WEED MANAGEMENT IN *KHARIF* RICE (*Oryza sativa* L.) ESTABLISHED BY DIFFERENT METHODS

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MAY, 2018

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A thesis submitted to the

DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH,
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(Agricultural University)
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in partial fulfillment of the requirements for the degree
of

Doctor of Philosophy
(Agriculture)

in

AGRONOMY

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CERTIFICATE

This is to certify that the thesis entitled **"WEED MANAGEMENT IN *KHARIF* RICE (*Oryza sativa* L.) ESTABLISHED BY DIFFERENT METHODS"** submitted to the Faculty of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra State in partial fulfillment of the requirements for the degree of **DOCTOR OF PHILOSOPHY (AGRICULTURE)** in **AGRONOMY**, embodies the results of the piece of *bona-fide* research carried out by **Mr. SHENDAGE GANESH BALASO** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma. All the assistance and help received during the course of investigation and the sources of literature have been duly acknowledged by him.

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THESIS ABSTRACT

The field experiment was conducted on plot No. 24 of 'B' block of Agronomy Department Farm, College of Agriculture, Dapoli. Dist. Ratnagiri during *Kharif* seasons 2016 and 2017 to study the "Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods".

The field experiment was laid out in a strip plot design comprising of twenty five treatment combinations replicated thrice. The horizontal strips comprised five rice establishment methods *viz.,* Sowing of dry seeds by drum seeder at onset of monsoon (M_1), Sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field (M_2), Broadcasting of sprouted seeds (*Rahu)* on puddled field (M_3), SRI (System of Rice Intensification) method (M_4) and Conventional transplanting (M_5). The vertical strips consisted five weed management practices *viz.,* Need based two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Pre-emergence application of Oxadiargyl 80 WP @ 100 g ha^{-1} + 1 hand weeding at 20/30 DAS/DAT (W_2), Pre-emergence application of Oxadiargyl 80 WP @ 100 g ha^{-1} + 1 hand weeding at 40/60 DAS/DAT (W_3), Pre-emergence application of Oxadiargyl 80 WP

@ 100 g ha^{-1} + Post emergence application of Almix 20 WP @ 4 g ha^{-1} (W_4) and Unweeded control (W_5).

The soil of the experimental plot was uniform, levelled and well drained. It was sandy clay loam in texture, low in available nitrogen (216.12 kg ha^{-1}), phosphorus (9.22 kg ha^{-1}) and potassium (205.75 kg ha^{-1}), moderately high in organic carbon (0.94%) and slightly acidic in reaction (5.80). It was lateritic in nature and reddish brown in colour.

The sowing of dry seeds by drum seeder was done at onset of monsoon as per the treatments. The nursery for conventional transplanting and SRI method was done on the same day of sowing of dry seeds by drum seeder. Similarly, seeds were kept for soaking in water on the same day of nursery sowing for sowing of sprouted seeds (*Rahu*) by drum seeder and broadcasting sprouted seeds (*Rahu*) on puddled field. Two days sprouted seeds were sown in the puddled field by drum seeder and broadcasting as per the treatments. In SRI and conventional transplanting methods 12 and 21 days old seedlings were transplanted, respectively on puddled field as per the treatments. FYM, half N and full dose of P_2O_5 and K_2O was applied as basal dose and remaining half dose of N was applied at tillering and panicle initiation stages in equal splits. The other usual common packages of practices were followed time to time and periodical growth observations were recorded at an interval of 30 days. Crop was harvested at physiological maturity and data on yield attributes and yield were recorded.

SRI method of rice transplanting produced maximum and significantly higher grain and straw yield over rest of the establishment methods followed by conventional transplanting during individual years as well as in pooled data. On the basis of pooled data, the magnitude of increase in grain yield recorded under broadcasting of sprouted seeds on puddled field, sowing of sprouted seeds by drum seeder on puddled field, conventional transplanting and SRI method over sowing of dry seeds by drum seeder were 4.06, 6.57, 15.18 and 17.77 per cent, respectively. Increase in yields due to transplanting methods over rest of the establishment methods were the results of increased growth and yield attributes *viz.*, plant height (cm), number of functional leaves m^{-2}, number of tillers m^{-2}, dry matter accumulation m^{-2}, number of panicles m^{-2}, length of panicle (cm), weight $panicle^{-1}$ (g), number of filled grains $panicle^{-1}$ and test weight (g) during both the years.

The minimum weed density (m^{-2}) and total dry weight of weeds (q ha^{-1}) were observed in SRI method which were at par with conventional transplanting, sowing of sprouted seeds by drum seeder, broadcasting of sprouted seeds and significantly lower as compared to sowing of dry seeds by drum seeder.

The maximum and significantly higher N, P, K content in grain and straw and their uptake were recorded under SRI method as compared to rest of the establishment methods except conventional transplanting during both the years. The protein content in rice grain followed similar trend to that of N content in grain. The N, P and K content and uptake by weeds was significantly higher under sowing of dry seeds by drum seeder. SRI method of transplanting recorded significantly lower values of N, P and K content and uptake by weeds over other establishment methods during both the years.

The values of available N, P_2O_5 and K_2O content of soil after harvest of rice under SRI method were significantly lower as compared to sowing of dry seeds by drum seeder, whereas available N, P_2O_5 and K_2O content under remaining establishment methods were more or less similar and more than SRI method and less than broadcasting of sprouted seeds. However, all these values were slightly higher compared to their initial levels, indicating the increased production of rice without reduction in soil fertility.

Sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field gave significantly the highest net returns and B: C ratio from *Kharif* rice as compared to other establishment methods during both the years as well as in pooled data, suggesting that this method of rice establishment could be an alternative for SRI and conventional transplanting methods.

