INTEGRATED WEED MANAGEMENT UNDER SYSTEM OF RICE INTENSIFICATION (SRI)

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Integrated weed management under system of rice intensification (SRI)"** is a bonafide record of research work done by me during the course of research and this thesis has not previously formed the basis for the award to me 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 **"Integrated weed management under system of rice intensification (SRI)"** is a record of research work done independently by Mr. Musthafa Kunnathadi under my guidance and supervision and that it has not previously formed the basis for award of any degree, fellowship or associateship to him.

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(Musthafa Kunnathadi)

Dedicated to

My

Loving Family

CONTENTS

Abbreviations and Expansion

Abbreviation		Expansion
@	-	At the rate of
a.i.	-	Active ingredient
BC	-	Benefit:cost
cm	-	Centimetre
CD	-	Critical difference
CS	-	Conventional system
CW	-	Cono weeding
DAT	-	Days after transplanting
DMP	-	Dry matter production
DMRT	-	Duncan's Multiple Range Test
E	-	East
EC	-	Electrical conductivity
et al.	-	Co workers
Fb	-	Followed by
Fig.	-	Figure
G	-	Gram
g m^{-2}	-	Grams per metre square
h^{-1}	-	Per hour
ha^{-1}	-	Per hectare
HI	-	Harvest index
HW	-	Hand weeding
K	-	Potassium
KAU	-	Kerala Agricultural University
kg m^{-3}	-	Kilograms per cubic metre
m^{-2}	-	Per metre square
N	-	Nitrogen/ North
NGOs	-	Nongovernmental organizations
P	-	Phosphorus
pH	-	Negative logarithm of hydrogen ion concentration
PI	-	Panicle initiation
RARS	-	Regional Agricultural Research Station
RPM	-	Revolutions per minute
Rs. ha^{-1}	-	Rupees per hectare
SPSS	-	Statistical Package for the Social Sciences
SRI	-	System of rice intensification

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Introduction

1. INTRODUCTION

Rice has been cultivated sustainably for centuries through scientifically well defined and accepted management technologies and inputs. As a deviation from this, system of rice intensification (SRI), a set of certain management practices in rice cultivation derived from the work of a French Jesuit priest, Fr. Henri de Laulanie′ in Madagascar during the 1980s, is reported to offer increased productivity of rice with limited inputs (Laulanie, 1993). SRI management involves many departures from the methods conventionally recommended for rice cultivation. These management practices include: (a) transplanting younger seedlings, (b) widely spaced transplanting with one seedling per hill, (c) application of compost or other organic amendments, (d) intermittent irrigation before panicle initiation (PI) and shallow water management from PI to maturity, and (e) intensive manual and mechanical weed control starting from 10 days after transplanting and continuing until the canopy closes (Uphoff, 2002).

SRI technology is reported as an alternative sustainable low cost system to the conventional rice farming (Batuvitage, 2002) and the advocates of SRI claim that the approach would permit resource poor farmers to attain very high yields with infertile soil, without mineral fertilizer input and with reduced irrigation and fewer seed (Stoop *et al.*, 2002). Yield increase to the tune of 2 to 6 t ha^{-1} has been reported in SRI in Madagascar (Uphoff, 2002) and there are reports from various locations in India claiming 16 to 32 per cent yield advantage over the conventional system (Viraktamath, 2007; Sinha and Talati, 2007).

On the other hand, many criticisms have been raised against its assessed yield superiority over the conventional best management practices, the reliability of reported super high yields and the applicability in large scale rice farming systems (McDonald *et al.*, 2006; Senthilkumar *et al.* , 2008). However, SRI has been practised in 40 countries (Murugavel, 2011).

In Kerala, SRI has been introduced recently through certain NGOs, directly in the farmers' fields as demonstrations, without any scientific evaluation. There are contradictory claims on the yield advantage of SRI from different locations. Sindhu (2008) studied SRI and its modifications in *kole* lands and came to a conclusion that these are inferior in yield wherever farmers follow recommended package of practices. In view of the contradictory results it became necessary to compare the performance of SRI and conventional method of rice cultivation in more areas representing major rice farming situations in Kerala, viz. Palakkad (upland rice fields) and *Kole/Kuttanad* (low land kayal areas).

Heavy weed growth is the major problem faced by SRI in consequence to the wider spacing and lack of flooding in the field. Therefore SRI warrants repeated weeding using cono weeder. Cono weeding manually is a tiresome job that requires more labour investment, and hence is not being adopted successfully leading to occasional crop loss. Moreover, the use of manual cono weeder has been reported to cause drudgery to the operator (Ravindra *et al.*, 2006). These have further necessitated economic weed management strategies in SRI. Latif *et al.* (2005) have reported the effectiveness of using herbicides in SRI, which could reduce the labour for weeding and thereby minimize the economic loss in SRI. Further, an idea was also mooted from many quarters to develop a self propelled version of the cono weeder aiming at reducing drudgery to the operator.

In the above circumstances, the present study was undertaken with the following objectives:

1. To study the feasibility of system of rice intensification (SRI) in selected rice growing agro-ecological situations in the Kerala state, in comparison with conventional system of rice cultivation.

2. To identify the weed problems under SRI and developing an economic weed management strategy through assessment of integration of cono weeding with herbicides as well as hand weeding.

3. To develop a prototype of self propelled cono weeder and to test its weeding efficiency in rice.

Review of Literature

2. REVIEW OF LITERATURE

System of Rice Intensification (SRI) has been claimed to be a rice cultivation method that uses lesser inputs but increases the productivity of irrigated rice. Many claims and counter claims about its feasibility have been reported from various parts of the world, including some of the states in India, where the system was directly taken to the farmer's fields without much research backing. Motivated by the world wide propaganda on SRI, the rice farmers in a few pockets of Kerala too have started experimenting on it, without any scientific recommendation.

In India there are three principal systems of rice cultivation, i.e. dry, semi-dry and wet systems. The dry or upland rice cultivation is mainly confined to tracts receiving monsoons and not having adequate irrigation facilities. After bringing the soil to necessary tilth, seeds are sown broadcast at marginal soil moisture level.

Under the semi-dry system of rice cultivation, seeds are sown broadcast and the crop grows as a dry crop for about two months. Afterwards, when more water is available through the monsoon rains the field gets standing water and the crop is treated as a wet crop.

In wet or low land condition, land is puddled by repeated ploughing and seedlings are transplanted or sprouted seeds are broadcasted. Rice has been grown under flooded conditions for centuries for various reasons. Burial of weeds during puddling, assured plant population, reduced infiltration rate of water etc. are some of the advantages of this system (Chatterjee and Maiti, 1988). In addition, there is a belief that rice performs better under standing water (Reddy and Reddy, 1999).

In the recent times, another system of rice cultivation, known as the System of Rice Intensification (SRI) has been vigorously promoted as a method for substantial improvement in the yield of rice, through a set of synergistic management principles. Several reports project SRI as an alternative to the traditional flooded rice cultivation and claim as a promising method to address the problems of water scarcity, high energy use and environmental degradation (Batuvitage, 2002; Stoop *et al.*, 2002; Uphoff, 2002).

2.2. The System of Rice Intensification (SRI)

The system of rice intensification was developed around Antsirabe in Madagascar during 1983-84 by Father Henry de Laulanie, a French Jesuit priest and agriculturist (Association Tefy Saina, 1992). SRI technology is reported to have been successfully tried out in 40 countries (Murugavel, 2011), as an alternative sustainable low cost system to the conventional rice farming (Batuvitage, 2002). According to its proponents, SRI encompasses a set of five principles, each of them fairly simple, but working synergistically with the others in order to achieve higher grain yield (Uphoff, 2002).

2.2.1. The management practices in SRI

The management practices in the system of rice intensification include: (i) transplanting young (8 to 15 days old) seedlings, (ii) widely spaced transplanting with one seedling per hill in a square pattern, (iii) application of compost or other organic amendments, (iv) intermittent irrigation before panicle initiation (PI) and shallow water management from PI to maturity, and (v) mechanical weed control starting from 10 days after transplanting and continuing until the canopy closes (Stoop *et al.*, 2002). Uphoff (2001) and Senthilkumar *et al.* (2008) could observe yield increase in SRI through modification of irrigation, planting and weeding methods compared to the conventional method.

(i) Age of the seedlings

Numerous reports are available on the relationship between the age of seedlings at transplanting and the performance of rice crop. Phyllochron, which has been used to characterize the growth dynamics of cereals, is defined as the interval of leaf emergence. It varies with temperature, day length, nutrition, light intensity, planting density and humidity (Nemoto *et al.*, 1995). According to Katayama's tillering model, the first tiller of the main stem appears at the fourth phyllochron (Katayama, 1951), and hence SRI recommends transplanting of seedlings during the third phyllochron, the stage when the plant has only two leaves (8-14 days old), in order to avoid reduction in subsequent tillering and root growth (Laulanie, 1993). It was reported that if the rice seedling is transplanted later than the third phyllochron, the resulting plant will lose all of the incoming tillers from this first row of tillers which represents about 40 per cent of the total tillers, and that any further delay of transplantation leads to a bigger loss of tillers (Association Tefy Saina, 1992). Studies at the Directorate of Rice Research, Hyderabad have also shown the significance of age of seedling at transplanting under SRI (Viraktamath, 2007).

Results of many studies on SRI showed that seedlings as young as seven days old performed better than more aged seedlings (Makarim *et al.*, 2003; Thiyagarajan *et al.*, 2002a; Pasuquin *et al.*, 2008). Horie *et al.* (2005) reviewed the benefits and morphological effects of transplanting young seedlings and reported that younger seedlings have faster recovery from transplanting stresses and higher potential for tiller production than aged seedlings. Kim *et al.* (1999) also reported similar observations and opined that the younger seedlings have more vigour, root growth and lesser transplanting shock. According to them lesser leaf area during the initial growth stages stimulates cell division causing more stem elongation resulting in increased plant height. Early transplantation in conjunction with other practices allows greater realization of the tillering potential of rice plants (Association Tefy Saina, 1992). Krishna *et al.* (2008a) observed early flowering by 4 to 5 days in 8 day old seedlings compared to 25 day old seedlings.

In an investigation for finding out appropriate age of seedlings for transplanting in SRI, Singh (2006) observed that lesser the duration lesser is the seedling age that performs better under SRI. Thus the early maturing varieties exhibited better impact on grain yield, number of tillers per plant and root biomass per plant (per hill) with 10 day old seedlings as compared to other seedlings that aged more. Similarly, medium maturing varieties showed equally good response with 12 day old seedlings and late maturing varieties showed similar response with 16 day old seedlings.

Reddy *et al.* (2006) reported seasonal influence on the performance of seedlings based on their age. In wet season, transplanting 10 day old seedlings recorded significantly lower grain yield (56.59 q ha^{-1}) than 15 day (59.74 q ha^{-1}) and 20 day (59.48 q ha^{-1}) old seedlings, while during dry season transplanting 10 day and 15 day old seedlings recorded significantly higher grain yield (69.89 q ha^{-1} and 68.06 q ha^{-1}) over 20 day old seedling (61.92 q ha^{-1}).

Even though there are many reports on the benefits of planting young seedlings, conflicting reports are also there, as certain studies have shown better performance of old seedlings. Senthilkumar *et al.* (2008) and Latif *et al.* (2005) noted that although large amounts of total dry matter were produced under SRI planting, the use of young seedlings could not make any significant change in the grain yield. Yadao and Zamora (2007) also reported the superiority of conventional method over SRI from their observation that the conventional system using 21-25 day old seedlings planted at 2-3 seedlings per hill with continuous irrigation had higher root pulling resistance, leaf area index and harvest index, produced longer panicles with more filled grains and higher 1000 seed weight and recorded higher grain yield than SRI. A better performance, in terms of grain yield, with transplanting 20 day old seedling over 10 day old seedling was also reported by Anitha *et al.* (2007).

(ii) Number of seedlings transplanted per hill and spacing

Conventional methods are characterized by transplanting three or more seedlings per clump. Planting more seedlings per clump is thought to provide assurance to the farmers that if one plant dies others can still grow and thus can ascertain a lower percentage of missing hills.

SRI, however, recommends transplanting single seedling per clump (Association Tefy Saina, 1992). Barison (1997) reported that a single rice plant could express its tillering potential better than a larger number per clump. The author also observed that transplanting three seedlings together impeded rice growth in that the adjacent plants had to compete for nutrients, space and light. This competition repressed root growth and proliferation. When root systems are poorly developed, the plant devotes its energy for developing the seedlings in height at the cost of production of tillers.

Plant spacing was also found critical in the performance of rice under SRI (Viraktamath, 2007). SRI advocates a wider spacing of 25 cm x 25 cm or above, depending on the fertility of the soil, as with wider spacing, all leaves, including the lower ones, can be photosynthetically active and can contribute to the plant's pool of photosynthates and also to the roots' nutrient supply (Stoop *et al.*, 2002) thereby resulting in the spread of roots and healthy growth of plants (Association Tefy Saina, 1992). Based on the results of scientific studies, KAU (2007) has recommended 15 cm x 10 cm as the optimum spacing for short duration varieties and 20 cm x 10 cm for medium duration varieties.

Krishna and Biradarpatil (2009) compared seedlings of different ages planted at different spacing under SRI and found that 12 day old seedlings performed better under a wider spacing of 40 cm x 40 cm with higher seed yield per hectare and seed quality parameters. Mishra and Salokhe (2008) compared the effect of transplanting single seedling at different spacing along with intermittent flooding during the vegetative stage and found that a wider spacing of 30 cm x 30 cm improved root length, root density, root physiological activity and chlorophyll content of the upper and lower leaves, and led to higher grain yield over a narrower spacing of 20 cm x 20 cm under SRI, indicating synergistic effect of wider spacing on grain yield due to reduced intra hill competition.

Senthilkumar *et al.* (2008) reported yield advantage under SRI with a plant density of 25 hills m^{-2} over conventional planting with 50 hills m^{-2} and attributed it to a significantly larger tiller density and higher number of productive tillers under SRI. Bommayasamy *et al.* (2010) observed higher number of productive tillers m^{-2} (491) but lower number of filled grains per panicle (116.7) at 20 cm x 20 cm spacing and resulted in significantly higher grain yield (8.0 t ha^{-1}) and straw yield (9.1 t ha^{-1}) as compared to 25 cm x 25 cm or 30 cm x 30 cm spacing under SRI.

Singh and Ghosh (1988) reported that 25 per cent reduction in plant density had very little effect on yield. Physiological studies on SRI by Lin *et al.* (2005) showed that when the transplanting density was decreased from 1.95×10^5 to 0.75×10^5 hills ha^{-1} under SRI, the leaf area index remained constant, and light transmittance of canopy, photosynthetic rate and water use efficiency of the 9^{th} to 13^{th} leaves increased, while the transpiration rate of the leaf decreased, and the highest yield was obtained at a transplanting density of 1.65×10^5 hills ha^{-1}.

Although the tiller density of individual hill was higher under wider spacing, the total tiller production was higher with more plant population per unit area under closer spacing. Latif *et al.* (2005) reported higher yields under conventional planting when compared to SRI. The authors observed the highest yield of 7.53 t ha^{-1} at 25 cm x 15 cm spacing and the lowest yield of 5 t ha^{-1} at 40 cm x 40 cm spacing. These authors further reported the significance of conventional management following package of practices recommendations over SRI management through observations of higher grain yield, lower cost and higher profit (Latif *et al.* 2009). Mishra and Salokhe (2010) also reported no significant yield difference between SRI and conventional system, as wider spacing improved only the performance of individual hills, but tiller number per unit area remained a dominant determinant of yield. Tallest plants, highest total dry matter production and greatest leaf area index were observed under SRI with 25 cm x 25 cm spacing, while significantly higher tiller density per m^2 was at 15 cm x 10 cm spacing with same age of seedlings (14 days) (Vijayakumar *et al.*, 2004 and 2006a).

The influence of wider spacing in SRI as observed by Kumar *et al.* (2006a) was that SRI caused profuse tillering and maximum tiller number per hill (46.6 tillers $hill^{-1}$) at 40 cm x 40 cm spacing while conventionally grown crop (15 cm x 10 cm) produced 12.2 tiller $hill^{-1}$. Thus, the crop produced maximum number of productive tillers m^{-2} under conventional practice (353) and minimum at 40 cm x 40 cm spacing (208 tillers m^{-2}). Panicle length, grain number per panicle and 1000 grain weight were higher under SRI, however these were not significantly reflected in the yield, as the grain and straw yields were 4561 kg ha^{-1} and 4508 kg ha^{-1} under SRI and 4299 kg ha^{-1} and 4574 kg ha^{-1} under conventional practice, respectively. Islam *et al.* (2005) also reported reduction in tiller density per unit area with increase in plant spacing. Similar was their observation with the number of filled spikelets per panicle. Even though large spikelets were found in plants grown under SRI, no significant yield differences were observed among SRI and conventionally transplanted treatments and higher sterility was recorded with wider spacing. Thakur *et al.* (2009) also reported yield reduction at wider spacing and this was attributed mainly to less number of panicles m^{-2}. Sindhu (2008) reported similar observations that there were higher number of tillers $hill^{-1}$ and lesser number of tillers per unit area at wider spacing. At 30 cm x 30 cm spacing the number of tillers $hill^{-1}$ was 12.04, 15.42 and 16.13 at maximum tillering, panicle initiation and harvest stages, respectively, while it was 5.32, 5.28 and 5.43 at the respective stages in a closer spacing of 10 cm x 10 cm. However, on unit area basis a reverse trend was observed, i.e., 134 to 162 tillers m^{-2} at 30 cm x 30 cm spacing as against 495 to 533 tillers m^{-2} at 10 cm x 10 cm spacing.

Thakur *et al.* (2010b) observed significant improvement in the performance of individual hills under wider spacing in terms of root growth, xylem exudation rate, leaf number, leaf size, canopy angle, tiller number, panicle number, panicle length, grain number per panicle, grain filling, 1000 grain weight and straw weight irrespective of whether SRI or RMP (recommended management practice) was employed. Both sets of practices gave their maximum grain yield with the spacing of 20 cm × 20 cm, in which canopies had the highest leaf area index (LAI) and light interception during flowering stage, but the lowest yield was with 30 cm × 30 cm spacing, as a result of less plant population (11 m^{-2}), despite improved hill performance. During the ripening stage, hills with wider spacing had larger root dry weight and produced greater xylem exudates and these exudates were transported towards shoot at faster rates. These features contributed to the maintenance of higher chlorophyll levels, enhanced fluorescence and photosynthetic rates of leaves and supported more favourable yield attributes and grain yield in individual hills than in closely spaced plants.

Borkar *et al.* (2008) reported significant influence of SRI at wider spacing of 30 cm x 30 cm compared to 25 cm x 25 cm on number of productive tillers, dry matter accumulation and grain yield per plant, but grain and straw yields per unit land area was significantly higher with 20 cm x 15 cm spacing and this narrow spacing recorded the highest GMR, NMR and B: C ratio. Anitha *et al.* (2007) also reported similar results. Reddy *et al.* (2006) have reported higher yield of rice at a closer spacing of 10 cm x 10 cm over a wider spacing of 20 cm x 10 cm or even higher. Menete *et al.* (2008) observed a reduction of 2.2 to 11 per cent in rice grain yield under wider spacing. Thus, wider spacing beyond the optimum plant density, however does not give higher grain yield on area basis, and for achieving this combination of improved hills with optimum plant density must be worked out in SRI (Thakur *et al.*, 2010a).

(iii) Compost application

Proponents of SRI recommend the use of organic manure (compost) instead of chemical fertilizer (Association Tefy Saina, 1992). The idea is to capitalize on the biological resources and organic matter in the compost and to maintain optimum biological activity of the soil. This organic fertilizer application is believed to improve the soil structure and the continual release of nutrients. But, according to Tsujimoto *et al.* (2009) use of organic amendments is a time and energy consuming technique.

(iv) Soil moisture retention during vegetative phase

In low land rice culture water management is the most important practice that determines the productivity of other inputs such as nutrients, herbicides, pesticides, farm machinery and microbial activity. Irrigated rice is grown under standing water throughout the season as there is a belief that rice performs well under flooded condition. Under flooding, rice roots alter their root cortical cells by the creation of air pockets (aerenchyma) to facilitate oxygen transport to roots since the concentration of soluble oxygen in the water/soil interface is very low and the diffusive transport of oxygen is about 10^4 times lower in water than in air. Such cell lysis leads to the formation of gas filled cavities or lacunae which enhances the transport of oxygen from the shoot to the root tip (Drew, 1997; Puard *et al.*, 1989.; Vartapetian, 1993). Puard *et al.* (1989) noticed this mechanism when an upland rice variety was planted in a lowland condition with standing water, and they found that lack of oxygen leads to more aerenchymatous spaces in the root system. Rice plants, when grown under saturated condition, develop more hairy, fine and branched secondary adventitious roots near the root soil interface in order to absorb the dissolved oxygen in the oxidized layer close to the water soil interface (Obermueller and Mikkelsen, 1974).

SRI is based on the concept that deliberate flooding or poor drainage that keeps soil saturated is detrimental to the crop and degrades soil quality. It provides full potential for root growth by creating aerobic conditions through alternate wetting and drying. Here the paddy soil is kept moist and not continuously inundated or saturated during the vegetative phase of the plant. In these intermittent dry and flooded conditions there are fewer adventitious roots and more of tap roots and primary roots. Such rooting pattern is apparently the result of soil aeration brought about by intermittent drainage (Association Tefy Saina, 1992). Tsujimoto *et al.* (2009) suggested that more oxidative soil conditions during the vegetative growth stage under SRI water management maintains root activity and plant N uptake in later growth stages, and consequently results in higher yields. Keeping the soil moist and aerated during the vegetative growth period makes the roots to have access to both oxygen and water. Under continuous hypoxic conditions, rice roots degenerate with as many as 75 per cent dysfunctional by panicle initiation (Kar *et al.*, 1974).

Ceesay *et al.* (2006) reported the beneficial effects of repeated wetting and drying on rice growth. At 20 cm and 30 cm spacings, average grain yields with SRI water management practice were 7.3 t ha^{-1} and 6.6 t ha^{-1} respectively, while they were only 2.5 t ha^{-1} and 1.7 t ha^{-1} under continuous flooding. They attributed this to the increased nutrient availability and superior growing conditions which enhanced physiological development and grain yield. Rewetting dry soil reportedly facilitates nitrogen mineralization (Birch, 1958) and Cheng *et al.* (2002) reported a decreased denitrification and thereby a better nitrogen economy.

Under alternate flooding and drying of soils, aerobic and anaerobic bacteria and mycorrhizal fungi have an opportunity to contribute to plant growth (Brimecombe *et al.*, 2001). Under these conditions, there is increased N fixation

(Magdoff and Bouldin, 1970) and P solubilization (Turner and Haygarth, 2001). Triveni *et al.*(2006) reported a higher number of colony forming units (cfu g^{-1} soil) of total bacteria (76.8 x10^5), fungi (36 x 10^4), actinomycetes (147.5 x 10^3) and azotobacter (36.5 x 10^3) and a lesser number of phosphate solubilizing bacteria (PSB) (40.0 x 10^3) under SRI and a lower number of bacteria (47.5 x 10^5), fungi (16.5 x 10^4), actinomycetes (53.8 x 10^3) and azotobacter (32.1 x 10^3) and a higher number of PSB (62.0 x 10^3) under continuous flooded condition in the normal practice. This indicated that SRI method facilitated build up of useful soil micro flora, except phosphate solubilizing bacteria. Many species of bacteria and fungi produce phytohormones in the rhizosphere viz., auxins, cytokinins, ethylene etc. that regulate and promote root growth (Arshad and Frankenberger, 2001). But Hugar *et al.* (2009) did not observe any difference in the microbial counts under SRI, including total bacteria, fungi, actinomycetes, siderophore producers, fluorescent *Pseudomonas*, P solubilizers and N_2 fixers.

Senthilkumar *et al.* (2008) reported 41 per cent saving in irrigation water and no reduction in yield in the water saving irrigation compared to the conventional irrigation. Sandhu *et al.* (1980) and Li *et al.* (2005) also found no adverse effects on rice yields with intermittent irrigation at 1 to 5 days after disappearance of standing water which saved 25 to 50 per cent water compared to continuous submergence. Bindraban *et al.* (2006) reported water saving upto 50 per cent without penalty on yield for a range of experimental conditions. While discussing the pros and cons of SRI, Shaik (2009) also described water conservation as the major advantage of SRI. To produce 1 kg grain through SRI, Kumar *et al.* (2006a) worked out the water requirement as 2710 litres in contrast to 3720 litres through the conventional method. Reddy *et al.* (2005) also observed that the prime gain from SRI was its water saving rather than yield improving capability. Babu *et al.* (2006) reported water saving to the tune of 22 per cent in SRI and 39 per cent in SRI-eco compared to the conventional method, though the yields were similar in different crop establishment methods. No significant yield difference was noticed between intermittent irrigation and continuous flooding and hence there can be 50 per cent water saving through intermittent irrigation without affecting the yield (Anitha and Usha, 2008).

Contrary to the above findings Menete *et al.* (2008) observed in their field studies on SRI in the salt-affected soils in Mozambique that intermittent irrigation decreased rice grain yields by 41 to 46 per cent compared to conventional flooding. Similar was the finding by Dutta and Goswami (2006), wherein they reported the lowest yield in SRI under alternate wetting and drying at six days interval when compared to those under shallow submergence, continuous soil saturation as well as the traditional transplanted crop with continuous pounding of water. Luikham (2001) also reported adverse effect of widening of irrigation interval on cell division and cell enlargement resulting in progressive decrease in plant height. Mishra and Salokhe (2010) observed yield reduction upon transplanting single seedling at wider spacing under continuous flooding as compared to 3 to 4 seedlings per hill. This indicated that denser plant population produces more under hypoxic soil conditions, whereas sparser population benefits from aerobic soil conditions.

Flooding the rice field is a scientifically proven technology that influences the yield of rice. One of the key advantages of flooding paddy field is the increase in soil pH up to a level of 6.7 to 7.2. Such a condition favours the release of P element from aluminium or ferrous coated P. The cut off of soil oxygen supply, however, leads to a rapid decrease of the redox potential and thus a gradual appearance of soluble Mn, Fe and methane (Ponnamperuma, 1972). Reducing the degree of flooding in rice may lead to reduced yields, primarily due to changes in crop physiology and increased weed infestation (Datta, 1981; Bouman and Tuong, 2001; Warner *et al.*, 2006). Although increased yield with alternate wetting and drying has been reported (Zhang and Song, 1989), recent findings suggest that this is exception rather than rule (Belder *et al.*, 2004; Cabangon *et al.*, 2004; Tabbal *et al.*, 2002).

Precise control on irrigation water is always required for best results in SRI method. Shaik (2009) observed practical difficulty in the proper management of irrigation water in SRI field, i.e. to keep the soil moist, but not flooded, and allowing it to dry till it develops hair cracks. JiaGuo *et al.* (2004) also reported the complex and laborious nature of management measures for keeping the soil moist (not saturated) under SRI. Studies based on interviews with farmers by Gujja (2006) indicated the single most constraint for the farmers to continue SRI as water, not its availability but its management. Thus, the risk associated with irrigation, sometimes may affect the SRI adoption adversely (Senthilkumar *et al.*, 2008).

(v) Mechanical weeding

In SRI, weeds are controlled mechanically using a rotary pushed weeder, known as the cono weeder. The system relies on early and frequent weeding which varies from three to four times, the first in the series being done at 10 days after transplantation and the others at an interval of 10 to 12 days until the canopy closes (Association Tefy Saina, 1992). SRI recommends planting single seedling at wider spacing, i.e., from 25 cm x 25 cm to 50 cm x 50 cm in a square pattern, rather than in rows, so that weeding can be done using mechanical weeder perpendicularly in two directions instead of just one (Stoop *et al.*, 2002). Detailed reviews are given under 2.3.5.

2.2.2. Effects of SRI practices on growth parameters, yield attributes and yields of rice

Surveys done by Bilger (1996) showed that farmers who practiced SRI obtained a grain yield of 6.3 t ha^{-1} in Antananarivo and 8.0 t ha^{-1} around Antsirabe in Madagascar as against only 3.2 t ha^{-1} and 3.9 t ha^{-1} under conventional rice cultivation. Introduction of SRI practices was reported to increase rice yields from

2 t ha^{-1} to 6 t ha^{-1} on farmers' fields in Madagascar (Uphoff, 2002). Yield advantages of 16.6 per cent (Viraktamath, 2007) and 32 per cent (Sinha and Talati, 2007) were reported in SRI over normal transplanting. Experiments carried out in different parts of India showed yield increase of 9.3 to 68 per cent in SRI compared to the conventional practice (ICRISAT-WWF, 2008). Yield increase in SRI over traditional method has also been reported by Hussain *et al.* (2003), Singh and Talati (2005), Batuvitage (2006), Krishna *et al.* (2008b), Mao *et al.* (2008) and Geethalaksmi *et al.*(2011).

XuHui *et al.* (2006) reported the advantage of SRI that it improved the environment of individual plants through enhanced production potential, increased rooting ability and increased number of tillers per plant. JiaGuo *et al.* (2004) also observed improvement in the growth of individual rice plant under SRI. The authors could observe bigger leaf blades, especially for the functional leaves, more plant height and culm length, 12 per cent more stem diameter of the 4^{th} internode (from top) finally resulting in a very strong stem. Under SRI, as they reported, the length of leaf blade increased from 55.56 cm to 64.41 cm and the width from 1.67 cm to 1.87 cm compared to those in the conventional method. Leaf area index (LAI) was also much higher under SRI.

The plants receiving sufficient space to grow and an increased light transmission in the canopy normally attain increased plant height. A higher number of functional leaves, higher leaf area and higher total number of tillers per hill at wider spacing increase the photosynthetic rate and lead to taller plants (Shrirame *et al.*, 2000). An increase in plant height was also reported by Vijayakumar *et al.* (2006a). Senthilkumar *et al.* (2008) reported greater root dry weight in SRI (0.74 t ha^{-1} to 1.14 t ha^{-1} at panicle initiation stage and 1.54 t ha^{-1} to 2.13 t ha^{-1} at flowering stage) compared to conventional planting (0.7 t ha^{-1} to 0.94 t ha^{-1} at panicle initiation stage and 1.45 t ha^{-1} to 1.72 t ha^{-1} at flowering stage). A higher shoot and root length under SRI compared to conventional transplanting was further reported by Geethalakshmi *et al.* (2011).

Nissanka and Bandara (2004) attributed the higher grain yield in SRI to vigorous and healthy growth, and development of more number of productive tillers and leaves, ensuring greater resource use efficiency compared to conventional transplanting and broadcasting systems. Reddy *et al.* (2008) upon comparing SRI with traditional method observed higher values with number of tillers per hill (28.8 no. $hill^{-1}$), dry weight (121.16 g $hill^{-1}$), length of panicle (30.60 cm), grain yield (55.83 q ha^{-1}), straw yield (106.66 q ha^{-1}) and test weight (24.33 g). Krishna *et al.* (2008a) also reported similar results with respect to number of tillers, productive tillers as well as yield when 12 day old seedlings were transplanted at wider spacing of 40 cm x 40 cm. Singh *et al.* (2006a) observed significant increase in tiller number and panicle number m^{-2}, attributing to 10 per cent increase in grain yield under SRI over the mean grain yield under the conventional transplanting. The authors observed the highest tiller number (544 m^{-2}), panicle number (516 m^{-2}) and dry matter production (1330 g m^{-2}) under SRI, and the lowest tiller number (443 m^{-2}), panicle number (430 m^{-2}) and dry matter production (1104 g m^{-2}) under the conventional transplanting. In addition to these findings, Rahman *et al.* (2006) reported a lower percentage of unfilled grains per hectare under SRI. Further, Zode *et al.* (2008) reported increase in various attributes such as plant height (by 5.04%), number of effective tillers (by 40.25%), number of filled grains per panicle (by 29. 71%), panicle length (by 5.84%), grain yield (by 76.29%) and test weight (by 2.87%) under SRI when compared to the conventional system.

Yao *et al.* (2005) attributed the yield increase under SRI to higher leaf area index, chlorophyll content and dry matter production. Geethalakshmi *et al.* (2011) also reported a higher content of chlorophyll in SRI compared to conventional transplanting at flowering. SRI could form more photosynthetic organs, strengthen photosynthetic ability, produce higher dry matter, provide sufficient nutrient to sink continually, make the seed plumper, increase 1000 grain weight, seed setting percentage and filled grains per panicle, and finally obtain high yield.

According to Wang *et al.* (2002), SRI significantly increased root activity, soluble sugars, non-protein nitrogen and proline contents of leaf, dry matter translocation percentage from vegetative organs to grains and the quality significantly.

Obvious advance of tillering date, promoting healthy and strong growth of plants and increasing grains per spike etc. have been enlisted as advantages of SRI by Hua *et al.* (2006).

Along with a number of reports from different parts of the world on the yield advantages of SRI, there are many scientific results indicating that SRI did not increase the rice yield over the existing best management practices. Mahajan and Sarao (2009) and Abeysiriwardena *et al.* (2009) reported no yield advantage in SRI and Sindhu *et al.* (2006) attributed it to an adverse source sink relationship. Manjappa and Kelaginamani (2006) also observed no significant difference between SRI and normal method of rice cultivation with respect to the grain and straw yields. Similar findings were also reported by Sheehy *et al.* (2004) and Reddy *et al.* (2005).

Similarly, with respect to the yield attributes, research works carried out by Islam *et al.* (2005) showed a reduction in the number of filled spikelets per panicle under SRI which ultimately led to high sterility percentage. Maximum plant height, mean number of tillers and mean grain yield under conventional transplanting compared to SRI were reported by Mankotia *et al.* (2006). Sindhu (2008) also reported similar pattern of observations. FuXian *et al.* (2006) observed negative correlation of yield with the number of grains per panicle of rice hybrids grown under SRI. The hybrids with smaller panicle showed positive yield effect under SRI because of increased number of grains per panicle and total number of spikelets, whereas the hybrids with bigger panicle under SRI showed negative yield effect due to large decline in effective panicle and seed set percentage.

SRI, however, became controversial among the scientists as miraculous yields of 15 t ha^{-1} to 23 t ha^{-1} were reported (Rafaralahy, 2002). The proponents of SRI claimed that the higher yields of 7 t ha^{-1} to 15 t ha^{-1} were achievable in soils with low inherent fertility, greatly reduced rates of irrigation and without external inputs (Stoop *et al.*, 2002; Uphoff, 2002; Stoop and Kassam, 2005). However, the opponents criticized SRI for want of experimental evidences (Sinclair and Cassman, 2004; Sheehy *et al.*, 2005, Pandey *et al.*, 2010). In the context of high popularity of SRI, McDonald *et al.* (2006) assembled the data on comparison of SRI with conventional best management practices, conducted at different locations in different countries, in to a common data base and analyzed. They found that none of the experimental records of SRI, other than the one from Madagascar, showed yield increase by more than 22 per cent over the best management practices. Sheehy *et al.* (2004) reported that experiments conducted in three locations in China, comparing yields in the conventional system and in SRI have revealed no inherent additional advantage in SRI over the conventional system and that the original reports of extra ordinary high yields are likely to be the consequence of error. Supporting to this statement Kumar *et al.* (2006b) observed no significant increase in grain yield of rice under SRI in the first year of their study, but a significantly higher yield in the 2nd year. Shaik (2009), in his discussion on SRI, opined that there was no appreciable increase in yield under SRI compared to the conventional method and most of the farmers who initially tested this concept have shirked it off since 2006.

According to Uphoff (2003), a strong proponent of SRI, the SRI methods change the way plants, soil, water and nutrients are managed, rather than utilizing new variety seeds, inorganic fertilizers or other agrochemicals thereby increasing the rice yield without relying on external inputs and offering environmental and equity benefits. SRI requires more knowledge and skill on the part of farmers and initially more labour and he claimed that this greater labour intensity could be compensated by farmers achieving higher returns for labour.

With regard to the economics of paddy cultivation under SRI, Reddy *et al.* (2008) observed higher net profit (Rs. 40,773 ha^{-1}), benefit cost ratio (3.95) and per day profit (Rs. 351.49) under SRI. Both yield and gross return were significantly higher under SRI and net return was 59 per cent higher over the farmer practice (Rahman *et al.*, 2006). Higher net return (Rs. 28, 873 ha^{-1}) and benefit: cost ratio (2.16) under SRI were observed by Zode *et al.* (2008) also, compared to the conventional system. Sato and Uphoff (2007) reported an average yield increase of 78 per cent in SRI with reduction of 40 per cent in water use, 50 per cent in fertilizer application and 20 per cent in cost of production of the irrigated rice. Moreover, XuHui *et al.* (2006) reported that SRI could decrease the cost of raising seedlings and save irrigation water by 30 to 40 per cent.

Sinha and Talati (2007) reported 67 per cent higher net return and 8 per cent reduction in labour input in SRI over conventional paddy cultivation. They concluded that in West Bengal SRI adoption enabled farmers to enhance paddy yields, increase returns and save labour consistently, and enhance productivity with respect to the key inputs in terms of paddy output per unit of seed, fertilizer and labour day. They also added that SRI promises to be a significant alternative for not only raising paddy yields, but also for managing paddy based farming in resource starved regions.

While comparing the economics of rice growing as per package of practices recommendations, SRI and farmers practice, Latif *et al.* (2005) reported lower cost of production and higher net return for conventional practice. SRI required 12.9 per cent more labour than POP management and 19.2 per cent more than farmers practice and this higher labour was required for weeding. Reddy *et al.* (2005) observed that SRI causes no economic advantage to the farmers in terms of net returns and that the prime gain from SRI is its water saving rather than yield improving capability. Manjappa and Kelaginamani (2006) also observed no significant difference between SRI and normal method of rice cultivation with respect to gross return and net return.

Dobermann (2004) suggested that approaches such as SRI may serve the important needs of resource poor farmers in areas with poor soils, but are likely to have little potential for improving rice production in intensive irrigated systems on more favourable soils, where high yields could be achieved through implementation of more cost efficient management practices. Moser and Barrett (2003) studied the adoption dynamics of SRI in Madagascar and found that SRI was difficult to practise by most farmers as it required significantly additional labour input at a time of the year when liquidity is low and labour effort is high, and this calls into question the common assumption of the appropriateness of such a technology for small holders.

2.3. Weed management in rice

2.3.1. Weed spectrum in rice

Rice growing system has a profound influence on the intensity as well as flora of weeds. The tillage and moisture status in different systems such as wet seeded, semi-dry and transplanted rice vary greatly and so also the weed flora. Weed species in rice vary with soil, system of rice culture, water management, fertility level and weed control practices. Rice fields are colonized by terrestrial, semi aquatic or aquatic plants depending on the type of rice culture and the season (Moody and Drost, 1983).

More than 300 species in 100 genera belonging to more than 60 plant families have been reported as weeds in transplanted rice fields of China, the dominant weed species being *Echinochloa crusgalli, Scirpus planiculmis, Sagittaria pygmaea, Potamogeton distinctus, Paspalum distichum, Cyperus serotinus, Leptochloa chinensis, Monochoria chinensis, Cyperus difformis* and *Scirpus juncoides* (Zhang, 1996). Baki and Khir (1983) reported *Monochoria virginalis, Ludwigia adscendens, Fimbristylis miliacea, Scirpus grossus,* *Limnocharis flava, Leersia hexandra* and *Cyperus haspan* as major weeds in transplanted paddy fields of Malaysia.

Malik and Moorthy (1996) suggested *Echinochloa crusgalli, Echinochloa colona, Paspalum distichum, Cyperus iria, Ischaemum rugosum, Eragrostis japonica, Dactyloctenium aegyptium, Leptochloa chinensis, Sagittaria guayanensis, Cyperus difformis, Fimbristylis tenera, Eclipta alba* and *Ludwigia perennis* as major weed flora of transplanted rice of South Asia. According to Zafar (1988) *Echinochloa crusgalli, Cynodon dactylon, Digitaria* sp., *Cyperus* sp., *Fimbristylis miliacea, Eclipta alba, Sagittaria* sp., *Scirpus* sp., and *Monochoria vaginalis* were the important weeds of transplanted rice in Pakistan.

Many workers have tried to list important weed flora of transplanted rice in India. Predominant weed species identified were *Echinochloa crusgalli, Echinochloa colona, Digitaria filiformis, Ludwigia purpuria, Marsilea quadrifolia* and *Cyperus* sp. in Ranchi (Gosh and Singh, 1996); *Leptochloa chinensis, Echinochloa crusgalli, Eclipta alba*, and *Cyperus iria* in New Delhi (Phogat and Pandey, 1998); *Echinochloa crusgalli, Echinochloa colona, Panicum repens, Cyperus difformis, Cyperus iria, Marsilea quadrifolia* and *Jussiaea repens* in Bangalore (Nanjappa and Krishnamurthy, 1980); *Echinochloa crusgalli, Echinochloa colona, Cynodon dactylon, Cyperus rotundus, Cyperus difformis, Fimbristylis miliacea, Amaranthus viridis, Ludwigia parviflora* and *Ammania baccifera* in Varanasi (Mukherjee and Singh, 2005) and *Echinochloa colona, Echinochloa crusgalli, Cyperus iria, Cyperus difformis, Fimbristylis miliacea , Scirpus* sp., *Ammania baccifera, Brachiaria* sp., *Cyanotis axillaris, Eclipta alba, Ludwigia parviflora, Marsilea quadrifolia, Monochoria vaginalis, Rotala densiflora* and *Sphaeranthus indica* in Tamil Nadu (Venkataraman and Gopalan, 1995).

Jayasree (1987) and Suja (1989) reported the predominance of grasses and sedges in semi dry rice culture in Kerala with prominent grasses being *Isachne* *miliacea*, *Sacciolepis interrupta* and *Echinochloa colona*. After a detailed survey of the rice growing areas of the central zone of Kerala, Thomas *et al.* (1997) reported dominance of 48 weed species in semi dry rice culture and categorized them as 11 grasses, 6 sedges, 27 broad leaf weeds and 4 ferns. *Isachne miliacea* and *Sacciolepis interrupta* were the top rankers among the grasses; *Cyperus albomarginatus* and *Cyperus haspan* among the sedges and *Eriocaulon quinquagulare*, *Ludwigia perennis*, *Ammania baccifera*, *Dopatrium juncium* and *Eriocaulon cuspidatum* among the broad leaf weeds.

In wet seeded rice direct seeding techniques cause change in composition of weed communities with the less competitive dicotyledonous weeds and sedges being replaced by competitive grasses (Moody, 1993; Ho, 1996). Srinivasan and Palaniappan (1994) found the predominance of *Echinochloa* sp., *Cyperus difformis*, *Marsilea minuta* and *Eclipta alba* in South India, while Joseph (1986) reported a high population of *Scirpus supines* (*Schoenoplectus lateriflorus*), *Cyperus difformis* and *Cyperus iria* in wet sown rice. He also reported the predominance of *Scirpus supines* (*Schoenoplectus lateriflorus*) in transplanted rice, while *Cyperus difformis* and *Cyperus iria* were suppressed.

Thomas and Abraham (1998) reported *Echinochloa crusgalli, Monochoria vaginalis*, *Cyperus difformis, Cyperus iria, Fimbristylis miliacea, Sphenoclea zeylanica, Ludwigia perennis* and *Marsilea quadrifolia* as the major weeds of transplanted rice in Kerala. According to Jacob *et al.* (2005) the predominant weed species observed in the transplanted paddy fields of Instructional Farm, College of Agriculture, Vellayani were *Echinochloa colona, Echinochloa crusgalli and Leersia hexandra* among grasses, *Cyperus iria* and *Cyperus difformis* among sedges and *Ludwigia parviflora* and *Monochoria vaginalis* among broad leaf weeds.

Sindhu (2008), through a survey, identified the major weeds in the rice fields of Palakkad district as *Sacciolepis interrupta, Echinochloa* spp., *Oryza* *rufipogon, Cyperus iria, Fimbristylis miliacea, Amischophacelus axillaris* and *Ludwigia perennis* in Alathur taluk; *Sacciolepis interrupta, Echinochloa* spp., *Cyperus rotundus, Fimbristylis miliacea, Sphenoclea zeylanica* and *Chara* spp. in Mannarghat taluk; *Echinochloa* spp., *Leptochloa chinensis, Fimbristylis miliacea, Cyperus iria, Ludwigia perennis*, and *Limnocharis flava* in Chittoor taluk; *Echinochloa* spp., *Sacciolepis interrupta, Cyperus rotundus, Cyperus iria* and *Ludwigia perennis* in Ottapplam taluk and *Echinochloa* spp., *Sacciolepis interrupta, Cyperus rotundus, Cyperus iria, Fimbristylis miliacea* and *Ludwigia perennis* in Palakkad taluk.

In the *Kole* lands of Kerala, where rice is grown during September–October to February–March and the land remains submerged during rest of the year, Abraham and Thomas (2002) reported the existence of *Echinochloa stagnina* and *Echinochloa crusgalli* as the important grass weeds along with other dominant sedges such as *Fimbristylis miliacea*, *Cyperus iria* and *Cyperus difformis*. Along with these weeds Vidya (2003) also reported the existence of broad leaf weeds such as *Ludwigia parviflora, Lindernia crustacea, Limnocharis flava* and *Monochoria vaginalis*, and the fern *Marsilea quadrifolia.* In a recent survey conducted in the *Kole* lands, Sindhu (2008) identified *Echinochloa* spp., *Oryza rufipogon, Cyperus* spp., *Fimbristylis miliacea, Ludwigia perennis, Sphenoclea zeylanica, Eichhornia crassipes, Salvinia molesta, Monochoria vaginalis, Nymphaea nouchali* and *Lindernia crustacea* in the lower *Kole* areas comprising Alappad and Manakkody *Koles*, and *Echinochloa* spp., *Oryza rufipogon, Isachne miliacea, Cyperus rotundus, Fimbristylis miliacea, Monochoria vaginalis, Commelina benghalensis, Limnocharis flava, Sphenoclea zeylanica, Ludwigia perennis, Lindernia crustacea, Salvinia molesta* and *Marsilea quadrifoliata* in the upper *Kole* areas comprising Adat and Puzhakkal *Koles*.

2.3.2. Crop – weed competition

Weeds play a major role in reducing the productivity of field crops. Weeds are considered to be a potential pest causing upto 37 per cent yield loss of field crops compared with 22 per cent due to diseases, 29 per cent due to insects and 12 per cent due to others including storage pests and rodents (Sharma *et al.*, 2009). Thomas and Abraham (1998) stated the critical period of weed competition in rice as the period between 15 and 45 days after sowing, while weed competition during the first 15 days after sowing had no significant effect on grain yield of upland rice (Singh *et al.*, 1987). However, Lubigan and Vega (1971) reported that 20 *Echinochloa crusgalli* m^{-2}, competing from 7 to 14 days after emergence in the Philippines low land rice, reduced yield up to 20 per cent, and 40 plants m^{-2} reduced yield up to 40 per cent, but there was no further yield reduction from 60, 80 or 100 plants m^{-2}. Weeds emerging between 15 and 45 days after sowing will compete with the crop, resulting in substantial yield reduction.

The loss of rice yield due to weeds ranged from 10 to 70 per cent (Mani *et al.*, 1968; Shetty, 1973). According to Smith (1968) yield reduction due to weeds in rice can vary from 15 to 20 per cent in transplanted rice, 30 to 35 per cent in wet seeded rice and over 50 to 60 per cent in upland rice, while Datta (1981) reported 30 per cent yield reduction in transplanted rice, 45 per cent in rain fed low land direct seeded rice and 67 per cent in upland rice due to weeds. Pillai and Rao (1974) estimated a yield reduction of 30 to 35 per cent in direct seeded rice under puddled condition and Sankaran and Datta (1985) after reviewing the reports of many Indian workers estimated a yield reduction of 32 to 86 per cent in upland rice due to uncontrolled weed growth. Recent estimates show that average reduction in yield due to weeds varies from 12 to 72 per cent depending upon weed flora and extent of competition offered by weeds to the crop. Yield losses due to weeds are about 16 per cent in wheat, 40 in per cent rice and 40 per cent in maize (Sharma *et al.*, 2009). Regression studies by Singh and Dash (1988) showed that an increase in dry weight of weeds at the rate of 1 g m^{-2} decreased the grain yield of rice by 0.0074 t ha^{-1}. A yield loss of 73 to 86 per cent due to uncontrolled weed growth was reported by the Thrissur centre of AICRP WC (1992).

2.3.3. Nutrient removal by weeds

The nutrient concentration in weeds far exceeds the associated crops. Weeds are severe competitors for nutrients than for water (Loomis, 1958). Varying levels of nutrient removal by weeds have been reported as 24 kg N, 7.5 kg P_2O_5 and 30.5 kg K_2O ha^{-1} (Varughese,1978); 30-40 kg N, 10-15 kg P_2O_5 and 20-40 kg K_2O ha^{-1} (Sharma *et al.,* 2009); 19.4-33.7 kg N, 1.5-1.8 kg P_2O_5 and 17.4-33.7 kg K_2O ha^{-1} (Moorthy and Mittra, 1990) and 25.8 kg N, 3.65 kg P_2O_5 and 21.83 kg K_2O ha^{-1} (Ramamoorthy, 1991).

Highest uptake of N (56.1 kg ha^{-1}), P (24.9 kg ha^{-1}) and K (15.3 kg ha^{-1}) by the rice crop was observed in hand-weeded plots, while the removal of N, P and K by weeds was the highest in unweeded control plots and the lowest in hand weeded plots (Chungi and Ramteke, 1988; Varughese and Nair, 1986).

Weeds compete severely for nutrients and depending upon the intensity of weed growth, the depletion may be up to 86.5 kg N, 12.4 kg P and 134.5 kg K ha^{-1} and in addition 61, 15, 2523, and 166 g ha^{-1} each of Zn, Cu, Fe and Mn, respectively (Malik and Moorthy, 1996).

An aquatic weed *Chara* sp., in West Bengal, produced about 1060 kg ha^{-1} dry matter and removed 21.1 kg ha^{-1} N causing a reduction in rice yield up to 40 per cent (Guha, 1991). Chaurasia *et al.* (1983) reported more organic matter production and nutrient uptake by grass weeds than broad leaved weeds in the initial crop stages and a reverse pattern in the later stages. Both types of weeds removed considerable amounts of N and K, but P uptake was low.

2.3.4. Intensity of weeds in SRI

In a given environment, the weed vegetation is most strongly affected by the biotic factors and cultural practices like tillage, method of rice culture, fertilizer management, irrigation practices, cultivar grown and crop rotation (Kim and Moody, 1989). According to Sahid and Hossain (1995) one of the main purposes of flooding rice field is to control the weeds.

According to Arai (1967) transplanted crop has an initial growth advantage and hence weeds are less detrimental than direct seeded rice. However, SRI recommends planting single seedling at wider spacing and keeping the soil moist through alternate wetting and drying during the vegetative growth phase of the plant. This situation creates a congenial environment for proliferation of weeds and hence early and frequent weeding is essential under SRI (Singh *et al.*, 2010). Zimdahl *et a*l. (1987) have reported that water supply determines weed populations in upland or low land rice production systems, and Datta (1981) suggested that moist or saturated soil favoured the emergence and growth of grasses and sedges, which once established are difficult to control by flooding.

Plant spacing in transplanted rice as well as seeding rate in direct seeded rice determines its plant density, which in turn, determines the canopy created to help rice to shade and compete with weeds. Increased spacing between or within rows increases light penetration in to the canopy which enhances weed growth. Average seed production per surviving plants of some selected species was up to three times higher in the 30 cm spacing compared with 10 cm spacing in spring wheat (Mertens and Jansen, 2002).

The significant influence of higher seeding rates of cereals on reducing weed competition was recognized by Godel (1935). Gaffer *et al.* (1997) reported reduction in weed dry weight with increasing seed rate in wheat crop. Dry weight of weeds has been shown to decrease corresponding to increase in seed rate from 50 to 250 kg ha^{-1} (Moody, 1977).

Akobundu and Ahissou (1985) observed decreased weed weight and number of tillers and panicles per plant as inter-row distance was reduced. Singh *et al.* (1983) indicated that yield of water logged rice can be potentially increased if more seedlings are planted per hill at a spacing closer than normal practices. Increasing crop density through use of higher seed rate, narrower row spacing and closer plant spacing (within a row) are important weed management techniques as they enhance crop competitiveness by suppressing or smothering weeds (Rao, 2000). According to Younie and Tylor (1995), sowing the crop at narrow spacing increases the rate of crop growth and ground cover; however, increasing the seed rate provides better weed suppression than narrowing the row spacing. Reduction in weed competition due to the smothering effect of cowpea grown concurrently in semi-dry rice has been reported by Musthafa and Potty (2000) and Anitha *et al.* (2010), and the same effect in wet seeded rice has been reported by Anitha and Mathew (2010). The significant influence of canopy modification by altering plant spacing in maintaining a dominant position over weeds, which was indicated by the decreased weed problems as well as higher crop yield in closer plant spacing, was reported by Sindhu (2008). The author observed significant reduction in the number and dry matter production of weeds with an increase in plant density under closer spacing.

2.3.5. Weed management in SRI

The system (SRI) relies on early and frequent weeding which varies from 3 to 4 times, the first in the series being done at 10 days after transplanting and repeated at every 10-12 days interval until the plant growth and canopy closure restrict further weeding operation (Association Tefy Saina, 1992). Rangasamy *et al.* (1993) reported one third of the total cost of cultivation in rice being spent on weeding. Latif *et al.* (2005) observed 25 per cent more labour requirement for weeding in SRI compared to conventional practice. SRI requires more frequent mechanical weeding, and practising modified planting, i.e. square planting with wider spacing, is a prerequisite for the adoption of mechanical weeding, to allow the rotary or cono weeder to operate in between the plant rows in both directions (Haden *et al.*, 2007). In SRI, weeding is normally done by a mechanical hand weeder (rotating hoe or cono-weeder) which returns the weeds to the soil as green manure (Pandey, 2009).

Senthilkumar *et al.* (2008) reported significant yield increase through mechanical weeding and this was attributed to improved aeration of the soil and effects due to incorporation of the weed biomass through mechanical weeding (Uphoff, 2001; Stoop *et al.*, 2002). Yield increase through mechanical weeding using a rotary weeder has also been reported by Dinesh and Manna (1990) and Thiyagarajan *et al.* (2002b). Vijayakumar *et al.* (2004) compared the conventional and SRI weeding and reported increased grain yield and water productivity through SRI weeding.

The effects of long term organic amendments may be enhanced when combined with deep ploughing, rendering the soil even in deeper layers fertile. The effects of deep ploughing in accelerating soil nitrogen mineralization and facilitating the development of deep root systems in rice plants, resulting in the increase of plant N uptake and rice yield have been reported by Kundu *et al.* (1996) and Sharma *et al.* (1988). However, as opined by Tsujimoto *et al.* (2009), both deep ploughing and organic amendments are time and energy consuming techniques and cited deep ploughing as the most exhausting work among the management practices.

Uphoff (2001) reported stimulation of cell division by an increased root activity through incorporation of organic manure with mechanical weeder in SRI. Significant increase in root length (cm) and root volume (cm^3 $hill^{-1}$) at panicle initiation and flowering stages by mechanical weeding was reported by Nisha

(2002). The larger root system enables the plants indirectly to produce more N in their root zone by exuding photosynthates made from atmospheric CO_2 in the rhizosphere (Badalucco and Kuikman, 2001). Shad (1986) and Uphoff (2001) observed that under SRI, not only wider spacing but limited irrigation as well as mechanical weeding also contributed to increase tiller density per hill through increased soil aeration and root pruning.

