4.4	00.0
33	85.6	31.9	23.6	4.5	00.0
34	87.4	32.1	23.8	4.3	00.0
35	89.7	31.6	23.7	3.7	22.0
36	95.1	29.6	22.9	2.8	112.0
37	89.9	29.8	23.6	3.8	27.0
38	83.0	31.7	24.1	4.7	00.0
39	80.3	32.5	24.0	5.3	00.0
40	79.0	32.8	23.8	5.0	00.0
41	87.3	30.6	23.4	3.7	99.0
42	90.9	32.0	23.5	4.2	12.0
43	95.0	30.1	23.5	2.4	118.0
44	91.3	30.9	24.1	3.1	25.0

APPENDIX - II

Weather parameters during cropping period (December 2005-April 2006)

Standard weeks	Relative humidity (%)	Maximum temperature (°C)	Minimum temperature (°C)	Evaporation (mm)	Rainfall (mm)
50	95.6	29.5	22.7	3.4	90.8
51	95.1	30.8	23.4	7.2	4.9
52	95.1	31.4	21.6	9.2	00.0
1	95.9	32.1	22.8	7.7	00.0
2	92.1	32.2	23.7	3.9	13.2
3	93.4	28.6	20.8	6.6	9.2
4	96.0	31.2	21.7	9.5	00.0
5	93.0	31.8	22.4	8.5	00.0
6	90.3	32.2	22.4	9.0	00.0
7	91.0	32.2	22.5	9.3	00.0
8	91.1	32.4	23.2	9.3	00.0
9	94.0	31.6	23.9	8.1	4.1
10	92.6	32.3	23.6	8.2	24.2
11	94.4	32.9	24.0	8.9	00.0
12	94.4	32.8	24.6	8.1	1.1
13	96.0	32.9	24.7	8.9	19.7
14	91.3	32.5	23.6	7.1	55.2

STANDARDISATION OF SYSTEM OF RICE INTENSIFICATION (SRI) TECHNIQUE

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Abstract of the
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ABSTRACT

An experiment was conducted at College of Agriculture, Vellayani to compare the performance of rice under SRI and normal system of cultivation and to standardize the seedling age, spacing and weed management for rice under SRI system of cultivation. The investigation was programmed as two experiments, a pot culture trial followed by a field study.

The pot culture study to standardize the seedling age under SRI, was laid out in CRD with six treatments and five replications. The treatments included transplanting single seedling of 8, 10, 12, 14 and 16 days old. Transplanting 21 day old seedling @ three seedlings $hill^{-1}$ formed the control.

The results of the study revealed that the number of productive tillers were the highest for 12 day old seedlings which contributed to greater yield and this was on par with 14 and 16 day old seedlings. All the treatments were significantly superior to control in grain and straw yield.

Based on pot culture study, 12 day old seedlings were selected for field experiment.

The field experiment was laid out in factorial RBD with two factors, in nine treatment combinations and a control in three replications. The factors included were three spacings, *viz.*, 20 x 20 cm, 25 x 25 cm and 30 x 30 cm and three weed management practices, namely, hand weeding twice at 20 and 40 DAT, use of pre-emergent herbicide, butachlor @ 1.25 kg ai ha^{-1} followed by hand weeding, rotary weeding at 10 days interval starting from 10 DAT and a control (transplanting 21 day old seedlings at a spacing of 20 x 10 cm and hand weeded twice at 20 and 40 DAT).

Among the different spacings followed, closer spacing of 20 x 20 cm recorded higher growth characters and produced more number of productive tillers $hill^{-1}$ and per unit area. The closer spacings registered higher grain yield than 30 x 30 cm spacing, though not significant. However, all the SRI

treatments registered significantly higher values for growth characters and yield attributes thus resulting in a higher yield compared to control.

Among the weed management practices, the use of butachlor followed by hand weeding, recorded better growth attributes and productive tiller count $hill^{-1}$ thus contributing to a significantly higher grain yield which was on par with hand weeding twice.

Though the control plot recorded a significantly lower value for weed parameters during the early stages of observation, at later stages the variation between control and treatments was found insignificant.

The nutrient uptake by the crop was the highest at 20 x 20 cm spacing whereas for weeds, 25 x 25 cm spacing recorded higher values. Among the weed management practices, hand weeding twice recorded significantly lower nutrient uptake by weeds. The control plot was superior to other treatment combinations and registered significantly lower nutrient uptake by weeds.

The closer spacing of 20 x 20 cm along with the use of herbicide followed by hand weeding resulted in the highest net income and benefit-cost ratio. The net income and benefit-cost ratio in SRI treatments were higher than the control.

Compared to the existing method of rice cultivation, SRI treatments showed their superiority in augmenting the grain yield and income.