The highest grain and straw yield were recorded when the weeds were controlled by two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) as compared to other weed management practices during individual years as well as in pooled data. The magnitude of increase in grain yield recorded due to pre and post emergence application of Oxadiargyl + Almix (W_4), Integration of pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) or 1 HW at 20/30 DAS/DAT (W_2) and two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) over unweeded control (W_5) on pooled basis was 4.72, 9.25, 11.77 and 15.16 per cent, respectively. Increase in yields due to two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) over rest of the treatments were the results of increased growth and yield attributes *viz.*, plant height (cm), number of functional leaves m^{-2}, number of tillers m^{-2}, dry matter accumulation m^{-2}, number of panicles m^{-2}, length of panicle (cm), weight panicle^{-1} (g), number of filled grains panicle^{-1} and test weight (g) during both the years.

Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly the lowest weed density m^{-2} and total dry weight of weeds q ha^{-1} over rest of the treatments. Integration of pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) remained at par with pre and post emergence application of Oxadiargyl + Almix (W_4) and recorded significantly lower weed density m^{-2} as compared to unweeded control (W_5) during both the years of study. In recording total dry weight of weeds (q ha^{-1}) the treatment W_1 remained at par with W_3 and recorded significantly the lowest dry weight of weeds over W_2, W_4 and W_5 during both the years.

The P and K content in grain and straw and their uptake were increased significantly due to two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) as compared to other weed management practices during both the years. The N and protein content in rice grain significantly increased under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) as compared to other treatments except pre-emergence application of Oxadiargyl with 1 HW at 20/30 DAS/DAT (W_2) during 2017. The N, P and K content and uptake by weeds was significantly higher under unweeded control (W_5), whereas two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly lower values of N, P and K content and uptake by weeds over other weed management practices during both the years.

Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly lower values of available N, P_2O_5 and K_2O content of soil after harvest of rice as compared to other weed management practices. However, the values of available N, P_2O_5 and K_2O content in soil determined after harvest of crop were slightly higher compared to their initial values, indicating the increased production of rice without reduction in soil fertility.

Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) gave maximum and significantly higher net returns and B: C ratio over rest of the weed management treatments except pre-emergence application of Oxadiargyl with 1 HW at 20/30 DAS/DAT (W_2) during both the years as well as in pooled data indicating that the later treatment could be an alternative to 2 hand weedings at 20/30 and 40/60 DAS/DAT in managing weeds in *Kharif* rice established by different methods.

The highest net returns and B: C ratio from *Kharif* rice were obtained when rice crop was established by sowing of sprouted seeds (*Rahu*) using drum seeder with two hand weedings carried out at 20 and 40 DAS (M_2W_1) or pre-emergence application of Oxadiargyl + 1 hand weeding carried out at 20 DAS (M_2W_2) as compared to remaining treatment combinations during both the seasons as well as in pooled analysis.

Thus, these results clearly showed that pre-emergence application of Oxadiargyl along with 1 hand weeding carried out at 20 DAS in rice established by sowing of sprouted seeds (*Rahu*) using drum seeder on puddled field was found to be most profitable compared to costly transplanting method of rice establishment and manual weeding requiring more man days as well as to overcome constraints of labour scarcity due to increased urbanization, industrialization and high wage rates.

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop of the world and India, feeding more than half of the world's population every day. Rice provides 20 per cent of the world's dietary energy supply, while wheat supplies 19 per cent and maize 5 per cent (FAO, International year of rice, 2004). In Asia, it has a special significance, where about 90% of the rice is produced and consumed as a staple food. It is a predominant crop in lowland ecosystem. Globally it is cultivated in an area of 161.28 million hectares with an annual production of 715.75 million tonnes (Anonymous, 2016[a]). Among the various rice growing countries of the world, India has the largest area under rice and in case of production it stands next to China. In India, rice is the most important and extensively grown food grain crop, occupying an area of 44.11 million hectares with production of 105.48 million tonnes. However, productivity of India (2.39 tonnes ha^{-1}) is lower than the world average yields (4.4 tonnes ha^{-1}) and is much behind than the rice productivity of Egypt, Japan and China (Anonymous, 2016[b]). It has been suggested that by 2025, global rice production should increase by more than 50 per cent from mid 1990 levels to meet the demand (Subbaiah, 2010).

Rice is also an important cereal food crop of Maharashtra State, which contributes 3.6 per cent of area and 2.8 per cent of production of rice at national level. Total area, production and productivity of rice were 14.71 lakh hectares, 25.17 lakh tonnes and 1.71 tonnes ha^{-1}, respectively. Among the different rice growing states of India, there are regional imbalances with regard to average yield. The reasons are, more than 70 per cent of rice area is rainfed that depends on the marcey of rains, weed management problems, less fertilizer uses, cultivation of traditional varieties, insect and disease infestation, poor crop management and adherence of farmers to traditional crop management practices etc. which are responsible for limiting rice yields. Rice is the main food crop grown in *Konkan* region, which occupies an area of 3.79 lakh hectares with production 9.94 lakh tonnes and productivity of 2.61 tonnes ha^{-1} (Anonymous, 2016[c]).

Rice is grown either by direct seeding or by transplanting. In *Konkan*, rice is mostly grown by transplanting method. However, there are some pockets, where drilled and dibbled rice is also practiced. However, the weed infestation is the main problem in rice grown by drilling and dibbling. Weed and crop seeds germinate at the same time resulting in greater competition for space, light, moisture and nutrients from early stage of crop growth which brings down the yield drastically. In transplanted rice, where land is puddled and 3 to 4 weeks old seedlings are transplanted with the elimination of initial competition and withstanding the competition effectively during the later stage. The results revealed that both transplanted and direct seeded method needed nearly equal investment on cultivation, but transplanted rice required more initial expenditure for nursery raising and intensive labour oriented operation like uprooting of seedlings, transport of seedlings, puddling and transplanting which are time consuming and costlier too. Due to establishment of different industries in *Konkan* region and urbanisation scarcity of labours is posing a severe problem to agriculture in general and rice cultivation in particular. Though, the puddling operation in transplanted rice helps in retention of more water and direct seeded rice helps to maintain the physical properties of soil which proved advantageous in attaining desired tilth and timely sowing of the succeeding crop (Sharma *et al.* 2007).