Mrunalini and Ganesh (2008) listed the advantages of cono weeder as it enhanced the pace of work, doubled the work efficiency, saved time upto 76 per cent, optimized the human effort through improved postures and reduced the muscular fatigue as compared to the hand weeding process.

Anitha and Usha (2008) reported no significant yield difference between cono weeding and manual weeding, however, cono weeding could save the labour required for weeding by 35 human days and labour cost by Rs. 3125 ha^{-1} without affecting the yield of rice. Singh *et al.* (1985) compared the different weed control measures in upland rice and found that inter-row cultivation plus hand-weeding in the rows showed average yield increase of 0.5 t ha^{-1} and suggested as a substitute for the highly labour intensive hand-weeding. Hand weeding and rotary cultivation were more effective for controlling weeds and promoting yields than the use of herbicides in transplanted rice (Kulmi *et al.*, 1988). Pandey *et al.* (2009) also observed the highest yield with use of Japanese cono paddy weeder and the lowest with 2,4-D application. The cono weeder showed the greatest field capacity (0.0104 ha hr^{-1}), lowest cost of weeding and highest B: C ratio (2.70).

Despite the various reports on the apparent advantages, there was mention on the limitations while using cono weeder. Kumar *et al.* (2006c) reported that in the operation of rotary weeder, the grown up weeds could not be removed properly, though the physical handling of weeder is easy. Sindhu (2008) observed that although cono weeding under SRI reduced weed growth during initial stages of crop growth, in the later stages the weed problem was more. She further observed that cono weeding at 10 days interval from 10 days after transplanting to panicle initiation stage was not effective in controlling the weeds that grow very close to the plants. Datta (1981) had reported that mechanical weeding using inter row cultivators or rotory weeders is practical only in row seeded rice and does not remove weeds within or close to the rice hills, which can still cause marked reduction in yield. The attempt to demonstrate the SRI method in Kopplipadam in Mandarappilly watershed area in Kodakara block of Thrissur district, during 2005 was reported to be a failure due to severe infestation of weeds which could not be controlled by cono weeding alone (Anon., 2005).

As a matter of fact, Latif *et al.* (2005) reported highest yields in SRI from a combination of herbicide application and a single hand weeding. Herbicides reduced weed density at the early stages of rice growth and supplementary hand weeding controlled the weeds at later growth stages (Saha, 2005).

Pre-emergence application of Sofit @ 0.45 kg a.i. ha^{-1} followed by cono weeding at 30 days after sowing (DAS) and hand weeding at 30 DAS provided broad spectrum weed control throughout the crop season in drum-seeded rice, with a weed control efficiency of 98 per cent at 60 DAS and recorded the highest grain and straw yields (Jagadeesha *et al.*, 2009). Similarly, pre emergence application of pretilachlor @ 0.75 kg a.i. ha^{-1} followed by one mechanical weeding at 30 DAT recorded lower weed density, and was significantly superior to mechanical weeding three times at 15, 30 and 45 DAT at 40 days and 60 days stage. This resulted in the highest grain and straw yield of 48.73 and 42.40 per cent increase over unweeded check followed by mechanical weeding three times at 15, 30 and 45 DAT (Kavitha *et al.*, 2010). This was attributed to a complete removal of late emerging weeds by mechanical weeding at 30 DAT.

Sindhu (2008) reported better weed management in modified SRI, wherein the weeds were controlled by spraying post emergence herbicides Cyhalofop butyl (Clincher 10% EC) @ 0.08 kg a.i. ha^{-1} at 15 DAT followed by Chlorimuron ethyl

10% + Metsulfuron methyl 10% (Almix 20 WP) @ 4.0 g a.i. ha^{-1} + 0.2% surfactant at 20 DAT.

Upon comparing manual weeding with herbicides, Chandra and Tiwari (1998) observed higher return with the twice hand-weeded treatment than herbicides and untreated control whereas the cost: benefit ratio was higher in the herbicide (Oxadiazone) treatment in direct seeded puddled rice. In a study on SRI conducted at the Bangladesh Rice Research Institute Regional Station, Comilla during three rice growing seasons, Islam and Molla (2001) found that two hand weeding or one hand weeding plus herbicides can be recommended where labour is available, otherwise, only herbicides should be used to make weeding economical and rice production profitable.

Although the above review on literature indicates weed control efficiency and cost effectiveness with the use of herbicides in SRI, the studies on the use of herbicides in SRI are found very much limited so as to give a foolproof recommendation. Hence, the chances of inclusion of herbicides in the integrated weed management under SRI can be explored.

2. 4. Mechanical weeders

Drum seeder, self-propelled rice transplanter and SRI are being increasingly adopted by the rice farmers in our country. When the adoption of these technologies increased, the area under line-sown low land rice also increased, which facilitated increased use of cono weeder for the control of weeds. In the context of various positive aspects of cono weeding in SRI, it is essential to make available cono weeder that makes the operation untiring and drudgery free. Efforts from various corners, including farmers have started to develop much more labour-friendly and power operated models, but so far no foolproof unit has come out. This necessitates development of a self propelled unit from the presently available manual cono weeder. Years ago, a mechanical hand weeder was developed in Japan to facilitate weed removal between rows. It had various names and undergone modifications, but was widely known as rotating hoe or rotary hoe. Mechanical weeding using inter row cultivator or rotory weeder takes about 50 to 60 human hours to weed one hectare of rice field (Parthasarathy and Negi, 1977).

Engineers at the International Rice Research Institute (IRRI), Philippines subsequently developed a cono-weeder (conical weeder), which works better in various soils, especially heavy clay soils. An improved and modified IRRI cono weeder was developed for wet field conditions and it was compared with the conventional weeding practices. The field capacity of the weeder was 0.02 ha h^{-1} and gave a weeding efficiency of 80 per cent during the first weeding. The cost of weeding with this weeder amounted to Rs. 480 per hectare, while manual weeding did cost Rs. 1200 per hectare. Sixty per cent of time was saved in comparison to manual weeding (Parida, 2002). This modified IRRI cono weeder was further modified through the AICRP on Farm Implement and Machinery Centre, Acharya N.G. Ranga Agricultural University, Hyderabad and used for efficient weeding in rows. The implement reduced drudgery due to less time taken from 50 to 55 per cent and its use resulted in saving cost of operation by 45 per cent compared to hand weeding. The weeding efficiency varied between 75 and 100 per cent in heavy soil and loose soil, respectively. This manual cono weeder could operate an area of one acre in a day of 8 h (Sarma *et al.*, 2006).

The presently available cono weeder has two rotating cone shaped drums, with width adjustability. It has better soil working efficiency and operational simplicity. One of the major constraints in using these hand operated weeders is the physical effort that is needed to push the weeder in the wet and highly resistant clay soil. Datta (1981) and Moody (1991) found out that the push type cono weeders are difficult to use as they have to be moved back and forth and do not work well under conditions of highly dried soil, high inundation of flood water, existence of bigger sized weeds etc. Reports from China also indicated the complex and laborious nature of management measures for weeding under SRI (JiaGuo *et al.*, 2004). According to Kumar *et al.* (2006c), in the operation of cono weeder the soil gets tilled deeply and the weeds are uprooted thoroughly, but the farmers find it very hard to operate as it pains the chest and hands. While operating it, the farmer needs to strain much, which leads to fatigue and thereby ineffective and reduced frequency of weeding (Ravindra *et al.*, 2006).

Women labour is the most commonly used labour input, especially for weeding in rice. Sarma *et al.* (2006) conducted experiments on comparative analysis of physiological work load of women using manual cono weeder with those who practice conventional method of weeding in rice. They found out that the cono weeder could increase the work efficiency of woman by two times and save 76 per cent of the women's time through improvement brought into their pace of performance. Improvement could be brought in their postures, thereby facilitating them to walk comfortably along the rows while weeding with manual cono weeder. Significant relief in muscular and skeletal pains at neck and low back regions was also experienced by the women. The results from this ergonomic study are useful to establish that optimized technology through ergonomically designed weeders could potentially enhance the pace of work and the work efficiency of women in paddy weeding and reduce muscular fatigue at few sensitive zones.

Operational difficulties with the cono weeder were identified as constraints in SRI practice and the farmers demanded to develop a cost effective motor operated cono weeder (Charyl *et al.*, 2006; Manimekalai *et al.*, 2006). Labour intensity involved in SRI as well as non-availability of various models of weeders suited to different agro-situations have been identified by Rao and Goud (2007). For scaling up of SRI technique they suggested to redesign existing models of weeders to suit to specific situations. Shanmugasundaram *et al.* (2008) after studying the constraints, in the adoption of SRI, faced by the farmers of

Muthalamada panchayath in Palakkad district of Kerala suggested redesigning the cono weeder to ease the weeding operation.

Presently there are many types of weeders available from simple to complex and motorized weeders. Several innovative and cost effective designs were developed and experimented according to the requirements of the farmers and soil conditions. Efforts are still on to reduce the drudgery in weeding operation. The desirable qualities of a good weeder identified by the Watershed Support Services and Activities Network (WASSAN), Secunderabad, are built-in adjustability to change the width of the working area, hindrances to sticking of mud between the teeth of blades and with a guard attachment. It should be simple in design so that it can be manufactured or assembled locally. Also it should be made in different models so that the farmer has the option to choose one that is most suitable, rugged and sturdy and be all-weather proof (WASSAN, 2006).

In the case of existing power weeders, it was observed that due to heavy weight the equipment sinks deeper into the wet soil, and as a result the forward motion is impeded (Singh *et al.*, 2006b). A self propelled rotary power weeder has been developed by Singh *et al.* (2008) for working in wide row crops. It uses a 3 HP engine with 70 rpm and has a weight of 100 kg. A three stage reduction of the prime mover was incorporated and the shafts, pulley, chains, sprockets and blades have been properly designed to achieve optimum use of material.

Krishi Vigyan Kendra, Madurai has developed a light weight, portable, power operated, hand held weeder, in which the weeder drum draws its power from a knapsack power sprayer through a flexible transmission cable. This design reduced the physical effort in operating the weeder (Singh *et al.*, 2006b).

2.5. Differential performance of SRI under different locations

Yield performances of SRI are found to vary depending on the input management practices, geographical location, variety and natural resource management in different parts of the country. The soil type, nature of soil, soil moisture regime etc. also decide the performance of the system. Viraktamath and Kumar (2007) reported the differential response of rice varieties under SRI. As they reported, among the 34 cultivars tested at Raipur 12 performed better under traditional method while 24 responded well to SRI, and at Nellore in Andhra Pradesh all the ten varieties tested performed better under SRI.

Systematic evaluation of SRI in multilocation trials under the AICRIP co-ordinated trials at 21 locations viz., ARI Rajendranagar, Aduthurai, Almora, Arundhatinagar, Chiplima, Coimbatore, Jagdalpur, Karimgunj, Karjat, Kapurthala, Malan Mandya, Nawagam, Patna, Pantnagar, Pondicherry, Ranchi, Sabour, Siriguppa, Titabar, Umiam and Varanasi both during kharif 2004 and 2005 has revealed that the response is location specific, as only in half of the locations SRI was found to register higher yields than normal transplanting, and in general performance of SRI was found better in Southern and Central India (Viraktamath, 2007). The author also reported that performance of SRI was better in clay loam soils than in sandy loam soils, and in acidic soils (pH 5.4-6.5) as compared to alkaline soils (pH 7.5-8.1). Making and maintaining drainage channels was found to be a constraint in practising the SRI method, particularly in inceptisols (Charyl *et al.*, 2006).

SRI was found to be effective in all the 22 districts in the state of Andhra Pradesh on widely varying soils, but it was not more productive on saline soils (Uphoff, 2004). While evaluating the performance of rice under different establishment methods in Bhadra command area on red clay loam soils in Karnataka, during summer, Hugar *et al.* (2009) observed maximum total grain productivity, total fodder productivity, net profit, gross returns, B:C ratio, total tillers and effective tillers with SRI method of paddy cultivation. The study also showed that SRI method recorded the maximum uptake of N, P and K (199.6, 50.7 and 119.3 kg ha^{-1} respectively) compared to normal planting (186.7, 44 and 118.2 kg N, P and K ha^{-1} respectively). The increase in nutrient uptake in SRI has been attributed to a large and functional root system per unit area. The available P and total N status in the top 0-15 cm soil profile, was also found to be greater in SRI, by 10 to 15 and 5 percent, respectively, as compared to control at both vegetative as well as harvesting stages.

Vijayakumar *et al.* (2006b) recorded significantly higher grain yield and water productivity (0.610 kg m^{-3} and 0.494 kg m^{-3} of water in wet and dry seasons, respectively) under SRI in the deep, moderately well drained clay loam soils, low in available N (244 kg N ha^{-1}), medium in available P (17.2 kg P_2O_5 ha^{-1}) and high in available K (560 kg K_2O ha^{-1}), of Tamil Nadu Agricultural University, Coimbatore. But, further TNAU (2007) suggested modification as planting of 16-18 day old seedlings at a closer spacing of around 20 cm x 20 cm and application of chemical fertilizers for better yield.

Under the Kerala conditions, in the laterite loamy sand soils of the Ultisol group, a combination of management techniques in the conventional and the SRI has been found better than the SRI practices alone. Thus 20 days old double seedlings planted at a closer spacing of 20 cm x 15 cm along with intermittent irrigation and cono weeding resulted in higher rice production (Anitha *et al.*, 2007). Further, Anitha and Usha (2008) reported the SRI management techniques as inferior to the POP recommendations of the Kerala Agricultural University. Balachandran and Louis (2007) also reported the superiority of integrated crop management with 16 day old seedlings of rice var. Jyothi transplanted at 20 cm x 20 cm at two seedlings per hill over SRI, in terms of grain and straw yields and these higher yields were attributed to higher number of productive tillers coupled with higher plant population per unit area. Application of chemical fertilizers and use of post emergence herbicides for weed management have also been suggested as modifications in SRI by Sindhu (2008).

In the context of varying performance of SRI, it is understood that its feasibility is highly location specific and has to be studied in representative areas in detail.

Materials And Methods

3. MATERIALS AND METHODS

The experiments to evaluate the System of Rice Intensification (SRI) under varying agro-ecological situations in Kerala and to explore the possibility of integrating chemical/hand weeding in SRI were carried out during 2007 and 2008. An effort to develop a prototype of self propelled cono weeder was also undertaken in tandem.

The whole programme was carried out through two experiments:

Experiment No. 1.

Evaluation of weed control methods in SRI and conventional system.

Experiment No. 2.

Development of self propelled cono weeder and its field testing.

3.1. Evaluation of weed control methods in SRI and conventional system

Field experiments were conducted in two different agro-ecological rice growing tracts in the state viz., the irrigated lands in Palakkad district and the *Kole* lands in Thrissur district. The trials were conducted in the paddy fields at the Regional Agricultural Research Station (RARS), Pattambi in Palakkad district and in the farmers' fields of Alappad *Kole* in Thrissur district. At both locations, the experiments were conducted during the *Mundakan* season of 2007 and 2008.

3.1.1. Details of the experimental site

3.1.1.1. Location

The RARS, Pattambi under the Kerala Agricultural University (KAU) is located geographically at 10^0 49^1 N latitude, 76^0 12^1 E longitude and at an elevation of 25.40 m above the mean sea level.

The *Kole* lands, which form the rice granary of Thrissur and Malappuram districts comprise of a unique system in Kerala and extend over an area of 13,000 ha. The *Kole* fields are low lying tracts located 0.5 to 1.0 m below the mean sea level and hence a major portion of the area lies submerged for about six months in a year by the periodical inundation of flood water. The Alappad *Kole* is located at 75^0 58^1 N latitude and 76^0 11^1 E longitude and is lying at 1.0 m below the mean sea level.

3.1.1.2. Soil

The soil of the experimental area at the RARS, Pattambi belonged to the order Oxisols to which 58 per cent of the rice area of Kerala state belongs. These soils are medium in fertility, i.e., high in organic carbon and medium in available phosphorus and exchangeable potassium. The soil was sandy clay loam in texture and acidic in reaction with a pH of 4.96.

The Alappad *Kole* land soils are clayey in texture with pH 5.0 and belong to the Inceptisol group. The soils are high in organic carbon and available phosphorus and medium in exchangeable potassium.

The physical and chemical characteristics of soils of the experimental fields before commencement of the experiment are presented in Table 1.

Table 1. Physico-chemical properties of soils at the experimental sites

Parameters	Experimental location		Method of estimation
	RARS, Pattambi	Alappad *Kole*	
a) Mechanical composition			
Sand (%)	58.27	20.15	Hydrometer method (Piper, 1966)
Silt (%)	2.55	21.54	
Clay (%)	33.16	56.31	

b) Physical characteristics			
Bulk density ($kg\ m^{-3}$)	1.29	0.633 – 0.716	Core sampler method (Piper, 1966)
c) Chemical properties			
Ph	4.96	5.0	1:2.5 soil water suspension using pH meter (Jackson, 1958)
EC ($dS\ m^{-1}$)	0.011	0.037	1:2.5 soil water supernatant solution using EC bridge (Jackson, 1958)
Organic carbon (%)	1.00	2.86	Walkley and Black method (Piper, 1966)
Available P ($kg\ ha^{-1}$)	16.51 - 19.35	26.71	Bray-I extractant – ascorbic acid reductant - colorimetric method (Jackson, 1958)
Exchangeable K ($kg\ ha^{-1}$)	117.60	212.24	Neutral normal ammonium acetate extractant - flame photometry (Jackson, 1958)

3.1.1.3. Climate and weather

The RARS, Pattambi and Alappad *Kole* areas enjoy a tropical monsoon climate with more than 80 percent rainfall distributed through south-west and north-east monsoon showers. The weather conditions, which prevailed during the experimental periods, were largely normal. The weekly averages of important meteorological parameters prevailed during the experimental periods at both the locations are presented in Appendices I to IV respectively and illustrated in Fig. 1 and 2.

3.1.1.4. Cropping pattern

The experimental field at the RARS, Pattambi is a double crop wet land, where two crops of rice are conventionally practised during May-June to August-September and September-October to December-January. The first crop (May to September) is under semi-dry system where sowing is done in moist soil on receipt of pre-monsoon showers, and the second crop is an irrigated rice that is sown/transplanted in puddled condition.

In the Alappad *Kole* lands only one crop of rice is being cultivated during September-October to February-March and the area remains submerged during rest of the year. Transplanting is the common practice followed by the farmers and in some areas wet seeding is also practised. Irrigation is given from the canal water.

3.1.2. Materials

3.1.2.1. Seed

Jyothi (PTB 39), a red kernelled, bold grained and short duration (110 to 120 days) rice variety, which is the most widely accepted and popular high

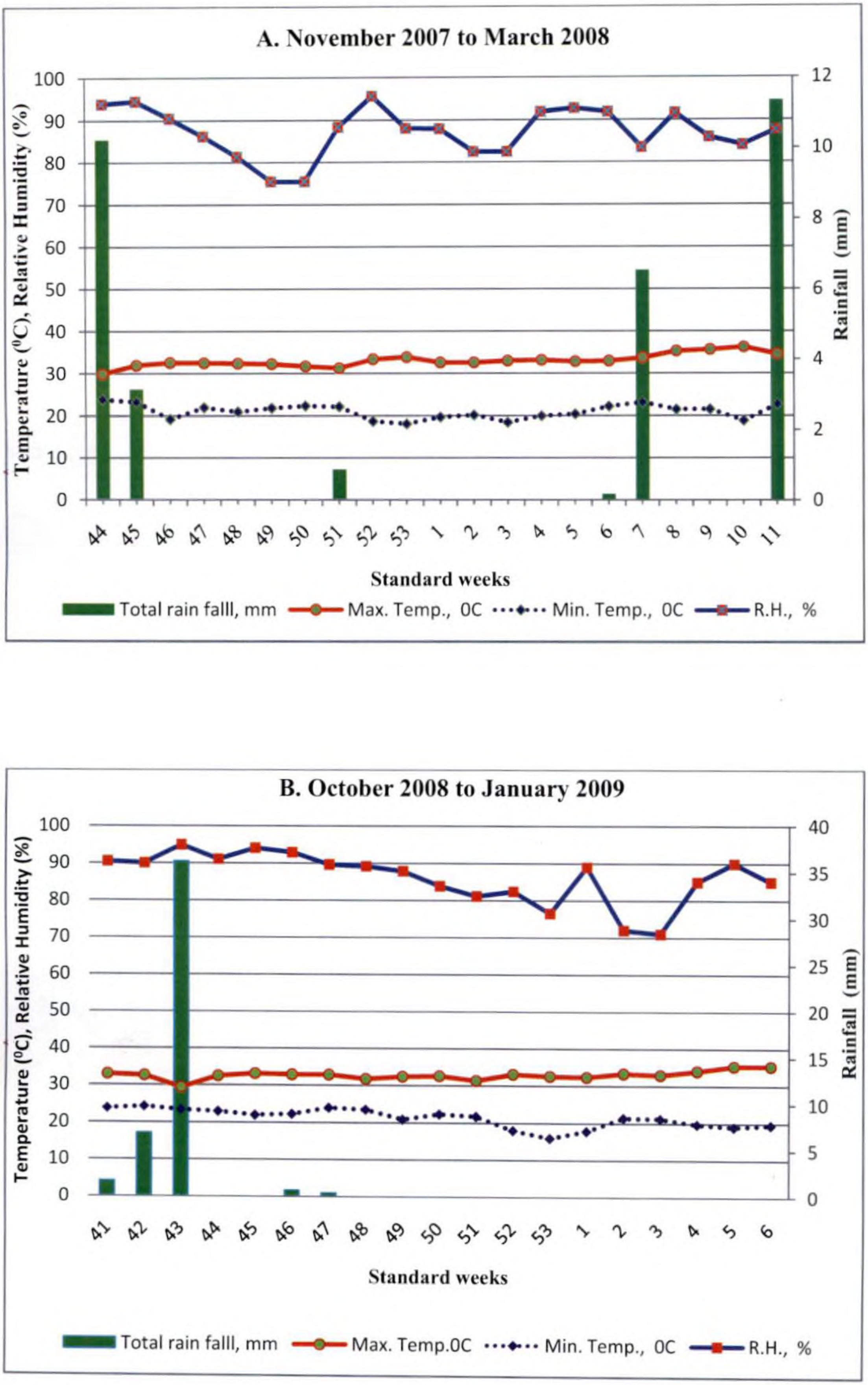


Fig. 1. Weather parameters during the experimental period at Pattambi

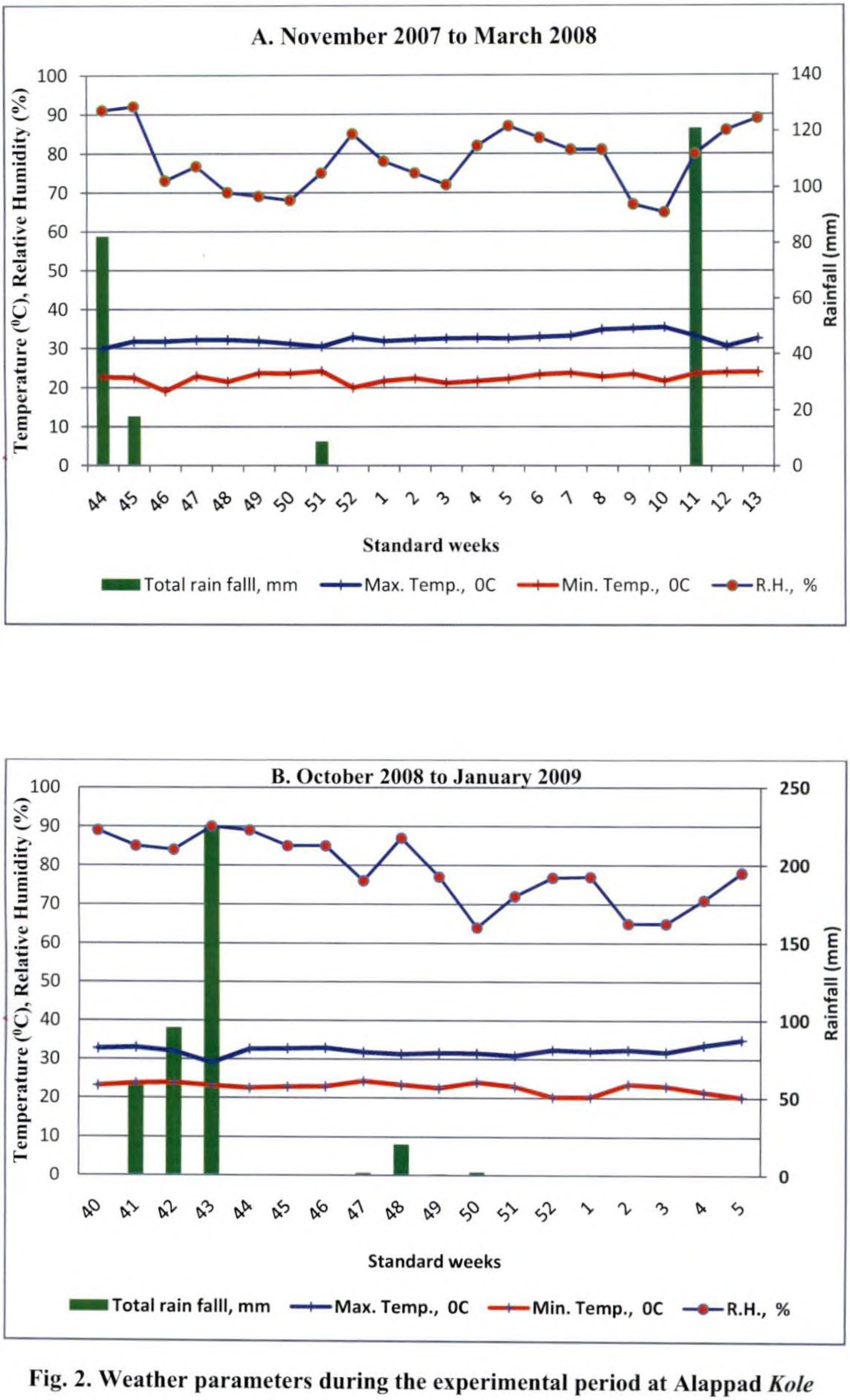


Fig. 2. Weather parameters during the experimental period at Alappad *Kole*

yielding variety in the state as a whole and *Kole* lands in particular, was used for the study, in both locations. Wider adaptability to different systems of cultivation, soil types and environmental conditions is a unique feature of this variety, making its extensive cultivation in a wide range of field conditions in the state during all the three seasons. It is moderately tolerant to brown plant hopper and rice blast, but susceptible to sheath blight.

3.1.2.2. Manure and fertilizer materials

Vermicompost (1.5% N, 0.4% P_2O_5, 1.8% K_2O) (KAU, 2007) was used as the organic manure, and chemical fertilizers urea (46.1% N), rajphos (20% P_2O_5) and muriate of potash (60% K_2O) were used to supply the plant nutrients N, P and K, respectively.

3.1.3. Treatments

Investigation to compare different methods of weed control in the two systems of rice cultivation, viz., the system of rice intensification (SRI) and the conventional system (CS) was carried out using two differently aged seedlings transplanted at two different spacing, i.e., 10 days old single seedling at 30 cm x 30 cm spacing (SRI) and 20 days old double seedlings at 20 cm x 10 cm spacing (CS).

The following were the sixteen treatments included in the experiment.

T1 SRI with four cono weedings at 10, 20, 30 and 40 days after transplanting (DAT)

T2 SRI with pre-emergence herbicide* followed by one hand weeding at 30 DAT

T3 SRI with pre-emergence herbicide* followed by one cono weeding at 30 DAT

T4	SRI with two cono weedings at 10 and 30 DAT
T5	SRI with one cono weeding at 10 DAT followed by one hand weeding at 30 DAT
T6	SRI with one cono weeding at 10 DAT followed by post emergence herbicides**
T7	SRI with post emergence herbicides** alone
T8	SRI with four cono weeding at 10, 20, 30 and 40 DAT + organic manure alone (the typical SRI)
T9	CS with four cono weedings at 10, 20, 30 and 40 DAT
T10	CS with pre-emergence herbicide* followed by one hand weeding at 30 DAT
T11	CS with pre-emergence herbicide* followed by one cono weeding at 30 DAT
T12	CS with two cono weedings at 10 and 30 DAT
T13	CS with one cono weeding at 10 DAT followed by one hand weeding at 30 DAT
T14	CS with one cono weeding at 10 DAT followed by post emergence herbicides**
T15	CS with post emergence herbicides** alone
T16	CS with two hand weedings at 20 and 40 DAT (Normal POP)

*Butachlor @1.25 kg ha^{-1} (Hiltaklor 50 EC).

**Cyhalofop butyl @ 0.1 kg ha^{-1} (Clincher 10% EC) at 18 DAT followed by Metsulfuron methyl 10% + Chlorimuron ethyl 10% (Almix 20% WP @ 4.0 g a.i. ha^{-1} + 0.2% surfactant at 20 DAT).

3.1.4. Design and layout

Design:	Randomized block design
Replications:	3

Gross plot size:	5.0 m x 4.0 m (The effective gross plots in SRI plots were 4.95 m x 4.0 m.)
Sampling area:	1.0 m strip along the 4.0 m side
Net plot size:	Plots with 30 cm x 30 cm spacing (SRI) – 9.80 m^2 (3.45 m x 2.85 m)
	Plots with 20 cm x 10 cm spacing (CS) – 14.40 m^2 (4.0 m x 3.6 m)

The layout plan and treatment allocation of the field experiments at RARS, Pattambi and Alappad *Kole* are given in Fig. 3 and 4, respectively.

3.1.5. Field culture

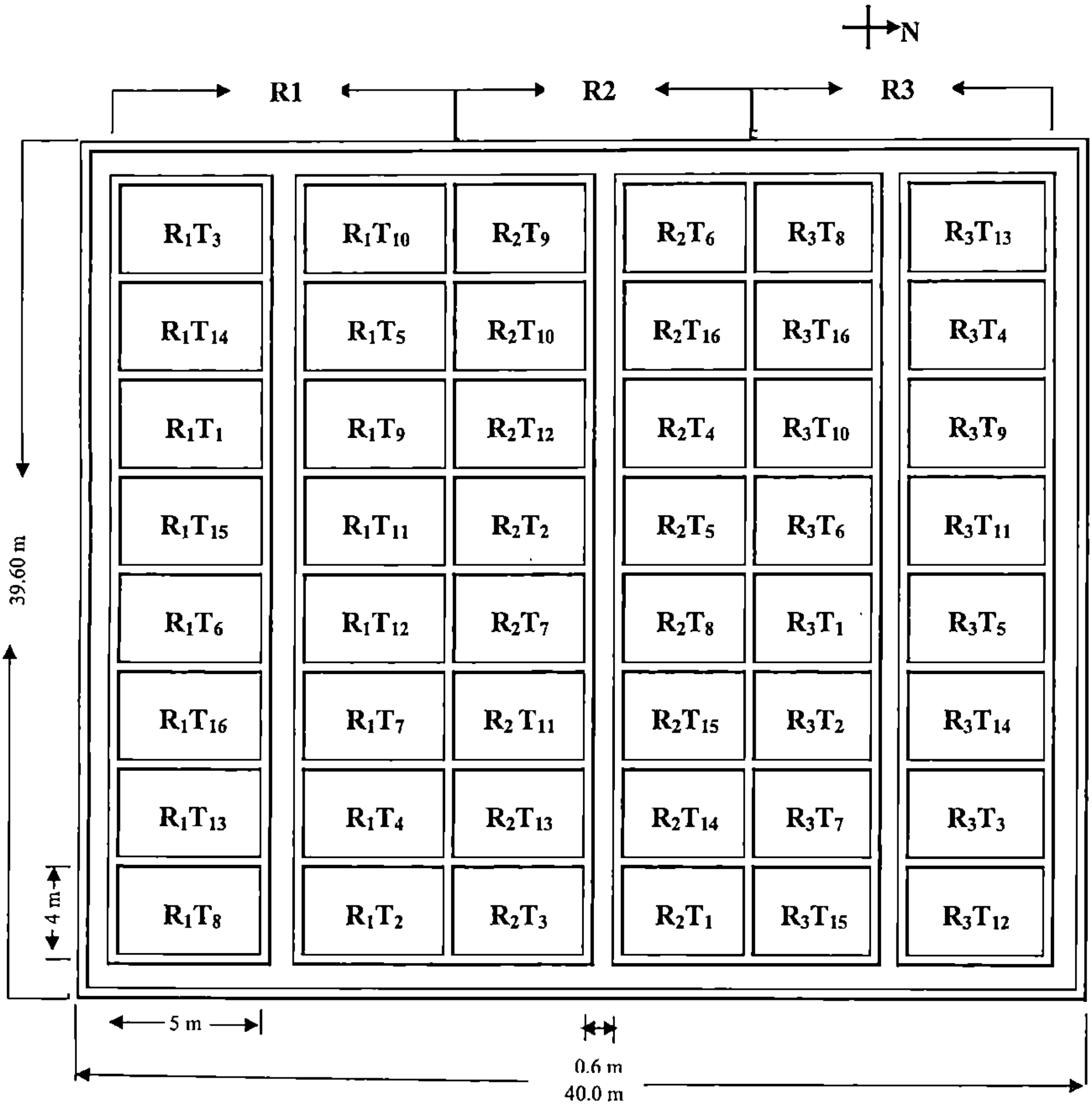
3.1.5.1. Nursery

Separate nurseries were raised for the two systems of cultivation. The nursery for the conventional system (20 days) was raised following the existing practice (KAU, 2007), and the nursery for the SRI (10 days) was prepared separately. Soil, sand and vermicompost were mixed at 2:1:1 proportion and prepared the nursery bed of 15 cm height, 1.0 m width and 5.0 m length. To prevent soil erosion, the bed on all sides was made secure with wooden reapers. Pre-soaked and sprouted seeds, @ 5 kg ha^{-1} were sparsely and thinly spread on the bed. A thin layer of vermicompost was spread over the seeds sown, in order not to expose the seeds to the direct sun. Watering was done twice daily (morning and evening) by sprinkling over the nursery bed using a rose can (WASSAN and CSA, 2006).

3.1.5.2. Main field

The main field was ploughed, puddled and levelled. In the conventional method of planting, 20 day old seedlings were transplanted at two seedlings per

Fig. 3. Layout plan of the field experiment at RARS, Pattambi

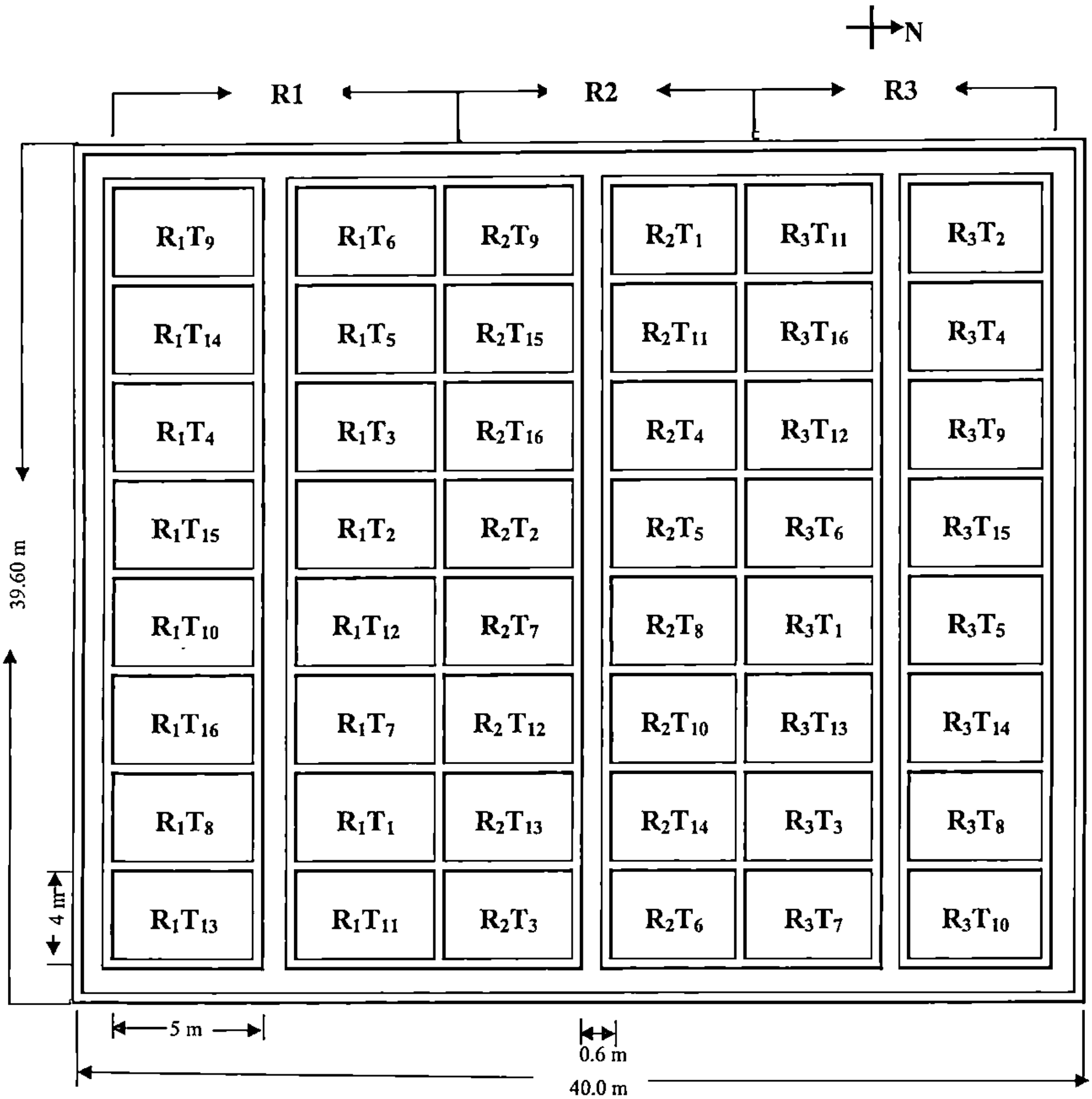


Treatments

T1 - SRI + CW-10, 20, 30, 40 DAT
T2 - SRI + Butachlor + HW-30 DAT
T3 - SRI + Butachlor + CW- 30 DAT
T4 - SRI + CW- 10, 30 DAT
T5 - SRI + CW- 10 DAT + HW-30 DAT
T6 - SRI + CW-10 DAT + Clincher fb Almix
T7 - SRI + Clincher fb Almix
T8 - SRI + CW-10, 20, 30, 40 DAT + OM

T9 - CS + CW-10, 20, 30, 40 DAT
T10 - CS + Butachlor + HW-30 DAT
T11 - CS + Butachlor + CW- 30 DAT
T12 - CS + CW- 10, 30 DAT
T13 - CS + CW- 10 DAT + HW-30 DAT
T14- CS + CW-10 DAT + Clincher fb Almix
T15 - CS + Clincher fb Almix
T16 - CS + HW – 20, 40 DAT

Fig. 4. Layout plan of the field experiment at Alappad *Kole*



Treatments

T1 - SRI + CW-10, 20, 30, 40 DAT
T2 - SRI + Butachlor + HW-30 DAT
T3 - SRI + Butachlor + CW- 30 DAT
T4 - SRI + CW- 10, 30 DAT
T5 - SRI + CW- 10 DAT + HW-30 DAT
T6 - SRI + CW-10 DAT + Clincher fb Almix
T7 - SRI + Clincher fb Almix
T8 - SRI + CW-10, 20, 30, 40 DAT + OM

T9 - CS + CW-10, 20, 30, 40 DAT
T10 - CS + Butachlor + HW-30 DAT
T11 - CS + Butachlor + CW- 30 DAT
T12 - CS + CW- 10, 30 DAT
T13 - CS + CW- 10 DAT + HW-30 DAT
T14- CS + CW-10 DAT + Clincher fb Almix
T15 - CS + Clincher fb Almix
T16 - CS + HW – 20, 40 DAT

hill, at a spacing of 20 cm x 10 cm, keeping 1.5 to 2 cm standing water in the field. In the SRI field, the land was kept almost fully drained so as to enable transplanting of 10 day old seedlings with seed and soil intact. Uprooting was done with utmost care to prevent any harm to the seedlings and transplanted one seedling each per hill, at a spacing of 30 cm x 30 cm (Plate 1).

a. Fertilizer management

Application of N, P and K was done as per the package of practices recommendations (KAU, 2007). Entire quantity of phosphorus was applied basally, potassium in two split doses, 50 per cent basally and 50 per cent at the panicle initiation stage and nitrogen in three split doses - 50 per cent basally, 25 per cent at the maximum tillering stage and the remaining 25 per cent at the panicle initiation stage. The treatment plot T8 was basally applied with vermicompost @ 7 t ha^{-1} and no further fertilizers were given.

b. Irrigation and Water management

In the conventional system, water management was done as per the package of practices recommendations (KAU, 2007). As the SRI specifically limits the use of water through alternate wetting and drying, irrigation in the SRI field was given just enough to get the soil saturated. Subsequent irrigations were given as and when the soil developed fine cracks. Thus the irrigation interval was four days at the RARS, Pattambi and seven days in the Alappad *Kole*. This pattern of irrigation was followed till the crop completed the tillering phase, and thereafter a standing water of 2.5 cm height was maintained as it was followed in the conventional method. Irrigation was stopped 15 days ahead of harvest in both the cases.

(a)

(b)

(c)

(d)

(e)

(f)

Plate 1. System of rice intensification (SRI) management practices: (a) germinated seeds ready for sowing, (b) 10 days old nursery, (c) use of single seedling, (d) transplanting at wider spacing, (e) mechanical weeding, (f)

c. Weed management

Weed management was done as per the technical programme. Use of herbicides, cono weeding and hand weeding were the methods followed (Plate 2).

i) Herbicides

The following table (Table 2) gives the details of herbicides used as per the technical programme.

Table 2. Details of the herbicides used in the experiment

Commercial product	Chemical name	Chemical family	Mode of action	Dose	Time & method of application
Hiltaklor 50 EC	Butachlor	Anilides	Pre emergence	1.25 kg a.i. ha^{-1}	Sprayed on 5th DAT
Clincher 10 EC	Cyhalofop butyl	Aryloxy phenoxy propionate	Post emergence & selective	0.1 kg a.i. ha^{-1}	Sprayed on 18th DAT
Almix 20 WP + 0.2% surfactant	Metsulfuron methyl 10% + Chlorimuron ethyl 10%	Sulfonyl urea group	Selective, contact, post-emergence	4.0 g a.i. ha^{-1}	Sprayed on 20th DAT

The pre emergence herbicide was sprayed uniformly on the soil surface using a knapsack sprayer fitted with a flat fan nozzle. The quantity of spray fluid used for both pre emergence as well as post emergence herbicides was 300 L ha^{-1}.

(a)

(b)

(c)

Plate 2. A view of the weed control methods tried in the experiment: (a) Use of herbicides, (b) Hand weeding, (c) Use of cono weeder

ii) Cono weeding

Cono weeder is a hand operated mechanical weeder used for uprooting and burying weeds in between the standing rows of rice in wet lands. It consists of two conical rollers with serrated blades rotating in the opposite direction. A float provided in the front portion prevents the unit from sinking into the puddled soil. It has a long handle made of mild steel tube. Cono weeder can be operated by a single person through the space in between the crop rows. On moving it through the field, the weeds get cut and trampled in to the soil. For easy movement of the cono weeder sufficient standing water is required in the field and hence, the fields were irrigated maintaining a thin film of water.

Cono weeding was carried out at 10, 20, 30 and 40 DAT, as per the technical programme. In the SRI field, it was done perpendicularly in two directions while in the conventional system it was just one, horizontally along the rows.

iii) Hand weeding

Hand weeding, as specified in the treatments, was done at 30 DAT as an integrated weed management approach, while the weed free plot was maintained by hand weeding twice, one at 20 DAT and second at 40 DAT.

d. Harvest

The crop was harvested at maturity. Plants in the border rows on all the four sides were harvested and removed from the field and not included in the net plot yield. Threshing, winnowing and cleaning were done on the same day and then kept for sun drying.

Plant protection measures were undertaken as per the recommendations of the Kerala Agricultural University (KAU, 2007). The details of all the field operations are given in Appendix 5.

3.1.6. Observations on the crop

3.1.6.1. Growth /biometric characters

a. Plant height

Height of five plants in each plot was measured from the base of the plant to the tip of the top leaf at active tillering and panicle initiation stages. At harvest, it was measured from the ground level to the tip of the longest panicle. The mean height was computed and expressed in cm (IRRI, 1980).

b. Number of tillers

Number of tillers was counted from five hills in each plot at active tillering, panicle initiation and harvest stages. The mean number of tillers was computed and expressed as number $hill^{-1}$ (IRRI, 1980).

The total number of tillers from all the hills in a quadrat of size 0.5 m x 0.5 m, selected at three places at random, was also counted at active tillering, panicle initiation and harvest stages. The mean expressed as number of tillers m^{-2} (IRRI, 1980).

c. Dry matter production

Five sample hills were uprooted, washed free of soil, air dried and then oven dried at 70-80^{0}C to constant weight. The dry matter production was computed at active tillering, panicle initiation and harvest stages and expressed in g $hill^{-1}$ and further derived to kg ha^{-1} (IRRI, 1980).

3.1.6.2. Root characteristics

a. Length of root

Lengths of roots in three randomly selected and uprooted hills, at panicle initiation stage, were measured and the mean expressed in cm (IRRI, 1980).

b. Root dry weight

At panicle initiation stage, the roots from three randomly selected and uprooted hills were washed free of soil and separated from the stem. They were first air dried and then oven dried at 70-80^{0}C to constant weight. The root dry weight was recorded and the mean expressed in g $hill^{-1}$ and further derived to kg ha^{-1} (IRRI, 1980).

3.1.6.3. Yield attributes

a. Number of panicles

The total number of panicles from five randomly selected hills was counted and the average expressed as number $hill^{-1}$ (IRRI, 1980). The total number of panicles in a quadrat of size 0.5 m x 0.5 m, selected at three places at random, was also counted and the mean expressed as number m^{-2} (IRRI, 1980).

b. Length of panicle

Length of five randomly selected panicles was measured as per the procedure (IRRI, 1980) and the mean expressed in cm.

c. Number of filled grains per panicle

The filled grains from five randomly selected panicles were counted, worked out the average and expressed as number panicle^{-1} (IRRI, 1980). The percentage of filled grains per panicle was also worked out using the procedure of IRRI (1980).

d. Thousand grain weight

One thousand grains were collected, at random, from the produce of each plot and their weight was recorded in g.

3.1.6.4. Grain yield

The grains from each net plot, after winnowing and cleaning, were weighed and recorded their fresh weights. Moisture percentages of three samples of grain were worked out and the grain yield was computed at 13 per cent moisture and expressed in kg ha^{-1} (IRRI, 1980).

3.1.6.5. Straw yield

The straw from each net plot was sun dried uniformly, weighed and expressed in kg ha^{-1} (IRRI, 1980).

3.1.6.6. Harvest index

Harvest index (HI) of the crop was calculated using the formula

$$HI = \frac{\text{Economic yield (Grain yield, kg ha}^{-1}\text{)}}{\text{Biological yield (Grain + straw yield, kg ha}^{-1}\text{)}}$$

3.1.7. Observations on weed incidence

3.1.7.1. Weed density

Observations on weeds were recorded from the sampling strip in each plot, using a quadrat of size 0.5 m x 0.5 m. The count of weeds from three spots in each plot was taken at 45 and 60 DAT and expressed the weed density as number of grasses, sedges and broad leaf weeds m^{-2}.

3.1.7.2. Weed dry weight

The weeds from the observational areas in each plot were uprooted, cleaned, dried initially in shade and then in a hot air oven at 70-80 ^{0}C and the dry weight was recorded in g m^{-2}.

3.1.7.3. Weed control efficiency

As there was no unweeded treatment included in the experiment weed control efficiency of individual treatment was not worked out.

3.1.7.4. Weed Index

The weed index (WI) was derived using the formula:

$$\text{Weed index (WI)} = \frac{(Y_{WF} - Y_T) \times 100}{Y_{WF}}$$

Where, Y_{WF} is the crop yield in weed-free plot, and Y_T is the crop yield in treated plot (Gill and Kumar, 1969).

3.1.8. Soil analysis

3.1.8.1. Physical analysis

Soil samples from the experimental area were collected before start of the experiment, and the mechanical composition and the bulk density of the experimental area were analyzed. Further, during the experiment, soil samples were collected from the individual treatment plots at panicle initiation stage of the crop and analyzed for their bulk density, through core sampler method (Piper, 1966) and expressed in kg m^{-3}.

3.1.8.2. Chemical analysis

Soil samples were collected from the field before start of the experiment and, from each individual plot at panicle initiation stage of the crop. The samples were dried in shade, powdered, sieved through 2 mm sieve and analyzed for pH, electrical conductivity (EC), organic carbon, available P and exchangeable K status using standard procedures as shown in Table 1.

The EC was expressed in dS m^{-1}, the content of organic carbon as percentage and that of available P and exchangeable K in kg ha^{-1}.

3.1.9. Plant analysis and nutrient uptake

The sample plants of rice as well as weeds collected from each plot at panicle initiation stage of the crop were initially air dried and then oven dried at 70-80 ^{0}C to constant weight. They were then ground well to pass through 0.5 mm mesh sieve, using a Wiley mill.

The ground samples were subjected to acid digestion as per the standard procedures, estimated their N, P and K contents, and expressed as percentage. The methods used for analysis of plant samples are given in Table 3.

Table 3. Methods used for analysis of plant samples

Nutrient	Digestion procedure	Method of estimation	Reference
Nitrogen	H_2SO_4 digestion	Distillation and titration using Microkjeldahl method	Jackson, 1958
Phosphorus	2:1 HNO_3-$HClO_4$ diacid digestion	Vanadomolybdophosphoric yellow colour method using Spectrophotometer	Jackson, 1958
Potassium	2:1 HNO_3-$HClO_4$ diacid digestion	Direct reading using Flame photometer	Jackson, 1958

Uptake of N, P and K by the rice crop as well as by the weeds at panicle initiation stage of the crop was calculated by multiplying the respective percentage values of N, P and K with the total dry matter produced at that particular stage, and expressed in kg ha^{-1}.

3.1.10. Economics

Total cost of cultivation was worked out taking into account the prevailing labour charge in the locality, cost of inputs and the extra treatment costs, and expressed in Rs. ha^{-1}. The gross return was calculated based on the local market prices of paddy and straw and expressed per hectare basis. Benefit: cost ratio (B: C ratio) was calculated using the formula:

$$\text{B: C ratio} = \frac{\text{Gross return (Rs. ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.2. Development of self propelled cono weeder and its field testing

As the second experiment, a model of self propelled cono weeder was designed in the first year of the study and it was further refined to develop a prototype of self propelled cono weeder as a single row machine for weeding in lowland rice. The developmental works on the existing manual cono weeder was undertaken in the engineering workshop at the RARS, Pattambi. The materials required for fabrication were collected locally, and for its development utilized the service of the local workshop and industry.

3.2.1. Components of the self propelled cono weeder

The components of the self propelled cono weeder included main frame, a prime mover, floats and a rotor (Plate 3).

3.2.1.1. Main frame

The main frame is made for mounting the engine with control units, float, and rotors. It was fabricated with 25 mm square MS Steel pipe. A handle made of mild steel pipe wiht 25 mm diameter is also attached to the frame.

3.2.1.2. Prime mover

An air cooled 2-stroke petrol engine is used as the prime mover to the cono weeder. It has a rated power of 0.9 kW at 5500 RPM with specific fuel consumption of 650 g kW^{-1} h^{-1}. A cooling fan is provided to cool the engine. Engine power is taken through a belt drive to the rotors using a large pulley and a

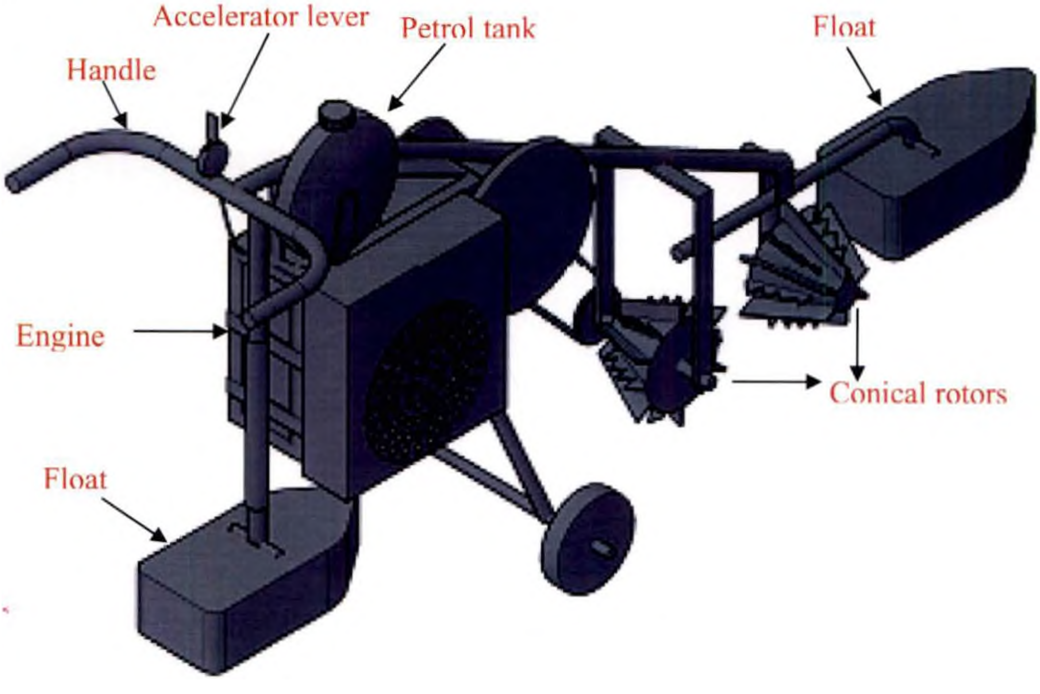


Plate 3. Components of the self propelled cono weeder

chain sprocket system. An accelerator is provided in the handle to control speed of the engine. A clutch engages and disengages the belt drive, which transmits the power from the engine to the rotor.

3.2.1.3. Floats

Two floats made of mild steel sheets and shaped into a hollow top covered boat, are provided each at the front and rear ends. The front end float is provided with a small swinging action to ensure flexibility. The rear end float with telescopic shaft is provided to prevent the weeder from sinking, especially in deeper clayey soils and to control the depth of operation.

3.2.1.4. Rotors

The rotors are detachable cone shaped frustums with smooth, serrated metal stripes welded along their periphery. The cono weeder has two conical rotors mounted in tandem with opposite orientation. As the rotor creates forward motion in the top soil, the smooth and serrated blades mounted alternately on the rotor uproot and bury the weeds in the soil. It facilitates a satisfactory weeding by the self propelled cono-weeder in a single forward pass without a push pull movement.

3.2.2. Working of the self propelled cono weeder

The engine rotates a small pulley of diameter 50 mm which is connected to the crankshaft. This pulley is further connected to a larger pulley of diameter 260 mm by means of a V-belt. This in turn is connected to the rotor (cone frustums) through a chain and sprocket arrangement. A 32- toothed chain with 18 toothed sprockets is used for further speed reduction and to operate the weeder under field conditions. This helped to cover an area of 0.1 ha h^{-1} with normal working speed of 2.0-3.0 km h^{-1}. The total weight of the unit is 36 kg.

Thus the forward motion of the weeder helps in entangling the weeds within the rotors and gets them uprooted. Further movement enables the weeds to get buried in the soil. The orthographic view of the self propelled cono weeder is shown in Fig. 5.