Transplanting of rice seedlings is an age old practice but in recent years, high wage rates and non availability of labours for transplanting at appropriate time leads to the reduction in yield of rice (Budhar and Tamilselvan, 2002). Though direct seeded rice (DSR) yield is comparable with transplanted crop, increased weed infestation is major drawback of this system. Success of DSR depends largely on effective weed control especially with chemical methods. The yield loss due to weeds is as high as 40 to 100 per cent in DSR (Choubey, *et al.* 2001). Though the hand weeding has been found effective, yet it is very expensive. Moreover, heavy demand of labour during peak period and its scarcity necessitates the use of alternative methods of weed control. Chemical weed control being cost-effective and less labour dependent is recommended to overcome this constraint under DSR. Broad-spectrum weed flora may not be controlled by herbicide alone, as flushes of weeds come up at different stages.

Rice is grown under different ecosystems *viz.,* irrigated, rainfed lowland, rainfed upland and flooded conditions by small and marginal farmers with labour intensive methods of production. In most of the Asian countries rice is established through transplantation, which is time consuming, laborious and costly. Broadcasting of pre-germinated seeds on the puddled soil is one of the methods of direct seeding. In direct seeded rice weed infestation and competition is very severe, because the crop and the weed seeds germinate simultaneously and compete for same pool of resources. In recent years several herbicides have been made available to manage the weeds in varied situations.

Method of stand establishment influences the performance of rice through its effect on growth and development. Direct seeding of sprouted seeds on puddled soil (wet seeding) by drum seeder holds special significance in the present day production systems by saving time, labour, energy and increasing profitability (Subbaiah and Balsubramanian, 2000). It is estimated that about 3000 to 5000 liters of water is required to produce 1 kg of rice by conventional transplanting method of rice cultivation (Rao *et al.* 2013).

The System of Rice Intensification (SRI) a technique for rice culture is being practiced in almost 22 countries. The proponents of SRI have claimed substantial increases in rice yields, sometimes as high as 3 to 4 times, with the consequent increase in the productivity of land, water and capital (Uphoff, 2002). SRI increases rice yield over the conventional method of cultivation by 32 per cent and net returns by 67 per cent, while decreases labour input by 8 per cent in West Bengal, India (Sinha and Talati, 2007). System of Rice Intensification (SRI), a revived method of transplanted rice cultivation by exploiting the genetic potential of rice provides a favourable growing environment to increase the productivity and economic returns. Besides, it enhances soil health with reduction in input use such as seeds, water, labours etc. Krishna *et al.* (2008) reported an enhanced tillering, early flowering, higher yield and better grain quality in SRI practices compared to conventional methods.

System of rice intensification (SRI) is an alternative methodology for traditional flooded rice cultivation under water scare areas with higher yielding, good tillering and better root traits. It was well proved that SRI was more accessible to small land holders (Stoop *et al.* 2002). For direct seeded rice, it is important to keep field weed free for first 30 days which is most critical period of crop weed competition. Therefore, use of pre-emergence or early post-emergence herbicides is effective and economical at initial stages. The pre-emergence or early post-emergence herbicide either prevents weed seeds or inhibits the growth of seedlings. Use of these herbicides along with post-emergence herbicides or cultural, mechanical and agronomic methods of weed control gives effective control of weeds. Moreover in *Kharif* season, due to continuous rains the manual weeding is problematic and uneconomic. Under these situations herbicides play a significant role in controlling the weeds and thereby increasing the production (Hussain *et al.* 2008).

Rice is grown mainly by transplanting that requires more labour and time. During the peak period of farm operations, the labour availability becomes scarce therefore, the farmers are switching to direct seeding under puddled conditions. Sustainable rice productivity have been increased by adopting new techniques like SRI method, which has been tried in many countries (Uphoff *et al.* 2013) and recorded significant yield improvement when compared to conventional practices. The extent of yield reduction due to weed infestation varies from 35 to 72 per cent in rice grown under transplanted condition (Mukherjee and Singh, 2004).

In rice, the traditional system of transplanting gives the crop a 14 to 21 day growth advantage over the weeds. The transplanting also enables rice to capture space earlier. This is because the young rice plants have leverage over germinating weeds due to shading and earlier establishment of root system. The immediate flooding after transplanting limits the establishment of many weeds. Similarly, in direct seeded method, the use of high seed rates could reduce weed infestation to a large extent. Therefore, the rice cultivation trend has been increasingly shifting to direct seeding as labour prices become higher.

In wetland rice culture, include manual and chemical weed control techniques. Hand weeding is the most useful method for controlling annual and certain perennial weeds that usually do not regenerate from underground parts. It is practical and traditional but labour intensive method, which usually takes around 120 h/ha, while chemical weed control takes around 4 h/ha. Moreover, hand weeding of young weeds at the initial crop growth stage is very difficult especially if the soil moisture is inadequate. Under such conditions, the use of herbicides could be the best alternative for weed control in both transplanted and direct seeded rice cultures. It is time, labour and energy saving technique, however, its indiscriminate use raises concerns for the individual's safety at particular and the environment at large. Researchers have reported the diminished growth parameters of weeds and simultaneous increase in rice crop due to the application of herbicides or other weed management tools.