3.2.3. Field testing of self propelled cono weeder

The prototype developed was field tested at the RARS, Pattambi in a mechanically transplanted paddy field in the conventional system and its effectiveness was worked out and compared with other treatments.

3.2.3.1. Treatments

The treatments included were the following.

1. Manual cono weeding twice at 15 and 30 DAT
2. Self propelled cono weeding twice at 15 and 30 DAT
3. Manual cono weeding four times at 10, 20, 30 and 40 DAT
4. Hand weeding twice at 20 and 40 DAT

3.2.3.2. Design and layout

Design:	Randomized Block Design
Replications:	6
Spacing:	22.5 cm x 10 cm
Gross plot size:	10.0 m x 2.0 m
Sampling area:	1.0 m strip along the 2.0 m side
Net plot size:	8.0 m^2 (8.0 m x 1.0 m)

The layout for field testing of the self propelled cono weeder and treatment allocation are shown in Fig. 6.

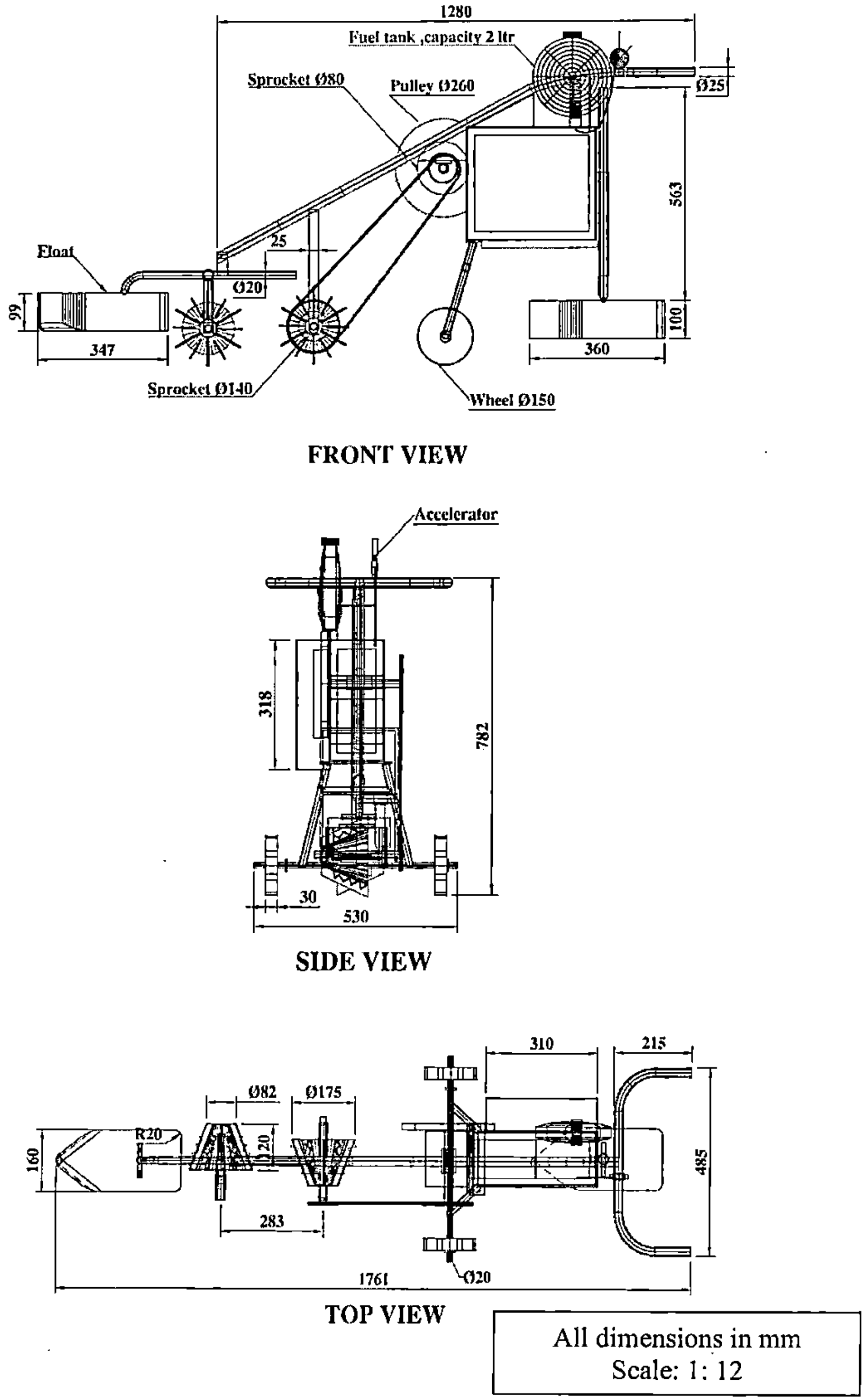
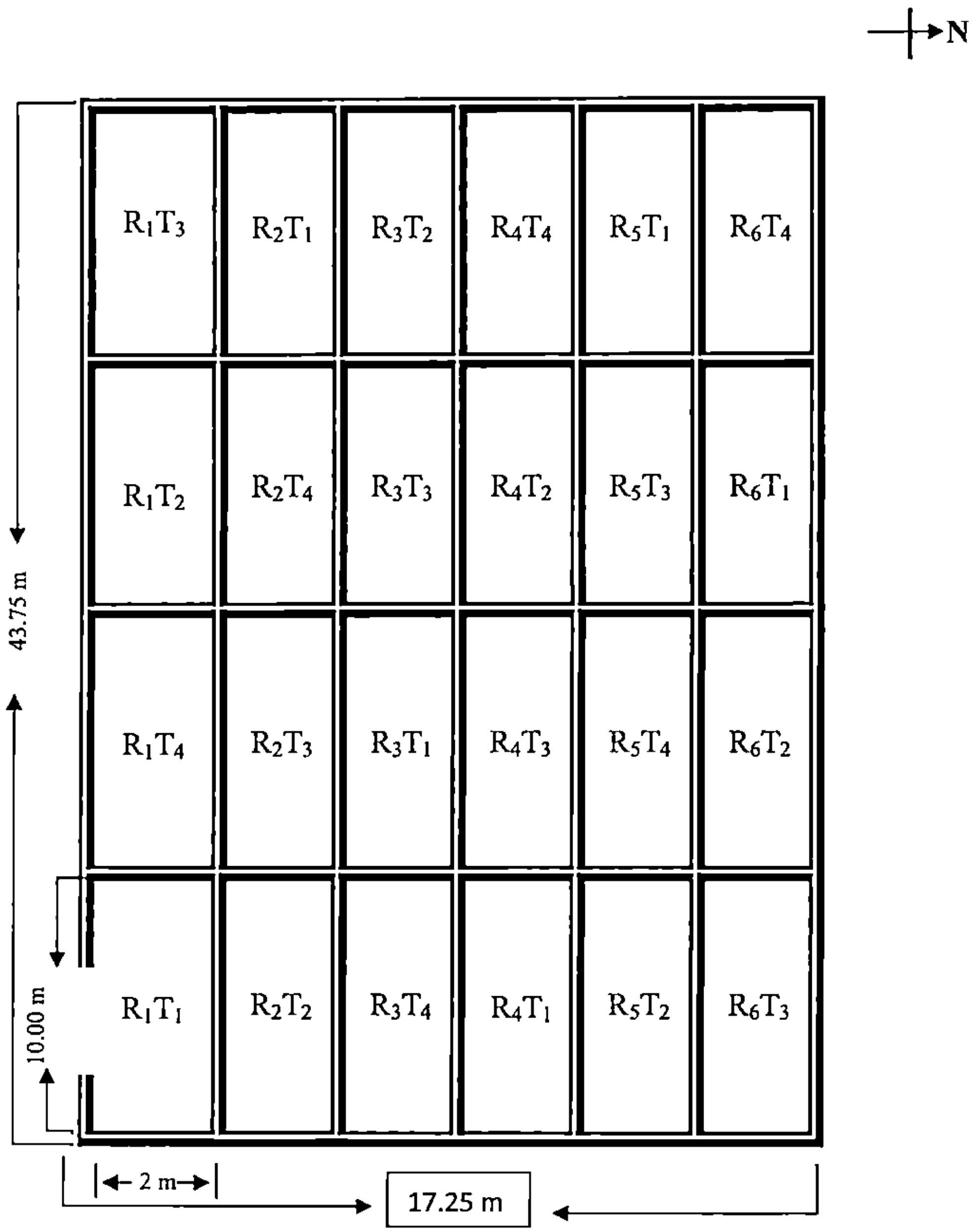


Fig. 5. Orthographic view of the self propelled cono weeder

Fig. 6. Layout plan for field testing of self propelled cono weeder at Pattambi



Treatments

1. Manual cono weeding at 15 and 30 days after transplanting
2. Self propelled cono weeding 15 and 30 days after transplanting
3. Manual cono weeding at 10, 20, 30 and 40 days after transplanting
4. Hand weeding at 20 and 40 days after transplanting

3.2.3.4. Observations recorded

a. Weed density

The number of weeds viz., grasses, sedges and broad leaf weeds in the sampling area in each plot was recorded from three spots using a quadrat of size 0.5 m x 0.5 m. The weed count was taken at 30 and 60 days after planting and expressed the weed density as number m^{-2}.

b. Weed dry weight

The weeds from the observational areas in each plot were uprooted, cleaned, dried initially in shade and then in a hot air oven at 70-80 ^{0}C and the dry weight was recorded in g m^{-2}.

c. Grain yield of rice

The grains from each net plot were winnowed, cleaned and sun dried and the weight expressed in kg ha^{-1} (IRRI, 1980).

d. Straw yield of rice

The straw from each net plot was uniformly dried in sun, weighed and the yield expressed in kg ha^{-1} (IRRI, 1980).

3.3. Statistical analysis

The data collected were compiled, tabulated and subjected to analysis of variance using the Statistical Package for the Social Sciences (SPSS), Version 16.0. The data on weed density and weed dry weight that showed wide variation between the treatments were subjected to square root transformation ($\sqrt{x + 0.5}$) to make the analysis of variance valid (Gomez and Gomez, 1984). Comparison among the treatment means was done by the Duncan's Multiple Range Test (DMRT) (Gomez and Gomez, 1984). Correlation coefficients between important characters, mainly the predictors of yield, were also attempted.

Results

4. RESULTS

Performance of the rice crop and the weed problems under the system of rice intensification (SRI) were studied through field experiments conducted during the *Mundakan* seasons of 2007 (1st year) and 2008 (2nd year), at two selected locations viz., RARS, Pattambi in Palakkad district and Alappad *Kole* in Thrissur district, representing the two major rice growing ecosystems in the state. Efforts were also made to develop a prototype of self propelled cono weeder and to evaluate its field efficiency. The data generated from the two experiments, viz., (1) Evaluation of weed control methods in SRI and conventional system, and (2) Development of self propelled cono weeder and its field evaluation, are presented and described in this chapter, after pooling them and subjecting to appropriate statistical analyses.

4.1. Evaluation of weed control methods in SRI and conventional system

4.1.1. Location I - Pattambi

4.1.1.1. Growth characters of rice

a. Plant height

The data on plant height of rice at different growth stages are presented in Table 4. At active tillering, the highest plant height (54.63 cm) was observed in conventional system with two hand weeding at 20 and 40 DAT (days after transplanting) (T16) which was on par with all the treatments in conventional system as well as the SRI treatment with cono weeding at 10, 20, 30 and 40 DAT with organic manure incorporation (T8) (the typical SRI), while it differed significantly from the remaining SRI treatments. The typical SRI treatment recorded a plant height of 66.52 cm at panicle initiation (PI stage) and this was immediately followed by conventional system with two hand weeding at 20 and

Table 4. Effect of the treatments on plant height (cm) of rice at different growth stages - Pattambi

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	38.21^{d}	45.73^{b}	41.97^{b}	61.67^{b}	58.07^{bcde}	59.87^{bcd}	73.73^{abc}	68.00^{a}	70.87^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	42.75^{cd}	47.53^{b}	45.14^{b}	60.87^{b}	52.55^{e}	56.71^{d}	76.47^{a}	67.87^{ab}	72.17^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	41.64^{cd}	43.07^{b}	42.36^{b}	57.80^{b}	58.07^{bcde}	57.93^{d}	77.00^{a}	64.73^{ab}	70.87^{ab}
T4 - SRI + CW- 10, 30 DAT	36.96^{d}	46.27^{b}	41.61^{b}	60.53^{b}	57.93^{bcde}	59.23^{bcd}	75.73^{ab}	66.47^{b}	71.10^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	41.00^{cd}	46.60^{b}	43.80^{b}	60.20^{b}	55.32^{de}	57.76^{cd}	72.60^{abcd}	68.00^{a}	70.30^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	41.86^{cd}	42.27^{b}	42.06^{b}	62.93^{b}	57.27^{cde}	60.10^{bcd}	77.07^{a}	66.80^{ab}	71.93^{ab}
T7 - SRI + Clincher** fb Almix***	40.71^{cd}	46.53^{b}	43.62^{b}	64.60^{b}	55.53^{de}	60.07^{bcd}	74.13^{abc}	61.80^{ab}	67.97^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	56.09^{a}	46.80^{b}	51.44^{a}	73.10^{a}	59.93^{bcd}	66.52^{a}	76.20^{a}	68.13^{a}	72.17^{a}
T9 - CS + CW-10, 20, 30, 40 DAT	50.52^{ab}	55.60^{a}	53.06^{a}	60.27^{b}	63.00^{abc}	61.63^{abcd}	67.34^{bcd}	65.30^{ab}	66.32^{b}
T10 - CS + Butachlor* + HW-30 DAT	50.21^{ab}	53.57^{a}	51.89^{a}	62.20^{b}	61.73^{abcd}	61.97^{abc}	74.16^{abc}	64.63^{ab}	69.40^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	45.27^{bc}	54.93^{a}	50.10^{a}	58.00^{b}	64.73^{ab}	61.37^{bcd}	66.23^{cd}	66.27^{ab}	66.25^{b}
T12 - CS + CW- 10, 30 DAT	49.50^{ab}	56.67^{a}	53.08^{a}	59.23^{b}	63.73^{abc}	61.48^{bcd}	67.10^{bcd}	65.27^{ab}	66.18^{b}
T13 - CS + CW- 10 DAT + HW-30 DAT	50.81^{ab}	57.33^{a}	54.07^{a}	59.97^{b}	64.53^{ab}	62.25^{abc}	63.90^{d}	67.73^{ab}	65.82^{b}
T14- CS + CW-10 DAT + Clincher** fb Almix***	50.46^{ab}	55.80^{a}	53.13^{a}	60.67^{b}	63.13^{abc}	61.90^{abc}	66.43^{cd}	66.20^{ab}	66.32^{b}
T15 - CS + Clincher** fb Almix***	50.87^{ab}	55.20^{a}	53.03^{a}	61.13^{b}	63.60^{abc}	62.37^{abc}	69.57^{abcd}	67.40^{ab}	68.48^{ab}
T16 - CS + HW – 20, 40 DAT	51.13^{ab}	58.13^{a}	54.63^{a}	59.67^{b}	67.60^{a}	63.63^{ab}	64.63^{d}	69.27^{a}	66.95^{ab}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

40 DAT, and they were at par. At harvest stage, SRI with pre emergence herbicide followed by hand weeding at 30 DAT (T2) and the typical SRI treatment recorded the highest plant height of 72.17 cm which was followed by SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5), and were at par.

b. Number of tillers

The data on tiller count hill^{-1} are presented in Table 5. It was observed that SRI treatments recorded significantly higher number of tillers hill^{-1} at all stages of observation. At active tillering, significantly higher number of tillers hill^{-1} (23.14) was recorded by the typical SRI treatment, and the second highest number of tillers hill^{-1} was recorded by cono weeding at 10 DAT followed by hand weeding at 30 DAT. At panicle initiation (PI) stage also the typical SRI treatment recorded significantly higher number of tillers hill^{-1} (22.53), and most of the SRI treatments were at par with it. At harvest stage, SRI with pre emergence herbicide followed by cono weeding at 30 DAT (T3) and cono weeding at 10 DAT followed by post emergence herbicides (T6) recorded maximum number of tillers hill^{-1} (24.67). Most of the treatments under SRI immediately followed it and kept parity with it.

The data on tiller number per unit area (number m^{-2}) are shown in Table 6. As against the observation on tiller number hill^{-1}, the number of tillers m^{-2} was significantly higher with treatments under conventional system at all stages of observation. At active tillering, the treatments under conventional system performed uniformly and produced significantly superior number of tillers m^{-2} over the treatments under SRI, and the highest number of tillers m^{-2} (428) was observed in conventional system with pre emergence herbicide followed by hand weeding at 30 DAT (T10). The same trend was observed at later stages also, and at PI stage, the highest number of tillers per unit area was recorded by conventional system with cono weeding at 10 and 30 DAT (T12) with which all other treatments in the conventional system were at par. Conventional system with post emergence herbicides (T15) recorded the highest number of tillers per unit

Table 5. Effect of the treatments on tiller count per hill (Number $hill^{-1}$) at different growth stages of rice - Pattambi

Treatments	Active tillering			Panicle initiation			Harvest		
	1^{st} year	2^{nd} year	Pooled	1^{st} year	2^{nd} year	Pooled	1^{st} year	2^{nd} year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	11.20^{bc}	7.93^{defg}	9.57^{cd}	20.67^{b}	9.67^{de}	15.17^{bc}	28.17^{c}	16.80^{de}	22.48^{a}
T2 - SRI + Butachlor* + HW-30 DAT	9.21^{bc}	8.53^{de}	8.87^{cd}	18.47^{b}	13.70^{ab}	16.08^{bc}	28.13^{a}	19.95^{bc}	24.04^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	9.59^{bc}	8.07^{defg}	8.83^{cd}	18.13^{b}	15.33^{ab}	16.73^{b}	27.40^{a}	21.93^{ab}	24.67^{a}
T4 - SRI + CW- 10, 30 DAT	10.48^{bc}	10.73^{bc}	10.61^{bc}	16.13^{bc}	10.73^{cd}	13.43^{c}	24.60^{a}	13.07^{f}	18.84^{b}
T5 - SRI + CW- 10 DAT + HW-30 DAT	12.00^{b}	12.07^{b}	12.04^{b}	20.20^{b}	13.27^{bc}	16.74^{b}	26.60^{a}	20.27^{abc}	23.44^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	11.93^{b}	9.33^{cd}	10.63^{bc}	20.00^{b}	13.20^{bc}	16.60^{b}	26.67^{a}	22.67^{a}	24.67^{a}
T7 - SRI + Clincher** fb Almix***	8.13^{c}	8.27^{def}	8.20^{d}	21.47^{b}	14.00^{ab}	17.73^{b}	26.47^{a}	18.27^{cd}	22.37^{a}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	26.67^{a}	19.60^{a}	23.14^{a}	29.07^{a}	16.00^{a}	22.53^{a}	27.70^{a}	15.27^{ef}	21.49^{ab}
T9 - CS + CW-10, 20, 30, 40 DAT	9.51^{bc}	5.60^{h}	7.56^{c}	10.73^{d}	7.27^{e}	9.00^{d}	10.62^{b}	7.67^{g}	9.14^{c}
T10 - CS + Butachlor* + HW-30 DAT	9.60^{bc}	7.53^{defgh}	8.57^{cd}	10.80^{d}	7.53^{e}	9.17^{d}	13.67^{b}	7.80^{g}	10.73^{c}
T11 - CS + Butachlor* + CW- 30 DAT	8.78^{bc}	6.47^{fgh}	7.63^{d}	10.47^{d}	7.67^{e}	9.07^{d}	12.33^{b}	8.10^{g}	10.22^{c}
T12 - CS + CW- 10, 30 DAT	8.70^{bc}	6.73^{efgh}	7.72^{d}	11.60^{cd}	7.13^{e}	9.37^{d}	11.33^{b}	7.50^{g}	9.42^{c}
T13 - CS + CW- 10 DAT + HW-30 DAT	8.83^{bc}	7.00^{efgh}	7.92^{d}	10.27^{d}	7.20^{e}	8.73^{d}	11.67^{b}	7.77^{g}	9.72^{c}
T14- CS + CW-10 DAT + Clincher** fb Almix***	8.69^{bc}	7.00^{efgh}	7.85^{d}	9.67^{d}	7.33^{e}	8.50^{d}	12.72^{b}	7.70^{g}	10.21^{c}
T15 - CS + Clincher** fb Almix***	8.67^{bc}	7.60d^{efg}	8.14^{d}	10.20^{d}	8.33^{de}	9.27^{d}	13.78^{b}	8.63^{g}	11.21^{c}
T16 - CS + HW – 20, 40 DAT	9.04^{bc}	6.27^{gh}	7.66^{d}	10.00^{d}	7.20^{e}	8.60^{d}	11.72^{b}	7.60^{g}	9.66^{c}

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fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 6. Effect of the treatments on tiller count per unit area (Number m^{-2}) at different growth stages of rice - Pattambi

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	124.4^{c}	88.2^{e}	106.3^{c}	229.6^{d}	107.4^{b}	168.5^{c}	313.0^{b}	186.7^{bcd}	249.8^{c}
T2 - SRI + Butachlor* + HW-30 DAT	102.3^{c}	94.8^{e}	98.6^{c}	205.2^{d}	152.2^{b}	178.7^{c}	312.6^{b}	221.7^{bc}	267.1^{c}
T3 - SRI + Butachlor* + CW- 30 DAT	106.6^{c}	89.6^{e}	98.1^{c}	201.5^{d}	170.4^{b}	185.9^{c}	304.4^{b}	243.7^{b}	274.1^{c}
T4 - SRI + CW- 10, 30 DAT	116.4^{c}	119.3^{e}	117.9^{c}	179.3^{d}	119.3^{b}	149.3^{c}	273.3^{b}	145.2^{d}	209.3^{c}
T5 - SRI + CW- 10 DAT + HW-30 DAT	133.4^{c}	134.1^{e}	133.7^{c}	224.4^{d}	147.4^{b}	185.9^{c}	295.6^{b}	225.2^{bc}	260.4^{c}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	132.6^{c}	103.7^{e}	118.1^{c}	222.2^{d}	146.7^{b}	184.4^{c}	296.3^{b}	251.9^{b}	274.1^{c}
T7 - SRI + Clincher** fb Almix***	90.3^{c}	91.9^{e}	91.1^{c}	238.5^{d}	155.6^{b}	197.0^{bc}	294.1^{b}	203.0^{bcd}	248.5^{c}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	296.3^{b}	217.8^{d}	257.1^{b}	323.0^{c}	177.8^{b}	250.4^{b}	307.8^{b}	169.6^{cd}	238.7^{c}
T9 - CS + CW-10, 20, 30, 40 DAT	475.3^{a}	280.0^{c}	377.7^{a}	536.7^{ab}	363.3^{a}	450.0^{a}	530.8^{a}	383.3^{a}	457.1^{b}
T10 - CS + Butachlor* + HW-30 DAT	480.2^{a}	376.7^{a}	428.4^{a}	540.0^{ab}	376.7^{a}	458.3^{a}	683.3^{a}	390.0^{a}	536.7^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	439.2^{a}	323.3^{bc}	381.3^{a}	523.3^{ab}	383.3^{a}	453.3^{a}	616.7^{a}	405.0^{a}	510.8^{ab}
T12 - CS + CW- 10, 30 DAT	435.0^{a}	336.7^{ab}	385.8^{a}	580.0^{a}	356.7^{a}	468.3^{a}	566.7^{a}	375.0^{a}	470.8^{ab}
T13 - CS + CW- 10 DAT + HW-30 DAT	441.7^{a}	350.0^{ab}	395.8^{a}	513.3^{ab}	360.0^{a}	436.7^{a}	583.3^{a}	388.3^{a}	485.8^{ab}
T14- CS + CW-10 DAT + Clincher** fb Almix***	434.3^{a}	350.0^{ab}	392.2^{a}	483.3^{b}	366.7^{a}	425.0^{a}	635.8^{a}	385.0^{a}	510.4^{ab}
T15 - CS + Clincher** fb Almix***	433.5^{a}	380.0^{a}	406.8^{a}	510.0^{ab}	416.7^{a}	463.3^{a}	689.2^{a}	431.7^{a}	560.4^{a}
T16 - CS + HW – 20, 40 DAT	452.2^{a}	313.3^{bc}	382.8^{a}	500.0^{ab}	360.0^{a}	430.0^{a}	585.8^{a}	380.0^{a}	482.9^{ab}

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OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

area at harvest (560 tillers m^{-2}). Among the SRI treatments, typical SRI treatment though produced higher number of tillers per unit area at active tillering and PI stages, showed a reduction in the number of tillers per unit area at harvest.

c. Dry matter production

The data on dry matter production by the rice plant at different growth stages are given in Table 7. At active tillering, cono weeding at 10 DAT followed by post emergence herbicides in conventional system (T14) produced significantly higher dry matter (4038 kg ha^{-1}) and this was followed by cono weeding at 10, 20, 30 and 40 DAT in the conventional system (T9). At PI stage also, T14 produced the highest quantity of dry matter (4882 kg ha^{-1}) and all the other conventional treatments followed it uniformly. The treatment T9 recorded the highest dry matter production (10364 kg ha^{-1}) at harvest and this was closely followed by cono weeding at 10 and 30 DAT in the conventional system (T12), and they were at par.

d. Root characteristics

The data on root length (cm), root dry weight $hill^{-1}$ (g $hill^{-1}$) and root dry weight ha^{-1} (kg ha^{-1}) observed at panicle initiation stage of the rice crop in the experimental field at Pattambi are presented in Table 8.

SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT recorded maximum root length (20.75 cm) and this was immediately followed by SRI with four cono weeding at 10, 20, 30 and 40 DAT. The root dry weight per individual hill was the highest (2.17 g $hill^{-1}$) in SRI with cono weeding at 10, 20, 30 and 40 DAT (T1) which was closely followed by SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5).

Table 7. Effect of the treatments on dry matter production (kg ha^{-1}) of rice at different growth stages - Pattambi

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	478.9^{f}	158.2^{c}	318.5^{f}	1429.0^{ef}	706.3^{e}	1067.7^{ef}	4778.5^{c}	2022.2^{efb}	3400.4^{ef}
T2 - SRI + Butachlor* + HW-30 DAT	438.9^{f}	135.2^{c}	287.0^{f}	2377.8^{de}	879.3^{e}	1628.5^{de}	5133.7^{c}	1461.5^{f}	3297.6^{ef}
T3 - SRI + Butachlor* + CW- 30 DAT	276.7^{f}	141.9^{c}	209.3^{f}	1605.0^{ef}	1401.5^{cde}	1503.3^{ef}	3768.2^{c}	1927.0^{ef}	2847.6^{f}
T4 - SRI + CW- 10, 30 DAT	596.3^{f}	208.9^{c}	402.6^{f}	851.0^{f}	1040.0^{de}	945.5^{f}	4431.1^{c}	2261.1^{def}	3346.1^{ef}
T5 - SRI + CW- 10 DAT + HW-30 DAT	734.4^{f}	147.0^{c}	440.7^{f}	2592.7^{de}	1704.1^{cd}	2148.4^{cd}	5876.7^{c}	3359.6^{c}	4618.2^{d}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	788.5^{f}	185.2^{c}	486.9^{f}	1324.3^{ef}	894.8^{e}	1109.5^{ef}	6105.9^{c}	3042.9^{cd}	4574.4^{d}
T7 - SRI + Clincher** fb Almix***	638.2^{f}	149.6^{c}	393.9^{f}	1689.3^{ef}	1062.6^{de}	1375.9^{ef}	4209.3^{c}	1555.6^{f}	2882.4^{f}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2227.4^{e}	507.0^{c}	1367.2^{e}	3194.3^{cd}	1941.9^{c}	2569.9^{c}	6325.6^{c}	2514.4^{cde}	4420.0^{de}
T9 - CS + CW-10, 20, 30, 40 DAT	3938.3^{bc}	3698.3^{a}	3818.3^{ab}	4956.5^{ab}	4150.0^{ab}	4553.3^{ab}	14015.0^{ab}	6713.3^{ab}	10364.2^{a}
T10 - CS + Butachlor* + HW-30 DAT	3523.3^{cd}	2423.3^{b}	2973.3^{d}	4474.2^{b}	3876.7^{ab}	4175.4^{b}	12643.3^{ab}	6146.7^{ab}	9395.0^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	3865.0^{bcd}	3493.3^{a}	3679.2^{abc}	4556.3^{ab}	4373.3^{a}	4516.5^{ab}	13551.7^{ab}	6078.3^{ab}	9815.0^{ab}
T12 - CS + CW- 10, 30 DAT	4668.3^{ab}	2743.3^{b}	3705.8^{abcc}	5376.8^{ab}	3950.0^{ab}	4663.4^{ab}	14421.7^{a}	5836.7^{b}	10129.2^{a}
T13 - CS + CW- 10 DAT + HW-30 DAT	2865.0^{de}	3830.0^{a}	3347.5^{bcd}	4276.0^{bc}	4430.0^{a}	4353.0^{ab}	8806.7^{d}	6903.3^{a}	7855.0^{c}
T14- CS + CW-10 DAT + Clincher** fb Almix***	3790.0^{bcd}	2690.0^{b}	3240.0^{cd}	4578.5^{ab}	4076.7^{ab}	4327.6^{ab}	11593.3^{bc}	6250.0^{ab}	8921.7^{bc}
T15 - CS + Clincher** fb Almix***	5211.7^{a}	2865.0^{b}	4038.3^{a}	5854.7^{a}	3908.3^{ab}	4881.5^{a}	12235.0^{abc}	6366.7^{ab}	9300.8^{ab}
T16 - CS + HW – 20, 40 DAT	4743.3^{ab}	2436.7^{b}	3590.0^{abc}	5354.2^{ab}	3573.3^{b}	4463.8^{ab}	9980.0^{cd}	5986.7^{ab}	7983.3^{c}

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fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 8. Effect of the treatments on root characteristics of rice at panicle initiation stage - Pattambi

Treatments	Root length (cm)			Root dry weight (g hill^{-1})			Root dry weight (kg ha^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	21.60b^{cd}	13.90^{ab}	17.75^{bc}	1.85^{cde}	0.86^{bcd}	1.36^{de}	205.4^{f}	95.9^{g}	150.7^{ef}
T2 - SRI + Butachlor* + HW-30 DAT	21.50^{bcd}	12.23^{bcd}	16.87^{bcd}	2.58^{ab}	1.02^{bc}	1.80^{bc}	286.9^{def}	113.7^{fg}	200.3^{ef}
T3 - SRI + Butachlor* + CW- 30 DAT	19.27^{cde}	9.73^{ef}	14.50^{de}	2.46^{abc}	0.93^{bcd}	1.67^{bcd}	273.2^{ef}	103.4^{g}	188.3^{ef}
T4 - SRI + CW- 10, 30 DAT	25.10^{ab}	11.77^{cd}	18.43^{abc}	1.24^{efg}	1.03^{bc}	1.13^{efgh}	137.2^{f}	113.9^{fg}	125.6^{f}
T5 - SRI + CW- 10 DAT + HW-30 DAT	28.70^{a}	12.80^{abc}	20.75^{a}	3.02^{a}	1.04^{bc}	2.03^{b}	336.0^{cdef}	115.7^{fg}	225.9^{ef}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	23.30^{bc}	9.70^{ef}	16.50^{cd}	1.51^{efg}	1.09^{b}	1.30^{ef}	167.9^{f}	121.7^{fg}	144.8^{ef}
T7 - SRI + Clincher** fb Almix***	22.80^{bc}	10.50^{de}	16.65^{cd}	2.21^{bcd}	1.09^{b}	1.65^{cd}	245.6^{ef}	121.3^{fg}	183.5^{ef}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	24.37^{abc}	14.63^{a}	19.50^{b}	2.64^{ab}	1.69^{a}	2.17^{a}	293.3^{def}	188.3^{ef}	240.8^{ef}
T9 - CS + CW-10, 20, 30, 40 DAT	15.73^{ef}	8.07^{fg}	11.90^{efg}	1.76^{def}	0.72^{cde}	1.24^{efg}	880.0^{a}	358.0^{b}	619.0^{a}
T10 - CS + Butachlor* + HW-30 DAT	14.03^{ef}	7.07^{ef}	10.55^{fg}	1.24^{efg}	0.72^{cde}	0.98^{fghi}	619.3^{b}	358.5^{b}	488.9^{bc}
T11 - CS + Butachlor* + CW- 30 DAT	11.67^{f}	7.00^{g}	9.33^{g}	1.19^{efg}	0.66^{de}	0.92^{ghi}	596.7^{b}	327.7^{bc}	462.2^{bcd}
T12 - CS + CW- 10, 30 DAT	16.27^{def}	8.57^{efg}	12.42^{ef}	1.12^{fgh}	0.97^{bcd}	1.04^{efghi}	558.0^{b}	485.0^{a}	521.5^{ab}
T13 - CS + CW- 10 DAT + HW-30 DAT	14.00^{ef}	8.57^{efg}	11.28^{fg}	0.95^{gh}	0.73^{cde}	0.84^{hij}	475.7^{bcd}	364.8^{b}	420.3^{bcd}
T14 - CS + CW-10 DAT + Clincher** fb Almix***	12.67^{f}	7.53^{f}	10.10^{fg}	0.47^{h}	0.54^{e}	0.50^{i}	233.5^{ef}	267.5^{cd}	250.5^{e}
T15 - CS + Clincher** fb Almix***	16.90^{f}	6.80^{g}	11.85^{fge}	1.03^{gh}	0.42^{e}	0.73^{ij}	514.3^{bc}	211.8^{de}	363.1^{d}
T16 - CS + HW – 20, 40 DAT	15.17^{ef}	9.67^{ef}	12.42^{ef}	0.86^{gh}	0.72^{cde}	0.79^{hij}	428.3^{bcde}	357.5^{b}	392.9^{cd}

Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification
CW – Cono weeding
* Butachlor @ 1.25 kg ha^{-1}

CS – Conventional System
HW – Hand weeding
** Cyhalofop butyl @ 0.1 kg ha^{-1}

fb – Followed by
DAT – Days after transplanting
OM – Organic manure
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

The root dry weight per hectare was significantly higher in conventional treatments and the highest quantity of dry matter was produced with cono weeding at 10, 20, 30 and 40 DAT (T9) (619 kg ha^{-1}), which was followed by cono weeding at 10 and 30 DAT in the conventional system (T12). The SRI treatments recorded significantly lower root dry weight ha^{-1}.

4.1.1.2. Yield attributes

Yield attributes of rice viz., productive tillers, number of filled grains per panicle, filled grain percentage and 1000 grain weight are presented in Tables 9 and 10.

a. Productive tillers/ Number of panicles

It is clear from the data in Table 9 that number of productive tillers $hill^{-1}$ was significantly higher in SRI treatments and the highest number (23.63 tillers $hill^{-1}$) was recorded by pre emergence herbicide followed by cono weeding at 30 DAT which was in uniformity with other SRI treatments. On the other hand, the number of productive tillers ha^{-1} was significantly higher in treatments with conventional system, wherein the treatment with post emergence herbicides recorded the highest number (533 tillers m^{-2}) which was followed by treatment with pre emergence herbicide followed by hand weeding at 30 DAT.

b. Panicle length

Panicle length was significantly superior in treatments under SRI. The typical SRI treatment recorded the longest panicle (20.54 cm) which was followed by SRI with pre emergence herbicide with cono weeding at 30 DAT (T3), cono weeding at 10 and 30 DAT (T4), and also with pre emergence herbicide followed by hand weeding at 30 DAT (T2).

Table 9. Effect of the treatments on number of productive tillers and panicle length of rice - Pattambi

Treatments	Productive tillers per hill (Number $hill^{-1}$)			Productive tillers per m^2 (Number m^{-2})			Panicle length (cm)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	27.97^{a}	15.93^{c}	21.95^{ab}	310.7^{ac}	177.0^{bc}	243.9^{d}	20.62^{ab}	19.59^{ab}	20.11^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	28.00^{a}	19.18^{ab}	23.59^{a}	311.1^{c}	213.2^{bc}	262.1^{d}	20.63^{ab}	20.30^{a}	20.47^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	26.93^{a}	20.33^{a}	23.63^{a}	299.3^{c}	225.9^{b}	262.6^{d}	20.95^{a}	20.07^{a}	20.51^{a}
T4 - SRI + CW- 10, 30 DAT	24.40^{a}	12.60^{d}	18.50^{b}	271.1^{c}	140.0^{c}	205.6^{d}	20.48^{ab}	19.53^{ab}	20.01^{abc}
T5 - SRI + CW- 10 DAT + HW-30 DAT	25.20^{a}	19.13^{ab}	22.17^{a}	280.0^{c}	212.6^{bc}	246.3^{d}	20.71^{ab}	20.31^{a}	20.51^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	26.67^{a}	19.73^{ab}	23.20^{a}	296.3^{c}	219.3^{b}	257.8^{d}	20.65^{ab}	20.12^{a}	20.39^{ab}
T7 - SRI + Clincher** fb Almix***	26.27^{a}	17.20^{bc}	21.73^{ab}	291.9^{c}	191.1^{bc}	241.5^{d}	21.09^{a}	19.67^{ab}	20.38^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	27.57^{a}	15.07^{cd}	21.32^{ab}	306.3^{c}	167.4^{bc}	236.9^{d}	21.49^{a}	19.59^{ab}	20.54^{a}
T9 - CS + CW-10, 20, 30, 40 DAT	10.02^{b}	7.27^{e}	8.64^{c}	500.8^{b}	363.3^{a}	432.1^{c}	18.56^{c}	18.66^{ab}	18.61^{de}
T10 - CS + Butachlor* + HW-30 DAT	13.43^{b}	7.17^{e}	10.30^{c}	671.7^{a}	358.3^{a}	515.0^{ab}	18.63^{c}	18.88^{ab}	18.76^{de}
T11 - CS + Butachlor* + CW- 30 DAT	11.93^{b}	7.57^{e}	9.75^{c}	596.7^{ab}	378.3^{a}	487.5^{abc}	18.69^{c}	18.87^{ab}	18.78^{de}
T12 - CS + CW- 10, 30 DAT	11.20^{b}	7.17^{e}	9.18^{c}	560.0^{ab}	358.3^{a}	459.2^{abc}	18.65^{c}	18.81^{ab}	18.73^{de}
T13 - CS + CW- 10 DAT + HW-30 DAT	11.05^{b}	6.93^{e}	8.99^{c}	552.5^{ab}	346.7^{a}	449.6^{bc}	19.57^{bc}	20.13^{a}	19.85^{abc}
T14- CS + CW-10 DAT + Clincher** fb Almix***	11.63^{b}	7.47^{e}	9.55^{c}	581.7^{ab}	373.3^{a}	477.5^{abc}	18.93^{c}	19.17^{ab}	19.05^{cde}
T15 - CS + Clincher** fb Almix***	13.05^{b}	8.27^{e}	10.66^{c}	652.5^{a}	413.3^{a}	532.9^{a}	19.20^{c}	19.57^{ab}	19.38^{bcd}
T16 - CS + HW – 20, 40 DAT	11.00^{b}	7.17^{e}	9.08^{c}	550.0^{ab}	358.3^{a}	454.2^{abc}	18.31^{c}	18.18^{b}	18.25^{e}

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* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

c. Number of filled grains per panicle

Data on number of filled grains per panicle are given in Table 10. It was observed from the pooled data that the number of filled grains panicle^{-1} was the highest (99.75) with typical SRI treatment and this was followed by SRI with pre emergence herbicide and cono weeding at 30 DAT(T3).

d. Filled grain percentage per panicle

It was observed from the pooled data that SRI with four cono weeding at 10, 20, 30 and 40 DAT (T1) recorded the highest percentage of filled grains panicle^{-1} (87.39 %).

e. 1000 grain weight

The weight of thousand grains was the highest (27.23 g) in conventional system with two hand weeding at 20 and 40 DAT (T16) (Table 10). All other treatments performed uniformly with it, but was significantly superior to conventional treatment with cono weeding at 10 DAT followed by post emergence herbicides (T14).

4.1.1.3. Grain yield

The effects of the treatments on grain yield, straw yield and harvest index of rice are presented in Table 11.

In the 1st year, significantly higher grain yield (3462 kg ha^{-1}) was recorded in the conventional system with CW at 10 DAT fb HW at 30 DAT whereas in the 2nd year it was significantly higher (2924 kg ha^{-1}) under SRI with cono weeding at 10 DAT followed by post emergence herbicides. Despite slight year wise variation, the pooled data showed the highest grain yield among all the treatments

Table 10. Effect of the treatments on number of filled grains and 1000 grain weight of rice – Pattambi

Treatments	Filled grains (Number panicle^{-1})			Filled grains (%)			1000 grain weight (g)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	95.19^{ab}	84.48^{cde}	89.84^{bc}	85.82^{a}	88.97^{a}	87.39^{a}	24.89^{a}	27.63^{a}	26.26^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	82.68^{bc}	93.38^{abc}	88.03^{bc}	76.59^{bc}	87.52^{a}	82.06^{b}	24.42^{a}	26.03^{abc}	25.23^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	85.64^{abc}	98.87^{a}	92.25^{ab}	74.98^{bc}	90.21^{a}	82.59^{ab}	27.02^{a}	26.40^{ab}	26.71^{ab}
T4 - SRI + CW- 10, 30 DAT	82.23^{bc}	84.19^{cde}	83.21^{bcd}	74.74^{bc}	86.92^{a}	80.83^{b}	25.99^{a}	26.33^{ab}	26.16^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	78.58^{bc}	96.67^{ab}	87.63b^{c}	73.48^{bc}	90.86^{a}	82.17^{b}	26.13^{a}	26.27^{abc}	26.20^{ab}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	83.13^{bc}	92.52^{abc}	87.83b^{c}	76.83^{bc}	89.43^{a}	83.13^{ab}	26.09^{a}	25.67^{bc}	25.88^{ab}
T7 - SRI + Clincher** fb Almix***	81.32^{bc}	84.85^{cde}	83.08b^{cd}	73.13^{c}	87.21^{a}	80.17^{b}	24.02^{a}	26.70^{ab}	25.36^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	100.62^{a}	98.88^{a}	99.75^{a}	75.21^{bc}	90.86^{a}	83.04^{ab}	24.70^{a}	26.33^{ab}	25.52^{ab}
T9 - CS + CW-10, 20, 30, 40 DAT	72.55^{c}	79.66^{de}	76.10^{d}	75.12^{bc}	85.49^{a}	80.31^{b}	25.63^{a}	25.40^{bc}	25.52^{ab}
T10 - CS + Butachlor* + HW-30 DAT	74.48^{c}	78.76^{de}	76.62^{d}	77.99^{bc}	85.94^{a}	81.96^{b}	26.28^{a}	26.07^{abc}	26.17^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	78.17^{c}	81.46^{de}	79.81^{cd}	79.05^{bc}	86.55^{a}	82.80^{ab}	25.20^{a}	26.00^{abc}	25.60^{ab}
T12 - CS + CW- 10, 30 DAT	79.50^{bc}	81.70^{de}	80.60^{cd}	80.81^{ab}	84.11^{a}	82.46^{ab}	27.24^{a}	26.23^{abc}	26.74^{ab}
T13 - CS + CW- 10 DAT + HW-30 DAT	82.13^{bc}	86.20^{cd}	84.17^{bcd}	75.97^{bc}	88.48^{a}	82.22^{b}	26.25^{a}	26.27^{abc}	26.26^{ab}
T14- CS + CW-10 DAT + Clincher** fb Almix***	81.47^{bc}	84.37^{cde}	82.92^{bcd}	78.80^{bc}	87.62^{a}	83.21^{ab}	24.36^{a}	24.63^{c}	24.50^{b}
T15 - CS + Clincher** fb Almix***	85.78^{abc}	88.43^{bcd}	87.10^{bc}	80.68^{ab}	86.56^{a}	83.62^{ab}	25.13^{a}	25.60^{bc}	25.36^{ab}
T16 - CS + HW – 20, 40 DAT	74.33^{c}	75.19^{e}	74.76^{d}	78.92^{bc}	84.20^{a}	81.56^{b}	26.99^{a}	27.47^{a}	27.23^{a}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 11. Effect of the treatments on grain and straw yields of rice - Pattambi

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Harvest Index		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1989^{fgh}	1777^{g}	1883^{fg}	1898^{bc}	1919de	1908^{cdef}	0.51^{cdefg}	0.48^{e}	0.49^{efg}
T2 - SRI + Butachlor* + HW-30 DAT	2501^{defg}	2449^{bc}	2475^{bcde}	2274^{abc}	2316^{bc}	2295^{ab}	0.52^{bcdef}	0.51^{cd}	0.52^{de}
T3 - SRI + Butachlor* + CW- 30 DAT	1197^{i}	2022^{defg}	1609^{g}	1852^{c}	2030^{cde}	1941^{bcdef}	0.40^{h}	0.50^{d}	0.45^{h}
T4 - SRI + CW- 10, 30 DAT	1908^{gh}	1831^{fg}	1869^{fg}	1774^{c}	2764^{a}	2269^{abc}	0.52^{bcdef}	0.40^{f}	0.46^{gh}
T5 - SRI + CW- 10 DAT + HW-30 DAT	2693^{bcdef}	2329^{bcde}	2511^{abcde}	2049^{abc}	2413^{b}	2231^{ab}	0.56^{abcde}	0.49^{d}	0.53^{de}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1753^{hi}	2924^{a}	2338de	2310^{abc}	2710^{a}	2510^{a}	0.43^{gh}	0.52^{cd}	0.48^{fgh}
T7 - SRI + Clincher** fb Almix***	1961^{fgh}	2610^{b}	2285de	2214^{abc}	2126^{bcd}	2170^{abcde}	0.47^{fgh}	0.55^{bc}	0.51^{ef}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2187^{efgh}	2148^{cdef}	2168^{ef}	2218^{abc}	2721^{a}	2470^{a}	0.50^{defg}	0.44^{e}	0.47^{fgh}
T9 - CS + CW-10, 20, 30, 40 DAT	2752^{abcde}	2084^{defg}	2418^{cde}	2434^{ab}	1568^{fg}	2001^{bcde}	0.53^{abcdef}	0.57^{ab}	0.55^{cd}
T10 - CS + Butachlor* + HW-30 DAT	3297^{abc}	2328^{bcde}	2812^{ab}	2533^{a}	1554^{fg}	2043^{bcdef}	0.57^{abcde}	0.60^{a}	0.58^{abc}
T11 - CS + Butachlor* + CW- 30 DAT	2558^{cdefg}	2155^{cdef}	2356de	2598^{a}	1349^{g}	1974^{bcdef}	0.49^{efg}	0.62^{a}	0.55^{bcd}
T12 - CS + CW- 10, 30 DAT	3138^{abcd}	2578^{b}	2858^{ab}	2271^{abc}	1595^{fg}	1933^{bcdef}	0.58^{abc}	0.62^{a}	0.60^{a}
T13 - CS + CW- 10 DAT + HW-30 DAT	3462^{a}	2113^{def}	2788^{abc}	2238^{abc}	1520^{fg}	1879^{def}	0.61^{a}	0.58^{ab}	0.60^{ab}
T14- CS + CW-10 DAT + Clincher** fb Almix***	3134^{abcd}	2000^{efg}	2567^{abcd}	2282^{abc}	1374^{g}	1828^{ef}	0.58^{abcd}	0.59^{ab}	0.59^{abc}
T15 - CS + Clincher** fb Almix***	3400^{ab}	2354^{bcd}	2877^{a}	2314^{abc}	1770^{ef}	2042^{bcdef}	0.60^{ab}	0.57^{ab}	0.58^{abc}
T16 - CS + HW – 20, 40 DAT	3108^{abcd}	2092^{defg}	2600^{abcd}	2140^{abc}	1370^{g}	1755^{f}	0.59^{ab}	0.61^{a}	0.60^{a}

Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification

CW – Cono weeding

* Butachlor @ 1.25 kg ha^{-1}

CS – Conventional System

HW – Hand weeding

** Cyhalofop butyl @ 0.1 kg ha^{-1}

fb – Followed by

DAT – Days after transplanting

OM – Organic manure

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

(2877 kg ha^{-1}) by the use of post emergence herbicides in the conventional system (T15), and this was followed by two cono weeding at 10 and 30 DAT (T12) and then by the application of pre emergence herbicide followed by hand weeding at 30 DAT in the conventional system (T10). The typical SRI and all other SRI treatments produced significantly lower grain yield.

4.1.1.4. Straw yield

In the 1st year, the yield of rice straw in the experiment at Pattambi was the highest (2598 kg ha^{-1}) in the conventional system with pre-emergence herbicide followed by cono weeding at 30 DAT, while in the 2nd year significantly higher values were observed in the SRI treatments. However, pooled data showed the highest straw yield (2510 kg ha^{-1}) in SRI with cono weeding at 10 DAT followed by post emergence herbicides (T6) and this was followed by the typical SRI, and they were at par.

4.1.1.5. Harvest Index

Significantly higher values of harvest index were observed in the conventional treatments. As seen from the pooled data, the highest harvest index was recorded by the conventional system with two cono weeding at 10 and 30 DAT (T12) and also by two hand weeding at 20 and 40 DAT (T16).

4.1.1.6. Nutrient content and uptake by rice

The data on N, P and K content in rice plant at panicle initiation stage are presented in Table 12. It was observed from the data that the rice plant under SRI with pre emergence herbicides followed by hand weeding at 30 DAT recorded the highest content of nitrogen (3.36%), and this was immediately followed by SRI treatment with pre emergence herbicide followed by cono weeding at 30 DAT. All the treatments in the conventional system recorded significantly lower content

Table 12. Effect of the treatments on nutrient content (%) of rice at panicle initiation stage - Pattambi

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	3.173^{ab}	2.987^{a}	3.080^{ab}	0.289^{e}	0.279^{e}	0.284^{h}	2.029^{ab}	1.222^{b}	1.626^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	3.547^{a}	3.173^{a}	3.360^{a}	0.336^{abcd}	0.323^{bcd}	0.330^{bcdef}	2.125^{a}	1.347^{ab}	1.736^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	3.267^{ab}	3.080^{a}	3.173^{ab}	0.354^{ab}	0.353^{abc}	0.353^{ab}	1.784^{bcd}	1.592^{a}	1.688^{a}
T4 - SRI + CW- 10, 30 DAT	2.800^{bcd}	3.080^{a}	2.940^{abc}	0.330^{bcd}	0.315^{bcde}	0.322^{defg}	1.872^{abc}	1.376^{ab}	1.624^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.987^{abc}	2.893^{a}	2.940^{abc}	0.310^{cde}	0.302^{cde}	0.306^{fgh}	1.774^{bcd}	1.295^{ab}	1.535^{abc}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	2.707^{bcde}	2.893^{a}	2.800^{bc}	0.310^{cde}	0.288^{de}	0.299^{gh}	1.926^{abc}	1.454^{ab}	1.690^{a}
T7 - SRI + Clincher** fb Almix***	2.707^{bcde}	2.800^{ab}	2.753^{bc}	0.316^{cde}	0.327^{bcde}	0.322^{efg}	1.655^{cde}	1.478^{ab}	1.567^{abc}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2.520^{cdef}	2.053^{c}	2.287^{de}	0.342^{abc}	0.362^{abc}	0.352^{abcd}	1.558^{def}	1.453^{ab}	1.505^{abc}
T9 - CS + CW-10, 20, 30, 40 DAT	2.147^{efg}	2.053^{c}	2.100^{e}	0.346^{abc}	0.310^{bcde}	0.328^{bcdef}	1.426^{efg}	1.449^{ab}	1.437^{bcd}
T10 - CS + Butachlor* + HW-30 DAT	1.867^{g}	1.960^{c}	1.913^{e}	0.336^{abcd}	0.303^{cde}	0.320^{efg}	1.381^{efg}	1.344^{ab}	1.363^{cde}
T11 - CS + Butachlor* + CW- 30 DAT	1.867^{g}	1.960^{c}	1.913^{e}	0.312^{cde}	0.341^{abcd}	0.326^{cdefg}	1.410^{efg}	1.290^{ab}	1.350^{cde}
T12 - CS + CW- 10, 30 DAT	2.053^{fg}	2.053^{c}	2.053^{e}	0.337^{abc}	0.365^{ab}	0.351^{abc}	1.303^{fg}	1.376^{ab}	1.340^{cde}
T13 - CS + CW- 10 DAT + HW-30 DAT	2.333^{defg}	1.773^{c}	2.053^{cd}	0.361^{ab}	0.361^{abc}	0.361^{a}	1.252^{g}	1.215^{b}	1.234^{de}
T14- CS + CW-10 DAT + Clincher** fb Almix***	2.800^{bcd}	2.333^{bc}	2.567^{e}	0.355^{ab}	0.344^{abcd}	0.350^{abcd}	1.207^{gh}	1.521^{ab}	1.364^{cde}
T15 - CS + Clincher** fb Almix***	1.960^{fg}	2.333^{bc}	2.147^{e}	0.301^{de}	0.391^{a}	0.346^{abcde}	0.964^{h}	1.394^{a}b	1.179^{e}
T16 - CS + HW – 20, 40 DAT	2.053^{fg}	1.960^{c}	2.007^{c}	0.370^{a}	0.334^{abcde}	0.352^{abc}	1.234^{g}	1.170^{b}	1.202^{e}

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HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

of nitrogen. Phosphorus content was recorded the highest (0.36%) by the conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT, and the second highest content was recorded by SRI with pre emergence herbicide followed by cono weeding at 30 DAT. Similar to nitrogen, the potassium content in rice was also the highest (1.74%) in SRI with pre emergence herbicide followed by hand weeding at 30 DAT, which was followed by SRI treatments with cono weeding at 10 DAT followed by post emergence herbicides and by pre emergence herbicide followed by cono weeding at 30 DAT, and these treatments were at par with it.

Uptake of nutrients viz., nitrogen, phosphorus and potassium by rice plant at panicle initiation stage is presented in Table 13. The highest uptake of N (111 kg ha^{-1}) was observed with cono weeding at 10 DAT followed by post emergence herbicides in conventional system, followed by the conventional treatment with post emergence herbicides alone.

Phosphorus uptake was also found more with conventional treatments with the highest uptake (16.86 kg ha^{-1}) being recorded by the conventional system with post emergence herbicides alone and this was followed by treatment with two cono weeding at 10 and 30 DAT. The uptake of potassium was also higher in the conventional treatments and the highest uptake (65.53 kg ha^{-1}) was recorded by conventional system with four cono weeding at 10, 20, 30 and 40 DAT, which was followed by most of the conventional treatments, which were at par.

4.1.1.7. Soil characteristics

The effect of treatments on soil properties viz., bulk density, soil reaction (pH) and electrical conductivity (EC) at panicle initiation stage of rice are presented in Table 14.