Rice is cultivated as conventional transplanting, SRI (System of Rice Intensification), drum seeded and broadcast under wet land condition. The method of crop establishment in rice largely affects the initial plant stand and uniformity. Since last decades increasing labour costs and their unavailability at peak time have resulted in a general shift in rice production system from transplanted rice to direct seeded rice, of which wet seeding has been the main method of crop establishment. Weeds are the main problem of direct seeded wet land rice as pre germinated seeds and already existed weed seed in soil weed seed bank grow simultaneously thereby inviting competition for resources like moisture, nutrient and light. Most of the introduced herbicides are selective and are specified to control only one or two types of weeds. Weeds have variable growth habits and life cycles and they even vary under different cultural practices. Therefore, the use of chemicals only cannot effectively control weeds in all situations.

Improper planting technique is one of the important factors limiting rice yield. The conventional method of planting rice in India is through transplanting after raising nursery, which is not only more laborious and time consuming but also expensive and inconvenient. Conventional method of transplanting can be replaced by direct seeding thereby reducing labour needs by more than 20 per cent in terms of working hours required. In such situation, direct seeding is helpful because of less labour and time requirement, low cost of cultivation due to skipping of nursery raising and transplanting, maintaining recommended plant population and early crop maturity by 7 to 12 days (Gill, 2008). Productivity of direct seeded rice is comparable with conventional transplanting method (Yadav and Singh 2006 and Gangwar *et al.* 2008).

In recent years, rice production systems are undergoing several changes and one of such changes is shifting from transplanted rice to direct sown rice due to increased cost of labour and non availability of labour during peak periods of agricultural operations. Sowing of sprouted rice seeds in wet puddled soils offers an attractive alternative and labour saving technique for stand establishment to the traditional transplanting. Wet seeded rice is gaining momentum in India and it has the advantages of quick and easier planting, reduces labour requirement and increased water use efficiency. However, direct seeded rice is associated with several constraints like heavy weed infestation, water management immediately after sowing and lack of perfect levelling etc. Among them, heavy infestation of heterogeneous weed flora becomes the biggest biological constraint as rice and weed seeds germinate simultaneously (Subramanian *et al.* 2004). The failure and success of the drum seeded rice depends on weed and water management practices.

Weed infestation and weed competition are more in direct seeded rice as compared to transplanted rice, because the land is exposed till the initial seedling establishment in direct seeded rice. Crop establishment and weed management techniques are critical in rice farming. So, keeping this point in the view present investigation entitled, "Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods" was conducted at Agronomy Farm, College of Agriculture, Dapoli during *Kharif* season of 2016 and 2017 with following objectives:

1. To find out suitable rice establishment method that can be an alternative for cost involving manual transplanting method.
2. To find out effective weed management practices for *Kharif* rice.
3. To study the interaction effects between establishment methods and weed management practices on growth, yield and quality of *Kharif* rice.
4. To work out the economics of various treatments.

CHAPTER II

REVIEW OF LITERATURE

The brief review of relevant and recent research work related to the research topic entitled "Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods" has been done and presented in this chapter. The available literature regarding to the aspect under investigation is reviewed under the following heads.

2.1 Effect of establishment methods on *Kharif* rice

2.1.1 Effect on growth attributes

2.1.2 Effect on yield attributes and yield

2.1.3 Effect on weed density

2.1.4 Effect on quality and uptake of nutrients

2.1.5 Economics

2.2 Effect of different weed management practices on *Kharif* rice

2.2.1 Effect on growth attributes

2.2.2 Effect on yield attributes and yield

2.2.3 Effect on weed density

2.2.4 Effect on quality and uptake of nutrients

2.2.5 Economics

2.3 Interaction effect between establishment methods and weed management practices on *Kharif* rice

2.3.1 Effect on growth attributes

2.3.2 Effect on yield attributes and yield

2.3.3 Effect on weed density

2.3.4 Effect on quality and uptake of nutrients

2.3.5 Economics

2.1 Effect of establishment methods on *Kharif* rice

2.1.1 Effect on growth attributes

Field experiment conducted on sandy loam soils of Chiplima, Orissa by Halder and Patra (2007) revealed that the maximum number of tillers (420 m^{-2}) was recorded with line transplanting than 8 rows-drum seeded rice (380 m^{-2}) due to higher number of mother plants in line transplanting under puddled condition.

Hassan *et al.* (2010) conducted field experiment at Research Farm of Birsa Agricultural University, Ranchi during *Kharif* 2008 and 2009 and reported that SRI method recorded the highest plant height (70 cm) and lowest number of effective tillers (293 m^{-2}) followed by transplanting (67 cm and 310 m^{-2}), wet seeded (66 cm and 305 m^{-2}) and drum seeded (66 cm and 276 m^{-2}) rice.

Saha *et al.* (2010) observed that SRI (System of rice intensification) showed maximum plant height (82.5 cm), number of tillers (312.37 m^{-2}) and dry matter production (558 g m^{-2}) as compared to drum seeder, line sowing and broadcasting methods of rice cultivation, respectively.

Raj *et al.* (2013) observed that hills m^{-2} were significantly influenced by the establishment techniques in which broadcasting of pre germinated seeds recorded the maximum hills m^{-2} (98). This was attributed to the fact that in direct seeding hills m^{-2} is

more due to spread of more number of seeds per unit area. This was followed by drum seeding of pre germinated seeds producing 50 hills m^{-2} and manual transplanting (48 hills m^{-2}).

Mohanty *et al.* (2014) conducted a field experiment at the Instructional Farm of Krishi Vigyan Kendra, Shyamakhunta, Odisha during the wet seasons of 2009 and 2010 and recorded the highest plant height (125.9 and 126.8 cm) and dry matter accumulation (1203.25 and 1245.10 g m^{-2}) under SRI method when compared with conventional transplanting (119.7 and 120.7 cm, 1088.16 and 1133.03 g m^{-2}) and drum seeding (115.1 and 115.0 cm, 1066.51 and 1101.97 g m^{-2}), respectively.

Jat *et al.* (2015) carried out a field experiment on rice-wheat cropping system during the rainy (*Kharif*) and winter (*Rabi*) seasons of 2012-13 and 2013-14 at Agricultural Research Farm, Banaras Hindu University, Varanasi. Results revealed that, SRI method recorded the highest plant height (123.5 cm), number of tillers hill^{-1} (18.5) and dry matter accumulation hill^{-1} (69.4 g) at harvesting over normal transplanting (118.6 cm, 15.2 and 62.8 g) during both the years.

Sharma *et al.* (2015) conducted a field experiment at Jammu during 2008-09 and 2009-10 on rice-wheat cropping system. Results indicated that the wet seeding of rice recorded significantly more number of productive tillers m^{-2} (271.98) than the SRI method (252.55) and conventional transplanting (247.93) but recorded at par

with direct seeding (265.62) during *Kharif* 2009 and 2010.

Kumar (2015) carried out field experiments during *Kharif* and *Rabi* 2011-12 at Agricultural Research Station, Kanyakumari, Tamil Nadu, to evaluate the performance of different establishment techniques of rice cultivation. Results revealed that the maximum plant height (99 and 98 cm), number of tillers hill^{-1} (27 and 24) and dry matter production (7790 and 7610 kg ha^{-1}) were recorded under SRI square planting as compared to line planting, wet seeding and drum seeding.

Babu *et al.* (2015) conducted a field experiment during two consecutive *Kharif* seasons of 2013 and 2014 at ICAR Research Farm, Gangtok, Sikkim and observed significantly higher plant height (93.7 and 92.2 cm), dry matter accumulation (29.9 and 29.5 g hill^{-1}) and tillers m^{-2} (193.9 and 186) with SRI as compared to conventional planting (91 and 89.1 cm, 25.3 and 23.9 g, 161.3 and 154.5 m^{-2}) during both the years.

Parameswari and Srinivas (2016) conducted a field experiment during *Kharif* seasons of 2010 and 2011 at College Farm, College of Agriculture, Acharya N. G. Ranga Agricultural University, Hyderabad. Results revealed that, the maximum plant height was observed under transplanted rice (84.16 and 85.50 cm) and it was comparable with SRI (82.70 and 84.36 cm) but was significantly higher than direct seeded rice (78.37 and

79.83 cm) under puddle condition during both the years.

Basha *et al.* (2017) reported that, manually transplanting under puddle condition produced more number of effective tillers (277 m^{-2}) than line sowing of sprouted seeds without puddling (269 m^{-2}) in a study on the effect of different tillage system on growth and yield of rice.

Sahoo *et al.* (2017) conducted a field experiment during *Kharif* 2012 and 2013 at Regional Research and Technology Transfer Station, Odisha. Results indicated that, SRI method recorded the highest plant height (96.8 and 97.2 cm) and tillers (602.3 and 595.7 m^{-2}) followed by conventional transplanting (94.0 and 94.4 cm, 441.0 and 439.3 m^{-2}). Broadcasting recorded the lowest plant height (91.6 and 92.0 cm) and tillers (426.0 and 425.7 m^{-2}), respectively during both the years.

2.1.2 Effect on yield attributes and yield

Subbulakshmi and Pandian (2002) conducted a field experiment on sandy loam soils of Killikulam, Tamil Nadu. Results revealed that the maximum number of panicles (465 m^{-2}), grains $panicle^{-1}$ (92) and grain yield (5496 kg ha^{-1}) was found with line transplanted rice than drum seeded rice (424 m^{-2}, 91 and 4574 kg ha^{-1}, respectively) due to less weed density in transplanted condition.

Singh *et al.* (2003) reported the highest grain yield (49.24 q ha^{-1}) with transplanting than wet seeding (45.74

q ha^{-1}) and dry seeding (40.83 q ha^{-1}) due to less weed density and competition between crop and weeds under transplanting on silty loam soils of N. D. University of Agriculture and Technology, Faizabad, Uttar Pradesh.

Manjappa and Kataraki (2004) recorded higher grain yield with drum seeder (6721 kg ha^{-1}) than broadcasting method (6261 kg ha^{-1}) due to better weed management in drum seeded rice at Agricultural Research Station, Sirsi hill region of Karnataka.

Chandrasekhar *et al.* (2004) conducted an experiment during *Kharif* 2002 in Arupathy and Kathiramangalam villages of Nagapattinam districts of Tamil nadu and reported that under SRI, there was 45.7 and 40.3 per cent increase in grain yield over that of conventional method of rice cultivation, respectively. Enhanced grain yield of 7650 and 5680 kg ha^{-1} was harvested at Arupathy and Kathiramangalam villages, respectively. Similarly, three on farm trials were conducted at Lalgudi block of Trichirappali district of Tamilnadu. The results revealed that higher yield was obtained by all the farmers in SRI method.

Singh *et al.* (2004) observed significantly higher grain yield with transplanting method (4588 kg ha^{-1}) than broadcasting (2733 kg ha^{-1}) of sprouted rice seeds on silty loam soils of Agronomy Research Farm of the N. D. University of Agriculture and Technology, Faizabad, U.P.

Singh *et al.* (2005) conducted a field experiment at Crop Research Centre of G. B. P. University of Agriculture and Technology, Pantnagar during *Kharif* and *Rabi* seasons of 2002-03 and 2003-04. They observed that transplanted rice recorded the highest number of grains panicle^{-1} (145 and 165) and grain yield (3635 and 4181 kg ha^{-1}) compared to wet seeding in puddled soil (102 and 115, 3290 and 4035 kg ha^{-1}), respectively.