Table 13. Effect of the treatments on nutrient uptake (kg ha^{-1}) by rice at panicle initiation stage - Pattambi

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	45.08^{fg}	21.18^{e}	32.88^{gh}	4.12^{ef}	1.94^{f}	3.03^{f}	28.52^{cd}	8.34^{e}	17.12^{fg}
T2 - SRI + Butachlor* + HW-30 DAT	83.77^{bcd}	27.83^{de}	54.46^{ef}	7.98^{de}	2.85^{ef}	5.36^{de}	50.53^{b}	11.95^{de}	28.36^{de}
T3 - SRI + Butachlor* + CW- 30 DAT	51.63^{defg}	43.16^{cd}	47.55^{efg}	5.70^{ef}	4.94^{de}	5.32^{de}	29.17^{cd}	22.4^{cd}	25.64^{def}
T4 - SRI + CW- 10, 30 DAT	23.43^{g}	31.80^{cde}	27.73^{h}	2.80^{f}	3.29^{ef}	3.04^{f}	16.05^{d}	14.36^{de}	15.37^{g}
T5 - SRI + CW- 10 DAT + HW-30 DAT	77.93^{cdef}	48.80^{c}	63.28^{de}	8.05^{de}	5.14^{de}	6.58^{d}	45.99^{bc}	22.31^{cd}	33.04^{cd}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	35.28^{g}	26.24^{de}	31.18^{gh}	4.07^{ef}	2.58^{ef}	3.31^{ef}	25.82^{d}	12.84^{de}	18.62^{fg}
T7 - SRI + Clincher** fb Almix***	46.68^{efg}	29.71^{de}	37.96^{fgh}	5.30^{ef}	3.47^{ef}	4.41^{ef}	27.67^{d}	15.72^{de}	21.42^{efg}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	79.82^{bcde}	38.61^{cde}	57.79^{e}	10.92^{cd}	6.97^{d}	9.01^{c}	49.40^{b}	27.88^{c}	38.32^{c}
T9 - CS + CW-10, 20, 30, 40 DAT	108.33^{abc}	85.07^{ab}	96.57^{abc}	17.12^{ab}	12.85^{bcd}	14.92^{ab}	70.98^{a}	59.73^{a}	65.53^{a}
T10 - CS + Butachlor* + HW-30 DAT	80.33^{bcde}	75.98^{ab}	79.62^{cd}	14.94^{bc}	11.71^{c}	13.35^{b}	60.02^{ab}	53.07^{a}	56.56^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	85.03^{bcd}	85.75^{ab}	86.15^{bc}	14.22^{bc}	14.90^{ab}	14.75^{ab}	64.13^{ab}	56.42^{a}	60.88^{ab}
T12 - CS + CW- 10, 30 DAT	111.51^{abc}	81.26^{ab}	95.80^{abc}	18.18^{ab}	14.41^{abc}	16.37^{a}	70.36^{a}	54.11^{a}	62.75^{ab}
T13 – CS + CW- 10 DAT + HW-30 DAT	99.12^{abc}	78.36^{ab}	89.37^{bc}	15.44^{ab}	16.02^{a}	15.72^{a}	53.63^{ab}	53.9^{a}	53.66^{b}
T14 - CS + CW-10 DAT + Clincher** fb Almix***	127.02^{a}	94.92^{a}	110.93^{a}	16.24^{ab}	13.98^{abcd}	15.18^{ab}	55.36^{ab}	61.76^{a}	59.01^{ab}
T15 - CS + Clincher** fb Almix***	115.40^{ab}	89.79^{ab}	104.62^{ab}	17.65^{ab}	15.31^{ab}	16.86^{a}	56.57^{ab}	54.03^{a}	57.41^{ab}
T16 - CS + HW – 20, 40 DAT	109.21^{abc}	70.71^{b}	89.64^{bc}	19.74^{a}	11.93^{cd}	15.73^{a}	65.46^{ab}	41.73^{b}	53.43^{b}

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OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 14. Effect of the treatments on soil characteristics at panicle initiation stage - Pattambi

Treatments	Bulk density (kg m^{-3})			pH			Electrical conductivity (dS m^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1.287^{b}	1.144^{abc}	1.215^{b}	4.61^{a}	4.60^{bc}	4.61^{bc}	0.022^{a}	0.007^{ab}	0.015^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	1.455^{a}	1.108^{bc}	1.282^{ab}	4.64^{a}	4.61^{bc}	4.63^{bc}	0.017^{c}	0.008^{ab}	0.012^{abc}
T3 - SRI + Butachlor* + CW- 30 DAT	1.311^{ab}	1.255^{ab}	1.283^{ab}	4.82^{a}	4.62^{bc}	4.72^{ab}	0.022^{ab}	0.008^{ab}	0.015^{ab}
T4 - SRI + CW- 10, 30 DAT	1.395^{ab}	1.046^{c}	1.220^{b}	4.66^{a}	4.69^{ab}	4.67^{abc}	0.019^{abc}	0.007^{ab}	0.013^{abc}
T5 - SRI + CW- 10 DAT + HW-30 DAT	1.285^{b}	1.035^{c}	1.160^{b}	4.70^{a}	4.61^{bc}	4.66^{abc}	0.018^{abc}	0.008^{ab}	0.013^{abc}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.322^{ab}	1.046^{c}	1.184^{b}	4.74^{a}	4.63^{abc}	4.69^{abc}	0.020^{abc}	0.008^{b}	0.014^{bc}
T7 - SRI + Clincher** fb Almix***	1.308^{ab}	1.197^{abc}	1.253^{ab}	4.77^{a}	4.64^{abc}	4.71^{abc}	0.019^{abc}	0.007^{ab}	0.013^{abc}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1.300^{ab}	1.052^{c}	1.176^{b}	4.77^{a}	4.72^{a}	4.75^{a}	0.022^{ab}	0.011^{a}	0.017^{a}
T9 - CS + CW-10, 20, 30, 40 DAT	1.325^{ab}	1.135^{abc}	1.230^{ab}	4.79^{a}	4.73^{a}	4.76^{a}	0.019^{abc}	0.007^{ab}	0.013^{abc}
T10 - CS + Butachlor* + HW-30 DAT	1.419^{ab}	1.306^{a}	1.363^{a}	4.69^{a}	4.64^{abc}	4.67^{abc}	0.016^{c}	0.007^{ab}	0.011^{d}
T11 - CS + Butachlor* + CW- 30 DAT	1.261^{b}	1.216^{abc}	1.238^{ab}	4.71^{a}	4.61^{bc}	4.66^{abc}	0.018^{bc}	0.007^{ab}	0.012^{cd}
T12 - CS + CW- 10, 30 DAT	1.298^{ab}	1.214^{abc}	1.256^{ab}	4.68^{a}	4.57^{c}	4.63^{bc}	0.017^{c}	0.007^{ab}	0.012^{abc}
T13 - CS + CW- 10 DAT + HW-30 DAT	1.397^{ab}	1.187^{abc}	1.292^{ab}	4.76^{a}	4.56^{c}	4.66^{abc}	0.017^{c}	0.007^{ab}	0.012^{cd}
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.304^{ab}	1.138^{abc}	1.221^{b}	4.69^{a}	4.55^{c}	4.62^{bc}	0.020^{abc}	0.006^{c}	0.013^{abc}
T15 - CS + Clincher** fb Almix***	1.283^{b}	1.145^{abc}	1.214^{b}	4.64^{a}	4.55^{c}	4.60^{c}	0.017^{c}	0.007^{ab}	0.012^{cd}
T16 - CS + HW – 20, 40 DAT	1.270^{b}	1.131^{abc}	1.201^{b}	4.66^{a}	4.55^{c}	4.61^{bc}	0.018^{bc}	0.011^{a}	0.014^{bc}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

a. Bulk density

There was not much variation among the treatments in soil bulk density values. The lowest bulk density was observed in SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT, but most of the treatments were at par with it.

b. pH and Electrical conductivity

Highest pH value was recorded by the treatment with four cono weeding in conventional system closely followed by the typical SRI treatment, and they were on par with most of the other treatments. Electrical conductivity was the highest in the typical SRI treatment but the other treatments did not differ much among themselves.

c. Available nutrients in the soil

The effect of treatments on the status of nutrient availability in the soil viz., organic carbon, available phosphorus and exchangeable potassium at panicle initiation stage of rice are presented in Table 15. The organic carbon percentage did not vary significantly among the different treatments. The content of available phosphorus in the soil was the highest (19.32 kg ha^{-1}) in the typical SRI treatment which varied significantly from the other treatments. The second highest value was recorded by conventional system with four cono weeding at 10, 20, 30 and 40 DAT. Potassium availability was also the highest (105 kg ha^{-1}) with the typical SRI treatment.

4.1.1.8. Study on weeds and their control

Observations on weed density and weed dry weight were recorded at 45 and 60 DAT. Weeds were separately counted for grasses, sedges, and broad leaf

Table 15. Effect of the treatments on soil nutrient contents at panicle initiation stage - Pattambi

Treatments	Organic Carbon (%)			Available Phosphorus (kg ha^{-1})			Exchangeable Potassium (kg ha^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1.08^{a}	0.95^{ab}	1.01^{a}	19.29^{abcede}	7.57^{hi}	13.43^{cd}	112.00^{abcd}	60.85^{bcd}	86.43^{bcd}
T2 - SRI + Butachlor* + HW-30 DAT	1.07^{a}	0.92^{abc}	1.00^{a}	17.57^{bcde}	8.58^{fghi}	13.08^{d}	107.15^{abcd}	67.95^{ab}	87.55^{bcd}
T3 - SRI + Butachlor* + CW- 30 DAT	1.11^{a}	0.89^{abc}	1.00^{a}	18.22^{abcde}	7.46^{hi}	12.84^{d}	123.95^{ab}	62.35^{bc}	93.15^{ab}
T4 - SRI + CW- 10, 30 DAT	1.08^{a}	0.92^{abc}	1.00^{a}	19.88^{abc}	7.16^{i}	13.52^{cd}	100.05^{bcd}	55.63^{bcdef}	77.84^{cde}
T5 - SRI + CW- 10 DAT + HW-30 DAT	1.12^{a}	0.94^{ab}	1.03^{a}	16.69^{e}	8.82^{efgh}	12.75^{d}	103.04^{bcd}	60.85^{bcd}	81.95^{bcde}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.13^{a}	0.86^{abc}	1.00^{a}	17.16^{cde}	8.52^{fghi}	12.84^{d}	103.41^{abcd}	78.40^{a}	90.91^{bc}
T7 - SRI + Clincher** fb Almix***	1.06^{a}	1.00^{a}	1.03^{a}	18.58^{abcde}	8.05^{ghi}	13.31^{d}	114.61^{abc}	60.48^{bcde}	87.55^{bcd}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1.14^{a}	0.89^{abc}	1.01^{a}	19.76^{abc}	18.87^{a}	19.32^{a}	131.79^{a}	78.40^{a}	105.09^{a}
T9 - CS + CW-10, 20, 30, 40 DAT	1.07^{aa}	0.67^{c}	0.87^{a}	19.53^{abcd}	15.92^{b}	17.72^{b}	109.76^{abcd}	53.01^{cdef}	81.39^{bcde}
T10 - CS + Butachlor* + HW-30 DAT	1.05^{a}	0.75^{abc}	0.90^{a}	17.16^{cde}	10.41^{cd}	13.79^{cd}	96.69^{bcd}	50.77^{cdef}	73.73^{de}
T11 - CS + Butachlor* + CW- 30 DAT	1.07^{a}	0.73^{abc}	0.90^{a}	17.99^{abcde}	8.93^{defgh}	13.46^{cd}	107.89^{abcd}	45.17^{f}	76.53^{cde}
T12 - CS + CW- 10, 30 DAT	1.07^{a}	0.78^{abc}	0.92^{a}	16.98^{de}	9.94^{cdef}	13.46^{cd}	105.65^{abcd}	47.79^{ef}	76.72^{cde}
T13 - CS + CW- 10 DAT + HW-30 DAT	1.10^{a}	0.74^{abc}	0.92^{a}	20.59^{a}	9.47^{defg}	15.03^{c}	88.11^{cd}	45.92^{f}	67.01^{e}
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.08^{a}	0.80^{abc}	0.94^{a}	18.70^{abcde}	10.18^{cde}	14.44^{cd}	98.56^{bcd}	49.28^{def}	73.92^{de}
T15 - CS + Clincher** fb Almix***	1.18^{a}	0.73^{abc}	0.96^{a}	20.12^{ab}	10.00^{cdef}	15.06^{c}	88.11^{cd}	48.91^{def}	68.51^{e}
T16 - CS + HW – 20, 40 DAT	1.05^{a}	0.75^{abc}	0.90^{a}	18.93^{abcde}	11.12^{c}	15.03^{c}	84.75^{d}	49.65^{cdef}	67.20^{e}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional System

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

weeds (BLWs). Important weeds observed in the rice field at Pattambi included grass weed *Isachne miliacea,* sedges *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea*, and *Schoenoplectus lateriflorus* and broad leaf weeds *Sphenoclea zeylanica*, *Ludwigia perennis* and *Dopatrium junce*um (Plate 4).

a. Weed density

The data on weed density (number m^{-2}) at 45 and 60 days after planting at Pattambi are presented in Tables 16 and 17, respectively.

At 45 DAT, the highest density of weeds (123 m^{-2}) was recorded in SRI with two cono weeding at 10 and 30 DAT which was followed by SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT and also cono weeding four times at 10, 20, 30 and 40 DAT. The density of grass weeds was the highest (3.33 m^{-2}) in conventional treatment with four cono weeding at 10, 20, 30 and 40 DAT and then by the SRI treatment with two cono weeding at 10 and 30 DAT. The density of sedges was the highest (81.33 m^{-2}) in SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT, which was followed by the SRI treatment with two cono weeding at 10 and 30 DAT. The density of broad leaf weeds was also the highest (49 m^{-2}) in SRI with two cono weeding at 10 and 30 DAT, which was closely followed by SRI treatments with four cono weeding at 10, 20, 30 and 40 DAT as well as cono weeding at 10 DAT followed by hand weeding at 30 DAT, and these were at par.

It was also observed from the pooled mean that the total weed density at 45 DAT was the lowest in the conventional treatment with cono weeding at 10 DAT followed by hand weeding at 30 DAT and this was followed by pre emergence herbicide followed by hand weeding at 30 DAT as well as by two hand weeding at 20 and 40 DAT in the conventional system. The density of sedges was also the lowest in the conventional treatment with cono weeding at 10 DAT

Isachne miliacea

Cyperus iria

Schoenoplectus lateriflorus

Fimbristylis miliacea

Sphenoclea zeylanica

Ludwigia perennis

Monochoria vaginalis

Plate 4. Major weeds in the rice field at Pattambi

Table 16. Effect of the treatments on weed density (Number m^{-2}) at 45 days after transplanting – Pattambi

Treatments	Grasses			Sedges			Broad leaf weeds			Total weeds		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	0.71^{b} (0.00)	1.65^{ab} (2.67)	1.29^{ab} (1.33)	4.37^{c} (18.67)	10.22^{f} (104.0)	7.86^{c} (61.33)	1.65^{de} (2.67)	8.95^{a} (80.00	6.45^{a} (41.33)	4.66^{de} (21.33)	13.67^{ab} (186.67)	10.22^{a} (104.0)
T2 - SRI + Butachlor* + HW-30 DAT	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{f} (0.00)	2.18^{de} (5.33)	1.65^{hi} (2.67)	0.71^{f} (0.00)	5.27^{bc} (27.33)	3.76^{cd} (13.67)	0.71^{g} (0.00)	5.76^{d} (32.67)	4.10^{e} (16.33)
T3 - SRI + Butachlor* + CW- 30 DAT	0.71^{b} (0.00)	2.12^{a} (4.00)	1.58^{ab} (1.41)	0.71^{f} (0.00)	3.12^{d} (9.33)	2.26^{gh} (4.67)	0.71^{f} (0.00)	3.97^{cd} (15.33)	2.85^{de} (7.67)	0.71^{g} (0.00)	5.39^{d} (28.67)	3.84^{ef} (14.33)
T4 - SRI + CW- 10, 30 DAT	1.65^{ab} (2.67)	1.65^{ab} (2.67)	1.76^{a} (2.67)	7.06^{a} (49.33)	0.71^{f} (0.00)	8.49^{ab} (24.67)	6.47^{a} (41.33)	7.51^{a} (56.00)	7.01^{a} (48.67)	9.69^{a} (93.33)	12.37^{bc} (152.67)	11.11^{a} (123.0)
T5 - SRI + CW- 10 DAT + HW-30 DAT	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{f} (0.00)	12.76^{a} (162.67)	9.04^{a} (81.33)	0.71^{f} (0.00)	9.01^{a} (81.33)	6.39^{a} (40.67)	0.71^{g} (0.00)	15.62^{a} (244.00)	11.06^{a} (122.0)
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.91^{ab} (4.00)	0.71^{c} (0.00)	1.47^{ab} (2.00)	4.80^{bc} (22.67)	0.71^{f} (0.00)	3.43^{ef} (11.33)	4.52^{b} (20.00)	3.23^{cde} (22.67)	4.38^{bc} (21.33)	6.87^{c} (46.67)	3.23^{de} (22.67)	5.78^{d} (34.67)
T7 - SRI + Clincher** fb Almix***	1.18^{ab} (1.33)	0.71^{c} (0.00)	1.00^{ab} (0.67)	7.04^{a} (49.33)	0.71^{f} (0.00)	5.01^{e} (24.67)	4.81^{b} (22.67)	1.91^{de} (4.00)	3.72 ^{c} ^{d}(13.33)	8.58 (73.33)	1.91^{e} (4.00)	6.25^{cd} (38.67)
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1.18^{ab} (1.33)	0.71^{c} (0.00)	1.00^{ab} (0.67)	3.72^{d} (13.33)	8.23^{c} (67.33)	6.39^{d} (40.33)	2.92^{c} (8.00)	5.46^{bc} (30.00)	4.39^{bc} (19.00)	4.81^{de} (22.67)	9.87^{c} (97.30)	7.76^{b} (60.00)
T9 - CS + CW-10, 20, 30, 40 DAT	2.18^{a} (5.33)	1.18^{bc} (1.33)	1.79^{a} (3.33)	5.20^{b} (26.67)	1.65^{ef} (2.67)	3.88^{e} (14.67)	4.37^{b} (18.67)	2.12^{de} (5.33)	3.51^{cd} (12.00)	7.15^{c} (50.67)	2.92^{de} (9.33)	5.51^{d} (30.00)
T10 - CS + Butachlor* + HW-30 DAT	1.18^{ab} (1.33)	1.18^{bc} (1.33)	1.29^{ab} (1.33)	0.71^{f} (0.00)	1.18^{ef} (1.33)	1.00^{i}j (0.67)	0.71^{f} (0.00)	0.71^{e} (0.00)	0.71^{f} (0.00)	1.18^{g} (1.33)	1.44^{e} (2.67)	1.47^{gh} (2.00)
T11 - CS + Butachlor* + CW- 30 DAT	1.65^{ab} (2.67)	0.71^{c} (0.00)	1.29^{ab} (1.33)	3.71^{d} (13.33)	1.65^{ef} (2.67)	2.90^{fg} (8.00)	2.12^{d} (4.00)	1.65^{de} (4.00)	2.03^{ef} (4.00)	4.51^{de} (20.00)	2.30^{e} (6.67)	3.66^{ef} (13.33)
T12 - CS + CW- 10, 30 DAT	1.91^{ab} (4.00)	0.71^{c} (0.00)	1.47^{ab} (2.00)	7.13^{a} (50.67)	2.39^{de} (5.33)	5.32^{d} (28.00)	6.87^{a} (46.67)	1.91^{de} (4.00)	5.08^{b} (25.33)	10.09^{a} (101.3)	3.03^{de} (9.33)	7.47^{bc} (55.33)
T13 - CS + CW- 10 DAT + HW-30 DAT	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{f} (0.00)	0.71^{f} (0.00)	0.71j (0.00)	0.71^{f} (0.00)	0.71^{e} (0.00)	0.71^{f} (0.00)	0.71^{g} (0.00)	0.71^{e} (0.00)	0.71^{h} (0.00)
T14 - CS + CW-10 DAT + Clincher** fb Almix***	0.71^{b} (0.00)	1.65^{ab} (2.67)	1.29^{ab} (1.33)	5.21^{b} (26.67)	0.71^{f} (0.00)	3.72^{e} (13.33)	0.71^{f} (0.00)	0.71^{e} (0.00)	0.71^{f} (0.00)	5.21^{d} (26.67)	1.65^{e} (2.67)	3.89^{ef} (6.67)
T15 - CS + Clincher** fb Almix***	1.18^{ab} (1.33)	0.71^{c} (0.00)	1.00^{ab} (0.67)	2.92^{e} (8.0)	1.18^{ef} (1.33)	2.26^{h} (4.67)	1.18^{ef} (1.33)	1.18^{de} (1.33)	1.29^{f} (1.33)	3.30^{f} (10.67)	1.44^{e} (2.67)	2.65^{fg} (6.67)
T16 - CS + HW – 20, 40 DAT	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{b} (0.00)	0.71^{f} (0.00)	1.44^{ef} (2.67)	1.18^{i}j (1.33)	0.71^{f} (0.00)	1.83^{de} (5.33)	1.44^{f} (2.67)	0.71^{g} (0.00)	2.12^{e} (8.00)	1.65^{gh} (4.00)

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification
CW – Cono weeding
OM – Organic manure
DAT – Days after transplanting
fb – Followed by
CS – Conventional system
HW – Hand weeding
*Butachlor @ 1.25 kg ha-1
** Cyhalofop butyl @ 0.1 kg ha-1
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

followed by hand weeding at 30 DAT, while grasses and broad leaf weeds were comparatively less in density in most of the treatments in the conventional system.

While comparing the various weed control strategies under SRI, it was noticed from the pooled data that the total weed density at 45 DAT was the highest with two cono weeding at 10 and 30 DAT. Cono weeding at 10, 20, 30 and 40 DAT as well as cono weeding at 10 DAT followed by hand weeding at 30 DAT also invited higher weed density, while it was significantly reduced with pre emergence herbicide followed by cono weeding at 30 DAT as well as with pre emergence herbicide followed by hand weeding at 30 DAT.

The data on density of weeds at 60 DAT are presented in Table 17. At 60 DAT, the total weed density was the highest (155 m^{-2}) in SRI treatment with two cono weedings at 10 and 30 DAT which differed significantly from all other treatments. Grasses were higher with pre emergence herbicide followed by hand weeding at 30 DAT in SRI, while higher densities of sedges and broad leaf weeds at 60 DAT were observed with SRI treatment with two cono weeding at 10 and 30 DAT.

At 60 DAT the total weed density was the lowest in conventional treatment with pre emergence herbicide followed by cono weeding at 30 DAT and this was closely followed by cono weeding at 10 DAT followed by post emergence herbicides as well as by pre emergence herbicide followed by hand weeding at 30 DAT in the conventional system. It was also observed from the data that the densities of sedges and broad leaf weeds at 60 DAT were the lowest in the conventional treatment with pre emergence herbicide followed by cono weeding at 30 DAT, while the grass weeds were the lowest in the conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT.

Table 17. Effect of the treatments on weed density (Number m^{-2}) at 60 days after transplanting – Pattambi

Treatments	Grasses			Sedges			Broad leaf weeds			Total weeds		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1.65^{bcd} (2.67)	1.18^{c} (1.33)	1.47^{cde} (2.00)	6.74^{bc} (45.33)	10.56^{a} (111.33)	8.87^{ab} (78.33)	5.55^{cd} (30.67)	5.68^{a} (32.00)	5.63^{b} (31.33)	8.85^{de} (78.67)	12.03^{a} (144.67)	10.57^{b} (111.67)
T2 - SRI + Butachlor* + HW-30 DAT	1.18^{cd} (1.33)	3.33^{a} (10.67)	2.53^{a} (6.00)	10.23^{a} (104.7)	6.45^{e} (41.33)	8.56^{bc} (73.00)	7.95^{b} (64.00)	5.69^{a} (32.00)	6.94^{a} (48.00)	13.00^{a} (170.0)	9.18^{cd} (84.00)	11.27^{b} (127.00)
T3 - SRI + Butachlor* + CW- 30 DAT	2.65^{ab} (6.67)	0.71^{c} (0.00)	1.94^{abcd} (3.33)	9.81^{a} (98.67)	7.69^{cd} (58.67)	8.85^{ab} (78.67)	8.93^{abc} (18.67)	5.93^{a} (34.67)	5.21^{bcd} (26.67)	11.08^{b} (124.0)	9.69^{c} (93.33)	10.43^{b} (108.67)
T4 - SRI + CW- 10, 30 DAT	1.18^{cd} (1.33)	1.18^{c} (1.33)	1.29^{def} (1.33)	9.90^{a} (98.67)	9.39^{b} (88.00)	9.67^{a} (93.33)	9.43^{a} (89.33)	5.69^{a} (32.00)	7.81^{a} (60.67)	13.70^{a} (189.3)	11.02^{b} (121.33)	12.47^{a} (155.33)
T5 - SRI + CW- 10 DAT + HW-30 DAT	1.65^{bcd} (2.67)	2.65^{b} (6.67)	2.23^{ab} (4.67)	5.15^{def} (26.00)	7.59^{d} (57.33)	6.48^{d} (41.67)	4.37^{cde} (18.67)	5.36^{a} (28.67)	4.90^{bcd} (23.67)	6.92^{fgh} (47.33)	9.65^{c} (92.67)	8.40^{cd} (70.00)
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.44^{bcd} (2.67)	2.39^{b} (5.33)	2.08^{abc} (4.00)	5.69^{cde} (32.00)	2.86^{f} (8.00)	4.52^{ef} (20.00)	3.88^{e} (14.67)	2.86^{b} (8.00)	3.42^{ef} (11.33)	7.03^{efgh} (49.33)	4.67^{f} (21.33)	5.97^{cf} (35.33)
T7 - SRI + Clincher** fb Almix***	2.39^{abc} (5.33)	1.18^{c} (1.33)	1.94^{abcd} (3.33)	7.05^{bc} (49.33)	8.36^{c} (69.33)	7.73^{c} (59.33)	4.60^{cde} (20.67)	1.18^{c} (1.33)	3.38^{ef} (11.00)	8.71^{def} (75.33)	8.51^{de} (72.00)	8.61^{c} (73.67)
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1.65^{bcd} (2.67)	0.71^{c} (0.00)	1.29^{de} (1.33)	6.36^{bcd} (40.00)	7.24^{d} (52.00)	6.82^{d} (46.00)	1.91^{f} (4.00)	3.80^{b} (14.67)	3.06^{f} (9.33)	6.86^{gh} (46.67)	8.19^{e} (66.67)	7.56^{d} (56.67)
T9 - CS + CW-10, 20, 30, 40 DAT	2.12^{abc} (4.00)	2.39^{b} (5.33)	2.23^{ab} (4.67)	5.17^{def} (26.67)	0.71^{g} (0.00)	3.69^{fg} (13.33)	3.89^{e} (14.67)	2.86^{b} (8.00)	3.42^{ef} (11.33)	6.75^{gh} (45.33)	3.68^{g} (13.33)	5.44^{ef} (29.33)
T10 - CS + Butachlor* + HW-30 DAT	2.92^{a} (8.00)	0.71^{c} (0.00)	2.08^{abc} (4.00)	4.51^{efg} (20.00)	0.71^{g} (0.00)	3.23^{gh} (10.00)	5.33^{cde} (28.00)	0.71^{c} (0.00)	3.80^{ef} (20.67)	7.51^{defghi} (56.00)	0.71^{h} (0.00)	5.34^{f} (28.00)
T11 - CS + Butachlor* + CW- 30 DAT	2.12^{abc} (4.00)	0.71^{c} (0.00)	1.94^{bcde} (2.00)	3.38^{g} (11.33)	0.71^{g} (0.00)	2.44^{h} (5.647)	4.21^{de} (17.33)	1.18^{c} (1.33)	3.12^{f} (9.33)	5.74^{h} (32.67)	1.18^{h} (1.33)	4.16^{g} (17.00)
T12 - CS + CW- 10, 30 DAT	1.65^{bcd} (2.67)	0.71^{c} (0.00)	1.29^{def} (1.33)	7.42^{b} (54.65)	0.71^{g} (0.00)	5.27^{e} (27.33)	7.30^{b} (54.67)	0.71^{c} (0.00)	5.19^{bcd} (27.33)	10.55^{bc} (112.0)	0.71^{h} (0.00)	7.48^{d} (56.00)
T13 - CS + CW- 10 DAT + HW-30 DAT	0.71^{d} (0.00)	0.71^{c} (0.00)	0.71^{f} (0.00)	5.07^{def} (25.33)	0.71^{g} (0.00)	3.62^{g} (12.67)	5.86^{c} (34.00)	1.18^{c} (1.33)	4.25^{cde} (17.67)	7.73^{defg} (59.33)	1.18^{h} (1.33)	5.55^{ef} (30.33)
T14- CS + CW-10 DAT + Clincher** fb Almix***	2.39^{abc} (5.33)	0.71^{c} (0.00)	1.76^{bcd} 2.67)	3.89^{fg} (14.67)	0.71^{g} (0.00)	2.79^{gh} (7.33)	5.81^{c} (33.33)	1.18^{c} (1.33)	4.21^{de} (17.33)	7.33^{defgh} (53.33)	1.18^{h} (1.33)	5.27^{f} (27.33)
T15 - CS + Clincher** fb Almix***	1.18^{c} (1.33)	0.71^{c} (0.00)	1.00^{ef} (0.67)	4.64^{efg} (21.33)	0.71^{g} (0.00)	3.32^{gh} (6.67)	7.38^{b} (54.00)	0.71^{c} 0.00)	5.24^{bc} (27.00)	8.78^{de} (76.67)	0.71^{h} (0.00)	6.23^{ef} (38.33)
T16 - CS + HW – 20, 40 DAT	2.39^{abc} (5.33)	0.71^{c} (0.00)	1.76^{bcd} (2.67)	6.98^{bc} (48.67)	0.71^{g} (0.00)	4.96^{e} (24.33)	5.45^{cd} (29.33)	0.71^{c} (0.00)	3.89^{ef} (14.67)	9.12^{cd} (83.33)	0.7^{h} (0.00)	6.47^{e} (41.67)

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification
CS – Conventional system
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
*Butachlor @ 1.25 kg ha^{-1}
DAT – Days after transplanting
** Cyhalofop butyl @ 0.1 kg ha^{-1}
fb – Followed by
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

b. Weed dry weight

The effect of treatments on weed dry weight (g m^{-2}) is presented in Table 18.

As observed from the pooled data, at 45 DAT dry weight of weeds was the highest (38 g m^{-2}) in the SRI treatment with two cono weeding at 10 and 30 DAT, which differed significantly from all other treatments and was followed by the conventional system with four cono weeding at 10, 20, 30 and 40 DAT. The lowest weed dry weight at 45 DAT was observed in conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT which was followed by SRI treatment with pre emergence herbicide followed by hand weeding at 30 DAT. Conventional system with two hand weeding at 20 and 40 DAT as well as pre emergence herbicide application followed by hand weeding at 30 DAT also resulted in lower weed dry weight at 45 DAT.

Among the SRI treatments weed dry weight at 45 DAT was significantly reduced by the application of pre emergence herbicides followed by hand weeding at 30 DAT as well as by pre emergence herbicides followed by cono weeding at 30 DAT.

At 60 DAT, the highest weed dry weight was observed in SRI with four cono weeding at 10, 20, 30 and 40 DAT which differed significantly from all other treatments and was followed by SRI with two cono weeding at 10 and 30 DAT. The weed dry weight at 60 DAT was comparatively lower in all the treatments under the conventional system and significantly lower weed dry weight was recorded by conventional system with post emergence herbicides as well as with cono weeding at 10 DAT followed by hand weeding at 30 DAT.

As seen from the pooled mean, the weed dry weight at 60 DAT in SRI was higher in treatments with four cono weeding as well as with two cono weeding,

Table 18. Effect of the treatments on weed dry weight (g m^{-2}) at 45 and 60 DAT and weed index – Pattambi

Treatments	45 DAT			60 DAT			Weed Index		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	2.78^{e} (7.27)	3.97^{e} (15.27)	3.43^{de} (11.27)	7.73^{b} (61.41)	13.62^{a} (185.67)	11.12^{a} (123.54)	35.83^{abc}	15.22^{a}	27.54^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	0.71^{g} (0.00)	0.89^{fg} (0.36)	0.81^{i} (0.18)	4.16^{def} (17.03)	5.95^{d} (35.73)	5.13^{d} (26.38)	18.82^{bcde}	-17.14^{def}	4.11^{cde}
T3 - SRI + Butachlor* + CW-30 DAT	0.71^{g} (0.00)	1.76^{efg} (2.59)	1.34^{gh} (1.30)	2.94^{efg} (8.17)	9.01^{b} (80.68)	6.70^{c} (44.43)	60.01^{a}	3.138^{abcd}	36.71^{a}
T4 - SRI + CW- 10, 30 DAT	4.90^{c} (23.82)	7.26^{a} (52.44)	6.21^{a} (38.13)	10.78^{a} (120.43)	7.64^{c} (59.25)	9.44^{b} (89.84)	38.13^{abc}	12.58^{ab}	27.87^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	0.71^{g} (0.00)	1.98^{ef} (3.47)	1.49^{fgh} (1.73)	4.36^{de} (18.83)	8.59^{e} (73.59)	4.33^{de} (18.29)	12.39^{bcdefg}	-11.40^{cdef}	2.78^{cde}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	4.59^{c} (20.62)	1.95^{ef} (3.30)	3.53^{de} (11.96)	3.67^{defg} (12.99)	3.82^{e} (14.19)	3.75^{ef} (13.59)	40.95^{ab}	-39.97^{g}	8.061^{c}
T7 - SRI + Clincher** fb Almix***	2.52^{e} (5.87)	3.54^{cd} (12.07)	3.08^{de} (8.97)	5.01^{bc} (24.63)	6.11^{d} (38.33)	6.55^{c} (43.15)	36.25^{abc}	-25.01^{f}	11.05^{c}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	3.61^{d} (12.57)	5.46^{b} (29.73)	4.64^{c} (21.15)	4.09^{defg} (16.28)	9.25^{b} (85.21)	7.16^{c} (50.75)	27.32^{bcd}	-2.66^{bcde}	15.56^{bc}
T9 - CS + CW-10, 20, 30, 40 DAT	6.89^{a} (47.09)	2.82^{de} (7.46)	5.26^{b} (27.28)	5.12^{cd} (25.84)	1.99^{f} (3.53)	3.89^{e} (14.69)	8.51^{cdefg}	0.46^{abcd}	5.88^{cd}
T10 - CS + Butachlor* + HW-30 DAT	0.71^{g} (0.00)	1.48^{fg} (1.76)	1.16^{hi} (0.88)	3.23^{defg} (10.10)	0.71^{f} (0.00)	2.34^{gh} (5.05)	-11.31^{efg}	-11.54^{cdef}	-10.59^{de}
T11 - CS + Butachlor* + CW-30 DAT	4.73^{c} (22.04)	2.01^{ef} (3.71)	3.65^{d} (12.87)	5.25^{cd} (27.30)	1.59^{f} (2.04)	3.88^{e} (14.67)	15.62^{bcdef}	-3.16^{bcde}	8.05^{c}
T12 - CS + CW- 10, 30 DAT	5.83^{b} (33.57)	2.63^{de} (6.69)	4.54^{c} (20.13)	7.02^{bc} (48.85)	0.71^{f} (0.00)	4.99^{d} (24.43)	-8.11^{efg}	-23.23^{f}	-12.84^{e}
T13 - CS + CW- 10 DAT + HW-30 DAT	0.71^{g} (0.00)	0.71^{g} (0.00)	0.71^{i} (0.00)	1.97^{g} (3.41)	1.58^{f} (2.00)	1.79^{h} (2.71)	-18.04^{g}	-1.10^{bcde}	-9.81^{de}
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.86^{f} (2.97)	1.45^{fg} (2.69)	1.77^{fg} (2.83)	2.12^{fg} (3.99)	1.92^{f} (3.27)	2.02^{gh} (3.630	-7.48^{efg}	4.41^{abc}	-1.17^{cde}
T15 - CS + Clincher** fb Almix***	2.32^{ef} (4.88)	1.25^{fg} (1.65)	1.92^{f} (3.27)	2.06^{fg} (3.76)	0.71^{f} (0.00)	1.54^{h} (1.88)	-14.71^{fg}	-12.48^{def}	-12.75^{e}
T16 - CS + HW – 20, 40 DAT	0.71^{g} (0.00)	1.19^{fg} (1.39)	1.01^{hi} (0.69)	3.92^{fg} (14.86)	0.71^{f} (0.00)	2.81^{fg} (7.43)	0.00^{defg}	0.00^{abcd}	0.00^{cde}

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification
CW – Cono weeding
OM – Organic manure
DAT – Days after transplanting
fb – Followed by

CS – Conventional system
HW – Hand weeding
*Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

while it was significantly reduced by cono weeding at 10 DAT followed by post emergence herbicides.

c. Weed index

The weed index values at Pattambi are given in Table 18. SRI with pre emergence herbicides followed by cono weeding at 30 DAT recorded maximum weed index and this was followed by SRI with two cono weeding at 10 and 30 DAT and then by SRI with four cono weeding at 10, 20, 30 and 40 DAT. The lowest weed index was recorded by conventional system with two cono weeding at 10 and 30 DAT and the second lowest value was recorded by conventional system with post emergence herbicides.

d. Nutrient removal by weeds

The effects of treatments on the nutrient contents and removal of nutrients viz., nitrogen, phosphorus and potassium by the weed plants at panicle initiation of the rice crop at Pattambi are presented in Tables 19 and 20. The highest removal of N, P and K was recorded by SRI with four cono weeding at 10, 20, 30 and 40 DAT which was significantly superior to all other treatments, and this was followed by SRI with two cono weeding at 10 and 30 DAT.

The nutrient removal values were significantly lower in conventional treatments. Conventional system with post emergence herbicides (T15), cono weeding at 10 DAT followed by post emergence herbicides (T14) as well as cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) showed lower removal of nitrogen, phosphorus and potassium.

Among the SRI treatments the lowest N, P and K removal was observed with cono weeding at 10 DAT followed by post emergence herbicides (T6).

Table 19. Effect of the treatments on nutrient content (%) of weeds at 60 DAT - Pattambi

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1.960^{bcd}	1.960^{cde}	1.960^{bcd}	0.339^{bcde}	0.307^{ab}	0.323^{ab}	1.580^{abcd}	1.463^{a}	1.521^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	2.147^{b}	2.427^{ab}	2.287^{ab}	0.377^{ab}	0.303^{ab}	0.340^{a}	1.805^{ab}	1.507^{a}	1.656^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	2.707^{a}	2.240^{bcd}	2.473^{a}	0.349^{abcd}	0.323^{a}	0.336^{a}	1.783^{ab}	1.414^{a}	1.599^{ab}
T4 - SRI + CW- 10, 30 DAT	1.587^{cde}	2.333^{abc}	1.960^{bcd}	0.308^{def}	0.315^{ab}	0.311^{ab}	1.462^{abcde}	1.507^{a}	1.484^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	1.400^{e}	2.707^{a}	2.053^{bcd}	0.315^{cdef}	0.302^{ab}	0.308^{abc}	1.669^{abc}	1.609^{a}	1.639^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	2.147^{b}	2.147^{bcd}	2.147^{abc}	0.393^{a}	0.295^{ab}	0.344^{a}	1.743^{abc}	1.334^{a}	1.539^{ab}
T7 - SRI + Clincher** fb Almix***	1.493^{de}	1.960^{cde}	1.727^{d}	0.397^{a}	0.295^{ab}	0.346^{a}	1.353^{bcde}	1.594^{a}	1.473^{abc}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2.053^{bc}	1.960^{cde}	2.007^{bcd}	0.362^{abc}	0.285^{ab}	0.324^{ab}	1.397^{bcde}	1.393^{a}	1.395^{abc}
T9 - CS + CW-10, 20, 30, 40 DAT	1.587^{cde}	1.867^{cde}	1.727^{d}	0.281^{f}	0.272^{ab}	0.276^{c}	1.104^{e}	1.471^{a}	1.287^{bc}
T10 - CS + Butachlor* + HW-30 DAT	1.773^{bcde}	0.000^{f}	0.887^{e}	0.308^{def}	0.000^{c}	0.154^{d}	1.141^{de}	0.000^{b}	0.571^{f}
T11 - CS + Butachlor* + CW- 30 DAT	2.147^{b}	1.547^{e}	1.847^{cd}	0.354^{abcd}	0.267^{b}	0.311^{ab}	1.135^{de}	1.189^{a}	1.162^{cd}
T12 - CS + CW- 10, 30 DAT	2.053^{bc}	0.000^{f}	1.027^{e}	0.301^{def}	0.000^{c}	0.151^{d}	1.312^{cde}	0.000^{b}	0.656^{ef}
T13 - CS + CW- 10 DAT + HW-30 DAT	1.867^{bcde}	1.827^{de}	1.847^{cd}	0.290^{ef}	0.287^{ab}	0.289^{bc}	1.459^{abcde}	1.497^{a}	1.478^{abc}
T14- CS + CW-10 DAT + Clincher** fb Almix***	2.053^{b}	0.000^{cde}	1.027^{bcd}	0.332^{bcdef}	0.000^{ab}	0.166^{abc}	1.448^{abcde}	0.000^{a}	0.724^{abc}
T15 - CS + Clincher** fb Almix***	1.913^{bcde}	0.000^{f}	0.957^{e}	0.302^{def}	0.000^{c}	0.151^{d}	1.876^{a}	0.000^{b}	0.938^{de}
T16 - CS + HW – 20, 40 DAT	1.587^{cde}	0.000^{f}	0.793^{e}	0.335^{bcde}	0.000^{c}	0.168^{d}	1.430^{abcde}	0.000^{b}	0.715^{ef}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 20. Effect of the treatments on nutrient removal (kg ha^{-1}) by weeds at 60 DAT - Pattambi

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	11.71^{b}	36.39^{a}	24.05^{a}	2.03^{b}	5.73^{a}	3.88^{a}	9.63^{b}	27.13^{a}	18.38^{a}
T2 - SRI + Butachlor* + HW-30 DAT	3.52^{cd}	8.58^{c}	6.05^{de}	0.64^{de}	1.09^{de}	0.87^{d}	3.02^{cd}	5.39^{de}	4.20^{d}
T3 - SRI + Butachlor* + CW- 30 DAT	2.23^{e}	18.16^{b}	10.20^{c}	0.29^{de}	2.59^{b}	1.44^{c}	1.48^{cd}	11.35^{b}	6.42^{c}
T4 - SRI + CW- 10, 30 DAT	19.53^{a}	13.65^{b}	16.59^{b}	3.73^{a}	1.83^{cd}	2.78^{b}	17.27^{a}	8.81^{bc}	13.04^{b}
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.64^{e}	4.81^{cde}	3.72^{efg}	0.59^{de}	0.53^{ef}	0.56^{de}	3.19^{cd}	2.85^{ef}	3.02^{de}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	2.79^{e}	3.09^{de}	2.94^{efg}	0.51^{de}	0.42^{ef}	0.46^{def}	2.26^{cd}	1.92^{f}	2.09^{def}
T7 - SRI + Clincher** fb Almix***	7.60^{abc}	7.70^{cd}	7.65^{cd}	1.89^{ab}	1.17^{de}	1.53^{c}	6.52^{bc}	6.15^{cd}	6.34^{c}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	3.32^{cd}	16.91^{b}	10.12^{c}	0.59^{de}	2.43^{bc}	1.51^{c}	2.25^{cd}	11.93^{b}	7.09^{c}
T9 - CS + CW-10, 20, 30, 40 DAT	4.14^{cd}	0.65^{e}	2.40^{fg}	0.73^{cde}	0.10^{f}	0.41^{def}	2.84^{cd}	0.52^{f}	1.68^{ef}
T10 - CS + Butachlor* + HW-30 DAT	1.78^{e}	0.00^{e}	0.89^{g}	0.31^{de}	0.00^{f}	0.16^{ef}	1.18^{d}	0.00^{f}	0.59^{f}
T11 - CS + Butachlor* + CW- 30 DAT	5.92^{abc}	0.32^{e}	3.12^{efg}	0.96^{bcde}	0.05^{f}	0.51^{def}	3.06^{cd}	0.24^{f}	1.65^{ef}
T12 - CS + CW- 10, 30 DAT	9.99^{bc}	0.00^{e}	5.00^{def}	1.48^{bcd}	0.00^{f}	0.74^{de}	6.47^{bc}	0.00^{f}	3.24^{de}
T13 - CS + CW- 10 DAT + HW-30 DAT	0.64^{e}	0.37^{e}	0.51^{g}	0.10^{e}	0.06^{f}	0.08^{f}	0.50^{d}	0.30^{f}	0.40^{f}
T14 - CS + CW-10 DAT + Clincher** fb Almix***	0.81^{e}	0.61^{e}	0.71^{g}	0.13^{e}	0.09^{f}	0.11^{ef}	0.57^{d}	0.50^{f}	0.54^{f}
T15 - CS + Clincher** fb Almix***	0.72^{e}	0.00^{e}	0.36^{g}	0.11^{e}	0.00^{f}	0.06^{f}	0.72^{d}	0.00^{f}	0.36^{f}
T16 - CS + HW – 20, 40 DAT	2.38^{e}	0.00^{e}	1.19^{g}	0.50^{de}	0.00^{f}	0.25^{def}	2.14^{cd}	0.00^{f}	1.07^{ef}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

4.1.1.9. Economics of cultivation at Pattambi

The gross return (GR), net return (NR) and benefit: cost ratio (BCR) of rice cultivation at Pattambi are given in Table 21, as per Appendix VI. Gross return was the highest (Rs. 42322 ha^{-1}) in conventional treatment with post emergence herbicides alone and this was on par with conventional system with two cono weeding at 10 and 30 DAT. These were followed by pre emergence herbicide followed by hand weeding at 30 DAT as well as cono weeding at 10 DAT followed by hand weeding at 30 DAT in the conventional system. Net return also followed almost the same pattern, the highest amount (Rs. 9354 ha^{-1}) being recorded in the conventional system with two cono weeding at 10 and 30 DAT but it was on par with the conventional system with post emergence herbicides alone. The benefit:cost ratio followed the same pattern as that of net return and the highest ratio (1.29) recorded by the conventional system with two cono weeding at 10 and 30 DAT was immediately followed by the conventional system with post emergence herbicides alone (1.27) and were at par. The other treatments recorded significantly lower B: C ratio.

4.1.2. Location II - Alappad *Kole*

4.1.2.1. Growth characters of rice

a. Plant height

The data on height of rice plant observed from the field experiments at Alappad *Kole* are presented in Table 22 and the following observations were made from the pooled data. At active tillering plant height was the highest (64.06 cm) in SRI with two cono weeding at 10 and 30 DAT. SRI with post emergence herbicides recorded the highest plant height at panicle initiation (90.50 cm) and this was immediately followed by SRI with two cono weeding at 10 and 30 DAT,

Table 21. Economics of rice cultivation as affected by the treatments – Pattambi

Treatments	Gross return (Rs. ha^{-1})			Net return (Rs. ha^{-1})			B:C ratilo		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	29746^{fgh}	26790^{g}	28268de	-9540^{ef}	-12496^{g}	-11018^{h}	0.76^{ef}	0.68^{e}	0.72^{g}
T2 - SRI + Butachlor* + HW-30 DAT	37290^{defgh}	36601^{bc}	36946^{abc}	-3496de	-4185^{def}	-3840^{efg}	0.91^{de}	0.90^{cd}	0.91^{def}
T3 - SRI + Butachlor* + CW- 30 DAT	18609^{i}	30335^{defg}	24472^{e}	-17627^{f}	-5901^{def}	-11764^{h}	0.51^{f}	0.84^{cd}	0.68^{g}
T4 - SRI + CW- 10, 30 DAT	28481^{gh}	28397^{fg}	28439de	-8005^{ef}	-8089^{f}	-8047^{gh}	0.78^{ef}	0.78^{de}	0.78^{fg}
T5 - SRI + CW- 10 DAT + HW-30 DAT	39751^{bcdef}	35022^{bcd}	37387^{abc}	-1985^{cde}	-6714^{ef}	-4349^{fg}	0.95^{cde}	0.84^{cd}	0.90^{ef}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	26849^{hi}	43644^{a}	35246^{c}	-10817^{ef}	5978^{a}	-2420^{cdef}	0.71^{ef}	1.16^{a}	0.94^{de}
T7 - SRI + Clincher** fb Almix***	29662^{fgh}	38659^{b}	34160^{c}	-5554^{e}	3443^{ab}	-1056^{bcdef}	0.84^{e}	1.10^{a}	0.97^{cde}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	32836^{efgh}	32797^{cdef}	32817^{cd}	-3249de	-3288^{cde}	-3268^{defg}	0.91^{de}	0.91^{cd}	0.91^{def}
T9 - CS + CW-10, 20, 30, 40 DAT	40961^{bcde}	30739^{defg}	35850^{bc}	6975^{abc}	-3247^{cde}	1864^{bcd}	1.21^{abc}	0.90^{cd}	1.05^{bcd}
T10 - CS + Butachlor* + HW-30 DAT	48684^{abc}	34150^{bcde}	41417^{ab}	11698^{ab}	-2836^{cde}	4431^{ab}	1.32^{ab}	0.92^{bc}	1.12^{b}
T11 - CS + Butachlor* + CW- 30 DAT	38405^{cdefg}	31514^{defg}	34959^{c}	5194^{bcd}	-1697^{cd}	1748^{bcde}	1.16^{bcd}	0.95^{bc}	1.05^{bcd}
T12 - CS + CW- 10, 30 DAT	46198^{abc}	37682^{b}	41940^{a}	13612^{ab}	5096^{ab}	9354^{a}	1.42^{ab}	1.16^{a}	1.29^{a}
T13 - CS + CW- 10 DAT + HW-30 DAT	50712^{a}	31107^{defg}	40910^{ab}	14001^{ab}	-5604^{def}	4199^{ab}	1.38^{ab}	0.85^{cd}	1.11^{bc}
T14- CS + CW-10 DAT + Clincher** fb Almix***	46156^{abcd}	29377^{efg}	37766^{abc}	11515^{ab}	-5264^{def}	3125^{bc}	1.33^{ab}	0.85^{cd}	1.09^{bc}
T15 - CS + Clincher** fb Almix***	49921^{ab}	34722^{bcd}	42322^{a}	16505^{a}	1306^{bc}	8906^{a}	1.49^{a}	1.04^{ab}	1.27^{a}
T16 - CS + HW – 20, 40 DAT	45651^{abcd}	30662^{defg}	38157^{abc}	8165^{ab}	-6824^{ef}	671^{bcdef}	1.22^{abc}	0.82^{cd}	1.02^{bcde}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 22. Effect of the treatments on plant height (cm) of rice at different growth stages – Alappad *Kole*

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	53.49^{ab}	69.73^{abc}	61.61^{ab}	81.97^{abcd}	95.58^{ab}	88.78^{abc}	102.32^{ab}	97.50^{abc}	99.91^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	49.56^{bcde}	70.80^{abc}	60.18^{ab}	77.10^{cd}	94.13^{abc}	85.62^{abcde}	102.80^{a}	95.65^{bcde}	99.23^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	52.81^{ab}	69.47^{abc}	61.14^{ab}	80.57^{abcd}	96.27^{ab}	88.42^{abcd}	97.37^{abcd}	96.45^{abcd}	96.91^{bc}
T4 - SRI + CW- 10, 30 DAT	54.85^{a}	73.27^{ab}	64.06^{a}	80.47^{abcd}	100.07^{a}	90.27^{a}	102.47^{ab}	102.50^{a}	102.48^{a}
T5 - SRI + CW- 10 DAT + HW-30 DAT	50.74^{abc}	72.83^{ab}	61.79^{ab}	75.10^{bcd}	96.60^{ab}	87.52^{abcd}	103.47^{a}	98.87^{ab}	101.17^{ab}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	52.99^{a}	69.97^{abc}	61.48^{ab}	84.23^{abc}	94.73^{ab}	89.48^{ab}	101.10^{abc}	96.60^{abcd}	98.85^{ab}
T7 - SRI + Clincher** fb Almix***	50.99^{abc}	75.80^{a}	63.39^{ab}	82.63^{abcd}	98.37^{a}	90.50^{a}	101.95^{abc}	97.20^{abc}	99.58^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	48.30^{bcde}	66.80^{abc}	57.55^{abc}	75.63^{d}	93.70^{abcd}	84.67^{abcde}	94.93^{cd}	91.80^{cdefg}	93.37^{cd}
T9 - CS + CW-10, 20, 30, 40 DAT	51.47^{abc}	64.10^{abc}	57.79^{abc}	85.07^{ab}	87.00^{bcd}	86.03^{abcde}	91.93^{d}	90.73^{defgh}	91.33^{d}
T10 - CS + Butachlor* + HW-30 DAT	50.44^{abcd}	62.70^{bc}	56.57^{bc}	84.37^{abc}	84.60^{cde}	84.48^{abcde}	90.67^{d}	89.40^{fgh}	90.03^{d}
T11 - CS + Butachlor* + CW- 30 DAT	45.75^{de}	59.97^{c}	52.86^{c}	80.79^{abcd}	84.22^{cde}	82.51^{de}	95.27^{bcd}	90.03^{efgh}	92.65^{cd}
T12 - CS + CW- 10, 30 DAT	51.11^{abc}	63.43^{bc}	57.27^{abc}	86.33^{a}	87.13^{bcde}	86.73^{abcde}	93.73^{d}	92.67^{cdefg}	93.20^{cd}
T13 - CS + CW- 10 DAT + HW-30 DAT	51.99^{abc}	62.63^{bc}	57.31^{abc}	85.57^{ab}	87.60^{bcde}	86.58^{abcde}	94.80^{cd}	93.73^{bcdef}	94.27^{cd}
T14- CS + CW-10 DAT + Clincher** fb Almix***	44.68^{e}	59.83^{c}	52.25^{c}	79.45^{abcd}	82.80^{e}	81.13^{e}	92.53^{d}	87.20^{gh}	89.87^{d}
T15 - CS + Clincher** fb Almix***	45.35^{e}	60.77^{c}	53.06^{c}	83.50^{abc}	83.83^{de}	83.67^{bcde}	93.60^{d}	85.33^{h}	89.47^{d}
T16 - CS + HW – 20, 40 DAT	47.04^{cde}	69.57^{abc}	58.3^{abc}	81.80^{abcd}	83.60^{de}	82.70^{cde}	90.07^{d}	89.80^{efgh}	89.93^{d}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

which were at par. SRI with two cono weeding at 10 and 30 DAT recorded greater plant height at harvest stage also (102.48 cm).

b. Number of tillers

The data on tiller count hill^{-1} are presented in Table 23. It was observed that SRI treatments recorded significantly higher number of tillers hill^{-1} at all the stages of observation. At active tillering stage significantly higher number of tillers hill^{-1} (23.63 to 25.95) was recorded by all the SRI treatments other than the one which is considered to be typical SRI (T8). At PI stage SRI with CW at 10 DAT followed by post emergence herbicide recorded the highest number of tillers hill^{-1} and this was followed by SRI with post emergence herbicides alone, which were at par. At harvest stage, SRI with four CW at 10, 20, 30 and 40 DAT as well as SRI with pre emergence herbicide followed by CW at 30 DAT recorded significantly superior number of tillers hill^{-1}.

The data on tiller number per unit area (number m^{-2}) are shown in Table 24. As against the observation on tiller number hill^{-1}, the number of tillers m^{-2} was significantly higher with treatments under the conventional system. At active tillering significantly superior number of tillers m^{-2} was observed in the conventional system with post emergence spray of herbicides. This treatment recorded the highest number at PI stage also. Conventional system with four cono weeding recorded the maximum number of tillers m^{-2} at harvest. At all stages of observation, the lowest number of tillers m^{-2} was recorded by the typical SRI treatment.

c. Dry matter production

The data on dry matter production by the rice plant (Table 25) showed that conventional system with CW at 10 DAT followed by post emergence herbicides produced the highest dry matter (3658 kg ha^{-1}) at active tillering. At panicle

Table 23. Effect of the treatments on tiller count per hill (Number $hill^{-1}$) at different growth stages of rice – Alappad *Kole*

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	21.43^{a}	28.13^{ab}	24.78^{a}	34.80^{b}	30.80^{a}	32.80^{b}	24.85^{a}	27.27^{a}	26.06^{a}
T2 - SRI + Butachlor* + HW-30 DAT	18.25^{ab}	29.00^{a}	23.63^{a}	38.60^{a}	30.47^{a}	34.53^{ab}	20.33^{b}	26.42^{a}	23.38^{bc}
T3 - SRI + Butachlor* + CW- 30 DAT	21.02^{a}	29.80^{a}	25.41^{a}	37.47^{ab}	32.00^{a}	34.73^{ab}	22.53^{ab}	28.87^{a}	25.70^{a}
T4 - SRI + CW- 10, 30 DAT	17.25^{b}	30.67^{a}	23.96^{a}	21.33^{d}	30.67^{a}	26.00^{d}	15.72^{c}	27.60^{a}	21.66^{c}
T5 - SRI + CW- 10 DAT + HW-30 DAT	21.69^{a}	27.20^{ab}	24.45^{a}	30.27^{c}	28.27^{ab}	29.27^{c}	16.73^{c}	26.20^{a}	21.47^{c}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	20.59^{ab}	31.27^{a}	25.93^{a}	39.73^{a}	33.80^{a}	36.77^{a}	22.88^{ab}	27.93^{a}	25.41^{ab}
T7 - SRI + Clincher** fb Almix***	19.56^{ab}	32.33^{a}	25.95^{a}	38.07^{ab}	32.73^{a}	35.40^{a}	21.88^{ab}	28.87^{a}	25.38^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	10.17^{cd}	23.73^{b}	16.95^{b}	16.67^{e}	24.83^{b}	20.75^{e}	10.33^{d}	22.00^{b}	16.17^{d}
T9 - CS + CW-10, 20, 30, 40 DAT	11.23^{cd}	12.67^{c}	11.95^{c}	11.93^{f}	14.00^{c}	12.97^{fg}	11.40^{d}	11.70^{c}	11.55^{e}
T10 - CS + Butachlor* + HW-30 DAT	11.06^{cd}	11.07^{c}	11.07^{c}	11.53^{f}	13.00^{c}	12.27^{fg}	8.67^{d}	11.07^{c}	9.87^{ef}
T11 - CS + Butachlor* + CW- 30 DAT	9.13^{d}	10.13^{c}	9.63^{c}	11.73^{f}	10.73^{c}	11.23^{g}	8.23^{d}	8.67^{c}	8.45^{f}
T12 - CS + CW- 10, 30 DAT	10.11^{cd}	12.93^{c}	11.52^{c}	11.60^{f}	13.40^{c}	12.50^{fg}	9.00^{d}	11.93^{c}	10.47^{ef}
T13 - CS + CW- 10 DAT + HW-30 DAT	10.44^{cd}	12.67^{c}	11.55^{c}	11.73^{e}	12.73^{c}	12.23^{fg}	10.22^{d}	11.93^{c}	11.08^{e}
T14- CS + CW-10 DAT + Clincher** fb Almix***	13.00^{c}	13.27^{c}	13.13^{c}	15.00^{ef}	12.47^{c}	13.73^{fg}	9.27^{dd}	10.07^{c}	9.67^{ef}
T15 - CS + Clincher** fb Almix***	12.63^{cd}	14.07^{c}	13.35^{c}	14.20^{ef}	13.73^{c}	13.97^{f}	8.90^{d}	10.00^{c}	9.45^{ef}
T16 - CS + HW – 20, 40 DAT	10.88^{cd}	9.87^{c}	10.37^{c}	11.52^{f}	12.07^{c}	11.79^{fg}	9.67^{d}	11.42^{c}	10.54^{ef}

Values followed by same letters do not differ significantly in DMRT
fb – Followed by
SRI – System of rice intensification
CS – Conventional System
DAT – Days after transplanting
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 24. Effect of the treatments on tiller count per unit area (Number m^{-2}) at different growth stages of rice – Alappad *Kole*

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	238.1^{e}	312.6^{de}	275.4^{f}	386.7^{cd}	342.2^{c}	364.4^{ef}	276.1^{c}	303.0^{d}	289.5^{e}
T2 - SRI + Butachlor* + HW-30 DAT	202.8^{e}	322.2^{de}	262.5^{f}	428.9^{c}	338.5^{c}	383.7^{ef}	225.9^{c}	293.5^{d}	259.7^{e}
T3 - SRI + Butachlor* + CW- 30 DAT	233.6^{e}	331.1^{de}	282.3^{ef}	416.3^{c}	355.6^{c}	385.9^{ef}	250.4^{c}	320.7^{cd}	285.6^{e}
T4 - SRI + CW- 10, 30 DAT	191.7^{ef}	340.7^{de}	266.2^{f}	237.0^{e}	340.7^{c}	288.9^{gh}	174.7^{cd}	306.7^{cd}	240.7^{ef}
T5 - SRI + CW- 10 DAT + HW-30 DAT	241.0^{e}	302.2^{de}	271.6^{f}	336.3^{d}	314.1^{c}	325.2^{fg}	185.9^{cd}	291.1^{d}	238.5^{ef}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	228.7^{e}	347.4^{de}	288.1^{ef}	441.5^{c}	375.6^{c}	408.5^{e}	254.3^{c}	310.4^{cd}	282.3^{e}
T7 - SRI + Clincher** fb Almix***	217.4^{e}	359.3^{cd}	288.3^{ef}	423.0^{c}	363.7^{c}	393.3^{ef}	243.2^{c}	320.7^{cd}	282.0^{e}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	113.0^{f}	263.7^{e}	188.3^{g}	185.2^{e}	275.9^{e}	230.6^{h}	114.8^{d}	244.5^{d}	179.6^{f}
T9 - CS + CW-10, 20, 30, 40 DAT	561.5^{abc}	633.3^{abc}	597.4^{abc}	596.7^{b}	700.0^{a}	648.3^{abc}	570.0^{a}	585.0^{a}	577.5^{a}
T10 - CS + Butachlor* + HW-30 DAT	553.2^{bcd}	553.3^{bcd}	553.3^{cd}	576.7^{b}	650.0^{ab}	613.3^{cd}	433.3^{b}	553.3^{ab}	493.3^{bcd}
T11 - CS + Butachlor* + CW- 30 DAT	456.3^{d}	506.7^{de}	481.5^{de}	586.7^{b}	536.7^{b}	561.7^{de}	411.7^{b}	433.3^{bc}	422.5^{d}
T12 - CS + CW- 10, 30 DAT	505.7^{cd}	646.7^{ab}	576.2^{bc}	580.0^{b}	670.0^{ab}	625.0^{bcd}	450.0^{b}	596.7^{a}	523.3^{abc}
T13 - CS + CW- 10 DAT + HW-30 DAT	521.8^{cd}	633.3^{abc}	577.6^{bc}	586.7^{b}	636.7^{ab}	611.7^{cd}	510.8^{ab}	596.7^{a}	553.8^{ab}
T14- CS + CW-10 DAT + Clincher** fb Almix***	650.0^{a}	663.3^{ab}	656.7^{ab}	750.0^{a}	623.3^{ab}	686.7^{ab}	463.3^{b}	503.3^{ab}	483.3^{bcd}
T15 - CS + Clincher** fb Almix***	631.3^{ab}	703.3^{a}	667.3^{a}	710.0^{a}	686.7^{a}	698.3^{a}	445.0^{b}	500.0^{ab}	472.5^{cd}
T16 - CS + HW – 20, 40 DAT	543.8^{bcd}	493.3^{de}	518.6^{cd}	575.8^{b}	603.3^{ab}	589.6^{cd}	483.3^{ab}	570.8^{a}	527.1^{abc}

Values followed by same letters do not differ significantly in DMRT

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SRI – System of rice intensification

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CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 25. Effect of the treatments on dry matter production (kg ha^{-1}) of rice at different growth stages – Alappad *Kole*

Treatments	Active tillering			Panicle initiation			Harvest		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1373.7^{de}	2690.4^{cdef}	2032.0^{c}	2846.7^{def}	4078.9^{c}	3462.8^{gh}	7889.3^{efg}	10217.0^{efg}	9053.2^{ef}
T2 - SRI + Butachlor* + HW-30 DAT	1170.7^{e}	2757.8^{cde}	1964.3^{c}	2394.8^{efg}	6751.1^{ab}	4573.0^{def}	10129.6^{de}	7205.6^{h}	8667.6^{ef}
T3 - SRI + Butachlor* + CW- 30 DAT	935.2^{e}	2276.7^{defg}	1605.9^{c}	1345.6^{hi}	4185.9^{c}	2765.7^{h}	7310.0^{fg}	7860.0^{gh}	7585.0^{f}
T4 - SRI + CW- 10, 30 DAT	1570.4^{de}	2077.8^{defg}	1824.1^{c}	2032.2^{fgh}	7536.3^{a}	4784.3^{cdef}	6182.2^{g}	10131.1^{efg}	8156.7^{ef}
T5 - SRI + CW- 10 DAT + HW-30 DAT	1020.7^{e}	2917.4^{cd}	1969.1^{c}	2713.3^{ef}	7148.2^{ab}	4930.7^{cdef}	6203.7^{g}	9506.7^{efgh}	7855.2^{ef}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1673.7^{cde}	1740.4^{efg}	1707.0^{c}	3239.3^{cde}	5524.4^{bc}	4381.9^{efg}	6578.5^{g}	8508.9^{fgh}	7543.7^{f}
T7 - SRI + Clincher** fb Almix***	990.7^{e}	2015.2^{defg}	1503.0^{c}	1820.0^{gh}	6289.6^{ab}	4054.8^{efg}	9772.6^{def}	8428.2^{fgh}	9100.4^{ef}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	783.3^{e}	1933.3^{defg}	1358.3^{c}	927.0^{i}	7242.6^{ab}	4084.8^{efg}	5337.0^{g}	8694.1^{fgh}	7015.6^{f}
T9 - CS + CW-10, 20, 30, 40 DAT	3940.0^{a}	1691.7^{efg}	2815.8^{b}	3708.3^{bcd}	4296.7^{c}	4002.5^{fg}	12103.3^{bcd}	17961.7^{b}	15032.5^{ab}
T10 - CS + Butachlor* + HW-30 DAT	4175.0^{a}	1540.0^{g}	2857.5^{b}	4148.3^{ab}	7241.7^{ab}	5695.0^{abc}	16273.3^{a}	10086.7^{efg}	13180.0^{bcd}
T11 - CS + Butachlor* + CW- 30 DAT	2211.7^{bcd}	3730.0^{abc}	2970.8^{ab}	4088.3^{abc}	8233.3^{a}	6160.8^{a}	16085.0^{a}	13091.7^{cd}	14588.3^{abc}
T12 - CS + CW- 10, 30 DAT	3730.0^{a}	3470.0^{bc}	3600.0^{ab}	3718.3^{bcd}	6488.3^{ab}	5103.3^{bcde}	13135.0^{bc}	11453.3^{de}	12294.2^{d}
T13 - CS + CW- 10 DAT + HW-30 DAT	3996.7^{a}	1601.7^{fg}	2799.2^{b}	3240.0^{cde}	8130.0^{a}	5685.0^{abc}	13715.0^{ab}	15376.7^{c}	14545.8^{abc}
T14- CS + CW-10 DAT + Clincher** fb Almix***	2696.7^{b}	4618.3^{a}	3657.5^{a}	2578.3^{efg}	6916.7^{ab}	4747.5^{cdef}	14393.3^{ab}	11016.7^{def}	12705.0^{cd}
T15 - CS + Clincher** fb Almix***	2478.3^{bc}	3470.0^{bc}	2974.2^{ab}	4465.0^{ab}	6551.7^{ab}	5508.3^{abcd}	10670.0^{cd}	8665.0^{efgh}	9667.5^{e}
T16 - CS + HW – 20, 40 DAT	2596.7^{b}	4418.3^{ab}	3507.5^{ab}	4665.0^{a}	7525.0^{a}	6095.0^{ab}	10206.7^{de}	20973.3^{a}	15590.0^{a}

Values followed by same letters do not differ significantly in DMRT

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CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

initiation, conventional system with pre emergence herbicide followed by CW at 30 DAT produced the highest dry matter (6161 kg ha^{-1}) and this was followed by two hand weeding in the conventional system, which were at par. Conventional system with two hand weeding at 20 and 40 DAT recorded the highest dry matter at harvest (15590 kg ha^{-1}) and this was followed by the treatment under conventional system with four cono weeding at 10, 20, 30 and 40 DAT, which were at par. All the SRI treatments, especially the typical SRI produced lower quantity of dry matter throughout the crop growth.

d. Root characteristics

The data on root length (cm), root dry weight per plant (g $hill^{-1}$) and root dry weight per unit area (kg ha^{-1}) observed at panicle initiation stage of the rice crop in the experimental field at Alappad *Kole* are presented in Table 26.

Significantly higher root length of the rice plant was observed in SRI with four CW at 10, 20, 30 and 40 DAT (22.60 cm) and this was followed by SRI with CW at 10 DAT followed by post emergence herbicide. Individual plants/hills in the conventional system produced comparatively shorter roots. With respect to root dry weight per individual hill (g $hill^{-1}$) the highest value (2.80 g $hill^{-1}$) was recorded in SRI with CW at 10, 20, 30 and 40 DAT immediately followed by SRI with CW at 10 DAT followed by post emergence herbicide, which were at par.

The root dry weight per hectare was significantly higher in conventional system with pre emergence herbicide followed by cono weeding at 30 DAT (364 kg ha^{-1}) and the second highest value (329 kg ha^{-1}) was recorded by conventional system with pre emergence herbicide followed by hand weeding at 30 DAT, which were at par.

Table 26. Effect of the treatments on root characteristics of rice at panicle initiation stage – Alappad *Kole*

Treatments	Root length (cm)			Root dry weight (g hill^{-1})			Root dry weight (kg ha^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	27.77^{a}	17.43^{a}	22.60^{a}	1.41^{b}	4.35^{a}	2.80^{a}	156.26^{abc}	483.70^{ab}	319.98^{abc}
T2 - SRI + Butachlor* + HW-30 DAT	20.87^{cd}	11.83^{bcd}	16.35^{de}	1.96^{a}	2.86^{b}	2.41^{b}	217.59^{a}	318.15^{efgh}	267.87^{bcde}
T3 - SRI + Butachlor* + CW- 30 DAT	22.07^{c}	11.67^{cd}	16.87^{cd}	1.39^{b}	1.62^{c}	1.50^{d}	154.00^{abc}	179.63^{i}	166.81^{f}
T4 - SRI + CW- 10, 30 DAT	17.07^{de}	16.33^{a}	16.70^{d}	0.74^{c}	3.02^{b}	1.88^{c}	82.70^{bc}	335.19^{defg}	208.94^{ef}
T5 - SRI + CW- 10 DAT + HW-30 DAT	23.37^{bc}	15.50^{ab}	19.43^{bc}	1.68^{ab}	3.40^{b}	2.54^{b}	186.63^{a}	377.78^{bcdef}	282.20^{bcd}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	26.63^{ab}	12.57^{bc}	19.60^{b}	1.96^{a}	3.30^{b}	2.63^{ab}	217.37^{a}	366.30^{cdef}	291.83^{bcd}
T7 - SRI + Clincher** fb Almix***	23.27^{bc}	10.83^{cde}	17.05^{bcd}	1.45^{b}	3.25^{b}	2.35^{b}	161.41^{ab}	360.74^{cdef}	261.07^{bcde}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	17.90^{de}	17.10^{a}	17.50^{bcd}	0.59^{c}	4.25^{a}	2.42^{b}	65.37^{c}	471.85^{abc}	268.61^{bcde}
T9 - CS + CW-10, 20, 30, 40 DAT	14.97^{ef}	7.53^{e}	11.25^{gh}	0.44^{c}	0.36^{d}	0.40^{e}	220.00^{a}	181.67^{i}	200.83^{ef}
T10 - CS + Butachlor* + HW-30 DAT	14.23^{ef}	10.17^{cde}	12.20^{fgh}	0.45^{c}	0.86^{d}	0.66^{e}	225.50^{a}	431.67^{abcde}	328.58^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	17.20^{de}	10.50^{cde}	13.85^{efg}	0.41^{c}	1.04^{cd}	0.73^{e}	206.17^{a}	521.67^{a}	363.92^{a}
T12 - CS + CW- 10, 30 DAT	17.07^{de}	11.17^{cde}	14.12^{ef}	0.44^{c}	0.56^{d}	0.50^{e}	220.00^{a}	278.33^{fghi}	249.17^{cde}
T13 - CS + CW- 10 DAT + HW-30 DAT	11.87^{f}	9.83^{cde}	10.85^{h}	0.44^{c}	0.65^{d}	0.54^{e}	218.33^{a}	326.67^{defgh}	272.50^{bcde}
T14- CS + CW-10 DAT + Clincher** fb Almix***	12.83^{f}	8.07^{de}	10.45^{h}	0.44^{c}	0.45^{d}	0.44^{c}	218.00^{a}	225.00^{ghi}	221.50^{def}
T15 - CS + Clincher** fb Almix***	14.30^{ef}	7.17^{e}	10.73^{h}	0.48^{c}	0.43^{d}	0.46^{e}	241.50^{a}	216.67^{hi}	229.08^{def}
T16 - CS + HW – 20, 40 DAT	14.93^{ef}	10.87^{cde}	12.90^{fgh}	0.39^{c}	0.88^{d}	0.64^{e}	195.17^{a}	441.67^{abcd}	318.42^{abc}

Values followed by same letters do not differ significantly in DMRT
fb – Followed by
SRI – System of rice intensification
CS – Conventional system
DAT – Days after transplanting
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

4.1.2.2. Yield attributes

The data on yield attributes of rice viz., productive tillers, panicle length, number of filled grains per panicle, filled grain percentage and 1000 grain weight, are presented in Tables 27 and 28.

a. Productive tillers/Number of panicles

The data on number of productive tillers $hill^{-1}$ (Table 27) showed significant difference among the treatments. SRI with cono weeding at 10, 20, 30 and 40 DAT recorded the highest number of productive tillers $hill^{-1}$ (25.53) and this was followed by SRI with pre emergence herbicide followed by cono weeding at 30 DAT, SRI with post emergence herbicide alone and SRI with cono weeding at 10 DAT followed by post emergence herbicide, which were at par. The number of productive tillers $hill^{-1}$ was the lowest (8.28) in conventional system with pre emergence herbicide followed by cono weeding at 30 DAT.

The number of productive tillers m^{-2} was significantly higher in treatments with conventional system. Conventional system with cono weeding at 10, 20, 30 and 40 DAT produced the maximum number of productive tillers m^{-2} (568.33). This was followed by and at par with three treatments under conventional system viz., cono weeding at 10 DAT followed by hand weeding at 30 DAT, two cono weeding at 10 and 30 DAT and two hand weeding at 20 and 40 DAT. The typical SRI treatment recorded the lowest number of productive tillers m^{-2} (176.67).

b. Panicle length

The data on length of panicle are presented in Table 27. It was noticed from the pooled data that SRI with pre emergence herbicide followed by hand weeding at 30 DAT recorded the maximum panicle length (22.35 cm) followed by other SRI treatments, and they were at par.

Table 27. Effect of the treatments on number of productive tillers and panicle length of rice – Alappad *Kole*

Treatments	Productive tillers per hill (Number $hill^{-1}$)			Productive tillers per m^2 (Number m^{-2})			Panicle length (cm)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	24.85^{a}	26.20^{a}	25.53^{a}	276.1^{c}	291.1^{c}	283.6^{d}	22.14^{ab}	21.69^{ab}	21.91^{a}
T2 - SRI + Butachlor* + HW-30 DAT	19.83^{bc}	25.78^{a}	22.81^{bc}	220.4^{cd}	286.5^{c}	253.4^{d}	21.86^{abc}	22.85^{a}	22.35^{a}
T3 - SRI + Butachlor* + CW- 30 DAT	22.53^{ab}	27.53^{a}	25.03^{ab}	250.4^{cd}	305.9^{c}	278.2^{d}	22.54^{a}	21.93^{ab}	22.23^{a}
T4 - SRI + CW- 10, 30 DAT	15.28^{d}	26.92^{a}	21.10^{c}	169.7^{de}	299.1^{c}	234.4^{de}	21.98^{abc}	22.25^{ab}	22.12^{a}
T5 - SRI + CW- 10 DAT + HW-30 DAT	16.73^{cd}	25.33^{a}	21.03^{c}	185.9^{cde}	281.5^{c}	233.7^{de}	22.48^{a}	21.85^{ab}	22.16^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	21.88^{ab}	26.67^{a}	24.28^{ab}	243.2^{cd}	296.3^{c}	269.7^{d}	21.44^{abcd}	21.35^{bc}	21.39^{ab}
T7 - SRI + Clincher** fb Almix***	21.72^{ab}	28.00^{a}	24.86^{ab}	241.3^{cd}	311.1^{c}	276.2^{d}	22.45^{a}	21.72^{ab}	22.08^{a}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	10.33^{e}	21.47^{b}	15.90^{d}	114.8^{e}	238.5^{c}	176.7^{e}	19.41^{e}	22.20^{ab}	20.81^{bc}
T9 - CS + CW-10, 20, 30, 40 DAT	11.40^{e}	11.33^{c}	11.37^{e}	570.0^{a}	566.7^{a}	568.3^{a}	20.28^{cde}	19.89^{d}	20.09^{c}
T10 - CS + Butachlor* + HW-30 DAT	8.67^{e}	10.72^{c}	9.69^{ef}	433.3^{b}	535.8^{a}	484.6^{bc}	21.33^{abcd}	19.77^{d}	20.55^{bc}
T11 - CS + Butachlor* + CW- 30 DAT	8.23^{e}	8.33^{c}	8.28^{f}	411.7^{b}	416.7^{b}	414.2^{c}	19.99^{de}	20.13^{cd}	20.06^{c}
T12 - CS + CW- 10, 30 DAT	9.00^{e}	11.53^{c}	10.27^{ef}	450.0^{b}	576.7^{a}	513.3^{ab}	19.81^{de}	20.38^{cd}	20.09^{c}
T13 - CS + CW- 10 DAT + HW-30 DAT	10.22^{e}	11.23^{c}	10.73^{e}	510.8^{ab}	561.7^{a}	536.3^{ab}	20.77^{abcde}	19.33^{d}	20.05^{c}
T14- CS + CW-10 DAT + Clincher** fb Almix***	9.27^{e}	9.67^{c}	9.47^{ef}	463.3^{b}	483.3^{ab}	473.3^{bc}	20.61^{bcde}	19.57^{d}	20.09^{c}
T15 - CS + Clincher** fb Almix***	8.90^{e}	9.60^{c}	9.25^{ef}	445.0^{b}	480.0^{ab}	462.5^{bc}	20.52^{bcde}	19.39^{d}	19.96^{c}
T16 - CS + HW – 20, 40 DAT	9.67^{e}	10.75^{c}	10.21^{ef}	483.3^{ab}	537.5^{a}	510.4^{ab}	20.50^{bcde}	19.68^{d}	20.09^{c}

Values followed by same letters do not differ significantly in DMRT
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SRI – System of rice intensification
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HW – Hand weeding
OM – Organic manure
* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

c. Number of filled grains panicle^{-1}

It can be observed from the data in Table 28 that SRI with post emergence herbicide alone produced the highest number of filled grains panicle^{-1} (126.09) and this was closely followed by SRI treatments with pre emergence herbicide followed by hand weeding at 30 DAT, cono weeding at 30 DAT followed by hand weeding at 30 DAT, pre emergence herbicide followed by cono weeding at 30 DAT, and cono weeding at 10 DAT followed by post emergence herbicides, and they were at par.

d. Filled grain percentage panicle^{-1}

The percentage of filled grains on the panicle was the highest (92.16%) in conventional system with cono weeding at 10, 20, 30 and 40 DAT and this differed significantly from the treatment under conventional system with two hand weeding (86.96%), while all other treatments were at par with it.

e. 1000 grain weight

The weight of thousand grains, as presented in Table 28, was the highest (30.85 g) in conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT. The treatments, SRI with cono weeding at 10, 20, 30 and 40 DAT, conventional system with pre emergence herbicide followed by cono weeding at 30 DAT, SRI with pre emergence herbicide followed by hand weeding at 30 DAT, and conventional system with pre emergence herbicide followed by hand weeding at 30 DAT immediately followed it and were at par.

4.1.2.3. Grain yield

Effects of the treatments on grain yield, straw yield and harvest index of rice are presented in Table 29. In the 1st year, significantly higher grain yield

Table 28. Effect of the treatments on number of filled grains and 1000 grain weight of rice – Alappad *Kole*

Treatments	Filled grains (Number panicle^{-1})			Filled grains (%)			1000 grain weight (g)		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	101.07^{d}	120.00^{abc}	110.53^{b}	84.62^{abc}	90.91^{ab}	87.76^{ab}	30.243^{ab}	30.567^{ab}	30.405^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	119.50^{bc}	131.13^{a}	125.32^{a}	85.93^{abc}	88.47^{ab}	87.20^{ab}	30.763^{ab}	29.300^{ab}	30.032^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	120.83^{bc}	121.00^{abc}	120.92^{a}	87.52^{abc}	89.72^{ab}	88.62^{ab}	29.423^{abc}	29.367^{ab}	29.395^{abc}
T4 - SRI + CW- 10, 30 DAT	95.53^{d}	116.82^{bc}	106.18^{bc}	86.83^{abc}	93.01^{ab}	89.92^{ab}	28.203^{bc}	29.267^{ab}	28.735^{bc}
T5 - SRI + CW- 10 DAT + HW-30 DAT	119.87^{bc}	125.78^{b}	122.83^{a}	84.07^{bc}	92.90^{ab}	88.49^{ab}	29.863^{ab}	30.367^{ab}	30.115^{ab}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	128.50^{ab}	111.92^{c}	120.21^{a}	91.45^{a}	87.38^{b}	89.41^{ab}	26.640^{c}	29.500^{ab}	28.070^{c}
T7 - SRI + Clincher** fb Almix***	130.92^{a}	121.27^{ab}	126.09^{a}	89.79^{ab}	90.53^{ab}	90.16^{ab}	29.540^{abc}	29.500^{ab}	29.520^{abc}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	84.50^{ef}	121.07^{abc}	102.78^{bc}	90.40^{ab}	90.01^{ab}	90.21^{ab}	28.827^{abc}	28.900^{b}	28.863^{bc}
T9 - CS + CW-10, 20, 30, 40 DAT	101.25^{d}	95.75^{d}	98.50^{def}	90.63^{ab}	93.69^{ab}	92.16^{a}	28.840^{abc}	29.767^{ab}	29.303^{abc}
T10 - CS + Butachlor* + HW-30 DAT	113.15^{c}	86.34^{d}	99.75^{cde}	87.98^{abc}	87.93^{ab}	87.95^{ab}	29.900^{ab}	29.967^{ab}	29.933^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	95.33^{b}	97.67^{d}	96.50^{defg}	88.34^{abc}	93.44^{ab}	90.89^{ab}	29.497^{abc}	31.033^{a}	30.265^{ab}
T12 - CS + CW- 10, 30 DAT	80.52^{f}	96.20^{d}	88.36^{g}	88.07^{abc}	94.65^{a}	91.36^{ab}	29.140^{abc}	30.167^{ab}	29.653^{abc}
T13 - CS + CW- 10 DAT + HW-30 DAT	97.72^{b}	92.64^{d}	95.18^{defg}	88.12^{abc}	90.08^{ab}	89.10^{ab}	31.630^{a}	30.067^{ab}	30.848^{a}
T14- CS + CW-10 DAT + Clincher** fb Almix***	92.50^{de}	89.00^{d}	90.75^{efg}	84.33^{bc}	90.94^{ab}	87.63^{ab}	29.257^{abc}	29.267^{ab}	29.262^{abc}
T15 - CS + Clincher** fb Almix***	95.87^{d}	95.33^{d}	95.60^{defg}	87.82^{abc}	91.66^{ab}	89.74^{ab}	29.573^{abc}	29.833^{ab}	29.703^{abc}
T16 - CS + HW – 20, 40 DAT	85.67^{ef}	93.20^{d}	89.43^{fg}	82.04^{c}	91.87^{ab}	86.96^{b}	28.320^{bc}	29.167^{ab}	28.743^{abc}

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OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 29. Effect of the treatments on grain yield, straw yield and Harvest Index of rice – Alappad *Kole*

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})			Harvest Index		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	4551^{d}	5146^{bc}	4849^{de}	3796^{a}	4175^{bc}	3985^{b}	0.54^{c}	0.55^{a}	0.55^{cdef}
T2 - SRI + Butachlor* + HW-30 DAT	3569^{e}	5944^{a}	4757^{e}	2376^{c}	4394^{bc}	3385^{c}	0.60^{abc}	0.58^{a}	0.59^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	4612^{d}	5212^{abc}	4912^{cde}	3673^{a}	4065^{bc}	3869^{bc}	0.56^{c}	0.56^{a}	0.56^{bcde}
T4 - SRI + CW- 10, 30 DAT	2490^{f}	5179^{bc}	3835^{f}	2653^{c}	4559^{b}	3606^{bc}	0.49^{d}	0.53^{b}	0.51^{f}
T5 - SRI + CW- 10 DAT + HW-30 DAT	5258^{bcd}	5700^{ab}	5479^{bc}	2742^{bc}	4614^{b}	3678^{bc}	0.66^{a}	0.55^{a}	0.60^{a}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	5012^{cd}	5782^{ab}	5397^{bcd}	3483^{ab}	4504^{b}	3994^{b}	0.59^{bc}	0.56^{a}	0.58^{abc}
T7 - SRI + Clincher** fb Almix***	5104^{cd}	5130^{bc}	5117^{bcde}	3673^{a}	4263^{bc}	3968^{b}	0.58^{bc}	0.55^{a}	0.56^{bcd}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1507^{g}	4772^{c}	3139^{g}	1179^{d}	3713^{c}	2446^{d}	0.56^{c}	0.56^{a}	0.56^{bcde}
T9 - CS + CW-10, 20, 30, 40 DAT	4959^{cd}	4899^{c}	4929^{cde}	3512^{ab}	5757^{a}	4634^{a}	0.59^{bc}	0.46^{c}	0.52^{ef}
T10 - CS + Butachlor* + HW-30 DAT	6110^{ab}	5232^{abc}	5671^{ab}	3708^{a}	5861^{a}	4785^{a}	0.62^{ab}	0.47^{c}	0.55^{cdef}
T11 - CS + Butachlor* + CW- 30 DAT	5022^{cd}	5719^{ab}	5371^{bcd}	3690^{a}	5861^{a}	4776^{a}	0.58^{abc}	0.49^{bc}	0.54^{def}
T12 - CS + CW- 10, 30 DAT	4928^{cd}	5376^{abc}	5152^{bcde}	3843^{a}	5413^{a}	4628^{a}	0.56^{bc}	0.50^{bc}	0.53^{def}
T13 - CS + CW- 10 DAT + HW-30 DAT	6382^{a}	5764^{ab}	6073^{a}	4222^{a}	5996^{a}	5109^{a}	0.60^{abc}	0.49^{bc}	0.55^{cdef}
T14- CS + CW-10 DAT + Clincher** fb Almix***	6131^{ab}	5121^{bc}	5626^{ab}	4352^{a}	5435^{a}	4894^{a}	0.59^{bc}	0.49^{bc}	0.54^{def}
T15 - CS + Clincher** fb Almix***	5273^{bcd}	5232^{abc}	5252^{bcde}	3935^{a}	5547^{a}	4741^{a}	0.57^{bc}	0.49^{bc}	0.53^{def}
T16 - CS + HW – 20, 40 DAT	5640^{abc}	5486^{abc}	5563^{ab}	3759^{a}	5959^{a}	4859^{a}	0.60^{abc}	0.48^{c}	0.54^{cdef}

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* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

(6382 kg ha^{-1}) was recorded in the conventional system with CW at 10 DAT followed by HW at 30 DAT, whereas in the 2nd year it was significantly higher (5944 kg ha^{-1}) under SRI with pre emergence herbicide followed by hand weeding at 30 DAT which was on par with most of the other treatments. However, it was observed from the pooled data on grain yield that conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT produced the highest quantity of grain (6073 kg ha^{-1}) and this was immediately followed and kept parity with three treatments in conventional system viz., pre emergence herbicide followed by hand weeding at 30 DAT, cono weeding at 10 DAT followed by post emergence herbicide, and two hand weeding at 20 and 40 DAT. The treatment with typical SRI recorded the lowest grain yield (3139 kg ha^{-1}) at Alappad *Kole.*

4.1.2.4. Straw yield

The rice straw yield at Alappad *Kole* was higher in all the treatments in conventional system compared to the treatments in SRI. The pooled mean exhibited significant superiority of the treatments in conventional system in straw yield. The highest straw yield of 5109 kg ha^{-1} was recorded by cono weeding at 10 DAT followed by hand weeding at 30 DAT in conventional system, and other treatments in conventional system performed uniformly with it, while treatments in SRI differed significantly with it. The typical SRI treatment recorded the lowest straw yield (2446 kg ha^{-1}) at Alappad *Kole.*

4.1.2.5. Harvest Index

Harvest index was higher in SRI treatments in both years. The highest harvest index, as observed from the pooled mean, was recorded by SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT, which was immediately followed by SRI with pre emergence herbicide followed by hand weeding at 30 DAT.

4.1.2.6. Nutrient content and uptake by rice

The data on content of N, P and K in the rice plant at panicle initiation stage in the Alappad *Kole* are presented in Table 30. It was observed from the data that the rice plant under SRI with cono weeding at 10 DAT followed by post emergence herbicides recorded the highest content of nitrogen (2.89%), and this was immediately followed by SRI with two cono weeding at 10 and 30 DAT. Phosphorus content was the highest (0.42%) in SRI with post emergence herbicides alone as well as in conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT. SRI with cono weeding at 10 and 30 DAT recorded the highest content of potassium (1.79%) in rice, and this was followed by SRI with cono weeding at 10, 20, 30 and 40 DAT and SRI with pre emergence herbicide followed by hand weeding at 30 DAT.

The data on uptake of nutrients viz., nitrogen, phosphorus and potassium by rice at Alappad *Kole* at panicle initiation stage are presented in Table 31. Significantly higher uptake of nutrients was observed with treatments in conventional system. Conventional system with two hand weeding at 20 and 40 DAT recorded the highest N uptake (132 kg ha^{-1}) followed by conventional system with post emergence herbicide alone, which were at par. Phosphorus uptake was the highest (25 kg ha^{-1}) in conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT. Similarly, the highest uptake of potassium (93 kg ha^{-1})) was observed in conventional system with pre emergence herbicide followed by hand weeding at 30 DAT, and this was immediately followed by pre emergence herbicide followed by cono weeding at 30 DAT in the conventional system.

Table 30. Effect of the treatments on nutrient content (%) of rice at panicle initiation stage – Alappad *Kole*

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	2.987^{b}	1.960^{de}	2.473^{bcd}	0.514^{ab}	0.315^{abcd}	0.415^{ab}	1.956^{a}	1.557^{a}	1.756^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	2.707^{bc}	1.867^{def}	2.287^{cdef}	0.330^{e}	0.390^{abc}	0.360^{abc}	1.794^{ab}	1.544^{a}	1.669^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	2.893^{b}	1.960^{de}	2.427^{bcde}	0.371^{de}	0.188^{e}	0.280^{c}	0.803^{d}	0.783^{cd}	0.793^{f}
T4 - SRI + CW- 10, 30 DAT	2.987^{b}	2.427^{ab}	2.707^{ab}	0.539^{a}	0.271^{cde}	0.405^{ab}	1.876^{a}	1.696^{a}	1.786^{a}
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.520^{c}	2.520^{a}	2.520^{bc}	0.448^{abcd}	0.259^{cde}	0.353^{abc}	1.492^{cd}	1.637^{a}	1.565^{bc}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	3.360^{a}	2.427^{ab}	2.893^{a}	0.404^{bcde}	0.384^{abc}	0.394^{ab}	1.559^{bc}	1.590^{a}	1.574^{bc}
T7 - SRI + Clincher** fb Almix***	2.520^{c}	2.427^{ab}	2.473^{bcd}	0.505^{abc}	0.340^{abcde}	0.423^{a}	1.880^{a}	0.709^{d}	1.294^{de}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2.147^{d}	2.053^{cde}	2.100^{fgh}	0.455^{abcd}	0.350^{abcd}	0.403^{ab}	1.579^{bc}	1.557^{a}	1.568^{bc}
T9 - CS + CW-10, 20, 30, 40 DAT	1.120^{g}	1.867^{def}	1.493^{i}	0.415^{bcde}	0.203^{de}	0.309^{bc}	1.244^{c}	0.693^{b}	0.969^{f}
T10 - CS + Butachlor* + HW-30 DAT	1.493^{f}	1.587^{f}	1.540^{i}	0.390^{cde}	0.441^{ab}	0.416^{ab}	1.371^{cd}	1.780^{a}	1.576^{bc}
T11 - CS + Butachlor* + CW- 30 DAT	1.867^{de}	1.773^{ef}	1.820^{h}	0.379^{de}	0.387^{abc}	0.383^{abc}	1.234^{c}	1.567^{a}	1.401^{cd}
T12 - CS + CW- 10, 30 DAT	2.053^{de}	2.333^{abc}	2.193^{def}	0.352^{de}	0.433^{ab}	0.392^{ab}	1.227^{c}	1.213^{b}	1.220^{de}
T13 - CS + CW- 10 DAT + HW-30 DAT	1.680^{ef}	2.053^{cde}	1.867^{gh}	0.377^{de}	0.469^{a}	0.423^{a}	1.480^{cd}	1.267^{b}	1.374^{d}
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.680^{ef}	2.427^{ab}	2.053^{fgh}	0.398^{bcde}	0.363^{abc}	0.380^{abc}	1.302^{cd}	1.018^{bc}	1.160^{e}
T15 - CS + Clincher** fb Almix***	2.053^{de}	2.520^{a}	2.287^{cdef}	0.337^{de}	0.404^{abc}	0.370^{abc}	1.238^{c}	1.246^{b}	1.242^{de}
T16 - CS + HW – 20, 40 DAT	2.147^{d}	2.147^{bcd}	2.147^{efg}	0.412^{bcde}	0.307^{bcde}	0.360^{abc}	1.476^{cd}	1.235^{b}	1.356^{de}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 31. Effect of the treatments on nutrient uptake (kg ha^{-1}) by rice at panicle initiation stage – Alappad *Kole*

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	85.36^{bcd}	79.95^{d}	82.65^{f}	14.49^{abcd}	12.94^{cd}	13.72^{f}	55.46^{abc}	63.60^{def}	59.53^{de}
T2 - SRI + Butachlor* + HW-30 DAT	64.89^{def}	126.35^{bc}	95.62^{def}	7.93^{fgh}	26.18^{abc}	17.06^{cdef}	42.96^{bcde}	104.25^{abc}	73.61^{abcd}
T3 - SRI + Butachlor* + CW- 30 DAT	39.20^{gh}	82.04^{d}	60.62^{g}	4.99^{gh}	8.03^{d}	6.51^{g}	10.73^{f}	33.17^{f}	21.95^{g}
T4 - SRI + CW- 10, 30 DAT	60.97^{fg}	183.03^{a}	122.00^{ab}	10.80^{cdef}	19.98^{bcd}	15.39^{def}	37.90^{de}	127.53^{a}	82.71^{abc}
T5 - SRI + CW- 10 DAT + HW-30 DAT	68.87^{de}	180.13^{a}	124.50^{ab}	12.18^{bcdef}	18.41^{bcd}	15.30^{def}	40.66^{cde}	117.09^{ab}	78.87^{abcd}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	108.58^{a}	132.48^{bc}	120.53^{abc}	13.21^{bcde}	21.52^{bcd}	17.37^{bcdef}	51.00^{bcd}	87.74^{bcd}	69.37^{bcde}
T7 - SRI + Clincher** fb Almix***	45.83^{fg}	151.26^{c}	98.54^{cdef}	9.21^{efg}	21.24^{bcd}	15.22^{ef}	34.33^{e}	44.77^{ef}	39.55^{fg}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	19.82^{h}	149.17^{abc}	84.50^{ef}	4.20^{h}	25.49^{abc}	14.84^{ef}	14.63^{f}	112.89^{ab}	63.76^{cde}
T9 - CS + CW-10, 20, 30, 40 DAT	41.80^{fg}	81.65^{d}	61.72^{g}	15.39^{abcd}	8.62^{d}	12.01^{fg}	46.07^{bcde}	31.57^{f}	38.82^{fg}
T10 - CS + Butachlor* + HW-30 DAT	61.60^{efg}	114.09^{cd}	87.84^{ef}	16.23^{ab}	32.22^{ab}	24.23^{ab}	57.03^{ab}	128.73^{a}	92.88^{a}
T11 - CS + Butachlor* + CW- 30 DAT	77.11^{cde}	147.59^{abc}	112.35^{abcd}	15.63^{abc}	31.80^{ab}	23.72^{abc}	50.27^{bcd}	129.30^{a}	89.79^{ab}
T12 - CS + CW- 10, 30 DAT	76.10^{cde}	150.42^{abc}	113.26^{abcd}	13.08^{bcde}	29.27^{ab}	21.17^{abcde}	45.52^{bcde}	81.13^{bcd}	63.33^{cde}
T13 - CS + CW- 10 DAT + HW-30 DAT	54.43^{efg}	165.74^{ab}	110.08^{abcd}	12.22^{bcdef}	37.11^{a}	24.66^{a}	47.78^{bcde}	101.43^{abc}	74.60^{abcd}
T14- CS + CW-10 DAT + Clincher** fb Almix***	42.21^{efg}	168.23^{ab}	105.22^{bcde}	10.35^{def}	24.96^{abc}	17.65^{bcde}	33.92^{e}	69.83^{cde}	51.87^{ef}
T15 - CS + Clincher** fb Almix***	92.05^{abc}	165.65^{ab}	128.85^{a}	15.08^{abcd}	26.87^{abc}	20.97^{abcde}	55.18^{abc}	83.44^{bcd}	69.31^{bcde}
T16 - CS + HW – 20, 40 DAT	99.92^{ab}	163.41^{ab}	131.67^{a}	19.28^{a}	25.26^{abc}	22.27^{abcd}	68.81^{a}	97.90^{abcd}	83.35^{abc}

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HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

4.1.2.7. Soil characteristics

a. Bulk density, pH and Electrical conductivity

The effects of treatments on the physico chemical characteristics such as bulk density, soil reaction (pH) and electrical conductivity (EC) at panicle initiation stage of the rice crop are presented in Table 32. All these soil characteristics showed only very little variation among the treatments during both years, but their pooled values differed significantly. The lowest value of bulk density (0.59 kg m^{-3}) was recorded in SRI with post emergence herbicides alone, while conventional system with pre emergence herbicide followed by hand weeding at 30 DAT recorded the highest bulk density (0.71 kg m^{-3}) and they differed significantly. All other treatments were at par.

Among the various treatments, SRI with pre emergence herbicide followed by hand weeding at 30 DAT, SRI with cono weeding at 10 DAT followed by post emergence herbicide, and SRI with pre emergence herbicide followed by cono weeding at 30 DAT recorded significantly higher values of soil pH, while all other treatments were at par. The electrical conductivity was the highest in conventional system with hand weeding twice at 20 and 40 DAT as well as CW at 10 DAT followed by post emergence herbicide, while all other treatments performed uniformly.

b. Available soil nutrients

The effects of treatments on the status of available nutrients in the soil viz., organic carbon percentage, available phosphorus and exchangeable potassium at panicle initiation stage of the rice crop are presented in Table 33. The highest organic carbon percentage in the soil (3.17%) was observed in conventional system with cono weeding at 10 DAT followed by post emergence

Table 32. Effect of the treatments on soil characteristics at panicle initiation stage – Alappad *Kole*

Treatments	Bulk density (kg m^{-3})			pH			Electrical conductivity (dS m^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	0.611^{a}	0.648^{ab}	0.630^{ab}	4.35^{ab}	4.45^{b}	4.40^{ab}	0.076^{ab}	0.039^{ab}	0.057^{ab}
T2 - SRI + Butachlor* + HW-30 DAT	0.657^{a}	0.616^{b}	0.637^{ab}	4.51^{a}	4.63^{ab}	4.57^{a}	0.092^{ab}	0.033^{ab}	0.063^{ab}
T3 - SRI + Butachlor* + CW- 30 DAT	0.607^{a}	0.682^{ab}	0.645^{ab}	4.38^{ab}	4.66^{ab}	4.52^{a}	0.084^{ab}	0.033^{ab}	0.058^{ab}
T4 - SRI + CW- 10, 30 DAT	0.663^{a}	0.643^{ab}	0.653^{ab}	4.32^{ab}	4.60^{ab}	4.46^{ab}	0.088^{ab}	0.029^{b}	0.059^{ab}
T5 - SRI + CW- 10 DAT + HW-30 DAT	0.612^{a}	0.657^{ab}	0.634^{ab}	4.32^{ab}	4.78^{a}	4.55s	0.081^{ab}	0.030^{b}	0.056^{ab}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	0.602^{a}	0.629^{ab}	0.616^{ab}	4.26^{ab}	4.57^{ab}	4.42s^{b}	0.085^{ab}	0.033^{ab}	0.059^{ab}
T7 - SRI + Clincher** fb Almix***	0.587^{a}	0.595^{b}	0.591^{b}	4.37^{ab}	4.62^{ab}	4.50^{ab}	0.082^{ab}	0.035^{ab}	0.059^{ab}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	0.621^{a}	0.605^{b}	0.613^{ab}	4.33^{ab}	4.50^{b}	4.42^{ab}	0.080^{ab}	0.035^{ab}	0.058^{ab}
T9 - CS + CW-10, 20, 30, 40 DAT	0.646^{a}	0.603^{b}	0.625^{ab}	4.34^{ab}	4.67^{ab}	4.50^{ab}	0.076^{ab}	0.036^{ab}	0.056^{ab}
T10 - CS + Butachlor* + HW-30 DAT	0.682^{a}	0.731^{a}	0.707^{a}	4.28^{ab}	4.62^{ab}	4.45^{ab}	0.081^{ab}	0.038^{ab}	0.060^{ab}
T11 - CS + Butachlor* + CW- 30 DAT	0.590^{a}	0.653^{ab}	0.622^{ab}	4.38^{ab}	4.50^{b}	4.44^{ab}	0.081^{ab}	0.039^{ab}	0.060^{ab}
T12 - CS + CW- 10, 30 DAT	0.623^{a}	0.654^{ab}	0.639^{ab}	4.41^{ab}	4.47^{b}	4.44^{ab}	0.073^{ab}	0.040^{ab}	0.057^{ab}
T13 - CS + CW- 10 DAT + HW-30 DAT	0.684^{a}	0.633^{ab}	0.659^{ab}	4.40^{ab}	4.59^{ab}	4.50^{ab}	0.071^{b}	0.030^{ab}	0.051^{b}
T14- CS + CW-10 DAT + Clincher** fb Almix***	0.626^{a}	0.602^{b}	0.614^{ab}	4.20^{b}	4.45^{b}	4.33^{b}	0.096^{ab}	0.039^{ab}	0.068^{a}
T15 - CS + Clincher** fb Almix***	0.672^{a}	0.595^{b}	0.633^{ab}	4.26^{ab}	4.52^{b}	4.39^{ab}	0.081^{ab}	0.040^{a}	0.061^{ab}
T16 - CS + HW – 20, 40 DAT	0.660^{a}	0.684^{ab}	0.672^{ab}	4.33^{ab}	4.67^{ab}	4.50^{ab}	0.105^{a}	0.031^{ab}	0.068^{a}

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OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

herbicides and this was closely followed by the treatments with post emergence herbicides alone as well as with pre emergence herbicide followed by hand weeding at 30 DAT in the conventional system. Available phosphorus content was the maximum (17.93 kg ha^{-1}) in conventional system with cono weeding at 10, 20, 30 and 40 DAT, closely followed by two cono weeding at 10 and 30 DAT, which were at par. Content of exchangeable potassium in the soil was the highest (180 kg ha^{-1}) in SRI with post emergence herbicides alone (T7), and this was followed by SRI treatment with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5) and then by conventional treatment with cono weeding at 10, 20, 30 and 40 DAT (T9).

4.1.2.8. Studies on weeds and their control

Observations on weed density (Number m^{-2}) and weed dry weight (g m^{-2}) were recorded at 45 and 60 days after transplanting (DAT). The weed plants were categorized and counted separately to get individual density of grasses, sedges and broad leaf weeds (BLWs). The important weed species observed in the experimental field at Alappad *Kole* were *Echinochloa crusgalli, Echinochloa stagnina, Cynodon dactylon* (grasses), *Cyperus iria*, *Cyperus difformis*, *Cyperus haspan, Fimbristylis miliacea* (sedges), *Monochoria vaginalis*, *Ludwigia perennis, Limnocharis flava, Bacopa monneiri* and *Sphaeranthus indica* (broad leaf weeds) (Plate 5).

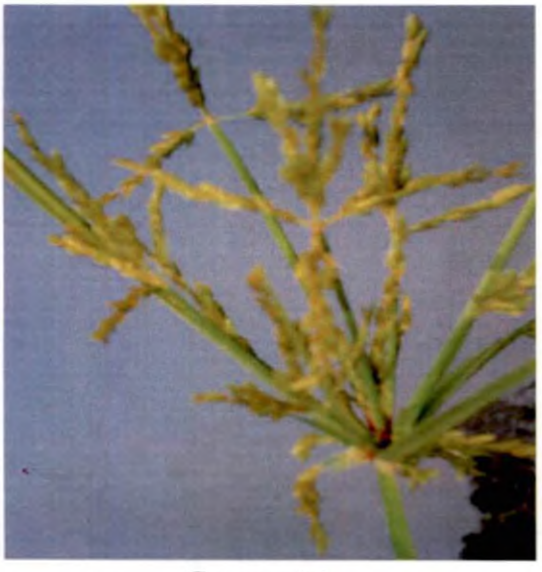
a. Weed density

The data on weed density (Number m^{-2}) at 45 and 60 DAT are presented in Tables 34 and 35, respectively.

At 45 DAT, weed density was more in SRI treatments and less in treatments with conventional system, especially with respect to grasses and sedges, while broad leaf weeds were found comparatively less in SRI. The highest

Echinochloa crusgalli

Echinochloa stagnina



Cyperus iria

Fimbristylis miliacea

Monochoria vaginalis

Ludwigia perennis

Plate 5. Major weeds in the rice field at Alappad *Kole*

Table 33. Effect of the treatments on soil nutrient contents at panicle initiation stage – Alappad *Kole*

Treatments	Organic Carbon (%)			Available Phosphorus (kg ha^{-1})			Exchangeable Potassium (kg ha^{-1})		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	2.72^{b}	2.78^{abc}	2.75^{d}	14.56^{bcd}	14.95^{b}	14.75abcd	154.19ab	133.28bc	143.73bc
T2 - SRI + Butachlor* + HW-30 DAT	2.85^{ab}	2.88^{abc}	2.87^{bcd}	14.73^{bcd}	15.84^{b}	15.28abcd	154.19ab	155.68bc	154.93abc
T3 - SRI + Butachlor* + CW- 30 DAT	2.80^{b}	2.80^{abc}	2.80^{cd}	12.19^{de}	14.08^{b}	13.13cd	142.99b	155.31bc	149.15bc
T4 - SRI + CW- 10, 30 DAT	2.83^{ab}	2.65^{c}	2.74^{d}	12.03^{de}	15.44^{b}	13.73bcd	158.29ab	145.23bc	151.76abc
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.82^{ab}	2.98^{abc}	2.90^{bcd}	19.37^{b}	15.03^{b}	17.20ab	193.01a	150.45bc	171.73ab
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	2.85^{ab}	2.99^{abc}	2.92^{bcd}	15.97^{bcd}	15.03^{b}	15.50abcd	160.53aab	139.63bc	150.08bc
T7 - SRI + Clincher** fb Almix***	2.89^{ab}	2.87^{abc}	2.88^{bcd}	17.28^{bc}	13.92^{b}	15.60abcd	190.40a	170.25d	180.33a
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	2.88^{ab}	2.84^{abc}	2.86^{bcd}	15.44^{bcde}	13.61^{b}	14.53abcd	164.64ab	128.43c	146.53bc
T9 - CS + CW-10, 20, 30, 40 DAT	2.82^{ab}	3.08^{abc}	2.95^{abcd}	14.55^{bcd}	21.30^{a}	17.93a	135.52b	205.33a	170.43abc
T10 - CS + Butachlor* + HW-30 DAT	2.91^{ab}	3.23^{a}	3.07^{ab}	14.14^{bcd}	14.74^{b}	14.44abcd	144.56b	166.13bc	155.35abc
T11 - CS + Butachlor* + CW- 30 DAT	2.89^{ab}	2.94^{abc}	2.92^{bcd}	15.92^{bcd}	15.97^{b}	15.95abc	159.79ab	156.05bc	157.92abc
T12 - CS + CW- 10, 30 DAT	2.91^{ab}	3.10^{abc}	3.01^{abc}	23.55^{a}	11.89^{b}	17.72a	142.99b	137.01bc	140.00c
T13 - CS + CW- 10 DAT + HW-30 DAT	2.94^{ab}	2.89^{abc}	2.92^{bcd}	11.30^{e}	12.92^{b}	12.11d	165.01ab	147.09bc	156.05abc
T14- CS + CW-10 DAT + Clincher** fb Almix***	3.21^{a}	3.13^{ab}	3.17^{a}	12.12^{de}	13.73^{b}	12.93cd	159.79ab	152.32bc	156.05abc
T15 - CS + Clincher** fb Almix***	2.94^{ab}	3.23^{a}	3.09^{ab}	16.57^{bc}	15.56^{b}	16.06abc	140.75b	148.21bc	144.48bc
T16 - CS + HW – 20, 40 DAT	3.08^{ab}	2.71^{bc}	2.90^{bcd}	13.45^{bcd}	17.14a^{b}	15.29abcd	151.76ab	147.47bc	149.61bc

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* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

density of total weeds (40 m^{-2}) was recorded in the typical SRI with cono weeding four times at 10, 20, 30 and 40 DAT along with organic manure incorporation, and this was closely followed by SRI treatment with cono weeding at 10 and 30 DAT. The density of grass weeds was the highest (22 m^{-2}) in the typical SRI treatment with CW four times at 10, 20, 30 and 40 DAT and application of organic manure, followed by SRI with two cono weeding at 10 and 30 DAT, and both were at par. The density of sedges was the highest (17 m^{-2}) in SRI with pre emergence herbicide followed by hand weeding at 30 DAT, closely followed by the typical SRI treatment, and both were at par. The density of broad leaf weeds was the highest (19 m^{-2}) in conventional system with hand weeding at 20 and 40 DAT, but it was closely followed by SRI treatments with cono weeding at 10 and 30 DAT and also by cono weeding at 10 DAT followed by hand weeding at 30 DAT.

It was also observed from the pooled mean that, at 45 DAT the lowest density of grass weeds (4 m^{-2}) was recorded in conventional system with cono weeding at 10 DAT followed by post emergence herbicides and this was followed by the conventional treatments with cono weeding at 10 DAT followed by hand weeding at 30 DAT as well as with hand weeding at 20 and 40 DAT. Density of sedges was comparatively lower in many treatments, while broad leaf weeds were found less dense in various treatments viz., SRI with cono weeding at 10 DAT followed by post emergence herbicides, SRI with pre emergence herbicide followed by cono weeding at 30 DAT as well as conventional system with cono weeding at 10 DAT followed by post emergence herbicides. The total weed density at 45 DAT was the lowest with cono weeding at 10 DAT followed by post emergence herbicides in SRI closely followed by the same treatment combination in the conventional system, and they were at par.