In comparison to direct seeded and transplanting method of rice sowing, Singh and Singh (2006) recorded the maximum number of effective tillers (13.5 m^{-2}), grains panicle^{-1} (140) and higher test weight (20.42 g) with transplanting than direct seeding (12.1 m^{-2}, 131 and 19.85 g, respectively) due to less crop weed competition in transplanted rice than direct seeded rice on sandy clay loam of Allahabad.

Ram *et al.* (2006) conducted a field trial at CCSH Agricultural University (Haryana) and concluded that the manual transplanting of rice gave significantly higher grain yield (70.8 q ha^{-1}), followed by direct seeding of rice in puddled soil (58.0 q ha^{-1}), whereas the lowest yield was obtained with dry seeding by seed drill (51.8 q ha^{-1}).

Haldar and Patra (2007) reported that seeding of sprouted seed with drum seeder was statically at par with line transplanting and the increase in grain yield was 38.0 and 21.5% over the farmer practices of

broadcasting, respectively. In broadcasting uneven distribution of seeds and improper depth of sowing reduced the initial plants per unit area which had left sufficient space to grow weeds in very initial stage resulting in poor yield attributes and yield than direct seeding in lines and transplanted crop.

Kumar *et al.* (2007) conducted a field trial for three consecutive years in *Kharif* 2004-05, 2005-06 and 2006-07 at Patna and found that SRI produced significantly higher grain yield (6.10 t ha^{-1}) as compared to transplanting (3.94 t ha^{-1}). SRI recorded a mean yield advantage of about 23% and 55% over standard practice on farmer's field and research station, respectively.

Mahajan and Rao (2009) reported that the transplanting of 10 days old seedlings following SRI scored significant with seed yield of 66.9 q ha^{-1} over the yield of 59.8 q ha^{-1} from the conventional transplanting with 30 days old seedlings.

Hassan *et al.* (2010) stated that SRI method recorded the highest panicle length (20 cm), 1000 grain weight (24.36 g), grain and straw yield (2802 and 7146 kg ha^{-1}) as compared to wet seeded and drum seeded rice.

In the yield attributes Singh and Singh (2010) observed that among different sowing methods, rice established by drum seeding of sprouted seeds produced significantly higher number of panicles m^{-2} (325.2), which was on par with wet seeding *i.e.* broadcasting of

sprouted seeds under puddled condition (299.4) followed by dry seeding (263.9) mainly because of minimum weed density and the lowest weed dry weight that might be due to the puddling effect.

Saha *et al.* (2010) reported that SRI (System of Rice Intensification) method recorded maximum yield attributes *viz.,* effective panicles m^{-2} (306.5), panicle weight (5.40 g), test weight (23.92 g), grain (5.47 t ha^{-1}) and straw yield (7.66 t ha^{-1}) as compared to drum seeder and broadcasting methods. The percentage increase in yield of SRI over transplanting method was found to be 5.20%.

Kumar *et al.* (2010) conducted a field experiment on sandy loam soil at Research Farm of SKUAST, Chatta, Jammu during the years 2006 and 2007 and concluded that among the establishment methods of rice, conventional (3992 and 4109 kg ha^{-1}) and system of rice intensification (3974 and 4068 kg ha^{-1}) methods recorded the highest grain yield and remained at par with each other during both years.

Rajiv (2013) conducted a field experiment in *Kharif* 2011 at Directorate of Seed Research, Kushmaur (Uttar Pradesh) on clayey and calcareous soil. The results revealed that the system of rice intensification (SRI) recorded significantly higher number of filled grains $panicle^{-1}$ (118.20) as compared to conventional method (108.70).

Mohanty *et al.* (2014) found that among all the crop establishment methods conventional transplanting recorded more number of panicles m^{-2} (252.9 and 271.8).

However, with respect to test weight (23.37 and 24.48 g), grain (6341 and 6969 kg ha^{-1}) and straw yield (7636 and 7486 kg ha^{-1}) SRI method recorded significantly the highest values. The other two treatments *i.e.* conventional transplanting and drum seeding recorded statistically similar values of the above yield attributes.

Kanthi *et al.* (2014) conducted a field experiment during *Kharif,* 2011 at the Agriculture College Research Farm, Naira, (AP). It was found that significantly more number of panicles m^{-2} (430), filled grains panicle^{-1} (125), test weight (24.23 g), grain and straw yield (5406 and 6278 kg ha^{-1}) were observed in transplanting. Drum seeding of sprouted seeds recorded higher grain and straw yield of rice (5071 and 6337 kg ha^{-1}) as compared to broadcasting of sprouted seeds (4432 and 6520 kg ha^{-1}).

Jat *et al.* (2015) found that, the SRI planting resulted in significantly higher grain (6.53 t ha^{-1}) and straw (8.71 t ha^{-1}) yield as compared to normal transplanting (5.69 and 7.70 t ha^{-1}) on pooled basis respectively.

Sharma *et al.* (2015) showed that SRI method recorded more number of grains panicle^{-1} (105.56 and 107.47), grain (48.36 and 50.25 q ha^{-1}) and straw (63.72 and 66.07 q ha^{-1}) yield as compared to conventional transplanting (102.60 and 103.47, 47.31 and 49.11, 62.39 and 65.10 q ha^{-1}, respectively) during both the years.

Kumar (2015) reported that, the SRI square planting recorded the highest number of panicles m^{-2} (233.4 and 221.4), number of grains $panicle^{-1}$ (212.5 and 199.9), panicle length (25.4 and 26.3 cm), grain (5520 and 5470 kg ha^{-1}) and straw yield (5610 and 5650 kg ha^{-1}) over remaining establishment methods.

Babu *et al.* (2015) observed that SRI method recorded significantly higher values of grain (3.40 and 3.29 t ha^{-1}) and straw (4.75 and 4.64 t ha^{-1}) yields as compared to conventional planting, respectively during both the years of study.