While comparing the various weed control strategies tested under SRI, it was noticed from the pooled data that the total weed density at 45 DAT was the highest in the typical SRI, while it was significantly reduced with cono weeding at

Table 34. Effect of the treatments on weed density (Number m^{-2}) at 45 days after transplanting - Alappad *Kole*

Treatments	Grasses			Sedges			Broad leaf weeds			Total weeds		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	3.51^{cd} (12.00)	3.12^{bcd} (9.33)	3.32^{bcd} (10.67)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	1.91^{bc} (4.00)	1.31^{d} (2.00)	3.51^{e} (12.00)	3.66^{cdef} (13.33)	3.59^{efgh} (12.67)
T2 - SRI + Butachlor* + HW-30 DAT	2.49^{de} (6.00)	2.39^{bcd} (5.33)	2.44^{bcde} (5.67)	5.72^{a} (32.33)	1.18^{a} (1.33)	3.45^{a} (16.83)	1.35^{de} (1.67)	2.86^{abc} (8.00)	2.10^{bcd} (4.83)	6.35^{abc} (40.00)	3.84^{cdef} (14.67)	5.09^{bcd} (27.33)
T3 - SRI + Butachlor* + CW- 30 DAT	3.34^{cd} (10.67)	3.12^{bcd} (9.33)	3.23^{bcd} (10.00)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	1.00^{e} (0.67)	1.44^{bc} (2.67)	1.22^{d} (1.67)	3.44^{e} (11.33)	3.50^{def} (12.00)	3.47^{fgh} (11.67)
T4 - SRI + CW- 10, 30 DAT	5.68^{a} (32.00)	3.57^{bc} (13.33)	4.63^{a} (22.67)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	3.87^{b} (14.67)	3.66^{ab} (13.33)	3.76^{a} (14.00)	6.86^{ab} (46.67)	5.20^{bc} (26.67)	6.03^{ab} (36.67)
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.39^{d} (5.33)	2.56^{bcd} (8.00)	2.47^{bcde} (6.67)	3.91^{bc} (15.00)	0.71^{a} (0.00)	2.31^{b} (7.50)	2.84^{bc} (8.33)	4.81^{a} (24.00)	3.83^{a} (16.17)	5.32^{ab} (28.67)	5.61^{ab} (32.00)	5.47^{abc} (30.33)
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	0.71^{f} (0.00)	4.14^{ab} (17.33)	2.42^{bcde} (8.67)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	0.88^{e} (0.33)	0.71^{c} (0.00)	0.79^{d} (0.17)	0.88^{f} (0.33)	4.14^{bcde} (17.33)	2.51^{h} (8.83)
T7 - SRI + Clincher** fb Almix***	1.25^{fg} (1.67)	5.81^{a} (33.33)	3.53^{b} (17.50)	0.71^{d} (0.00)	1.83^{a} (5.33)	1.27^{cd} (2.67)	0.71^{e} (0.00)	2.92^{abc} (10.67)	1.82^{cd} (5.33)	1.25^{f} (1.67)	6.96^{a} (49.33)	4.11^{def} (25.50)
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	5.11^{ab} (25.67)	4.22^{ab} (17.33)	4.67^{a} (21.50)	4.80^{ab} (22.67)	1.65^{a} (4.00)	3.22^{a} (13.33)	2.86^{bc} (8.00)	1.44^{bc} (2.67)	2.15^{bcd} (5.33)	7.54^{a} (56.33)	4.90^{bcd} (24.00)	6.22^{a} (40.17)
T9 - CS + CW-10, 20, 30, 40 DAT	4.40^{bc} (19.33)	2.59^{bcd} (6.67)	3.50^{bc} (13.00)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	2.65^{bcd} (6.67)	1.18^{c} (1.33)	1.91^{cd} (4.00)	5.09^{cd} (26.00)	2.86^{ef} (8.00)	3.97^{defg} (17.00)
T10 - CS + Butachlor* + HW-30 DAT	2.39^{defg} (5.33)	2.39^{bcd} (6.67)	2.39^{cde} (6.00)	1.65^{d} (4.00)	1.18^{a} (1.33)	1.41^{bcd} (2.67)	1.18^{e} (1.33)	2.39^{bc} (6.67)	1.78^{cd} (4.00)	3.30^{e} (10.67)	3.87^{cdef} (14.67)	3.58^{efgh} (12.67)
T11 - CS + Butachlor* + CW-30 DAT	3.32^{cd} (10.67)	3.03^{bcd} (9.33)	3.18^{bcd} (10.00)	2.97^{c} (8.67)	0.71^{a} (0.00)	1.84^{bc} (4.33)	3.84^{b} (14.67)	2.65^{abc} (6.67)	3.24^{ab} (10.67)	5.87^{bcd} (34.00)	4.01^{bcdef} (16.00)	4.94^{bcd} (25.00)
T12 - CS + CW- 10, 30 DAT	4.67^{ab} (22.00)	2.18^{bcd} (5.33)	3.43^{bcd} (13.67)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	3.62^{b} (12.67)	2.39^{bc} (6.67)	3.00^{abc} (9.67)	5.91^{bcd} (34.67)	3.50^{def} (12.00)	4.71^{cde} (23.33)
T13 - CS + CW- 10 DAT + HW-30 DAT	2.59^{de} (6.67)	1.18^{d} (1.33)	1.89^{e} (4.00)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	1.83^{cde} (5.33)	2.12^{bc} (4.00)	1.97^{bcd} (4.67)	3.40^{e} (12.00)	2.39^{def} (5.33)	2.89^{gh} (8.67)
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.65^{ef} (2.67)	1.83^{cd} (5.33)	1.74^{e} (4.00)	0.71^{d} (0.00)	1.44^{a} (2.67)	1.08^{cd} (1.33)	1.18^{e} (1.33)	1.44^{bc} (2.67)	1.31^{d} (2.00)	1.91^{f} (4.00)	3.30^{fg} (10.67)	2.61^{h} (7.33)
T15 - CS + Clincher** fb Almix***	3.50^{cd} (12.00)	1.18^{d} (1.33)	2.34^{de} (6.67)	1.65^{d} (4.00)	0.71^{a} (0.00)	1.18^{cd} (2.00)	2.92^{bc} (8.00)	0.71^{c} (0.00)	1.81^{cd} (4.00)	4.88^{d} (24.00)	1.18^{g} (1.33)	3.03^{fgh} (12.67)
T16 - CS + HW – 20, 40 DAT	1.65^{efg} (2.67)	2.45^{bcd} (8.00)	2.05^{e} (5.33)	1.44^{d} (2.67)	1.44^{a} (2.67)	1.44^{bcd} (2.67)	5.44^{a} (29.33)	2.56^{bc} (8.00)	4.00^{a} (18.67)	5.90^{bcd} (34.67)	4.31^{bcde} (18.67)	5.11^{bcd} (26.67)

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification; CW – Cono weeding; OM – Organic manure; DAT – Days after transplanting; fb – Followed by

CS – Conventional system; HW – Hand weeding; *Butachlor @ 1.25 kg ha^{-1}; ** Cyhalofop butyl @ 0.1 kg ha^{-1}; *** Almix 20 WP @ 4.0 g a.i. ha^{-1}

10 DAT followed by post emergence herbicides. Application of pre emergence herbicide followed by cono weeding at 30 DAT as well as cono weeding four times at 10, 20, 30 and 40 DAT were also found effective in reducing the total weed density in SRI, and were at par.

At 60 DAT also the weed density was higher in treatments with SRI compared to the treatments in the conventional system, as seen from the data presented in Table 35.

Typical SRI treatment with cono weeding four times at 10, 20, 30 and 40 DAT and application of organic manure recorded the highest density of total weeds at 60 DAT. Density of grass weeds at 60 DAT was the highest in SRI with cono weeding at 10 and 30 DAT and the least density of grass weeds was observed in conventional system with hand weeding at 20 and 40 DAT. Density of sedges was significantly superior in SRI with pre emergence herbicide followed by hand weeding at 30 DAT. Broad leaf weeds were the highest in density when SRI was practised with cono weeding at 10 DAT followed by hand weeding at 30 DAT, and lowest in density when conventional system was treated with post emergence herbicides alone, closely followed by conventional treatment with cono weeding at 10 DAT followed by post emergence herbicides. It was also observed from the data that the total weed density at 60 DAT was significantly reduced in the conventional system by the application of post emergence herbicides as well as through cono weeding at 10 DAT followed by hand weeding at 30 DAT.

b. Weed dry weight

The effect of treatments on dry weight (g m^{-2}) of weeds at 45 and 60 DAT in the experimental field at Alappad *Kole* is presented in Table 36.

Table 35. Effect of the treatments on weed density (Number m^{-2}) at 60 days after transplanting – Alappad *Kole*

Treatments	Grasses			Sedges			Broad leaf weeds			Total weeds		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	3.80^{bc} (14.00)	1.91^{ab} (4.00)	2.86^{abc} (9.00)	0.71^{d} (0.00)	1.18^{a} (1.33)	0.94^{d} (0.67)	2.56^{bcd} (8.00)	1.91^{bc} (4.00)	2.24^{cde} (6.00)	4.71^{b} (22.00)	3.66^{cdef} (13.33)	4.19^{de} 17.67)
T2 - SRI + Butachlor* + HW-30 DAT	4.33^{ab} (18.67)	1.18^{b} (1.33)	2.75^{abcd} (10.00)	4.53^{a} (20.00)	0.71^{a} (0.00)	2.62^{a} (10.00)	3.89^{a} (14.67)	2.86^{abc} (8.00)	3.37^{ab} (11.33)	7.32^{a} (53.33)	3.84^{cdef} (14.67)	5.58^{ab} (34.00)
T3 - SRI + Butachlor* + CW-30 DAT	2.92^{de} (8.00)	2.12^{ab} (4.00)	2.52^{bcde} (6.00)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	1.18^{ef} (1.33)	1.44^{bc} (2.67)	1.31^{efg} (2.00)	3.12^{d} (9.33)	3.50^{def} (12.00)	3.31^{efg} (10.67)
T4 - SRI + CW- 10, 30 DAT	4.94^{a} (24.00)	1.91^{ab} (4.00)	3.43^{a} (14.00)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	0.71^{f} (0.00)	3.66^{ab} (13.33)	2.18^{cdef} (6.67)	4.94^{b} (24.00)	5.20^{bc} (26.67)	5.07^{bc} (25.33)
T5 - SRI + CW- 10 DAT + HW-30 DAT	2.39^{ef} (5.33)	1.18^{b} (1.33)	1.78^{ef} (3.33)	2.39^{c} (5.33)	0.71^{a} (0.00)	1.55^{c} (2.67)	3.61^{ab} (12.67)	4.81^{a} (24.00)	4.21^{a} (18.33)	4.87^{b} (23.33)	5.61^{ab} (32.00)	5.24^{abc} (27.67)
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	2.92^{de} (8.00)	2.86^{a} (8.00)	2.89^{abc} (8.00)	3.53^{b} (12.00)	0.71^{a} (0.00)	2.12^{b} (6.00)	1.44^{def} (2.67)	0.71^{c} (0.00)	1.08^{fg} (1.33)	4.78^{b} (22.67)	4.14^{bcde} (17.33)	4.46^{cd} (20.00)
T7 - SRI + Clincher** fb Almix***	2.53^{ef} (6.00)	1.91^{ab} (4.00)	2.22^{cde} (5.00)	4.12^{ab} (17.00)	0.71^{a} (0.00)	2.41^{ab} (8.50)	0.71^{f} (0.00)	2.92^{abc} (10.67)	1.82^{cdef} (5.33)	4.79^{b} (23.00)	6.96^{a} (49.33)	5.88^{ab} (36.17)
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	4.95^{a} (24.00)	1.18^{b} (1.33)	3.06^{ab} (12.67)	3.38^{b} (11.00)	0.71^{a} (0.00)	2.04^{b} (5.50)	4.06^{a} (16.00)	1.44^{bc} (2.67)	2.75^{bc} (9.33)	7.18^{a} (51.00)	4.90^{bcd} (24.00)	6.04^{a} (37.50)
T9 - CS + CW-10, 20, 30, 40 DAT	3.71^{bc} (13.33)	1.18^{b} (1.33)	2.44^{bcde} (7.33)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	1.65^{cd} (2.67)	1.18^{c} (1.33)	1.41^{defg} (2.00)	4.04^{bc} (16.00)	2.86^{ef} (8.00)	3.45^{efg} (12.00)
T10 - CS + Butachlor* + HW-30 DAT	2.39^{ef} (5.33)	1.18^{b} (1.33)	1.78^{ef} (3.33)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	2.65^{bc} (6.67)	2.39^{bc} (6.67)	2.52^{bcd} (6.67)	3.50^{cd}(12.00)	3.87^{cdef} (14.67)	3.69^{def} (13.33)
T11 - CS + Butachlor* + CW-30 DAT	2.65^{ef} (6.67)	1.65^{ab} (2.67)	2.15^{cdef} (4.67)	1.18^{d} (1.33)	0.71^{a} (0.00)	0.94^{d} (0.67)	2.12^{cde} (4.00)	2.65^{abc} (6.67)	2.39^{bcde} (5.33)	3.54^{cd} (12.00)	4.01^{bcdef} (16.00)	3.77^{def} (14.00)
T12 - CS + CW- 10, 30 DAT	3.54^{cd} (12.00)	1.65^{ab} (2.67)	2.59^{bcde} (7.33)	1.65^{cd} (2.67)	0.71^{a} (0.00)	1.18^{cd} (1.33)	2.39^{cd} (5.33)	2.39^{bc} (6.67)	2.39^{bcde} (6.00)	4.53^{b} (20.00)	3.50^{def} (12.00)	4.02^{de} (16.00)
T13 - CS + CW- 10 DAT + HW-30 DAT	2.86^{def} (8.00)	1.18^{b} (1.33)	2.02^{def} (4.67)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	0.71^{f} (0.00)	2.12^{bc} (4.00)	1.41^{defg} (2.00)	2.86^{d} (8.00)	2.39^{fg} (5.33)	2.62^{gh} (6.67)
T14- CS + CW-10 DAT + Clincher** fb Almix***	2.26^{ef} (4.67)	1.65^{b} (2.67)	1.96^{def} (3.67)	1.65^{cd} (2.67)	0.71^{a} (0.00)	1.18^{cd} (1.33)	0.71^{f} (0.00)	1.44^{bc} (2.67)	1.08^{fg} (1.33)	2.79^{d} (7.33)	3.30^{def} (10.67)	3.05^{fg} (9.00)
T15 - CS + Clincher** fb Almix***	2.65^{ef} (6.67)	2.12^{ab} (4.00)	2.39^{bcde} (5.33)	0.71^{d} (0.00)	0.71^{a} (0.00)	0.71^{d} (0.00)	0.71^{f} (0.00)	0.71^{c} (0.00)	0.71^{g} (0.00)	2.65^{d} (6.67)	1.18^{g} (1.33)	1.91^{h} (4.00)
T16 - CS + HW – 20, 40 DAT	2.12^{f} (4.00)	0.71^{b} (0.00)	1.41^{f} (2.00)	1.65^{cd} (2.67)	0.71^{a} (0.00)	1.18^{cd} (1.33)	0.71^{f} (0.00)	2.56^{bc} (8.00)	1.63^{cdefg} (4.00)	2.65^{d} (6.67)	4.31^{bcde} (18.67)	3.48^{efg} (12.67)

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT
SRI – System of rice intensification
CW – Cono weeding
OM – Organic manure
DAT – Days after transplanting
fb – Followed by
CS – Conventional system
HW – Hand weeding
*Butachlor @ 1.25 kg ha-1
** Cyhalofop butyl @ 0.1 kg ha-1
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

A perusal of the data showed that at 45 DAT dry weight of weeds was the highest (128 g m^{-2}) in the typical SRI treatment and this was significantly superior to all other treatments. This was followed by conventional treatment with cono weeding at 10, 20, 30 and 40 DAT and then by SRI treatment with cono weeding at 10, 20, 30 and 40 DAT, which were at par. The weed dry weight at 45 DAT was the lowest in the conventional system with cono weeding at 10 DAT followed by post emergence herbicides, and conventional treatment with post emergence herbicides alone, which were at par. This was followed by hand weeding at 20 and 40 DAT.

Among the SRI treatments weed dry weight at 45 DAT was significantly reduced by the application of pre emergence herbicides followed by hand weeding at 30 DAT as well as by cono weeding at 10 DAT followed by post emergence herbicides.

At 60 DAT, weed dry weight was significantly higher in SRI treatments and the highest dry weight was recorded by cono weeding at 10 and 30 DAT and this was followed by pre emergence herbicides followed by cono weeding at 30 DAT in SRI. The weed dry weight at 60 DAT was the lowest when pre emergence herbicides followed by hand weeding at 30 DAT was given in the conventional system, and this was closely followed by conventional system with cono weeding at 10 DAT followed by post emergence herbicides.

As seen from the pooled mean, the weed dry weight at 60 DAT in SRI was significantly reduced by CW at 10 DAT followed by HW at 30 DAT and this was followed by the application of post emergence herbicides alone. Pre emergence herbicide followed by HW at 30 DAT was found at par with CW four times at 10, 20, 30 and 40 DAT with respect to weed dry weight at 60 DAT, but cono weeding either twice or four times could not reduce the weed dry weight at 60 DAT in SRI and so also in the conventional system.

Table 36. Effect of the treatments on weed dry weight (g m^{-2}) at 45 and 60 DAT and weed index – Alappad *Kole*

Treatments	45 DAT			60 DAT			Weed Index		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	10.64^{bc} (112.99)	7.54^{c} (58.01)	9.09^{b} (85.50)	13.37^{b} (178.32)	2.85^{cd} (7.65)	8.11^{d} (92.99)	19.39^{d}	6.15^{ab}	12.89^{cd}
T2 - SRI + Butachlor* + HW-30 DAT	5.58^{e} (30.67)	2.21^{fgh} (4.45)	3.90^{f} (17.56)	13.79^{b} (189.99)	2.77^{cde} (7.17)	8.28^{d} (98.58)	36.69^{c}	-8.59^{c}	14.38^{c}
T3 - SRI + Butachlor* + CW- 30 DAT	10.18^{bcd} (103.19)	4.69^{d} (21.55)	7.43^{c} (62.37)	13.69^{b} (187.91)	7.51^{a} (55.93)	10.60^{b} (121.92)	17.92^{d}	4.93^{abc}	11.51^{cde}
T4 - SRI + CW- 10, 30 DAT	9.81^{cd} (95.93)	4.37^{de} (18.72)	7.09^{cd} (57.33)	16.42^{a} (269.25)	7.69^{a} (59.39)	12.06^{a} (164.32)	55.79^{b}	5.54^{abc}	31.00^{b}
T5 - SRI + CW- 10 DAT + HW-30 DAT	5.62^{e} (31.25)	2.00^{fgh} (3.71)	3.81^{fg} (17.48)	9.42^{cd} (88.77)	1.89^{fg} (3.35)	5.66^{f} (46.06)	6.31^{def}	-3.99^{bc}	1.22^{def}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.32^{j} (1.99)	7.29^{c} (52.84)	4.00^{f} (26.42)	10.52^{c} (110.64)	7.84^{a} (61.12)	9.18^{c} (85.88)	10.83^{de}	-5.79^{bc}	2.63^{efg}
T7 - SRI + Clincher** fb Almix***	1.61^{ij} (3.72)	9.60^{b} (91.79)	5.15^{e} (45.89)	9.18^{d} (83.73)	4.55^{b} (20.75)	6.86^{e} (52.24)	9.23^{de}	6.33^{ab}	7.81^{cde}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	11.39^{b} (130.29)	11.15^{a} (125.91)	11.27^{a} (128.10)	16.93^{a} (287.43)	1.43^{fg} (1.55)	9.18^{c} (144.49)	73.38^{a}	12.88^{a}	43.57^{a}
T9 - CS + CW-10, 20, 30, 40 DAT	13.24^{a} (175.03)	3.94^{de} (15.13)	8.59^{b} (95.08)	10.31^{cd} (105.84)	2.07^{efg} (3.77)	6.19^{ef} (54.81)	11.95^{de}	10.70^{a}	11.36^{cde}
T10 - CS + Butachlor* + HW-30 DAT	3.72^{fg} (13.37)	3.00^{efg} (11.36)	3.36^{fg} (12.37)	4.26^{g} (18.17)	1.37^{g} (1.44)	2.82^{i} (9.81)	-8.54^{fg}	4.52^{abc}	-2.11^{fg}
T11 - CS + Butachlor* + CW- 30 DAT	10.67^{bc} (113.48)	4.80^{de} (22.77)	7.74^{c} (68.13)	7.02^{e} (49.21)	4.62^{b} (21.03)	5.82^{f} (35.12)	10.82^{de}	-4.64^{bc}	3.20^{def}
T12 - CS + CW- 10, 30 DAT	9.27^{d} (85.63)	3.36^{def} (11.09)	6.31^{d} (48.36)	9.75^{cd} (94.72)	2.79^{cde} (7.40)	6.27^{ef} (51.06)	12.35^{de}	1.99^{abc}	7.20^{cde}
T13 - CS + CW- 10 DAT + HW-30 DAT	4.69^{ef} (21.73)	1.69^{gh} (2.35)	3.19^{fg} (12.04)	7.21^{e} (51.77)	2.15^{def} (4.12)	4.68^{g} (27.95)	-13.06^{f}	-5.15^{bc}	-9.14^{g}
T14- CS + CW-10 DAT + Clincher** fb Almix***	3.00^{g} (8.63)	0.71^{h} (0.00)	1.86^{h} (4.31)	4.09^{g} (16.27)	2.72^{cde} (6.96)	3.41^{hi} (11.61)	-8.96^{fg}	6.25^{ab}	-1.44^{fg}
T15 - CS + Clincher** fb Almix***	3.67^{fg} (13.71)	0.71^{h} (0.00)	2.19^{h} (6.85)	4.59^{fg} (20.67)	3.22^{c} (9.89)	3.90^{gh} (15.28)	6.07^{def}	4.49^{abc}	5.25^{cdef}
T16 - CS + HW – 20, 40 DAT	2.66gh (6.57)	3.34def (10.65)	3.00g (8.61)	5.63f (31.24)	3.08c (9.00)	4.36g (20.12)	0.00efg	0.00abcd	0.00fg

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)
Values followed by same letters do not differ significantly in DMRT

SRI – System of rice intensification
CS – Conventional system
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
DAT – Days after transplanting
fb – Followed by
*Butachlor @ 1.25 kg a.i. ha^{-1}
** Cyhalofop butyl @ 0.1 kg a.i. ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

c. Weed index

The weed index values at Alappad *Kole* are given in Table 36. Significantly lower values of weed index were observed in treatments with conventional system while they were very high in SRI treatments. Conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT recorded the lowest weed index. The next higher values were observed in conventional treatments viz., pre emergence herbicides followed by hand weeding at 30 DAT, cono weeding at 10 DAT followed by post emergence herbicides and hand weeding at 20 and 40 DAT, which were at par. The typical SRI treatment with cono weeding at 10, 20, 30 and 40 DAT along with organic manure incorporation recorded the highest weed index among all the treatments.

d. Nutrient removal by weeds

The effect of treatments on the nutrient content and nutrient removal of nitrogen, phosphorus and potassium by the weed plants at panicle initiation of the rice crop is presented in Tables 37 and 38. The data visibly explained higher uptake of nitrogen, phosphorus and potassium by the weed plants in the SRI treatments at panicle initiation as compared to the conventional treatments. Therefore the highest removal of N (28 kg ha^{-1}) was recorded by SRI with cono weeding at 10 and 30 DAT and it was significantly higher to all other treatments, and this was followed by SRI with pre emergence herbicide followed by cono weeding at 30 DAT. The highest removal of phosphorus (7.34 kg P ha^{-1}) was recorded by the typical SRI treatment followed by SRI with cono weeding at 10 and 30 DAT. Potassium removal was the highest (32 kg K ha^{-1}) in SRI with cono weeding at 10 and 30 DAT and this was followed by the typical SRI treatment.

Lower nutrient removal values were observed in the conventional treatments, wherein removal of N, P and K was the lowest in pre emergence herbicide followed by hand weeding at 30 DAT, and this was followed by cono

Table 37. Effect of the treatments on nutrient content (%) of weeds at 60 DAT – Alappad *Kole*

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	1.773a^{b}	1.493^{de}	1.633^{cd}	0.582a	0.248^{c}	0.415a^{bc}	1.903a^{bcd}	1.497^{bcd}	1.700a^{bcde}
T2 - SRI + Butachlor* + HW-30 DAT	1.587a^{b}	1.650^{cde}	1.618^{cd}	0.535a^{bc}	0.232^{c}	0.383a^{bcd}	2.236a	1.460^{bcd}	1.848a^{bcde}
T3 - SRI + Butachlor* + CW- 30 DAT	1.773a^{b}	1.680^{cde}	1.727^{bcd}	0.485a^{bcd}	0.272^{bc}	0.378a^{bcd}	1.749^{bcd}	1.479^{bcd}	1.614^{cdef}
T4 - SRI + CW- 10, 30 DAT	1.680a^{b}	1.773^{cde}	1.727^{bcd}	0.465a^{bcd}	0.247^{c}	0.356^{bcd}	2.121a^{bc}	1.253^{d}	1.687a^{bcde}
T5 - SRI + CW- 10 DAT + HW-30 DAT	1.587a^{b}	1.960^{bc}	1.773^{bc}	0.470a^{bcd}	0.345a	0.408a^{bc}	1.864a^{bcd}	1.610^{bc}	1.737a^{bcde}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	1.960a	1.493^{de}	1.727^{bcd}	0.468a^{bcd}	0.243^{c}	0.356^{bcd}	2.025a^{bcd}	1.631^{bc}	1.828a^{bcde}
T7 - SRI + Clincher** fb Almix***	1.587a^{b}	1.867^{cd}	1.727^{bcd}	0.560a^{b}	0.330a	0.445a	2.201a^{b}	1.672^{bc}	1.936a^{bc}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	1.680a^{b}	2.283a^{b}	1.982a^{b}	0.507a^{bcd}	0.253^{c}	0.380a^{bcd}	1.719^{bcd}	1.427^{cd}	1.573^{def}
T9 - CS + CW-10, 20, 30, 40 DAT	1.960a	2.427a	2.193a	0.468a^{bcd}	0.313a^{b}	0.391a^{bcd}	1.855a^{bcd}	2.164a	2.010a
T10 - CS + Butachlor* + HW-30 DAT	1.307^{b}	1.493^{de}	1.400^{d}	0.383^{d}	0.232^{c}	0.308^{d}	1.705^{cd}	1.583^{bcd}	1.644^{bcdef}
T11 - CS + Butachlor* + CW- 30 DAT	1.867a	1.587^{cde}	1.727^{bcd}	0.600a	0.247^{c}	0.423a^{b}	2.151a^{bc}	1.591^{bcd}	1.871a^{bcd}
T12 - CS + CW- 10, 30 DAT	1.773a^{b}	1.960^{bc}	1.867^{bc}	0.468a^{bcd}	0.272^{bc}	0.370a^{bcd}	2.145a^{bc}	1.797^{b}	1.971a^{b}
T13 - CS + CW- 10 DAT + HW-30 DAT	1.867a	1.680^{cde}	1.773^{bc}	0.430^{bcd}	0.250^{c}	0.340^{bc}	1.625^{d}	1.410^{cd}	1.517^{ef}
T14- CS + CW-10 DAT + Clincher** fb Almix***	1.773a^{b}	1.493^{de}	1.633^{cd}	0.407^{cd}	0.213^{c}	0.310^{d}	1.147^{e}	1.490^{bcd}	1.318^{f}
T15 - CS + Clincher** fb Almix***	1.773a^{b}	1.400^{e}	1.587^{cd}	0.418^{cd}	0.253^{c}	0.336^{cd}	1.146^{e}	1.501^{bcd}	1.324^{f}
T16 - CS + HW – 20, 40 DAT	1.587a^{b}	1.587^{cde}	1.587^{cd}	0.523a^{bcd}	0.260^{bc}	0.392a^{bcd}	1.872a^{bcd}	1.585^{bcd}	1.728a^{bcde}

Values followed by same letters do not differ significantly in DMRT
fb – Followed by
SRI – System of rice intensification
CS – Conventional system
DAT – Days after transplanting
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

Table 38. Effect of the treatments on nutrient removal (kg ha^{-1}) by weeds at 60 DAT – Alappad *Kole*

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	31.67^{b}	1.15^{c}	16.41^{c}	10.31^{b}	0.19^{c}	5.25^{b}	34.10^{c}	1.13^{d}	17.61^{cd}
T2 - SRI + Butachlor* + HW-30 DAT	30.08^{b}	1.17^{c}	15.62^{c}	10.19^{b}	0.17^{c}	5.18^{b}	42.83^{b}	1.04^{d}	21.94^{b}
T3 - SRI + Butachlor* + CW- 30 DAT	33.51^{b}	9.4^{a}	21.45^{b}	8.89^{b}	1.52^{a}	5.20^{b}	32.82^{c}	8.30^{b}	20.56^{bc}
T4 - SRI + CW- 10, 30 DAT	45.32^{a}	10.53^{a}	27.92^{a}	12.6^{a}	1.49^{a}	7.04^{a}	56.56^{a}	7.39^{b}	31.98^{a}
T5 - SRI + CW- 10 DAT + HW-30 DAT	13.92^{de}	0.66^{c}	7.29^{def}	4.21^{cd}	0.12^{c}	2.16^{cde}	16.56^{de}	0.53^{d}	8.54^{d}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	21.88^{c}	9.12^{a}	15.50^{c}	5.18^{c}	1.49^{a}	3.33^{c}	22.43^{d}	9.96^{a}	16.20^{d}
T7 - SRI + Clincher** fb Almix***	13.24^{de}	3.78^{b}	8.51^{de}	4.65^{c}	0.67^{b}	2.66^{cd}	18.43^{d}	3.45^{c}	10.94^{e}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	48.29^{a}	0.35^{c}	24.32^{ab}	14.63^{a}	0.04^{c}	7.34^{a}	48.62^{b}	0.22^{d}	24.42^{b}
T9 - CS + CW-10, 20, 30, 40 DAT	20.90^{cd}	0.91^{c}	10.90^{d}	4.95^{c}	0.12^{c}	2.53^{cd}	19.58^{d}	0.82^{d}	10.20^{e}
T10 - CS + Butachlor* + HW-30 DAT	2.58^{f}	0.22^{c}	1.40^{h}	0.73^{e}	0.03^{c}	0.38^{g}	3.19^{fg}	0.23^{d}	1.71^{f}
T11 - CS + Butachlor* + CW- 30 DAT	9.21^{ef}	3.38^{b}	6.30^{efg}	2.95^{cde}	0.52^{b}	1.73^{def}	10.68^{ef}	3.34^{c}	7.01^{de}
T12 - CS + CW- 10, 30 DAT	16.98^{cd}	1.46^{c}	9.22^{de}	4.41^{cd}	0.21^{c}	2.31^{cde}	20.24^{d}	1.39^{d}	10.81^{e}
T13 - CS + CW- 10 DAT + HW-30 DAT	9.57^{ef}	0.69^{c}	5.13^{efgh}	2.22^{de}	0.10^{c}	1.16^{efg}	8.30^{fg}	0.58^{d}	4.44^{ef}
T14- CS + CW-10 DAT + Clincher** fb Almix***	2.90^{f}	1.05^{c}	1.97^{h}	0.66^{e}	0.15^{c}	0.41^{g}	1.87^{g}	1.05^{d}	1.46^{f}
T15 - CS + Clincher** fb Almix***	3.72^{f}	1.39^{c}	2.55^{gh}	0.86^{e}	0.25^{c}	0.56^{fg}	2.36^{g}	1.49^{d}	1.92^{f}
T16 - CS + HW – 20, 40 DAT	4.95^{f}	1.42^{c}	3.19^{fgh}	1.64^{e}	0.23^{c}	0.94^{fg}	5.85^{fg}	1.42^{d}	3.64^{ef}

Values followed by same letters do not differ significantly in DMRT

fb – Followed by

SRI – System of rice intensification

CS – Conventional system

DAT – Days after transplanting

CW – Cono weeding

HW – Hand weeding

OM – Organic manure

* Butachlor @ 1.25 kg ha^{-1}

** Cyhalofop butyl @ 0.1 kg ha^{-1}

*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

weeding at 10 DAT followed by post emergence herbicides and then by application of post emergence herbicides alone. Cono weeding at 10 DAT followed by hand weeding at 30 DAT as well as hand weeding at 20 and 40 DAT in the conventional system also influenced in reducing the nutrient removal by weeds.

Among the SRI treatments the lowest record of N, P and K removal was shown by cono weeding at 10 DAT followed by hand weeding at 30 DAT. Application of post emergence herbicides alone also influenced in reducing the nutrient removal by weeds in SRI.

4.1.2.9. Economics of cultivation at Alappad *Kole*

The gross return (GR), net return (NR) and benefit: cost ratio (BCR) of rice cultivation at Alappad *Kole* are given in Table 39, as per Appendix VI. Gross return was the highest (Rs. 90130 ha^{-1}) in conventional treatment with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) and this was significantly superior to all other treatments. This was followed by conventional treatments with pre emergence herbicide followed by hand weeding at 30 DAT (T10), cono weeding at 10 DAT followed by post emergence herbicides (T14), and hand weeding at 20 and 40 DAT (T16), which were at par. Net return also followed the same pattern with highest amount (Rs. 53419 ha^{-1}) in conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13). The benefit: cost ratio was also the highest (2.46) in T13, and the second highest value was recorded uniformly by cono weeding at 10 DAT followed by post emergence herbicides (T14), and pre emergence herbicide followed by cono weeding at 30 DAT in the conventional system (T11).

Table 39. Economics of rice cultivation as affected by the treatments – Alappad *Kole*

Treatments	Gross return (Rs. ha^{-1})			Net return (Rs. ha^{-1})			B:C ratio		
	1st year	2nd year	Pooled	1st year	2nd year	Pooled	1st year	2nd year	Pooled
T1 - SRI + CW-10, 20, 30, 40 DAT	67505^{e}	76225^{bcd}	71865^{cd}	28219^{d}	36939^{cd}	32579^{ef}	1.72^{g}	1.94^{e}	1.83^{gh}
T2 - SRI + Butachlor* + HW-30 DAT	52348^{f}	87617^{a}	69982^{d}	11562^{e}	46831^{abc}	29196^{f}	1.28^{h}	2.15^{cde}	1.72^{hi}
T3 - SRI + Butachlor* + CW- 30 DAT	68245^{e}	77027^{abcd}	72636^{cd}	32009^{cd}	40791^{bcd}	36400^{def}	1.88^{efg}	2.13^{cde}	2.00^{efg}
T4 - SRI + CW- 10, 30 DAT	37520^{g}	77065^{abcd}	57292^{e}	1034^{e}	40579^{bcd}	20806^{g}	1.03^{h}	2.11^{cde}	1.57^{i}
T5 - SRI + CW- 10 DAT + HW-30 DAT	76351^{cd}	84416^{abc}	80384^{bc}	34615^{cd}	42680^{abcd}	38648^{cde}	1.83^{fg}	2.02^{de}	1.93^{fgh}
T6 - SRI + CW-10 DAT + Clincher** fb Almix***	73650de	85446^{ab}	79548^{bc}	35984^{cd}	47780^{abc}	41882^{bcd}	1.96^{defg}	2.27^{bcd}	2.11^{def}
T7 - SRI + Clincher** fb Almix***	75131de	76085^{bcd}	75608^{bcd}	39915^{bcd}	40869^{bcd}	40392^{cde}	2.13^{cdef}	2.16^{cde}	2.15^{cde}
T8 - SRI + CW-10, 20, 30, 40 DAT + OM	22274^{h}	70519^{d}	46397^{f}	-13811^{f}	34434^{d}	10312^{h}	0.62^{i}	1.95^{e}	1.29^{j}
T9 - CS + CW-10, 20, 30, 40 DAT	72944de	74342^{cd}	73643^{cd}	38958^{bcd}	40356^{bcd}	39657^{cde}	2.15^{cdef}	2.19^{bcde}	2.17^{cde}
T10 - CS + Butachlor* + HW-30 DAT	89251^{abc}	79102^{abcd}	84177^{ab}	52265^{ab}	42116^{abcd}	47191^{abc}	2.41^{abc}	2.14^{cde}	2.28^{abcd}
T11 - CS + Butachlor* + CW- 30 DAT	74001de	85930^{ab}	79965^{bc}	40790^{bcd}	52719^{a}	46754^{abc}	2.23^{abcde}	2.59^{a}	2.41^{ab}
T12 - CS + CW- 10, 30 DAT	72835de	80671^{abcd}	76753^{bcd}	40249^{bcd}	48085^{ab}	44167^{bcd}	2.24^{abcde}	2.48^{ab}	2.36^{abc}
T13 - CS + CW- 10 DAT + HW-30 DAT	93576^{a}	86685^{ab}	90130^{a}	56865^{a}	49974^{ab}	53419^{a}	2.55^{ab}	2.36^{bc}	2.46^{a}
T14- CS + CW-10 DAT + Clincher** fb Almix***	90189^{ab}	77124^{abcd}	83657^{ab}	55548^{a}	42483^{abcd}	49016^{ab}	2.60^{a}	2.23^{bcde}	2.41^{ab}
T15 - CS + Clincher** fb Almix***	77759^{bcde}	78788^{abcd}	78277^{bcd}	44343^{abc}	45372^{abc}	44858^{bc}	2.33^{abcd}	2.36^{abc}	2.34^{abc}
T16 - CS + HW – 20, 40 DAT	82713^{abcd}	82768^{abc}	82741^{ab}	45227^{abc}	45282^{abc}	45255^{abc}	2.21^{bcdef}	2.21^{bcde}	2.21^{bcde}

Values followed by same letters do not differ significantly in DMRT
fb – Followed by
SRI – System of rice intensification
CS – Conventional system
DAT – Days after transplanting
CW – Cono weeding
HW – Hand weeding
OM – Organic manure
* Butachlor @ 1.25 kg ha^{-1}
** Cyhalofop butyl @ 0.1 kg ha^{-1}
*** Almix 20 WP @ 4.0 g a.i. ha^{-1}

4.2. Field testing of the self propelled cono weeder

A model of self propelled cono weeder designed during first year of the study (Plate 6) was further refined to develop a prototype of the self propelled cono weeder (Plate 7) and it was field tested for its effectiveness in weeding in comparison with manual cono weeding and hand weeding. The testing was conducted in the paddy field at RARS, Pattambi during 2009 under the conventional system and the results obtained are presented below.

4.2.1. Weed density

Observations on the density (number m^{-2}) of different types of weeds viz., grasses, sedges and broad leaf weeds were made at 30 and 60 days after transplanting (DAT) and the data recorded are presented in Table 40.

Density of all types of weeds was the minimum with hand weeding at both the stages of observation. Use of self propelled cono weeder as well as manual cono weeding at 15 and 30 DAT responded almost uniformly in reducing the weed density, especially at 30 days after planting.

4.2.2. Weed dry weight

The data on weed dry weight (g m^{-2}) are presented in Table 41. Hand weeding at 20 and 40 DAT recorded the lowest weed dry weight at 30 and 60 DAT and it differed significantly from the cono weeding treatments. Use of self propelled cono weeder at 15 and 30 DAT recorded the second lowest weed dry weight at 30 DAT, while at 60 DAT it was by manual cono weeding four times.

Plate 6. The self propelled cono weeder – Model 1

Plate 7. Prototype of the self propelled cono weeder and its field testing

Table 40. Effect of self propelled cono weeding, manual cono weeding and hand weeding on weed density (Number m^{-2}) in rice

Treatments	30 DAT				60 DAT			
	Grasses	Sedges	Broad leaf weeds	Total weeds	Grasses	Sedges	Broad leaf weeds	Total weeds
T1 - Manual cono weeding at 15 and 30 DAT	2.722 (7.00)	11.631 (137.17)	7.741 (60.17)	14.23 (204.33)	1.428 (1.83)	8.859 (79.00)	5.513 (30.33)	10.507 (111.17)
T2 – Self propelled cono weeding at 15 and 30 DAT	2.325 (5.00)	10.172 (103.67)	9.93 (98.33)	14.387 (207.00)	1.507 (2.17)	10.377 (107.67)	6.547 (42.67)	12.352 (152.50)
T3 - Manual cono weeding at 10, 20, 30 and 40 DAT	1.514 (2.00)	6.404 (41.33)	6.819 (46.33)	9.437 (89.67)	1.354 (1.83)	8.886 (79.00)	5.972 (35.67)	10.785 (116.50)
T4 - Hand weeding at 20 and 40 DAT	1.085 (0.83)	1.576 (2.83)	2.235 (4.67)	2.873 (8.33)	1.354 (1.83)	2.905 (8.17)	4.111 (16.50)	5.174 (26.50)
CD (0.05)	**0.332**	**0.785**	**0.545**	**0.82**	**NS**	**0.584**	**0.495**	**0.663**

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses) DAT – Days after transplanting

Table 41. Effect of self propelled cono weeding, manual cono weeding and hand weeding on weed dry weight and rice yield

Treatments	Weed dry weight ($g\ m^{-2}$)		Yield ($kg\ ha^{-1}$)	
	30 DAT	**60 DAT**	**Grain**	**Straw**
T1 - Manual cono weeding at 15 and 30 DAT	5.593 (30.893)	10.686 (114.918)	2157.10	2189.60
T2 – Self propelled cono weeding at 15 and 30 DAT	4.303 (18.142)	11.66 (136.063)	2264.59	2450.61
T3 - Manual cono weeding at 10, 20, 30 and 40 DAT	4.703 (21.767)	8.691 (75.545)	2195.17	2430.89
T4 - Hand weeding at 20 and 40 DAT	1.047 (0.657)	3.07 (9.127)	2277.74	2102.46
CD (0.05)	**0.270**	**0.651**	**110.95**	**127.06**

(Values are $\sqrt{x + 0.5}$ transformed, original values in parentheses)   DAT – Days after transplanting

4.2.3. Yield of grain and straw

The data on the yield of grain and straw of rice are presented in Table 41. Grain yield was the highest in the hand weeded plot, while straw yield was higher with the use of self propelled cono weeder at 15 and 30 DAT as well as manual cono weeding four times.

Discussion

5. DISCUSSION

The study comprised of two subprojects viz., (1) feasibility of system of rice intensification (SRI) with integrated weed management in two different agro-ecosystems in the state viz., Pattambi in Palakkad district and Alappad *Kole* in Thrissur district, and (2) development of a prototype of self propelled cono weeder and testing in the field. The findings are discussed in this chapter, under the following headings.

5.1. Effectiveness of integrated weed management under SRI vis-a-vis conventional system

5.2. Feasibility of SRI at Pattambi and Alappad *Kole*

5.3. Improvisation of cono weeder as a self propelled unit

5.1. Effectiveness of integrated weed management under SRI vis-a-vis conventional system

Among the different treatments at Pattambi, the highest total weed density and weed dry weight at 45 days after planting were observed in SRI with two cono weedings at 10 and 30 DAT (days after transplanting) (T4) (Plate 8). At 60 days after planting also, the treatment T4 recorded the highest weed density while the highest weed dry weight was recorded in SRI with four cono weedings at 10, 20, 30 and 40 DAT (Fig. 7 and 8).

At Alappad *Kole,* the total weed density and weed dry weight at 45 days after planting were the highest in the typical SRI with cono weeding four times at 10, 20, 30 and 40 DAT and organic manure incorporation (T8) (Plate 9). At 60 days after planting the total weed density was the highest in the typical SRI treatment while the highest weed dry weight was recorded in the SRI treatment with cono weeding at 10 and 30 DAT (Fig. 9 and 10). Uptake of nitrogen, phosphorus and potassium by the weeds was significantly higher in all the SRI

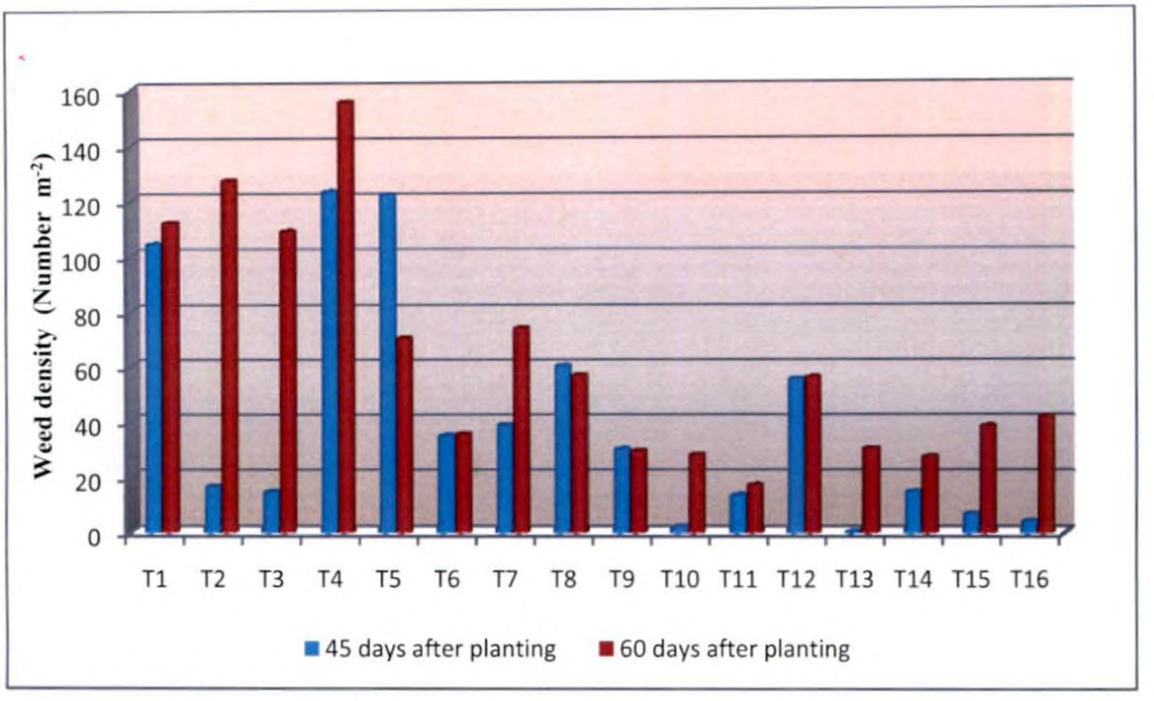


Fig. 7. Effect of the treatments on weed density at 45 and 60 days after transplanting (at Pattambi)

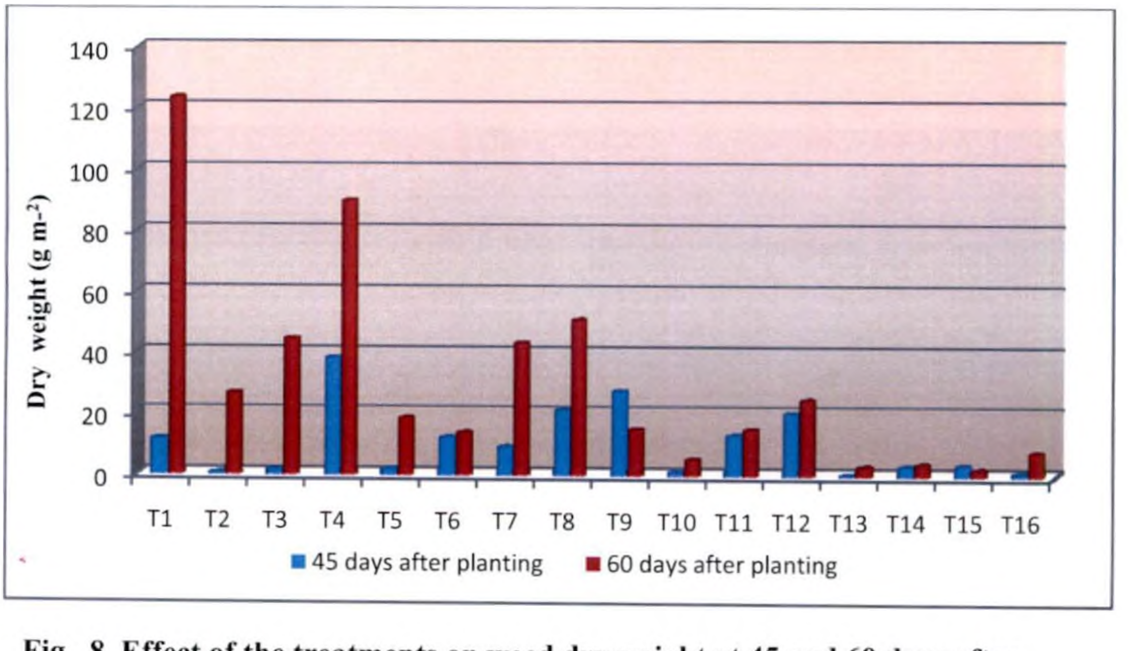


Fig. 8. Effect of the treatments on weed dry weight at 45 and 60 days after transplanting (at Pattambi)

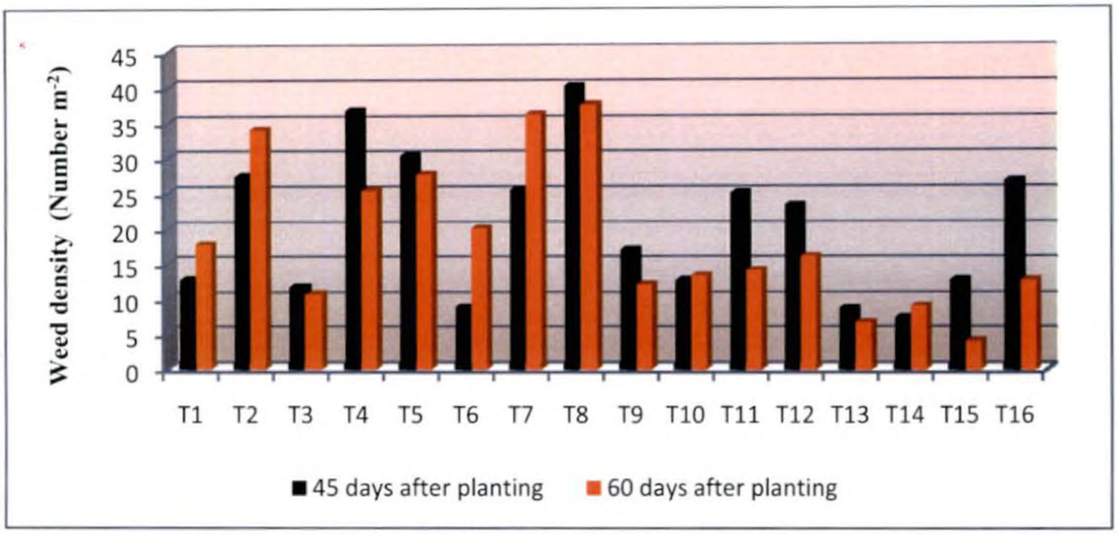


Fig. 9. Effect of the treatments on weed density at 45 and 60 days after transplanting (at Alappad *Kole*)

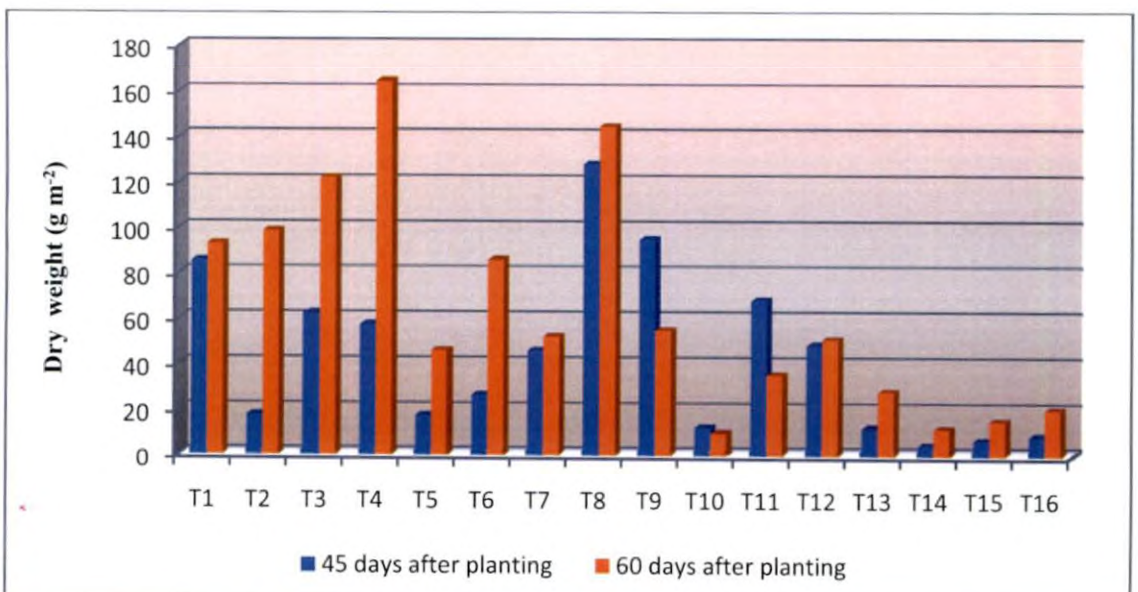


Fig. 10. Effect of the treatments on weed dry weight at 45 and 60 days after transplanting (at Alappad *Kole*)

Plate 8. Heavy occurrence of weeds at 45 days – SRI field after two cono weeding (at Pattambi)

(a) **(b)**

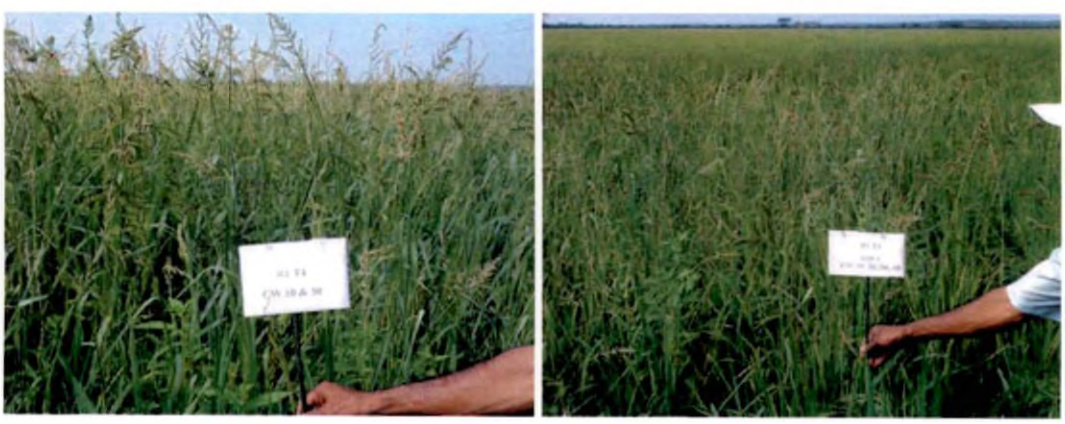


Plate 9. Heavy weed growth at 45 days: (a) SRI after two cono weeding, (b) the typical SRI after four cono weeding (at Alappad *Kole*)

treatments compared to the conventional treatments. The typical SRI treatment recorded the highest weed index and this was reflected finally in the lowest grain and straw yields among all the treatments (Fig. 11).

The results clearly indicated higher occurrence of weeds in the system of rice intensification compared to the conventional system. In SRI, the practice of alternate wetting and drying creates a congenial environment for proliferation of weeds and hence early and frequent weeding is essential (Singh *et al.*, 2010). Zimdahl *et al.* (1987) have reported that water supply determines weed density in upland or low land rice production systems. When younger seedlings are planted at wider spacing, they take much time to get established and develop canopy coverage. Increased spacing between or within rows increases light penetration to the soil surface which enhances weed growth (Mertens and Jansen, 2002). A thick crop canopy in narrow row spacing creates low light regime at the ground level and suppresses weed growth (Shenk, 1982). Increasing crop density through the use of higher seed rate, narrower row spacing and closer plant spacing (within a row) are important weed management techniques as they enhance crop competitiveness by suppressing or smothering weeds (Rao, 2000). The significant influence of narrower spacing in reducing weed competition, especially in cereal crops, has been reported by Moody (1977) and Gaffer *et al.* (1997). Sindhu (2008) also reported significant reduction in the number and dry matter production of weeds with an increase in plant density under closer spacing. Akobundu and Ahissou (1985) observed decreased weed weight as inter-row distance was reduced. Thus a higher weed competition under SRI compared to conventional system can be attributed to the congenial environment enjoyed by the weeds through wider plant spacing and aerobic soil condition.

It was also observed from the results that cono weeding either twice or four times in this study could not check the weed growth even in the initial phases of crop growth in SRI as well as conventional system. At Pattambi, the weed densities at 45 and 60 days after transplanting were the highest in SRI with two

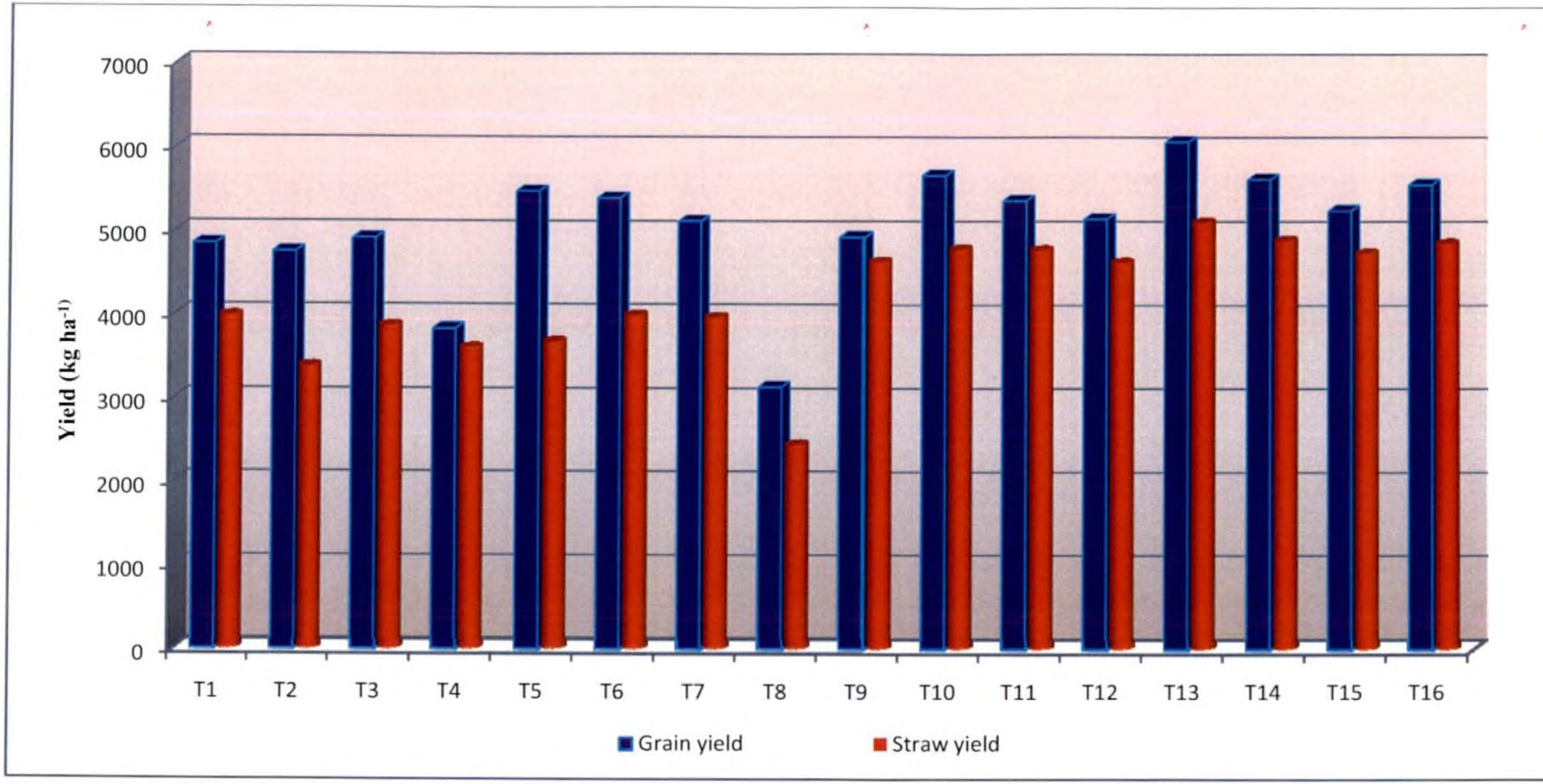


Fig. 11. Grain and straw yield of rice as influenced by the treatments (at Alappad *Kole*)

cono weeding at 10 and 30 DAT. SRI with cono weeding at 10, 20, 30 and 40 DAT as well as cono weeding at 10 DAT followed by hand weeding at 30 DAT also resulted in higher weed density (Table 16) and weed dry weight (Table 18). At Alappad *Kole* also, cono weeding four times, though showed marginal reduction in weed density in the initial phase, was not effective towards the later stages, and the weed dry weight was not at all reduced through cono weeding. Not only that, the typical SRI with four cono weedings and organic manure recorded the highest density and dry weight of weeds throughout the weed competition period at Alappad *Kole*. As cono weeder is operated in the interspaces, only the weeds existing in the inter row spaces will be removed, retaining the weeds adhering to the base of the rice hill (Plate 10). An increased weed dry weight even with lower density of weeds in the cono weeded plots at Alappad *Kole* may be due to the fact that the weeds existed at the base of rice hills grew vigorously and produced more dry matter. Consequent to a higher weed dry weight, the nutrient removal by the weeds was also higher in the plots weeded through cono weeding, whereas the crop in the other plots recorded lower uptake. Thus cono weeding alone was not seen as an effective technology for weed management. Sindhu (2008) also has reported that cono weeding at 10 days interval from 10 DAT to panicle initiation was not effective in controlling the weeds that grow very close to the plants.

Significant yield increase due to improved aeration of the soil and effects due to incorporation of the weed biomass through mechanical weeding in SRI have been reported by Uphoff (2001) and Stoop *et al.* (2002). But cono weeding four times in this study at Pattambi though recorded the highest percentage of filled grains per panicle, could no way influence the grain yield. Similar was the observation with the typical SRI treatment, which significantly improved the length of panicle as well as number of filled grains per panicle but not the yield. A reduced number of productive tillers combined with increased weed density and weed dry weight as well as higher nutrient removal by the weeds might be the reason attributed to this phenomenon.

(a)

(b)

(c)

(d)

Plate 10. Limitations of cono weeding: (a) Removes weeds in the inter row spaces only; (b), (c) and (d) Escaped weeds near the rice hills

The above findings reiterate the inefficacy of cono weeding for proper weed management and points out to explore the possibility of integrating cono weeding with hand weeding or herbicides for controlling the weeds in both SRI and conventional systems.

At Pattambi, conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) recorded the lowest weed density and weed dry weight at 45 days after planting. At 60 days after planting, weed density was the lowest in the conventional system with pre emergence herbicide followed by cono weeding at 30 DAT (T11) (Fig. 7 and 8). The treatment T13 as well as conventional system with post emergence herbicides (T15) reduced the weed dry weight at 60 days after planting, the nutrient removal by the weeds and the weed index. The treatment T15 increased the number of productive tillers per unit area, panicle length, number of filled grains panicle^{-1} and 1000 grain weight, and produced the highest grain yield of 2877 kg ha^{-1} (Fig. 12) (Plate 11). This was 32.73 per cent higher than the grain yield in the typical SRI treatment. Conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) also produced yield on par with this, but the former recorded higher net return and B:C ratio, which was significantly higher than the recommended practice of two hand weeding at 20 and 40 DAT.

In the SRI field at Pattambi, density of grass weeds was less whereas that of sedges and broad leaf weeds dominated at 45 and 60 days after planting (Table 16and 17). The grass weed *Isachne miliacea*, commonly seen in Pattambi rice fields, is a spreading type weed, while the major sedges observed viz. *Cyperus iria* and *Fimbristylis miliacea* and dicot weed *Sphenochlea zeylanica* grow taller than rice, mainly in the early growth phase of rice. This might be the reason for a reduced density of grasses and increased densities of sedges and broad leaf weeds at Pattambi.

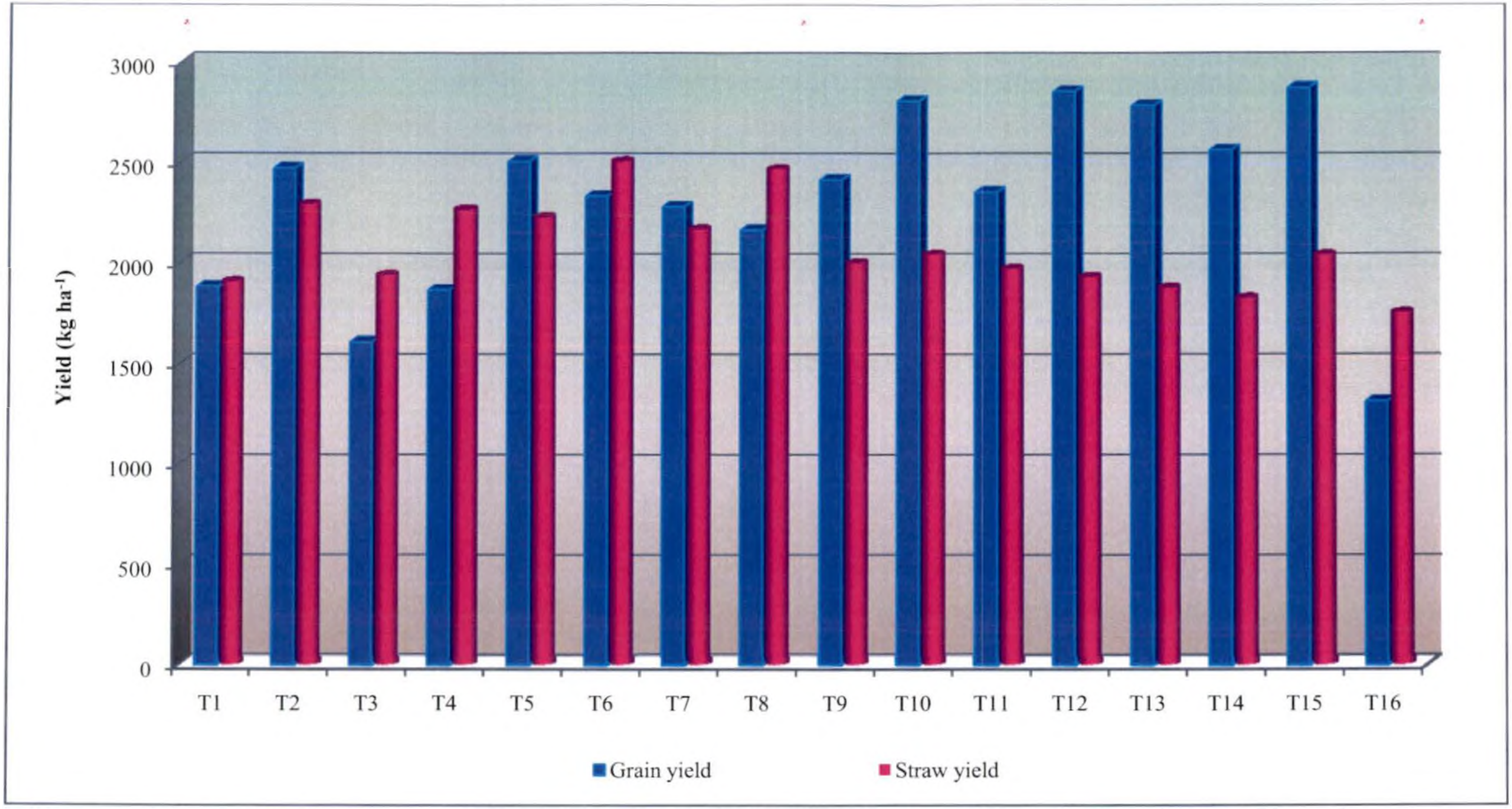


Fig. 12. Grain and straw yield of rice as influenced by the treatments (at Pattambi)

Among the different weed control methods tried under SRI at Pattambi, pre emergence herbicide combined with cono weeding at 30 DAT (T3) recorded the lowest weed density at 45 days after planting (Fig. 7). This was on par with pre emergence herbicide combined with hand weeding at 30 DAT (T2). The latter recorded the lowest weed dry weight at 45 days after planting and the former followed it (Fig. 8). Pre emergence herbicide combined with hand weeding at 30 DAT reduced the densities of sedges and total weeds and the weed dry weight at 45 days after planting, and showed the lowest weed index in the SRI treatments. At 60 days after planting, cono weeding at 10 DAT combined with post emergence herbicides (T6) recorded the lowest densities of sedges, broad leaf weeds and total weeds in SRI, and thereby reduced the dry weight and nutrient removal by the weeds (Fig. 7 and 8) (Plate 13). SRI with pre emergence herbicide followed by hand weeding at 30 DAT (T2) increased the number of productive tillers hill^{-1}, the length of panicle and the number of filled grains panicle^{-1} and produced significantly higher grain yield which was 14.18 per cent higher compared to the typical SRI treatment (Fig. 12).

At Alappad *Kole*, the total weed density and weed dry weight at 45 and 60 days after planting were the lowest in the conventional system with cono weeding at 10 DAT followed by post emergence herbicides (T14). The treatment reduced the density of all types of weeds, reduced the nutrient removal by the weeds and recorded lower weed index. Conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13), pre emergence herbicide followed by hand weeding at 30 DAT (T10) and use of post emergence herbicides (T15) were also equally effective in controlling the weeds, especially at 60 days after planting, and the former recorded the lowest weed index (Fig. 9 and 10).

At Alappad *Kole*, conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) recorded higher number of productive tillers per unit area, higher 1000 grain weight and the highest grain yield of 6073 kg ha^{-1}. This was on par with the conventional treatment with cono

Plate 11. Best performed fields at Pattambi: (a) Conventional system with post emergence herbicides, (b) Conventional system with cono weeding + hand weeding

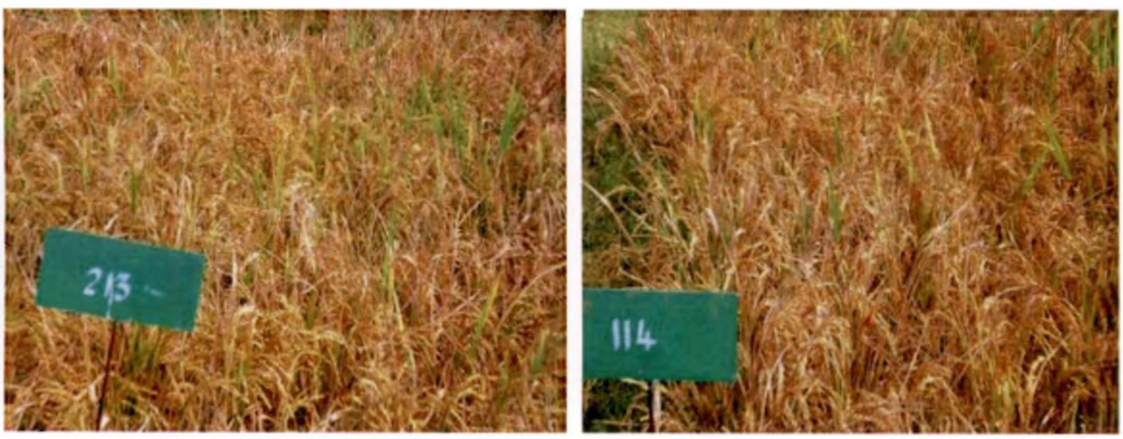


Plate 12. Best performed fields at Alappad *Kole* (a) Conventional system with cono weeding + hand weeding, (b) Conventional system with cono weeding + post emergence herbicides

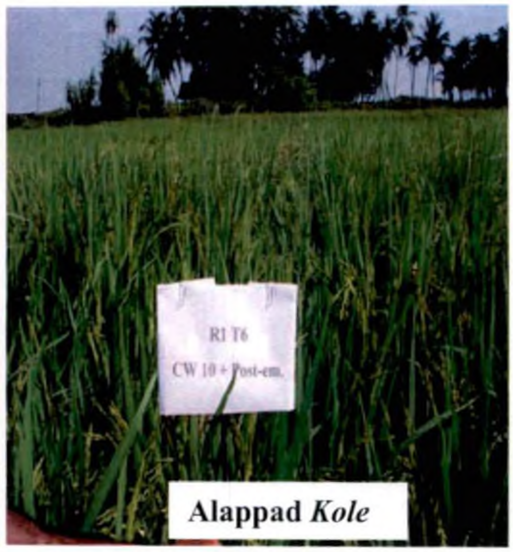
weeding at 10 DAT followed by post emergence herbicides (T14) as well as with pre emergence herbicide followed by hand weeding at 30 DAT (T10) (Fig. 11) (Plate 12). Thus conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T13) showed a grain yield advantage of 2934 kg ha^{-1} and an increase of 93.47 per cent than the grain yield in the typical SRI treatment (T8). The treatment T13 also produced the highest straw yield (5109 kg ha^{-1}) which was 108.86 per cent higher than the straw yield recorded under the typical SRI (Fig. 11) and the highest gross return and B:C ratio (Table 39).

At Alappad *Kole,* higher density of grasses and sedges, but a lower density of broad leaf weeds was observed under SRI at 45 days after planting. *Echinochloa crusgalli* and *Echinochloa stagnina,* the two major grass weeds which usually grow taller than the rice plant, accounted for a major part of the weed flora at Alappad *Kole*. *Echinochloa stagnina* is a typical weed of *Kole* and *Kuttanad* regions where rice is cultivated in the reclaimed backwater areas. SRI with wider spacing might have favoured the growth of these grass weeds in the early phases resulting in their higher density and dry weight. On the other hand, *Monochoria vaginalis* and *Ludwigia perennis,* the two major broad leaf weeds observed, are lower in height than rice and are more susceptible to shading by the rice canopy, which might have resulted in their lower density.

In the SRI plots at Alappad *Kole,* the total weed density and weed dry weight at 45 days after planting were reduced through cono weeding at 10 DAT followed by post emergence herbicides (T6) and this was followed by cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5) in reducing the weed dry weight (Plate 13). At 60 days after planting, the lowest weed density was recorded by the treatment receiving pre emergence herbicide followed by cono weeding at 30 DAT (T3), while dry weight was the lowest with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5). The treatment T5 recorded maximum length of panicle, higher number of filled grains per panicle, higher 1000 grain weight (30.12 g) and finally led to the highest grain yield and

(a)

(b)



(c)

Plate 13. Success of integration in SRI: (a) and (b) SRI with one cono weeding + post emergence herbicides, (c) SRI with one cono weeding + hand weeding

higher harvest index among the SRI treatments. Similarly, cono weeding at 10 DAT followed by post emergence herbicides in SRI (T6) exhibited higher number of productive tillers hill^{-1}, higher panicle length and more number of filled grains panicle^{-1} and the second best grain yield among the SRI treatments (Fig. 11).

Effective weed control and related yield advantage through pre emergence application of pretilachlor @ 0.75 kg ha^{-1} followed by one mechanical weeding at 30 DAT have been reported by Jagadeesha *et al.* (2009) and Kavitha *et al.* (2010). These were attributed to complete removal of late emerging weeds by mechanical weeding at 30 DAT. Herbicides might have reduced the weed density at the early stages of rice and supplementary hand weeding might have controlled the weeds at later growth stages as reported by Saha (2005). Latif *et al.* (2005) have reported higher yield in SRI from a combination of herbicide application and a single hand weeding. A lower weed density at 40 days and 60 days stage through pre emergence application of pretilachlor @ 0.75 kg ha^{-1} followed by one mechanical weeding at 30 DAT and its significant superiority over mechanical weeding three times at 15, 30 and 45 DAT was reported by Kavitha *et al.* (2010). Good weed management as well as lower removal of nutrients by the weeds in SRI through post emergence herbicides Cyhalofop butyl (Clincher 10 EC) @ 0.08 kg a.i. ha^{-1} at 15 DAT followed by Chlorimuron ethyl 10 per cent + Metsulfuron methyl 10 per cent (Almix 20 WP) @ 4.0 g a.i. ha^{-1} + 0.2 per cent surfactant at 20 DAT, as observed in the present study, was also reported by Sindhu (2008). These results point out to the possibility of using herbicides for effective weed control in SRI.

Economic analysis of the treatments at Pattambi showed that the gross return, net return and B:C ratio were the highest in the treatments where the weeds were controlled by the post emergence herbicides in the conventional (T15) and SRI (T7) systems of growing rice. Cono weeding at 10 and 30 DAT (T12) was on par with the post emergence herbicide treatment (T15) in the conventional system; but it could not repeat its performance in SRI.

At Alappad *Kole,* in the conventional system, cono weeding followed by hand weeding (T13) or by post emergence herbicides (T14), pre emergence herbicide followed by cono weeding (T11) and post emergence herbicides alone (T15) were on par in the B:C ratio. The BCR of all the treatments under SRI were significantly lower than the above mentioned treatments. However, among the SRI treatments the best BCR was recorded when the weed control was done by post emergence herbicides (T7).

The analysis shows that weed control by post emergence herbicides is superior in both the systems. Eventhough hand weeding or cono weeding in some treatments performed on par with post emergence herbicides, considering the acute shortage and high wages for the labourers in Kerala, weed management through post emergence herbicides will be the preferable option for the farmers.

5.2. Feasibility of SRI at Pattambi and Alappad *Kole*

The system of rice intensification (SRI) has been introduced and demonstrated among rice farmers of Kerala as an alternative rice production technology, claiming more production with less input. The present study conducted at Pattambi and Alappad *Kole* conveyed the message that SRI intensifies or improves potential of the individual plant rather than improving the whole system, as seen from the observations discussed below.

5.2.1. Crop growth characters

Differential response of the growth parameters viz., height of plant, number of tillers and dry matter accumulation was noticed at different growth stages of rice. Plant height in the initial phase was higher in all the treatments under the conventional system, and was on par with the typical SRI treatment (T8) as well as with the conventional system with recommended package of practices (T16) at Pattambi, whereas towards the later growth phase significantly taller plants were observed under the typical SRI treatment. The dry matter production ha^{-1} was the highest in conventional system with post emergence herbicides upto PI stage and later on by two cono weeding under the conventional system itself. Optimum age of the seedlings combined with closer spacing in the conventional system might have boosted the height and dry matter production of rice during the vegetative phase. The 20 day old seedlings transplanted under conventional system had already advanced by 10 days in growth as compared to the 10 day old seedlings under SRI, and this advancement in growth might have helped the seedlings in the conventional system to compete for better resources, attaining more height in the early growth phase. Higher plant height under conventional system compared to SRI has been reported earlier by Mankotia *et al.* (2006). In SRI, the plants were showing more lateral growth rather than vertical growth in the initial growth phases through production of more number of tillers $hill^{-1}$. Reduced height and dry matter in the vegetative phase and increased height towards the later reproductive phase in SRI compared to conventional system may be due to the wider spacing which helps in better availability of resources and increased photosynthesis, thus resulting in better growth. At Alappad *Kole,* SRI with two cono weeding at 10 and 30 DAT recorded higher plant height at all the stages. Higher number of functional leaves, more leaf area and higher number of tillers $hill^{-1}$ at wider spacing have been reported to increase the photosynthetic rate leading to taller plants (Shrirame *et al.*, 2000).

The number of tillers $hill^{-1}$ was significantly higher in all the SRI treatments at both the locations (Tables 5 and 23). At Pattambi, the typical SRI produced 23.14, 22.53 and 21.49 tillers $hill^{-1}$ at active tillering, panicle initiation (PI) and harvest stages, respectively, while conventional system with two hand weeding (T16) produced only 7.66, 8.60 and 9.66 tillers $hill^{-1}$ at the respective stages (Fig. 13). At Alappad *Kole,* the typical SRI produced 16.95, 20.75 and 16.17 tillers $hill^{-1}$ at active tillering, panicle initiation (PI) and harvest stages, respectively, while conventional system with two hand weeding produced only 10.37, 12.07 and 10.54 tillers $hill^{-1}$ at the respective stages (Fig. 15). The highest

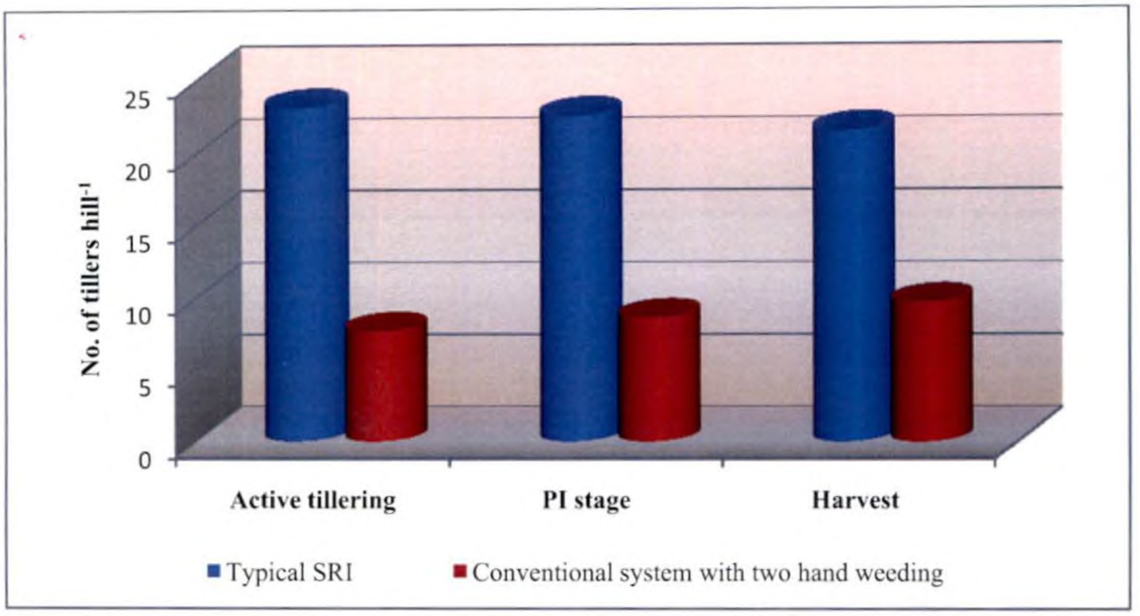


Fig. 13. Variation in the number of tillers hill^{-1} under typical SRI and conventional system (at Pattambi)

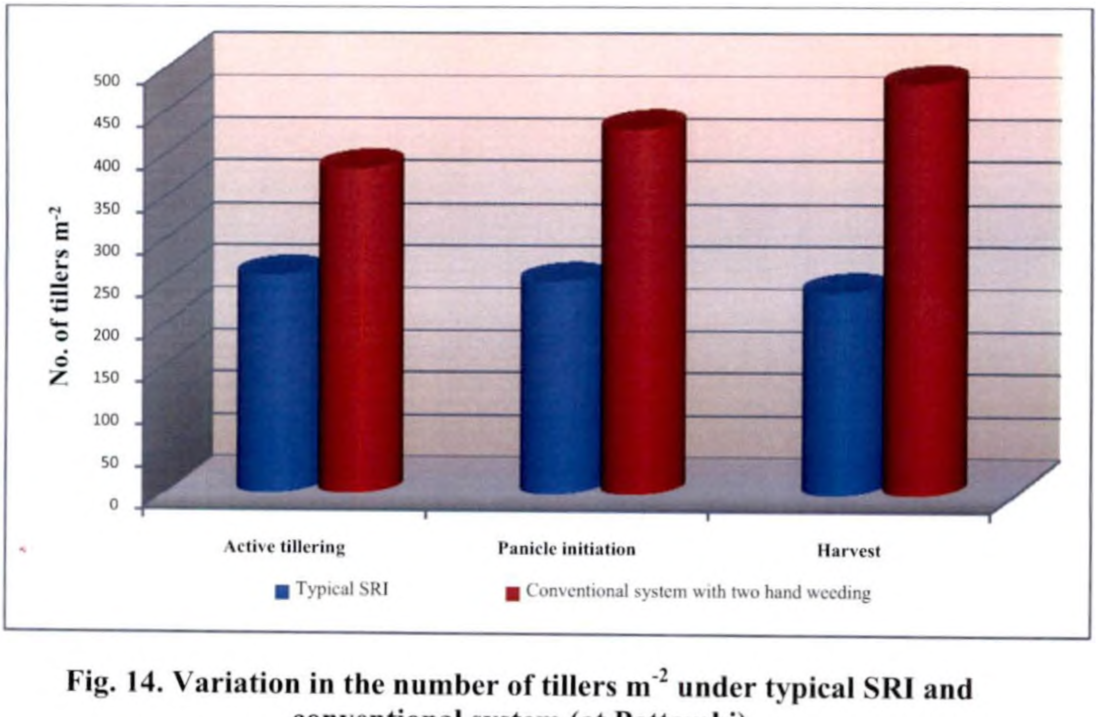


Fig. 14. Variation in the number of tillers m^{-2} under typical SRI and conventional system (at Pattambi)

number of tillers hill^{-1}, recorded at Alappad *Kole,* was 25.95 (SRI with post emergence herbicides) at active tillering, 36.77 (SRI with CW at 10 DAT followed by post emergence herbicide) at PI stage and 26.06 (SRI with four CW at 10, 20, 30 and 40 DAT) at harvest. Significantly higher number of tillers hill^{-1} in the SRI treatments may be the result of wider spacing wherein all the tiller buds, including that of secondary and tertiary tillers get favourable environment to grow and express their identity. Wider spacing reduces inter-plant competition for nutrients, water, light, and air, which accounts for significant enhancement in the performance of individual hill under SRI (Thakur *et al.,* 2010a). XuHui *et al.* (2006) have reported the advantages of SRI that it might improve the environment of individual plants, enhance their production potential, increase the rooting ability, and increase tillers hill^{-1}. The intermittent wet and dry soil condition unique to SRI might have energised the tillering potential of plants under SRI. It is natural that standing water reduces tillering; in SRI, there was no standing water in the field resulting in well aerated soil condition favouring better tillering. As reported by Shad (1986) and Uphoff (2001), not only wider spacing but limited irrigation as well as mechanical weeding also contributed to increased tiller density hill^{-1} in SRI through increased soil aeration and root pruning.

Eventhough the number of tillers hill^{-1} was higher in the SRI treatments, on unit area basis, they were significantly higher in treatments with conventional system at all stages of observation. At Pattambi, the typical SRI produced 257, 250 and 234 tillers m^{-2} at active tillering, PI and harvest stages, respectively while the conventional system with two hand weeding produced 383, 430 and 483 tillers m^{-2} at the respective stages (Fig. 14). At Pattambi, the typical SRI treatment also showed a reduction in the number of tillers per unit area at harvest. At Alappad *Kole,* the typical SRI produced only 188, 231 and 180 tillers m^{-2} at active tillering, PI and harvest stages, respectively while conventional treatment with two hand weeding produced 519, 590 and 527 tillers m^{-2} at the respective stages (Fig. 16). At both locations, significantly lower number of tillers m^{-2} was recorded by all the

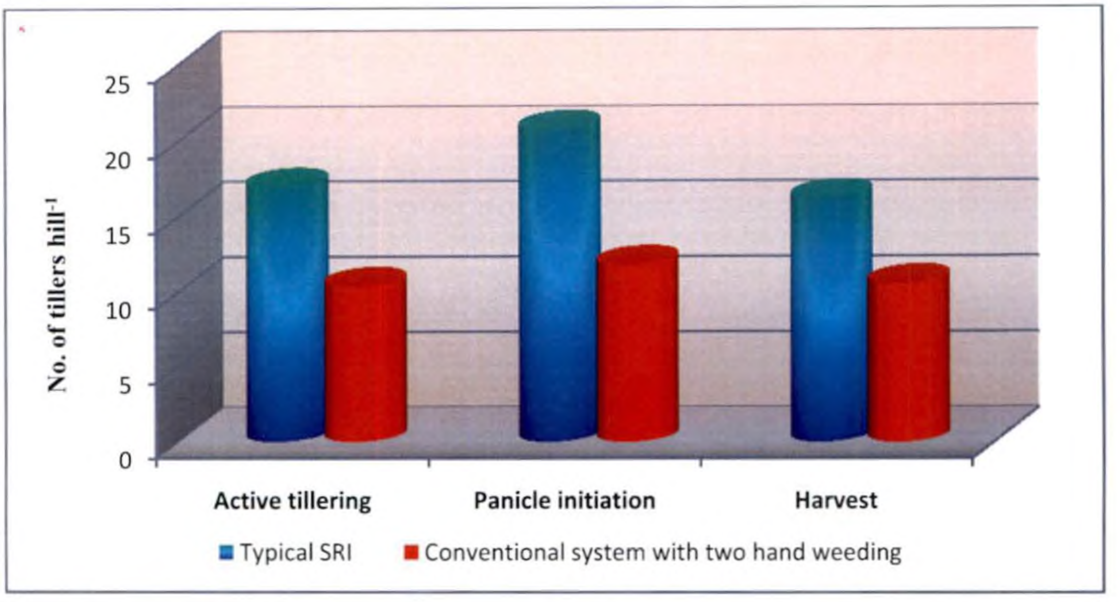


Fig. 15. Variation in the number of tillers hill^{-1} under typical SRI and conventional system (at Alappad *Kole*)

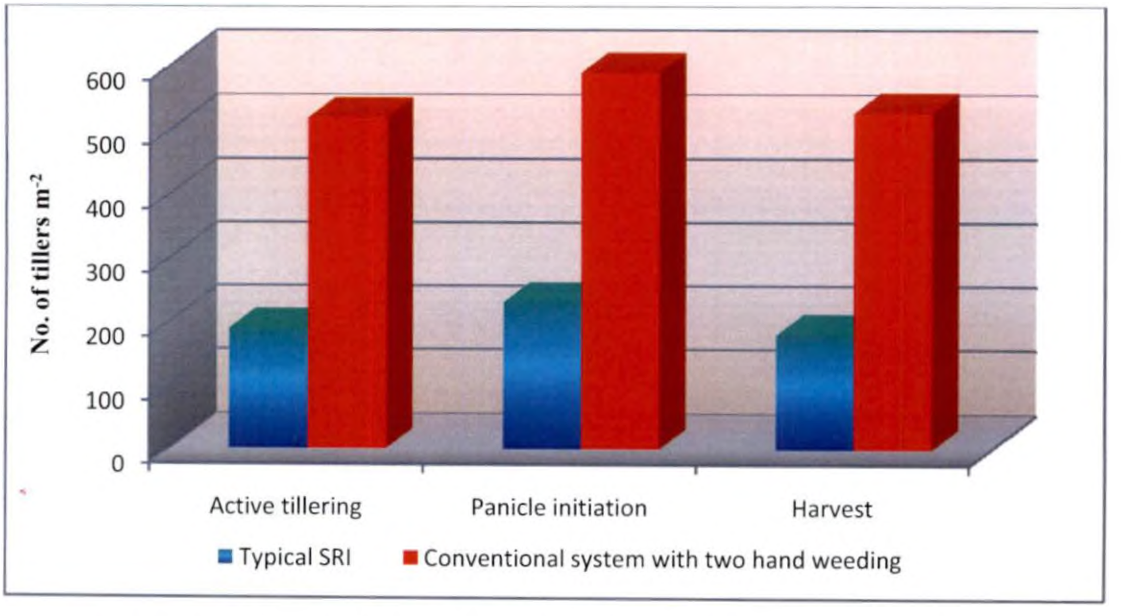


Fig. 16. Variation in the number of tillers m^{-2} under typical SRI and conventional system (at Alappad *Kole*)

treatments under SRI at any stage of observation. The dry matter production also followed the same pattern (Fig. 17).

Increased density of rice plants in response to narrower spacing has reflected in higher tiller density and dry matter production per unit area in the treatments under conventional system. SRI field with wider spacing of 30 cm x 30 cm could accommodate only 11-12 plants m^{-2} while conventionally transplanted field with narrower spacing of 20 cm x 10 cm could accommodate 50 plants m^{-2}. A higher dry matter production per unit area in the conventional treatment compared to SRI treatment might also be due to the greater plant density under conventional system as reported by Latif *et al.* (2005). Profuse tillering and maximum tiller number $hill^{-1}$ under wider spacing and maximum number of effective tillers m^{-2} under narrower spacing have been reported by Kumar *et al.* (2006a). Islam *et al.* (2005), Sindhu (2008) and Thakur *et al.* (2009) also reported reduction in tiller density per unit area with increase in plant spacing. Further, Mankotia *et al.* (2006) reported higher mean number of tillers per unit area under conventional method compared to SRI and Thakur *et al.* (2011) attributed this to greater number of hills per unit area under conventional method.

At Pattambi, the typical SRI produced taller plants with higher number of tillers $hill^{-1}$, higher number of filled grains $panicle^{-1}$ and higher straw yield ha^{-1}. This may be due to the unique effect of organic manure that was well incorporated through repeated cono weeding, and need not be due to the effect of cono weeding alone, as SRI with four cono weeding but without organic manure (T1) has produced shorter plants with less number of tillers $hill^{-1}$ and with lower straw yield ha^{-1}. This good response to applied organic manure at Pattambi is the reflection of a lower fertility status of the soil, as it was not observed in the organic matter rich *Kole* soil at Alappad (Table 24). The organic carbon content of Pattambi soil was only 1.0 per cent, whereas that of *Kole* soil was 2.86 per cent (Table 1). Stimulation of cell division by an increased root activity through incorporation of organic manure with mechanical weeder has been reported to

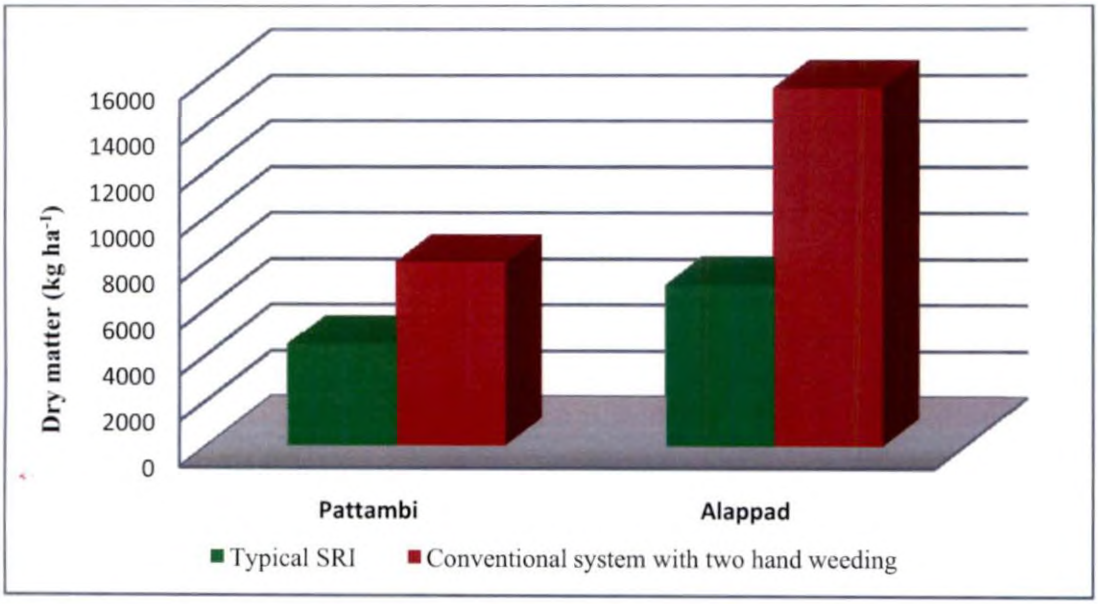


Fig. 17. Variation in the dry matter production of rice at harvest under typical SRI and conventional system (at Pattambi and Alappad *Kole*)

increase the shoot: root ratio (Uphoff, 2001). In the present study, the root length and root dry weight were more when organic manure followed by cono weeding was practised (Table 8). Moreover, alternate wetting and drying in the early phases under SRI might have increased the mineralization of N in the applied organic manure and increased its availability. Rewetting dry soil reportedly facilitates nitrogen mineralization (Birch, 1958) and decreases denitrification thereby providing better nitrogen economy (Cheng *et al.*, 2002). Higher content of soil organic carbon, available P and available K at panicle initiation was observed in the typical SRI treatment at Pattambi (Table 15).

In the organic matter rich Alappad *Kole,* the typical SRI treatment produced shorter plants with less number of tillers $hill^{-1}$ and lower dry matter production at all stages of observation. This has further led to lower number of productive tillers, shorter panicles and less number of filled grains $panicle^{-1}$ and finally to significantly lower grain and straw yields. Poor performance of crop in the organic manure applied field at Alappad *Kole* may be due to insufficient availability of nutrients for growth expression, as no chemical fertilizers were applied in the field after the basal application of vermicompost, which might have caused immobilization of N and its reduced availability. In a well drained soil, decomposition of organic matter is faster and there occurs immobilization, making heavy demand on nutritional elements, especially nitrogen (Ponnamperuma, 1972). On the contrary, it is seen that SRI with four cono weeding along with chemical fertilizers (T1) has produced higher number of tillers per hill at harvest (Table 23) and higher dry matter at active tillering (Table 25). This shows the significance of integrated nutrient management in rice through addition of organic manures and chemical fertilizers, even in organic matter rich soils, as against the SRI recommendation to use organic manure rather than chemical fertilizers (Uphoff, 2002). Further, it also recalls the importance of facilitation of mineralization of organic matter rather than addition of organic manure in soils with high organic matter content.

5.2.2. Root characteristics

The root characteristics studied viz., root length and root dry weight of the individual hill were significantly higher in SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT (T5) at Pattambi (Fig. 18a). SRI with CW at 10, 20, 30 and 40 DAT (T1) was also on par with it. At Alappad *Kole,* the root length was maximum in SRI with cono weeding at 10, 20, 30 and 40 DAT (T1) which was immediately followed by SRI with CW at 10 DAT followed by post emergence herbicide (T6) (Fig. 19a).

Higher root length and root dry weight hill^{-1} in SRI treatments (Plate 14) may be the result of combined effects of transplanting younger seedlings at wider spacing, alternate wetting and drying and the effect of cono weeding. Younger seedlings are supposed to produce more roots, and wider spacing facilitates formation of new roots, their retention and further spread. Singh (2006) has observed better root biomass per plant (per hill) with 10 day old seedlings compared to seedlings that aged more. Improvement in root length, root density and root physiological activity has been observed at wider spacing of 30 cm x 30 cm over narrower spacing of 20 cm x 20 cm by Mishra and Salokhe (2008) and Geethalakshmi *et al.* (2011). Thakur *et al.* (2010b) reported more root dry weight in hills with wider spacing (30 cm x 30 cm) over narrower spacing (20 cm x 20 cm). Stoop *et al.* (2002) explained the improvement in root characteristics under SRI as due to the contribution of leaves in wider spacing, all of which including the lower ones, become photosynthetically active and contribute to the plant's pool of photosynthate and to the roots' nutrient supply.

Better aeration in the soil, through alternate wetting and drying during the vegetative phase of the crop, also might have contributed to the increased root growth in SRI treatments. Zhang *et al.* (2009) have reported enhancement in root growth through the practice of alternate wetting and drying in rice, and he related this to increased root oxidation activity and root-sourced cytokinins, which, as

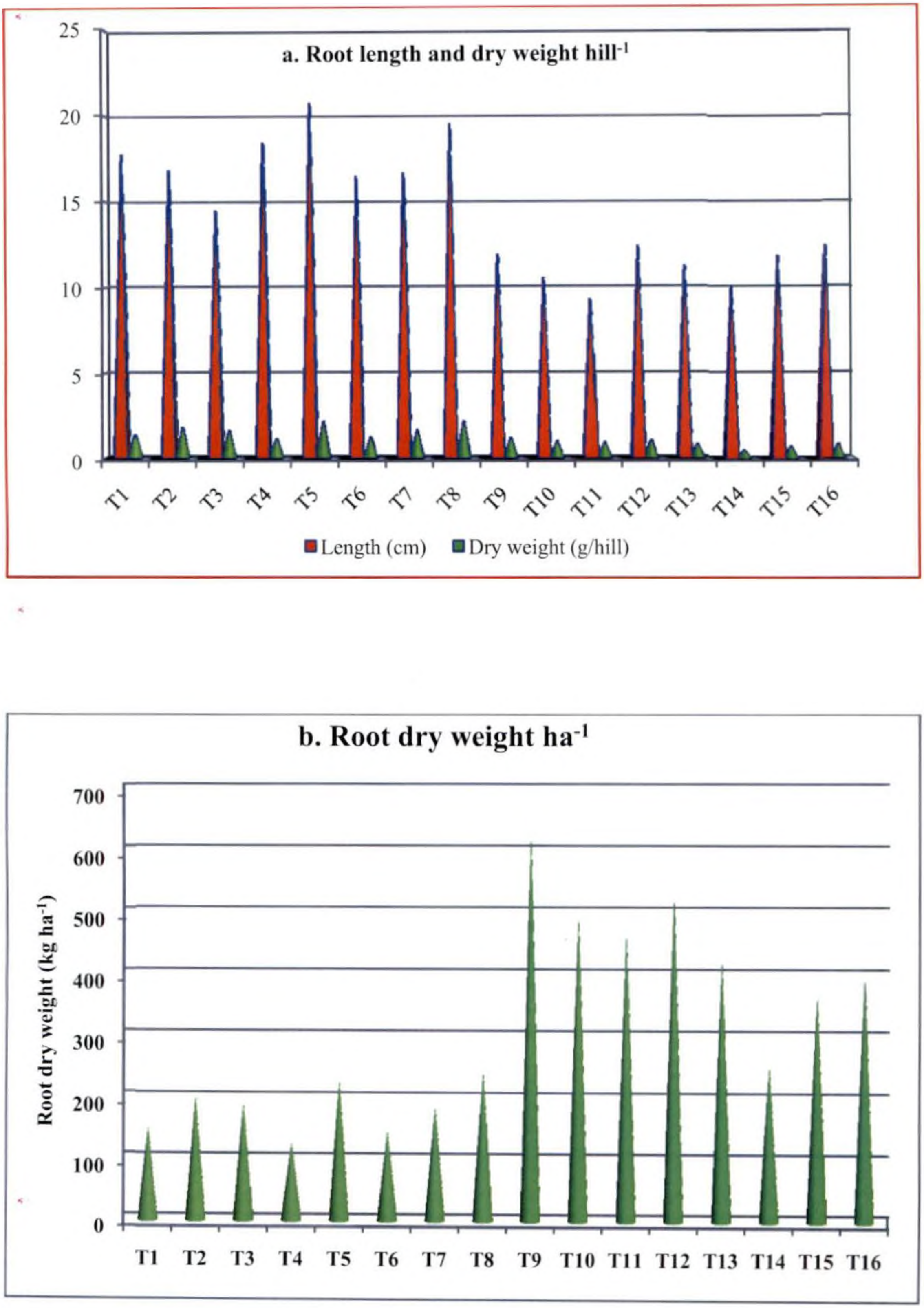


Fig. 18. Influence of the treatments on root characteristics of rice per hill and per hectare (at Pattambi)

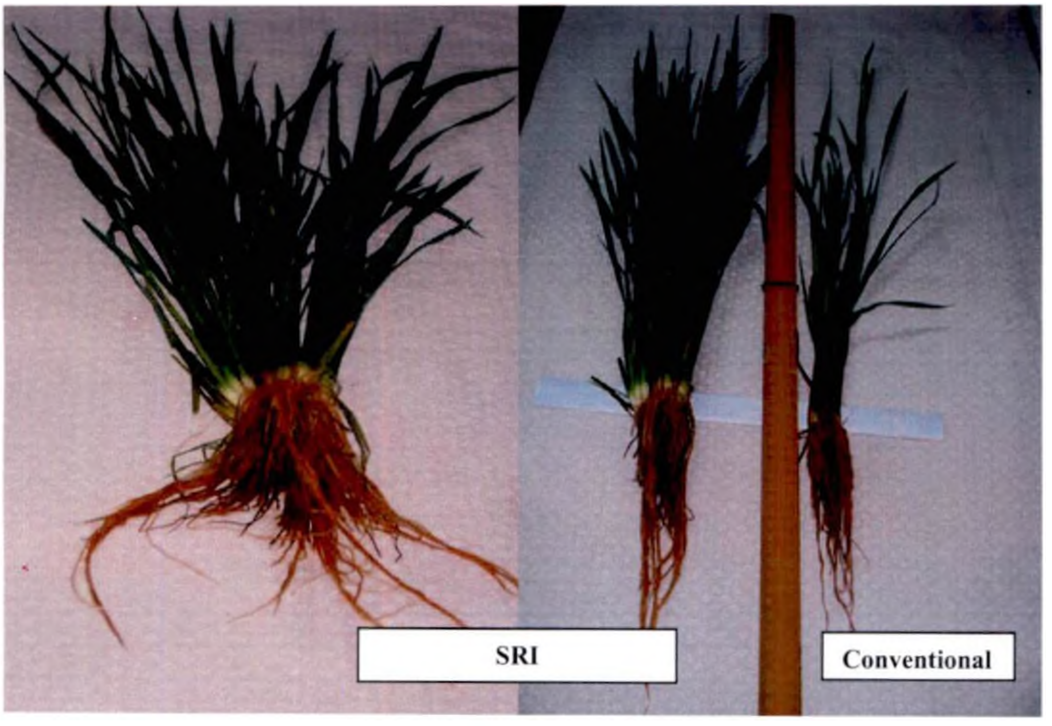
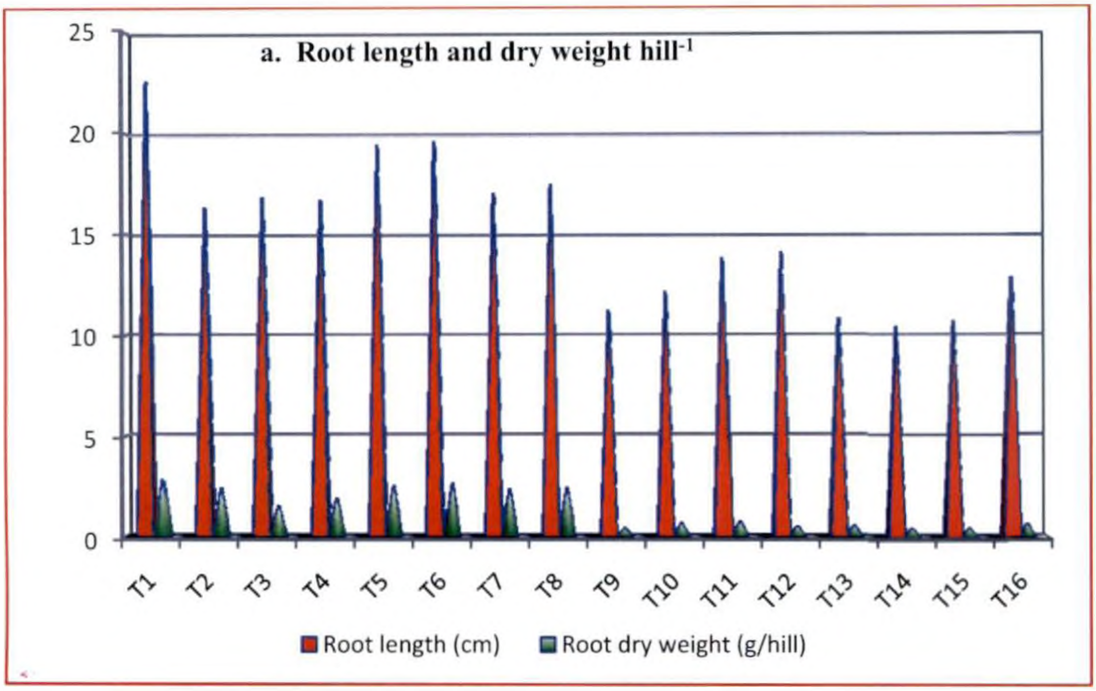


Plate 14. SRI increased the tillering, root length and root dry weight of the individual hill

reported by Yang *et al.* (2002) are believed to play a major role in promoting cell division thereby delaying senescence of the leaves. Tsujimoto *et al.* (2009) observed better root activity in rice due to more oxidative soil conditions during the vegetative growth phase through SRI water management. KAU (2007) recommends occasional draining of water in the rice nursery to encourage production of vigorous seedlings with short roots. The oxygenated soil in SRI might have promoted development of nodal roots at the initial growth stage when soil nutrients were not a limiting factor as reported by Mishra and Salokhe (2011). Increased rooting ability of plants under SRI has also been reported by XuHui *et al.* (2006). Lower root growth in the submerged field condition under conventional system may be due to accumulation of reduced iron on the root surfaces as there is excess release of reduced iron to the soil solution when laterite soils are flooded. High yielding varieties of rice tend to develop a coating of iron on the roots which may even restrict the absorption of nutrients (Marykutty *et al.*, 1992).

On the other hand, the root dry matter production ha^{-1} was significantly higher in conventional treatments and the highest root dry matter was produced with cono weeding at 10, 20, 30 and 40 DAT (T9) at Pattambi (Fig. 18b). At Alappad *Kole,* the root dry matter production ha^{-1} was significantly higher in conventional system with pre emergence herbicide followed by cono weeding at 30 DAT (T11) which was immediately followed by conventional system with pre emergence herbicide followed by hand weeding at 30 DAT (T10) (Fig. 19b). Although SRI treatments could improve the root characteristics of individual plants, this was not reflected on per unit area basis. This could be explained due to lower number of hills per unit area as a result of wider spacing in SRI. Thakur *et al.* (2011) observed considerably deeper roots with twice as heavy and more than double length and volume in SRI hills compared to the scientific management practice, but root dry weight was not significantly different on per unit area basis, mainly because of the greater number of hills in the latter plots.



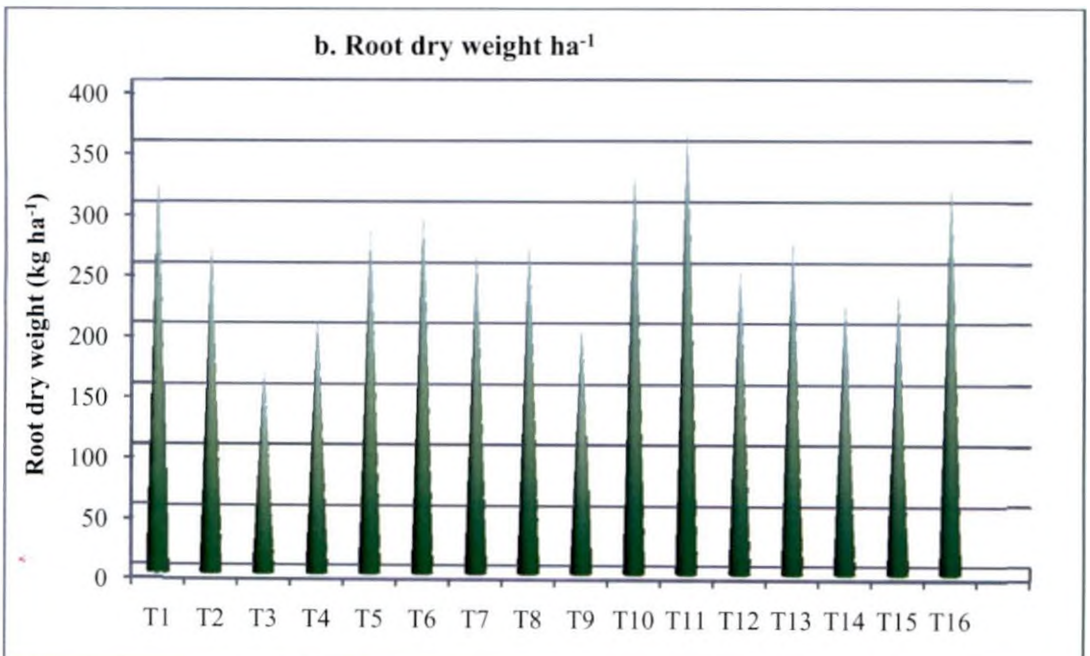


Fig. 19. Influence of the treatments on root characteristics of rice per hill and per hectare (at Alappad *Kole*)

5.2.3. Soil characteristics

Soils in typical SRI treatment recorded significantly higher contents of available phosphorus and exchangeable potassium at Pattambi (Table 15). At Alappad *Kole*, conventional system with cono weeding at 10 DAT followed by post emergence herbicides (T14) recorded the highest organic carbon percentage in the soil (3.17%). Available phosphorus content was the highest (17.93 kg ha^{-1}) in conventional system with cono weeding at 10, 20, 30 and 40 DAT (T9), closely followed by two cono weeding at 10 and 30 DAT (T12), which were at par. The content of exchangeable potassium in the soil was the highest in SRI with post emergence herbicides (T7) and the next higher value was recorded by SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT as well as conventional treatment with cono weeding at 10, 20, 30 and 40 DAT. These results indicate the influence of cono weeding on the availability of nutrients in the soil irrespective of the system of cultivation. Improved aeration of the soil through mechanical weeding (Uphoff, 2001; Stoop *et al.,* 2002) might have enhanced the nutrient availability in the soil.