Bohra and Kumar (2015) carried out a field experiment from 2007-08 to 2009-10 at Varanasi, Uttar Pradesh and reported that hand transplanting recorded the highest grains $panicle^{-1}$ (155.42), test weight (21.11 g), grain and straw yield (5.76 and 5.82 t ha^{-1}) as compared to direct seeding of sprouted rice seeds by drum seeder (141.67, 19.23 g, 4.98 and 5.59 t ha^{-1}).

Sahoo *et al.* (2017) reported that SRI method recorded the highest grain (6.5 and 6.6 t ha^{-1}) and straw yield (7.5 and 7.9 t ha^{-1}) of rice followed by conventional transplanting (5.1 and 5.0, 6.2 and 6.2 t ha^{-1}) and broadcasting (4.3 and 4.5, 5.3 and 5.7 t ha^{-1}) methods during both the years.

2.1.3 Effect on weed density

Subbulakshmi and Pandian (2002) reported maximum weed dry matter (74.3 kg ha^{-1}) with drum method of sowing than line transplanting (36.2 kg ha^{-1})

due to anaerobic condition in line transplanting that inhibited the germination of weed seeds.

Singh *et al* (2005) recorded the highest weed density and dry matter production in DSR (direct seeding in dry fields) and least in WSR (wet seeding in puddled soil) and TPR (transplanted rice) establishment methods at 30 day stage of growth. Similarly, non-grassy weeds and sedges were more in number in DSR than in WSR and TPR.

On sandy clay loam soils of Allahabad, Singh *et al.* (2007) found less dry weight of weeds at 60 days after planting under transplanted rice (2.44 g m^{-2}) than direct seeded rice (2.71 g m^{-2}), because of higher weed control efficiency with transplanting (48.72%) than direct seeding (37.18%).

Hassan *et al.* (2010) observed that transplanting and SRI methods recorded significantly lower weed density, dry weight of weeds and higher weed control efficiency at 30 and 60 DAS as compared to drum seeded and wet seeded rice.

Kumar *et al.* (2017) conducted a field experiment during *Kharif* 2016 at College Farm, College of Agriculture, Rajendranagar, Hyderabad and showed that, the transplanted rice recorded significantly lower density of grasses, sedges and broad leaved weeds as compared to direct seeded rice.

Paliwal *et al.* (2017) conducted a field experiment at Crop Research Centre of G. B. Pant University of

Agriculture and Technology, Pantnagar during *Kharif* 2015 and 2016. Results indicated that conventional transplanted rice recorded minimum density and biomass of grassy (6.3 and 6.2 m^{-2}, 8.8 and 8.4 g m^{-2}), sedges (2.8 and 3.6 m^{-2}, 2.9 and 3.9 g m^{-2}) and broad leaved weeds (4.4 and 3.7 m^{-2}, 3.6 and 3.1 g m^{-2}) during both the years as compared to direct seeded rice.

2.1.4 Effect on quality and uptake of nutrients

Transplanting method recorded significantly higher nitrogen uptake in grain (49.68 and 43.45 kg ha^{-1}) and straw (31.67 and 29.84 kg ha^{-1}) followed by broadcasting of sprouted seeds under puddled condition recording (44.20 and 40.00 kg ha^{-1}) in grain and (28.53 and 28.10 kg ha^{-1}) in straw, however, the lowest nitrogen uptake was found in direct seeding method (40.89 and 37.06 kg ha^{-1}) in grain and (26.63 and 25.38 kg ha^{-1}) in straw and the increase in total N uptake was 11.9 and 19.7% over broadcasting of sprouted seeds under puddled condition and 7.6 and 17.4% over direct seeding during the 1st and 2nd year of experiment, respectively as observed by Jaiswal and Singh (2001).

Singh and singh (2006) concluded from their research at Allahabad Agricultural University (UP) that N, P, K uptake by grain and straw were significantly higher in transplanted rice (84.1, 15.6, 110.8 kg ha^{-1}) than the direct seeded rice (78.2, 14.7, 105.5 kg ha^{-1}, respectively).

Hugar *et al.* (2009) conducted field experiments during *Kharif* season of 2006 and summer season of 2007 in Bhadra command area on red clay loam soils

and reported that SRI method recorded the maximum total uptake of nitrogen, phosphorus and potassium (268.5, 67.0 and 173.1 NPK kg ha^{-1}, respectively) during *Kharif* and (199.6, 50.7 and 119.3 NPK kg ha^{-1}, respectively) during summer compared to normal method of planting (224.1, 52.1 and 153.9 NPK kg ha^{-1}, respectively) during *Kharif* and (186.7, 44.2 and 118.2 kg NPK kg ha^{-1}, respectively) during summer.

Singh and Singh (2010) revealed that the nutrient uptake by the crop was significantly influenced by different rice establishment methods in which drum seeding of rice under puddled condition recorded the highest uptake of N (82.04 kg ha^{-1}), P (20.02 kg ha^{-1}) and K (112.2 kg ha^{-1}) followed by wet seeding *i.e.* broadcasting of sprouted seeds under puddled condition having nutrient uptake of N (71.62 kg ha^{-1}), P (17.54 kg kg ha^{-1}) and K (99.0 kg ha^{-1}) and dry seeding having nutrient uptake 63.71, 15.28 and 92.1 NPK kg ha^{-1}.

Kanthi *et al.* (2014) reported that transplanting method recorded the highest nitrogen (77.4 kg ha^{-1}), phosphorus (26.9 kg ha^{-1}) and potassium (121.5 kg ha^{-1}) uptake by rice crop at flowering stage which was comparable with semi-dry system (75.2, 25.6 and 116.1 NPK kg ha^{-1}) while, the lowest uptake (60.8, 20.9 and 101.1 NPK kg ha^{-1}) was associated with broadcasting of sprouted seeds, which was however, on par with drum seeding of sprouted seeds (62.4, 21.1 and 102.2 kg ha^{-1})

The uptake of these nutrients by grain and straw at harvesting also followed the similar trend.