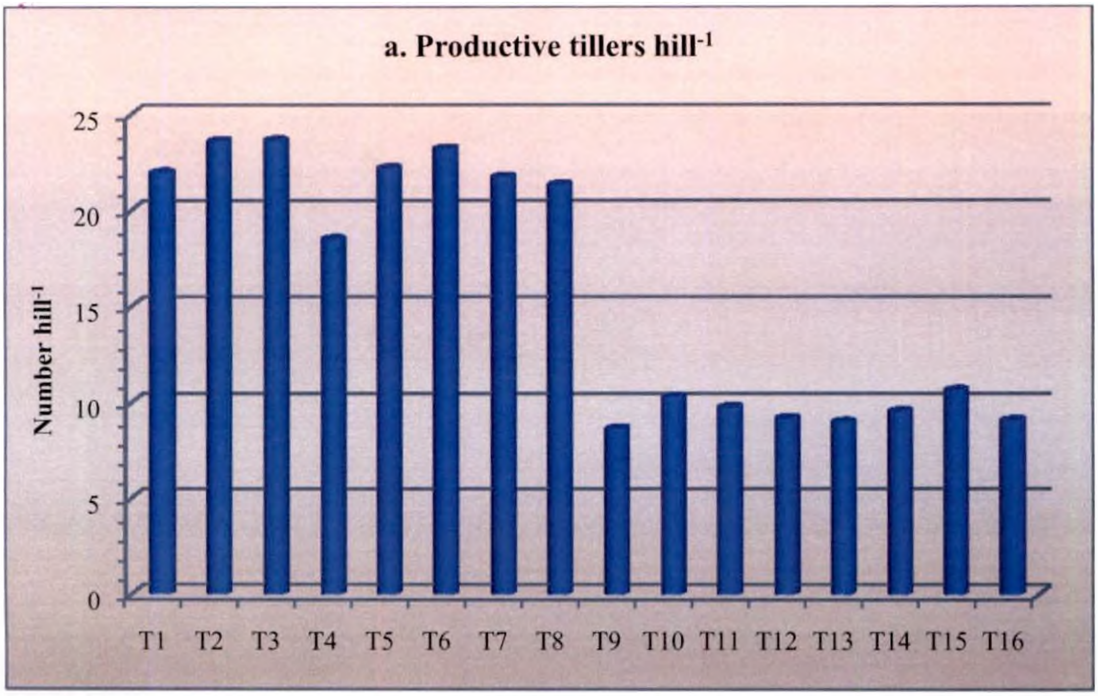
5.2.4. Nutrient content and uptake by rice

SRI with pre emergence herbicides followed by hand weeding at 30 DAT (T2) recorded the highest content of nitrogen and potassium in the rice plant at panicle initiation stage at Pattambi (Table 12). At Alappad *Kole,* SRI with cono weeding at 10 DAT followed by post emergence herbicides (T6) recorded the highest content of nitrogen, while potassium content was higher in SRI with cono weeding at 10 and 30 DAT (T4). At both locations, the content of nitrogen and potassium in rice plant was significantly higher in SRI treatments, while higher values of phosphorus content was noticed in plants under conventional system (T13). As reported by Mishra and Salokhe (2011), reduced competition under wider spacing in SRI might have favoured development of more lateral roots which helped to achieve greater absorption area, with higher cation exchange capacity favouring higher nutrient absorption from the soil by the individual plant. However, the uptake of N, P and K was higher in conventional treatments (Tables 13 and 31). Higher population density might have caused increased nutrient uptake from unit area under conventional system. Zhao *et al.* (2011) reported increased total N, P and K uptake by individual plants in SRI, but due to differences in plant population, the uptake of N, P and K by the crop on unit area basis was lower in SRI.

5.2.5. Yield attributes and yield

Yield parameters were comparatively higher under SRI than under conventional system at both locations. SRI treatments performed significantly superior in terms of number of productive tillers hill^{-1}, length of panicle and number of filled grains panicle^{-1}, but percentage of filled grains and thousand grain weights did not differ between the two systems. The number of productive tillers per unit area was significantly higher under conventional system. At Pattambi, SRI treatments produced 18.5 to 23 number of productive tillers hill^{-1} compared to 8.64 to 10.66 by the conventional treatments (Fig. 20a), while per unit area it was 432 to 533 m^{-2} in the conventional system as against 206 to 263 m^{-2} in the SRI (Fig. 20b). Similarly, at Alappad *Kole,* SRI treatments produced 15.90 to 25.53 numbers of productive tillers hill^{-1} compared to 8.25 to 11.37 by the conventional treatments (Fig. 21a), while per unit area it was only 176.67 to 283.61 m^{-2} in SRI as against 414.17 to 568.33 m^{-2} in the conventional system (Fig. 21b). The panicles in SRI treatments were comparatively longer than that in the conventional treatments. The number of filled grains panicle^{-1} was also significantly higher in SRI treatments, which ranged from 102.78 to 126.09, as against 88.36 to 99.75 in the conventional treatments, and at Pattambi it was 83.08 to 99.75 in SRI as against 74.76 to 87.10 in the conventional treatments.

Significant increase in the yield attributes of rice under the SRI treatments may be due to increased vigour of the plant because of higher root growth and the



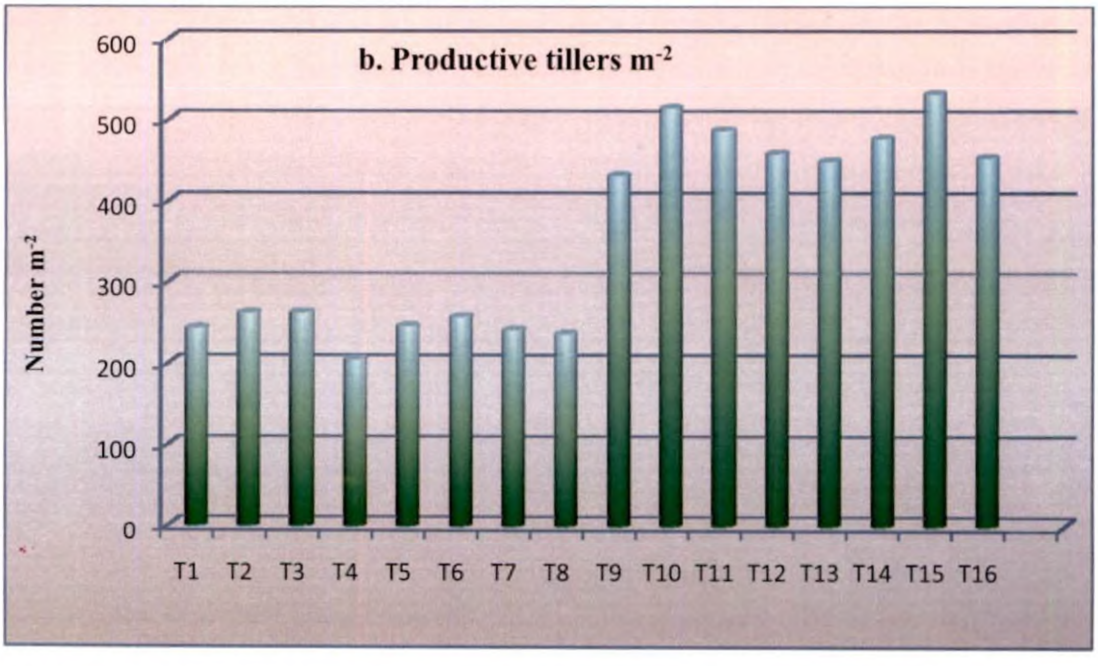
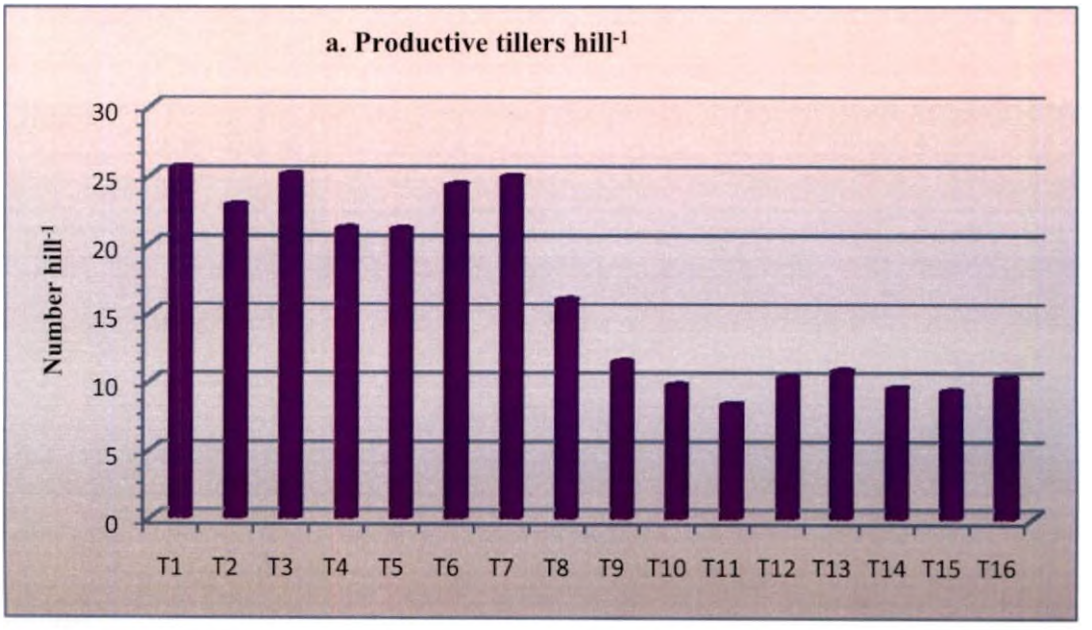


Fig. 20. Influence of the treatments on variation in the number of productive tillers hill^{-1} of rice and per hectare (at Pattambi)



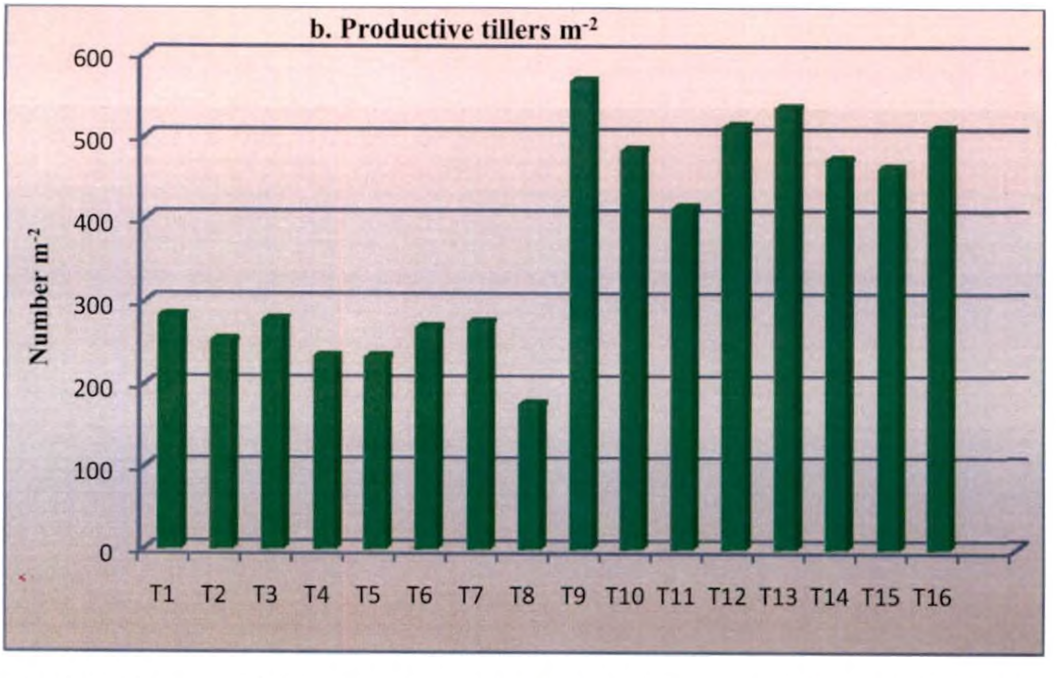


Fig. 21. Influence of the treatments on variation in the number of productive tillers hill^{-1} of rice and per unit area (at Alappad *Kole*)

related nutritional benefits, comb+ined with reduced inter-plant competition because of wider spacing. The length of panicle and the number of filled grains panicle^{-1} have shown positive correlation with the root length and root dry weight hill^{-1} at both locations (Tables 42 and 43). Development of more number of productive tillers hill^{-1} under SRI has been reported by Nissanka and Bandara (2004) and higher number of productive tillers m^{-2} at narrower spacing due to increased plant density per unit area has been reported by Bommayasamy *et al.* (2010). Thakur *et al.* (2010a) reported significant improvement in the performance of individual hills under wider spacing in terms of panicle number, panicle length, grain number panicle^{-1} and grain filling. Greater root length density and higher rate of root activity have been reported to affect the yield contributing parameters in SRI (Mishra and Salokhe, 2011). Increase in panicle length and grain number panicle^{-1} under SRI have been reported by Rahman *et al.* (2006) and Kumar *et al.* (2006a). Increased number of filled grains panicle^{-1} has been attributed to an increased dry matter translocation percentage from vegetative organs to the grains as reported by Wang *et al.* (2002). Akobundu and Ahissou (1985) observed decreased number of tillers and panicles hill^{-1} as inter-row distance was reduced.

In spite of possessing significantly improved yield attributes, SRI treatments could not translate these to the final grain yield, obviously due to decreased number of productive tillers or panicles per unit area. Significant variation in grain yield of rice between the two methods of planting was noticed at both locations (Fig. 11, 12).

Significant increase in yield in the conventional treatments might be because of the higher dry matter production, uptake of nutrients and number of productive tillers or panicles per unit area, associated with, though not significant, higher weight of 1000 grains. Correlation studies at both locations have shown positive correlation of grain yield with total dry matter production ha^{-1}, uptake of N, P and K ha^{-1} and total number of productive tillers ha^{-1} (Tables 42 and 43).

Table 42. Correlation between different parameters of rice at Pattambi

	Productive tiller/ m^2	Panicle length	No. of filled grains	Filled grain %	1000 seed wt.	Root length	Root dry wt./ hill	DMP/ hill	DMP/ ha	Org. C	Avail. P	Avail. K	Rice N, %	Rice P, %	Rice K, %	Rice N uptake	Rice P uptake	Rice K uptake	Grain yield	Straw yield
Prod. tiller/hill	-.596**	.781**	.622**	.173	.007	.814**	.746**	.561**	-.897**	.482**	-.261	.634**	.788**	-.453**	.755**	-.571**	-.787**	-.651**	-.499**	.559**
Prod. tiller/ m^2		-.526**	-.254	.182	.034	-.683**	-.596**	-.394**	.775**	-.404**	.046	-.541**	-.583**	.275	-.571**	.653**	.731**	.693**	.627**	-.275
Panicle length			.789**	.261	-.062	.601**	.610**	.535**	-.675**	.369**	-.110	.460**	.624**	-.295*	.529**	-.317*	-.510**	-.425**	-.303*	.461**
No. of filled grains				.479**	.014	.453**	.543**	.614**	-.401**	.337*	.169	.483**	.400**	-.107	.384**	-.174	-.312*	-.262	-.198	.488**
Filled grain %					.135	.050	-.004	.007	-.054	.026	-.076	.026	.187	-.266	.079	-.098	-.153	-.177	-.021	.047
1000 seed wt.						.099	.101	.034	.015	-.270	-.157	-.133	-.016	.026	-.017	.113	.098	.082	-.058	.029
Root length							.758**	.639**	-.760**	.508**	-.083	.571**	.589**	-.404**	.581**	-.546**	-.683**	-.609**	-.425**	.491**
Root dry wt./hill								.796**	-.605**	.391**	.071	.673**	.452**	-.215	.550**	-.345*	-.492**	-.337*	-.389**	.486**
DMP/Hill									-.295*	.314*	.288*	.612**	.283	-.042	.263	-.041	-.220	-.106	-.219	.435**
DMP/ha										-.474**	.346*	-.542**	-.804**	.486**	-.788**	.747**	.897**	.800**	.618**	-.452**
Org. C											-.190	.458**	.365*	-.182	.260	-.383**	-.437**	-.456**	-.238	.216
Avail. P												.194	-.423**	.304*	-.267	.210	.326*	.293*	.099	.082
Avail. K													.361*	-.240	.547**	-.369**	-.481**	-.343*	-.571**	.430**
Rice N, %														-.376**	.688**	-.441**	-.756**	-.652**	-.496**	.266
Rice P, %															-.399**	.457**	.578**	.432**	.200	-.328*
Rice K, %																-.576**	-.756**	-.520**	-.528**	.451**
Rice N uptake																	.895**	.919**	.511**	-.307*
Rice P uptake																		.926**	.606**	-.372**
Rice K uptake																			.559**	-.253
Grain yield																				.080

* Significant at the 0.05 level of significance ** Significant at the 0.01 level of significance

Table 43. Correlation between different parameters of rice at Alappad *kole*

	Productive tiller/ m^2	Panicle length	No. of filled grains	Filled grain %	1000 seed wt.	Root length	Root dry wt./hill	DMP/ hill	DMP/ ha	Org. C	Avail. P	Avail. K	Rice N, %	Rice P, %	Rice K, %	Rice N uptake	Rice P uptake	Rice K uptake	Grain yield	Straw yield
Prod. tiller/hill	-.487**	.792**	.836**	-.155	-.078	.818**	.871**	.841**	-.638**	-.367*	-.098	.065	.696**	-.076	.249	-.210	-.553**	-.318*	.073	-.609**
Prod. tiller/m2		-.547*	-.527**	.006	.186	-.590**	-.710**	-.745**	.285*	.343*	.042	-.045	-.506**	-.136	-.437**	-.022	.221	-.063	.051	.746**
Panicle length			.829**	-.201	-.117	.645**	.721**	.750**	-.470**	-.487**	-.035	.195	.486**	.067	.353*	-.201	-.341*	-.113	.099	-.516**
No. of filled				-.058	-.056	.645**	.749**	.760**	-.504**	-.359*	-.027	.258	.500**	-.031	.185	-.223	-.390**	-.250	.193	-.553**
Filled grain %					.113	-.086	-.183	-.119	-.073	.033	.091	-.066	-.054	.032	-.164	-.076	-.019	-.140	-.007	-.002
1000 seed wt.						-.043	-.075	-.080	.147	.289*	-.077	-.148	-.230	-.197	-.063	-.038	-.016	.038	.076	.139
Root length							.869**	.804**	-.443**	-.390**	.021	-.116	.609**	.078	.427**	-.077	-.348*	-.060	.110	-.622**
Root dry wt./hill								.925**	-.470**	-.356*	.014	.070	.659**	.067	.517**	-.058	-.390**	-.064	.057	-.750**
DMP/Hill									-.339*	-.324*	-.025	.063	.690**	.069	.535**	.090	-.332*	.044	.125	-.749**
DMP/ha										.272	.041	-.095	-.345*	.213	.223	.729**	.788**	.815**	.298*	.508**
Org. C											-.002	-.241	-.116	-.327*	-.326*	.231	-.022	-.021	-.089	.206
Avail. P												.343*	-.093	.073	-.024	.033	.078	.012	-.054	.035
Avail. K													-.090	.252	.022	-.111	.080	-.086	-.019	.073
Rice N, %														.016	.255	.355*	-.316*	-.127	.091	-.472**
Rice P, %															.525**	.234	.697**	.385**	.100	.088
Rice K, %																.346*	.347*	.695**	.209	-.257
Rice N uptake																	.549**	.658**	.299*	.207
Rice P uptake																		.732**	.312*	.497**
Rice K uptake																			.354*	.204
Grain yield																				.148

* Significant at the 0.05 level of significance ** Significant at the 0.01 level of significance

Kumar *et al.* (2006a) reported higher panicle length, grain number panicle^{-1} and 1000 grain weight under SRI, but they were not significantly reflected in the yield. Balachandran and Louis (2007) and Joseph *et al.* (2009) attributed the higher grain yield under the conventional system to higher number of productive tillers consequent to higher plant population per unit area. Yadao and Zamora (2007) also reported the superiority of conventional method with higher grain yield over SRI. Mishra and Salokhe (2010) reported no significant yield difference between SRI and conventional system, as wider spacing improved only the performance of individual hills, but tiller number per unit area remained a dominant determinant of yield. Menete *et al.* (2008) reported reduction in grain yield by 11.5 per cent under wider spacing (0.3 m) over narrower spacing (0.2 m). Over and above, it has to be understood that a factor increase in plant spacing results in a square factor decrease in plant density, and therefore necessitates very high gains in per-plant productivity. Thus, an optimum level of plant population should have to be maintained to attain better yield.

The straw yield at Alappad *Kole* was significantly higher in the conventional treatments than that in the SRI treatments, but at Pattambi, SRI treatments produced significantly higher straw yield (Fig. 11, 12). The highest straw yield at Pattambi (2510 kg ha^{-1}) was produced in SRI with CW at 10 DAT followed by post emergence herbicides. This treatment had shown a sudden jump in tiller production from panicle initiation to harvest during the 2nd year and this was seen reflected in the total dry matter production ha^{-1} and finally in higher straw yield. This might be due to the poor partitioning of photosynthates from source to sink by the late formed tillers which finally have contributed to the yield of rice straw rather than to the yield of rice grain, resulting in lower grain/straw ratio.

Economic analysis of the two systems of rice cultivation has shown higher gross return, net return and benefit: cost ratio in all the treatments under the conventional system compared to the treatments under SRI (Tables 21, 39) at Pattambi and Alappad *Kole*. Thus, the analysis of the performance of conventional and SRI systems of rice cultivation in two different rice growing ecosystems viz., Pattambi and Alappad *Kole* showed superiority of the conventional system with normal spacing of 20 cm x 10 cm over the SRI system with 30 cm x 30 cm spacing and repeated cono weeding, at both the locations.

5.3. Improvisation of cono weeder as a self propelled unit

In order to reduce the drudgery involved in using manual cono weeder in the low land rice cultivation, a prototype of the self propelled cono weeder was developed and tested in the paddy fields at RARS, Pattambi in the conventional system (Plate 7). The self propelled cono weeder composed of a main frame, a prime mover, two floats and a rotor. The main frame is made for mounting the engine with control units, floats, and rotors. The prime mover has a rated power of 0.9 kW at 5500 RPM with specific fuel consumption of 650 g kW^{-1} h^{-1}. Engine power is taken through a belt drive to the rotors using a chain sprocket system. The two floats help to ensure flexibility and prevent sinking of the unit in the muddy soil. The self propelled cono weeder has two conical rotors with smooth and serrated blades and are mounted in tandem with opposite orientation. As Datta (1981) and Moody (1991) reported, push type cono weeders are difficult to use as they have to be moved back and forth and do not work well under conditions of highly dry soil, high inundation of flood water, existence of bigger sized weeds etc. But the self propelled cono weeder when moves forward the weeds get entangled within the rotors and get uprooted, and further movement enables to get the weeds buried in the soil. Thus it works satisfactorily in a single forward pass.

The field capacity of the self propelled cono weeder was observed as 0.1 ha h^{-1}. It was operated in a normal working speed of 2.0-3.0 km h^{-1}. The working speed of the unit may be related to its higher self weight of 36 kg and the sticky nature of the paddy soil. Singh *et al.* (2006 b) reported that heavy weight of the existing power weeder caused it to sink deeper into the wet soil and impeded its forward motion. Hence, further refinement of the unit is essential to improve its field capacity. Moreover, a light weight unit will help the women labourers to operate it easily, thereby reducing the labour charges to minimum level. The self-propelled cono weeder has many desirable qualities of a good weeder as listed out by the Watershed Support Services and Activities Network (WASSAN, 2006) viz., simplicity in design as it was manufactured locally, and the rugged and sturdy composite of units suitably attached each other.

From the comparative studies on the effectiveness of self propelled cono weeder for weed control in rice with that of manual cono weeder it was found that self propelled cono weeder has a weeding efficiency on par with that of manual cono weeder when both were operated twice at 15 and 30 DAT, but it was inferior when manual cono weeder was operated four times. This necessitates further studies to standardize the intensity of operation of the self propelled cono weeder for efficient weeding.

Preliminary studies with the self propelled cono weeder indicate that cost of weeding with self propelled cono weeder will be around Rs. 1900 ha^{-1} compared to Rs. 7000 ha^{-1} for manual hand weeding and Rs. 4200 ha^{-1} for manual cono weeding. Some final refinement of the self propelled cono weeder developed under the study is going on. Once this is accomplished the self propelled cono weeder can be popularized.

Summary

6. SUMMARY

System of Rice Intensification (SRI) developed by a French Jesuit priest, Fr. Henri de Laulanie′ in Madagascar during the 1980s claims high productivity from less input compared to the conventional system of rice cultivation. The system was introduced in India with mixed results. Owing to wider spacing and non-flooded field situation, the high intensity of weed growth in the system warrants frequently repeated cono weeding, a highly tiresome and labour intensive operation. An effort was made to assess the performance of SRI vis-à-vis conventional system with special emphasis on weed problems and to develop an economic weed management strategy that could substitute the repeated cono weeding envisaged under SRI. The study also aimed at developing prototype of a self propelled cono weeder through modification of the existing manual cono weeder.

The field experiments laid out in randomized block design with 16 treatments in three replications were conducted at the Regional Agricultural Research Station (RARS), Pattambi in Palakkad district and in the farmers fields at Alappad *Kole* in Thrissur district, during the *Mundakan* seasons of 2007 and 2008. The soil at Pattambi was sandy clay loam in texture with pH 4.96 and medium in fertility, while that at Alappad *Kole* was clayey in texture with pH 5.0 and high fertility. The laboratory studies and the works on design and development of self-propelled cono weeder were done at RARS, Pattambi.

The salient findings of the study are summarized below.

a) Weed management studies under conventional and SRI systems at Pattambi

A major grass weed observed in the rice field at Pattambi was *Isachne miliacea.* Among sedges, *Cyperus iria*, *Cyperus difformis*, *Fimbristylis miliacea*, and *Schoenoplectus lateriflorus* dominated and among broad leaf weeds, *Sphenoclea zeylanica*, *Ludwigia perennis* and *Dopatrium junce*um were prominent.

The highest weed density and weed dry weight at 45 days after transplanting (DAT) were observed in SRI with two cono weedings at 10 and 30 DAT . At 60 days after transplanting also, this treatment recorded the highest weed density while the highest weed dry weight was in SRI with four cono weedings at 10, 20, 30 and 40 DAT . Cono weeding either twice or four times could not check the weed growth even in the initial phases of crop growth in SRI as well as conventional treatments. In SRI treatments, grass weeds were lesser whereas sedges and broad leaf weeds dominated at 45 and 60 days after planting.

Conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT recorded the lowest weed density and weed dry weight at 45 days after planting. At 60 days after planting, this treatment as well as conventional system with post emergence herbicides could reduce the weed dry weight, nutrient removal by the weeds and the weed index significantly. However, the gross return, net return and B:C ratio were the highest in the conventional system with post emergence herbicides treatment.

Among the different treatments under SRI, pre emergence herbicide followed by hand weeding at 30 DAT reduced the weed density and weed dry weight at 45 days after planting and recorded a lower weed index. At 60 days after planting the weed density and weed dry weight were the least with cono weeding at 10 DAT followed by post emergence herbicides, which also reduced the nutrient removal by the weeds at this stage. However, the highest B:C ratio was with post emergence herbicides alone.

b) Weed management studies under conventional and SRI systems at Alappad *Kole*

Major weed species observed in the experimental field at Alappad *Kole* were *Echinochloa crusgalli, Echinochloa stagnina, Cynodon dactylon* (grasses), *Cyperus iria, Cyperus difformis, Cyperus haspan, Fimbristylis miliacea* (sedges), *Monochoria vaginalis, Ludwigia perennis, Limnocharis flava, Bacopa monneiri* and *Sphaeranthus indica* (broad leaf weeds).

The density and dry weight of weeds at 45 and 60 DAT were higher in the typical SRI treatment, which was closely followed by SRI treatment with cono weeding at 10 and 30 DAT. Higher density of grasses and sedges but a lower density of broad leaf weeds were observed in the SRI treatments at 45 days after planting. Nutrient removal of nitrogen, phosphorus and potassium by the weeds and the weed index were higher in the typical SRI treatment.

The weed density and weed dry weight at 45 and 60 days after planting were the lowest in the conventional system with cono weeding at 10 DAT followed by post emergence herbicides. Cono weeding at 10 DAT followed by hand weeding at 30 DAT, pre emergence herbicides followed by hand weeding at 30 DAT and use of post emergence herbicides were also equally effective in controlling the weeds. The above treatments were on par in their B:C ratios.

The density and dry weight of weeds in SRI plots were the lowest with cono weeding at 10 DAT followed by post emergence herbicides and this was followed by cono weeding at 10 DAT followed by hand weeding at 30 DAT. These two treatments recorded higher number of productive tillers hill^{-1}, panicle length, filled grains panicle^{-1}, 1000 grain weight and the highest grain yield and harvest index among the SRI treatments. However, SRI with post emergence herbicides recorded the highest net return and B:C ratio among the SRI treatments.

The analysis shows that weed control by post emergence herbicides is superior in both the systems, and considering the acute shortage and high wages for the labourers in Kerala, weed management through post emergence herbicides will be the preferable option for the farmers.

c) Feasibility of SRI at Pattambi and Alappad *Kole*

Better performance of the treatments under conventional system was observed compared to those in the system of rice intensification in terms of yield and economic returns. SRI improved the performance of the individual plant rather than the rice cultivation system as a whole.

Wider plant spacing in SRI reflected in higher number of tillers $hill^{-1}$ and it was almost double that under the conventional system. At Pattambi, the typical SRI produced 23, 23 and 22 tillers $hill^{-1}$ at active tillering, panicle initiation (PI) and harvest stages, respectively, while conventional system with two hand weeding produced only 7.7, 8.6 and 9.7 tillers $hill^{-1}$ at the respective stages. At Alappad *Kole,* the typical SRI produced 17, 21 and 16 tillers $hill^{-1}$ at active tillering, panicle initiation (PI) and harvest stages, respectively, while conventional system with two hand weeding produced only 10, 12 and 11 tillers $hill^{-1}$ at the respective stages.

On the other hand, conventional system recorded higher tiller density and dry matter production per unit area. The typical SRI treatment, at Pattambi, could produce only 257, 250 and 234 tillers m^{-2} at active tillering, PI and harvest stages, respectively while the conventional system with two hand weeding produced 383, 430 and 483 tillers m^{-2} at the respective stages. At Alappad *Kole,* the typical SRI produced only 188, 231 and 180 tillers m^{-2} at active tillering, PI and harvest stages, respectively while the conventional system with two hand weeding produced 519, 590 and 527 tillers m^{-2} at the respective stages.

The root length and root dry weight hill^{-1} were significantly higher in SRI, while the root dry weight ha^{-1} was significantly higher in the conventional treatments.

The typical SRI treatment recorded significantly higher contents of available phosphorus in the soil at Pattambi. At Alappad *Kole*, conventional system with cono weeding at 10 DAT followed by post emergence herbicides recorded the highest organic carbon percentage (3.17%) and exchangeable potassium in the soil. Available phosphorus content was the highest in conventional system with cono weeding at 10, 20, 30 and 40 DAT.

At both locations, the content of nitrogen and potassium in rice plant was significantly higher in SRI treatments, while phosphorus content was higher in plants under conventional system.

The intensity of weeds was very high in SRI as compared to the conventional system as mentioned earlier.

The yield parameters of rice were higher in SRI treatments than under conventional system at both locations. SRI treatments performed significantly better in terms of number of productive tillers hill^{-1}, length of panicle and the number of filled grains panicle^{-1}. The number of productive tillers per unit area was significantly higher in the conventional treatments.

Significant variation in grain yield of rice between the two methods of planting was noticed at both locations. At Pattambi, the highest grain yield (2877 kg ha^{-1}) produced under the conventional system with post emergence herbicides was significantly superior to the highest grain yield (2511 kg ha^{-1}) recorded among the SRI treatments, and was 33 per cent higher than the grain yield in the typical SRI. This treatment increased the number of productive tillers m^{-2}, panicle length, number of filled grains panicle^{-1} and 1000 grain weight and recorded higher gross return and net return with a B:C ratio of 1.27, which was significantly higher than the B:C ratio (0.91) of the typical SRI treatment.

At Alappad *Kole,* conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT recorded higher number of productive tillers m^{-2}, filled grain percentage and 1000 grain weight and produced 6073 kg grain ha^{-1}, which was 93 per cent higher than the yield obtained in the typical SRI (3713 kg ha^{-1}). The gross return, net return and B:C ratio were also higher with this treatment.

At Alappad *Kole,* conventional system with cono weeding at 10 DAT followed by hand weeding at 30 DAT produced 5109 kg straw ha^{-1} as against 3678 kg ha^{-1} in the SRI with cono weeding at 10 DAT followed by hand weeding at 30 DAT and 2446 kg ha^{-1} by the typical SRI. On the other hand, at Pattambi the pooled mean showed significantly higher straw yield under SRI treatments.

Thus, the study showed the superiority of conventional system of rice cultivation at a spacing of 20 cm x 10 cm over SRI system at a spacing of 30 cm x 30 cm at both the two different rice growing ecosystems studied viz., the sandy loam soils at Pattambi and the clayey soils at Alappad *Kole*.

d) Development and field testing of self propelled cono weeder

A prototype of the self propelled cono weeder was developed and field tested. It works satisfactorily in a single forward pass, and could cover an area of 0.1 ha h^{-1}. Field study showed that it is an effective and simple machine for inter row weeding in rice. Preliminary studies indicate that the cost of weeding could be reduced through the use of self propelled cono weeder, which requires some final refinement before it is being popularized.

Future line of research

Based on the works conducted and the results generated, the following are some of the future lines of work suggested.

1. Studies may be conducted to find out an optimum spacing which can fully exploit the tillering potential of rice varieties and thus yield.
2. The shift in weed flora and the nutrient uptake pattern by the weeds observed under the SRI needs detailed studies.
3. Elaborate studies on the physical, chemical and biological changes that may occur in soil subjected to cono weeding.
4. Reducing the weight of the self-propelled cono weeder using light weight materials so as to improve its field capacity and make it gender friendly so that women labourers can also operate it.

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* Originals not seen.

Appendices

APPENDIX I

Weekly weather data during the experimental period (November 2007 to March 2008) at Pattambi

Std week No.	Month and date	Mean temperature (^0C)		R. H. (%)	Wind speed (km h^{-1})	Rainfall (mm $week^{-1}$)	Sunshine (h day^{-1})	Mean evaporation (mm day^{-1})
		Max.	Min.					
44	29 - N0v 4	29.77	23.70	93.86	2.47	10.24	4.88	2.57
45	5 – 11	31.83	23.13	94.43	2.66	3.14	5.60	2.84
46	12 -18	32.47	19.09	90.43	2.96	0.00	9.24	3.74
47	19 – 25	32.39	21.86	86.14	4.26	0.00	8.50	3.69
48	26 - Dec 2	32.30	20.87	81.29	4.93	0.00	9.41	4.46
49	3 – 9	32.14	21.74	75.43	9.14	0.00	8.90	5.60
50	10 – 16	31.61	22.24	75.43	6.46	0.00	5.26	3.83
51	17 – 23	31.17	22.07	88.29	6.73	0.86	4.89	4.03
52	24-30	33.27	18.59	95.57	3.20	0.00	9.27	4.10
53	31/12/2007	33.80	18.00	88.00	3.70	0.00	7.60	4.00
1	2008 Jan 1-7	32.50	19.59	87.86	7.06	0.00	9.19	5.00
2	8 -14	32.49	20.11	82.43	8.41	0.00	9.56	6.03
3	15 – 21	32.93	18.36	82.43	6.66	0.00	9.61	6.03
4	22 – 28	33.10	19.90	91.86	3.77	0.00	8.91	4.39
5	29 - Feb 4	32.77	20.34	92.71	3.77	0.00	8.67	4.34
6	5 – 11	32.89	22.16	91.86	3.36	0.17	6.54	4.26
7	12-18	33.63	23.10	83.43	4.64	6.53	7.56	4.20
8	19-25	35.24	21.46	91.57	4.27	0.00	9.44	5.47
9	26 – Mar 3	35.59	21.49	85.86	4.89	0.00	9.33	5.86
10	4 – 10	36.21	18.81	84.00	5.76	0.00	9.93	6.77
11	11 – 17	34.53	22.67	87.57	5.14	11.34	6.86	4.54
12	18-24	30.97	23.11	91.29	4.24	5.44	2.97	2.31
13	25 – 31	32.77	23.26	90.86	4.00	0.00	8.91	4.77

APPENDIX II

Weekly weather data during the experimental period (October 2008 to January 2009) at Pattambi

Std week No.	Month and date	Mean temperature (^{0}C)		R. H. (%)	Wind speed (km h^{-1})	Rainfall (mm $week^{-1}$)	Sunshine (h day^{-1})	Mean evaporation (mm day^{-1})
		Max.	Min.					
41	2008 Oct 7-	32.84	23.70	90.43	3.26	1.64	7.51	3.87
42	14 – 20	32.47	24.16	90.00	4.07	6.87	4.80	2.77
43	21 – 27	29.26	23.29	94.86	3.31	36.19	1.66	3.42
44	28 - N0v 3	32.36	22.87	91.00	2.49	0.00	8.29	3.04
45	4 – 10	33.04	21.91	94.00	2.26	0.00	8.50	3.17
46	11 -17	32.76	22.19	92.86	2.31	0.70	6.79	3.20
47	18 – 24	32.76	23.89	89.57	4.30	0.39	5.41	3.79
48	25 - Dec 1	31.64	23.43	89.14	3.04	0.00	3.94	2.51
49	2 – 8	32.30	20.83	87.86	4.03	0.00	6.80	3.74
50	9 – 15	32.50	22.27	83.86	7.27	0.00	7.89	4.79
51	16 – 22	31.29	21.70	81.14	9.43	0.00	5.73	4.97
52	23-29	33.00	17.93	82.43	5.01	0.00	9.23	4.90
53	30-31	32.50	15.90	76.50	4.90	0.00	9.50	5.05
1	2009 Jan 1-7	32.3	17.8	89.0	4.2	0.0	9.0	4.50
2	8 -14	33.3	21.4	72.0	10.1	0.00	9.5	6.80
3	15 – 21	32.9	21.2	71.0	10.7	0.00	9.4	7.30
4	22 – 28	34.0	19.7	85.0	4.7	0.00	8.4	5.40
5	29 - Feb 4	35.3	19.0	90.0	4.2	0.00	8.8	5.20
6	5 – 11	35.3	19.5	85.0	4.9	0.0	9.0	6.10

APPENDIX III

Weekly weather data during the experimental period (November 2007 to March 2008) at Vellanikkara, Thrissur

Std week No.	Month and date	Mean temperature (^0C)		R. H. (%)		Wind speed (km h^{-1})	Rainfall (mm $week^{-1}$)	Sunshine (h day^{-1})	Mean evaporation (mm day^{-1})
		Max.	Min.	Morning	Evening				
44	29 - N0v 4	29.8	22.6	91.0	73.0	2.5	82.1	3.8	2.5
45	5 – 11	31.7	22.4	92.0	64.0	2.9	17.7	5.4	2.9
46	12 -18	31.7	19.0	73.0	42.1	4.3	0	9.6	4.2
47	19 – 25	32.1	22.8	76.7	54.0	6.2	0	8.7	4.4
48	26 - Dec 2	32.1	21.4	70.0	45.0	6.3	0	9.9	4.9
49	3 – 9	31.8	23.6	69.0	43.0	12.5	0	8.9	6.8
50	10 – 16	31.1	23.5	68.0	44.0	8.7	0	4.7	5.3
51	17 – 23	30.4	24.1	75.0	59.0	9.8	8.7	3.6	4.4
52	24-31	32.8	19.9	85.0	41.0	4.4	0	8.4	4.9
1	2008 Jan 1-7	31.8	21.6	78.0	40.0	9.2	0	9.3	6.3
2	8 -14	32.2	22.3	75.0	38.0	8.9	0	10.0	6.4
3	15 – 21	32.5	21.1	72.0	32.0	7.0	0	10.0	6.0
4	22 – 28	32.6	21.6	82.0	46.0	4.5	0	9.0	4.0
5	29 - Feb 4	32.5	22.2	87.0	48.0	3.8	0	8.3	4.0
6	5 – 11	32.9	23.3	84.0	50.0	3.4	0	5.9	4.8
7	12-18	33.2	23.7	81.0	45.0	5.1	0	7.8	4.9
8	19-25	34.8	22.7	81.0	32.0	4.3	0	10.0	5.6
9	26 – Mar 3	35.1	23.4	67.0	28.0	5.6	0	9.2	6.7
10	4 – 10	35.4	21.6	65.0	23.0	5.7	0	9.4	7.6
11	11 – 17	33.2	23.6	80.0	55.0	5.1	121	5.3	4.9
12	18-24	30.6	23.9	86.0	70.0	5.1	0	3.7	2.8
13	25 – 31	32.6	24.0	89.0	59.0	3.4	0	8.0	4.2

APPENDIX IV

Weekly weather data during the experimental period (October 2008 to March 2009) at Vellanikkara, Thrissur

Std week No.	Month and date	Mean temperature (^{0}C)		R. H. (%)		Wind speed (km h^{-1})	Rainfall (mm week^{-1})	Sunshine (h day^{-1})	Mean evaporation (mm day^{-1})
		Max.	Min.	Morning	Evening				
40	2008 Oct 1-7	32.7	23.1	89	55	2.8	0	9.8	4.4
41	8 -14	33.0	23.7	85	65	3.2	59.9	6.0	3.7
42	15 - 21	32.0	23.9	84	68	4.6	95.2	4.8	3.1
43	22 - 28	29.0	23.1	90	78	3.1	225.5	1.5	1.8
44	29 - N0v 4	32.6	22.5	89	51	2.6	0	8.9	3.6
45	5 - 11	32.7	22.8	85	50	3.8	0	8.4	3.8
46	12 -18	32.9	22.9	85	51	3.2	0	6.8	3.7
47	19 - 25	31.8	24.3	76	62	6.2	1.5	4.3	3.9
48	26 - Dec 2	31.3	23.3	87	63	3.8	20.2	3.9	2.7
49	3 - 9	31.6	22.5	77	51	5.4	0.6	7.0	5.2
50	10 - 16	31.5	24.0	64	51.9	7.6	2.0	6.6	5.2
51	17 - 23	30.9	22.9	72	47	9.7	0	6.8	6.3
52	24-31	32.4	20.2	76.8	36	6.4	0	9.6	6.1
1	2009 Jan 1-7	32.0	20.2	77	39	5.8	0	9.6	5.3
2	8 -14	32.4	23.5	65	40	10.4	0	9.9	7.8
3	15 - 21	31.8	23.0	65	37.9	10.9	0	9.9	8.0
4	22 - 28	33.6	21.5	71	38	5.9	0	8.6	6.3
5	29 - Feb 4	35.0	20.2	78	27	5.0	0	9.6	5.9
6	5 - 11	34.5	21.8	69	28	5.9	0	9.9	6.9

APPENDIX V

CALENDAR OF OPERATIONS

Experiment at RARS, Pattambi

Operations	Date			
	1st year		2nd year	
	Conventional system	SRI	Conventional system	SRI
Nursery sowing	26.10.2007	05.11.2007	10.10.2008	20.10.2008
Main field preparation	14.11.2007	14.11.2007	29.10.2008	29.10.2008
Organic manure application	14.11.2007	14.11.2007	29.10.2008	29.10.2008
Transplanting	16.11.2007	16.11.2007	31.10.2008	31.10.2008
Basal fertilizer application	23.11.2007	23.11.2007	07.11.2008	07.11.2008
Application of Butachlor	20.11.2007	20.11.2007	07.11.2008	07.11.2008
Cono weeding at 10 DAT	26.11.2007	26.11.2007	01.11.2008	01.11.2008
Cono weeding at 20 DAT	06.12.2007	06.12.2007	11.11.2008	11.11.2008
Cono weeding at 30 DAT	16.12.2007	16.12.2007	21.11.2008	21.11.2008
Cono weeding at 40 DAT	26.12.2007	26.12.2007	31.11.2008	31.11.2008
Irrigation in the SRI plots	Continuous flooding	Once in 4 days	Continuous flooding	Once in 4 days
Application of Clincher	04.12.2007	04.12.2007	19.11.2008	19.11.2008
Application of Almix	06.12.2007	06.12.2007	21.11.2008	21.11.2008
Hand weeding	06.12.2007/ 16.12.2007/ 26.12.2007	16.12.2007	11.11.2008/ 21.11.2008/ 01.12.2008	21.12.2008
Top dressing of fertilizers	17.12.2007/ 08.01.2008	17.12.2007/0 8.01.2008	02.12.2008	02.12.2008
Harvesting	21.02.2008	10.03.2008	29.01.2009	17.02.2009

Appendix V contd.

Experiment at Alappad *Kole*

Operations	**Date**			
	Conventional system	**SRI**	**Conventional system**	**SRI**
Nursery sowing	19.11.2007	19.11.2007	26.09.2008	29.09.2008
Main field preparation	08.12.2007	26.11.2007	14.10.2008	08.10.2008
Organic manure application	08.12.2008	26.11.2007	14.10.2008	09.10.2008
Transplanting	10.12.2007	29.11.2007	16.10.2008	10.10.2008
Application of Butachlor	18.12.2007	05.12.2007	23.10.2008	16.10.2008
Basal fertilizer application	18.12.2007	06.12.2007	23.10.2008	18.10.2008
Cono weeding at 10 DAT	20.12.2007	09.12.2007	26.10.2008	20.10.2008
Cono weeding at 20 DAT	30.12.2007	19.12.2007	05.11.2008	30.10.2008
Cono weeding at 30 DAT	09.01.2008	29.12.2007	15.11.2008	09.11.2008
Cono weeding at 40 DAT	19.01.2008	08.01.2008	25.11.2008	19.11.2008
Irrigation in the SRI plots	Continuous flooding	Once in 7 days	Continuous flooding	Once in 7 days
Application of Clincher	29.12.2007	17.12.2007	04.11.2008	28.10.2008
Application of Almix	01.01.2008	19.12.2007	06.11.2008	30.10.2008
Hand weeding	30.12.2007/ 09.01.2008/ 19.01.2008	29.12.2007	06.11.2008/ 16.11.2008/ 26.11.2008	09.11.2008
Top dressing of fertilizers	14.01.2008	18.01.2008	19.11.2008	16.11.2008
Harvesting	26.03.2008	25.03.2008	23.01.2009	22.01.2009

APPENDIX – VI

Cost of cultivation of rice with different weed control methods under SRI and conventional transplanting, Rs. ha^{-1}

Items	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Seed	210	210	210	210	210	210	210	210	1260	1260	1260	1260	1260	1260	1260	1260
Nursery – Tractor	0	0	0	0	0	0	0	0	225	225	225	225	225	225	225	225
- Men	0	0	0	0	0	0	0	0	875	875	875	875	875	875	875	875
- Women	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
- Uprooting & transportation – Women	600	600	600	600	600	600	600	600	2400	2400	2400	2400	2400	2400	2400	2400
Land preparation – Tractor	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250
- Leveller	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125	1125
- Men	4200	4200	4200	4200	4200	4200	4200	4200	2800	2800	2800	2800	2800	2800	2800	2800
Transplanting - Men	1400	1400	1400	1400	1400	1400	1400	1400	0	0	0	0	0	0	0	
- Women	7200	7200	7200	7200	7200	7200	7200	7200	6000	6000	6000	6000	6000	6000	6000	6000
Organic manure - FYM	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650
- Application cost	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Fertilizers – Urea	915	915	915	915	915	915	915	0	915	915	915	915	915	915	915	915
- Rajphose	858	858	858	858	858	858	858	0	858	858	858	858	858	858	858	858
- MOP	378	378	378	378	378	378	378	0	378	378	378	378	378	378	378	378
- Application cost	1050	1050	1050	1050	1050	1050	1050	0	1050	1050	1050	1050	1050	1050	1050	1050
Water management	3150	3150	3150	3150	3150	3150	3150	3150	1400	1400	1400	1400	1400	1400	1400	1400
Weeding - Cono weeding	7000	0	2450	4200	2450	2450	0	7000	3500	0	1225	2100	1225	1225	0	0
- Herbicides - Butachlor	0	625	625	0	0	0	0	0	0	625	625	0	0	0	0	0
- Clincher	0	0	0	0	0	860	860	0	0	0	0	0	0	860	860	0
- Almix	0	0	0	0	0	320	320	0	0	0	0	0	0	320	320	0
- Spraying cost	0	875	875	0	0	1750	1750	0	0	875	875	0	0	1750	1750	0
- Hand weeding	0	7000	0	0	7000	0	0	0	0	5000	0	0	5000	0	0	7000
PP Chemicals	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400	400
- Spraying cost	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
Harvesting - Combine	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800	4800
Total	**39286**	**40786**	**36236**	**36486**	**41736**	**37666**	**35216**	**36085**	**33986**	**36986**	**33211**	**32586**	**36711**	**34641**	**33416**	**37486**

Cost of inputs and produces

	Rate	Fertilizers	Rate	Herbicides	Rate	Labour	Wage rate	Produces	Rate
Seed	Rs. 21 kg^{-1}	Urea	Rs. 5.90 kg^{-1}	Butachlor 50EC	Rs. 250 l^{-1}	Men	Rs. 350 day^{-1}	Paddy	Rs. 14 kg^{-1}
FYM	Rs. 530 t^{-1}	Rajphose	Rs. 4.90 kg^{-1}	Clincher 10 EC	Rs. 2150 l^{-1}	Women	Rs. 200 day^{-1}	Straw	Rs. 1 kg^{-1}
Carbaryl 50 WP	Rs. 400 kg^{-1}	MOP	Rs. 6.30 kg^{-1}	Almix 20 WP	Rs. 16 g^{-1}	Tractor 5hr ha^{-1}	Rs. 450 hr^{-1}		

INTEGRATED WEED MANAGEMENT UNDER SYSTEM OF RICE INTENSIFICATION (SRI)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

An experiment was conducted to assess the performance of system of rice intensification (SRI) vis-à-vis conventional system with special emphasis on weed problems under SRI and to develop an economic weed management strategy. Aiming at reducing drudgery while using manual cono weeder, it was also envisaged to develop the prototype of a self propelled cono weeder.

The field studies laid out in randomized block design with 16 treatments in three replications were conducted at RARS, Pattambi in Palakkad district and in farmers' fields at Alappad *Kole* in Thrissur district, during the *Mundakan* seasons of 2007 and 2008. The soil at Pattambi was lateritic sandy clay loam with pH 4.96 and medium fertility, and that at Alappad *Kole* was clayey in texture with pH 5.0 and of high fertility.

At both locations, the density and dry weight of weeds at 45 and 60 days after transplanting (DAT) were higher in all the SRI treatments especially when weed control was done through repeated cono weeding.

At Pattambi, weed density and weed dry weight were the lowest in conventional system with post emergence herbicides, which recorded lower nutrient removal by the weeds and the lowest weed index and also higher gross return, net return and B:C ratio. The weed density and dry weight in the SRI fields were the lowest with pre emergence herbicide followed by hand weeding at 30 DAT, but the use of post emergence herbicides showed higher B:C ratio.

At Alappad *Kole*, the weed density and dry weight, both at 45 and 60 DAT, were the lowest in conventional system with cono weeding at 10 DAT followed by post emergence herbicides. Cono weeding followed by hand weeding, pre emergence herbicides followed by hand weeding as well as the use of post emergence herbicides were also equally effective in controlling the weeds

in the conventional system, and were on par in the B:C ratios. In the SRI plots cono weeding at 10 DAT followed by post emergence herbicides recorded the lowest weed density and dry weight, however, use of post emergence herbicides recorded the highest net return and B:C ratio among the SRI treatments.

Thus, considering the acute shortage and high wages for the labourers in Kerala, weed management through post emergence herbicides will be the preferable option for the farmers in both conventional and SRI systems of rice cultivation.

Comparison between the two systems of rice cultivation at two different rice growing ecosystems showed that SRI improved the performance of individual hills through higher number of tillers hill^{-1}, root length and root dry weight hill^{-1}. On the other hand, the tiller number, dry matter production, root dry weight and productive tillers per unit area were higher in the conventional treatments. Owing to higher number of productive tillers per unit area the grain yield of conventional treatments was significantly higher than that of the typical SRI.

At Pattambi, conventional system with post emergence herbicides recorded higher number of productive tillers m^{-2}, panicle length, number of filled grains panicle^{-1}, 1000 grain weight and grain yield (2877 kg ha^{-1}), which was 33 per cent higher than the grain yield in the typical SRI. This treatment also recorded significantly higher B:C ratio (1.27) compared to that (0.91) of the typical SRI. However, the highest straw yield (2510 kg ha^{-1}) at Pattambi was observed in 'SRI with cono weeding at 10 DAT followed by post emergence herbicides', which was on par with the typical SRI treatment.

At Alappad *Kole*, higher number of productive tillers m^{-2}, more filled grain percentage, highest 1000 grain weight, highest grain yield (6073 kg ha^{-1}) and highest straw yield (5109 kg ha^{-1}) were recorded by conventional system with cono weeding followed by hand weeding, which showed an increase of 93 per cent in grain yield, with an additional yield of 2934 kg ha^{-1}, and 109 per cent in straw yield over the typical SRI and recorded the highest gross return, net return and B:C ratio (2.46).

Thus, the study showed the superiority of conventional system of rice cultivation at a spacing of 20 cm x 10 cm over the SRI system at a spacing of 30 cm x 30 cm at both the two different rice growing ecosystems studied viz., the sandy loam soils at Pattambi and the clayey soils at Alappad *Kole*.

Prototype of the self propelled cono weeder was developed and field tested. It works satisfactorily in a single forward pass, and covers an area of 0.1 ha h^{-1}. The field study showed that the self propelled cono weeder is effective for inter row weeding in rice, however, further refinement is needed to improve its weeding efficiency.