Mohanty *et al.* (2014) concluded that, the SRI method showed significantly the highest N, P and K uptake by grain (79.23, 13.79 and 15.13 NPK kg ha^{-1}) and straw (31.58, 8.14 and 98.61 NPK kg ha^{-1}) followed by conventional transplanting and drum seeding methods.

Jat *et al.* (2015) found that normal transplanting recorded higher residual status of N, P and K (223.6, 26.3 and 201.8 NPK kg ha^{-1}) in soil after harvesting of rice over SRI method (212.6, 25.6 and 197.0 NPK kg ha^{-1}) on pooled basis.

Dass *et al.* (2015) conducted an experiment at Indian Agricultural Research Institute, New Delhi and reported that the SRI method of rice planting recorded higher uptake of nitrogen (56.0 kg N ha^{-1}), phosphorus (11.39 kg P ha^{-1}) and potassium (91.6 kg K ha^{-1}) in grain as compared to conventional transplanting.

2.1.5 Economics

Nasurudeen and Mahesh (2004) compared the economics of rice cultivation in Karaikal region of Pondicherry (UT). They found that total cost hectare^{-1} was Rs. 15040 and Rs. 19735 for direct sown paddy and transplanted paddy, respectively. The yield level was found to be more in the case of transplanted paddy (4185 kg ha^{-1}) than that in the direct sown paddy (3590 kg ha^{-1}), however, net returns were more from direct

sown paddy (Rs. 6500 ha^{-1}) than that of transplanted paddy (Rs. 5375 ha^{-1}). In spite of the low yield level direct sown paddy proved to be more profitable as it reduced the requirement of resource and cost of cultivation.

Reddy *et al.* (2005) while comparing the economics of normal rice (transplanted) and SRI method found that the total operations cost of SRI method of rice (Rs. 9456.29 acre^{-1}) was higher than the total operational cost of normal rice (Rs. 8235.72 acre^{-1}). However, net returns acre^{-1} was high in the case of SRI method of rice (Rs. 7805 acre^{-1}) than the normal rice (Rs. 5915 acre^{-1}). The major attributing factor for the high operational cost in SRI method of rice was human labour. The study revealed that the higher total operational costs were compensating the yield advantage of SRI method of rice.

Sanjay *et al.* (2006) stated that line transplanting recorded significantly higher gross income (Rs. 31158 ha^{-1}) compared to drum seeding (Rs. 30829 ha^{-1}) and broadcasting method (Rs. 22032 ha^{-1}).

Yadav and Singh (2006) reported the highest benefit: cost ratio with drum seeding over transplanting due to less expenditure incurred in seeding and resulted in higher yields through better weed control in rice on silty loam soils of Agronomic Research Farm of N. D. University of Agriculture and Technology, Faizabad, Uttar Pradesh.

Singh *et al.* (2008) conducted a field experiment at G. B. Pant University of Agriculture and Technology, Pantnagar, on the performance of rice under different planting methods and reported that sowing of rice by drum seeding were equally good and gave higher net returns and enhanced B: C ratio than transplanted rice. Drum seeding recorded higher net income (Rs. 35060 ha^{-1}) and B: C ratio (3.07) against the manual transplanting (Rs. 25172 ha^{-1} and 2.00).

Mohanty *et al.* (2014) observed that, the gross returns (74595 and 81254 Rs ha^{-1}), net returns (26312 and 30418 Rs ha^{-1}) and returns Rs^{-1} (2.19 and 2.37) invested were the highest with SRI during both the years. SRI could fetch 16.8 and 23.7% higher gross return, 36.7 and 51.7% higher net return and 16.3 and 21.3% higher return Rs^{-1} invested than conventional transplanting and drum seeding, respectively.

Rana *et al.* (2014) conducted research at Bangladesh while analyzing the economical data reported that the highest net returns (23362.00 Rs. ha^{-1}) and cost benefit ratio (1:1.49) were noted in direct seeding of sprouted seeds followed by direct seeding of dry seeds (13814.00 Rs. ha^{-1} and 1:1.30) and transplanting method (8139.00 Rs. ha^{-1} and 1:1.14). However, the highest gross return was observed in direct seeding of sprouted seeds (71056 Rs. ha^{-1}) followed by transplanting method (67433 Rs. ha^{-1}) and direct seeding of dry seeds (60608.00 Rs. ha^{-1}).

Jat *et al.* (2015) indicated that, among the crop establishment methods, SRI planting fetched significantly more net returns (66133 Rs ha^{-1}) with output: input (2.86) ratio over normal transplanting (49877 Rs ha^{-1} and 2.27).

Sharma *et al.* (2015) reported that SRI method recorded significantly the highest net returns (56439 and 66319 Rs. ha^{-1}) and B: C ratio (1.44 and 1.73) over conventional transplanting (53582 and 64439 Rs ha^{-1}, 1.40 and 1.69) in two years study.

Kumar (2015) found that, SRI square planting proved to be the most profitable treatment in terms of the gross income (60810 and 60350 Rs ha^{-1}), net income (39398 and 37999 Rs ha^{-1}) and B: C ratio (2.84 and 2.70) during *Kharif* and *Rabi* seasons, as compared to other establishment methods.

Babu *et al.* (2015) indicated that SRI method of planting gave the highest gross returns (1, 31000 and 1, 27000 Rs ha^{-1}), net returns (84000 and 80000 Rs ha^{-1}) and B: C ratio (1.77 and 1.69) over conventional method of planting (97000 and 96000, 52000 and 50000, 1.14 and 1.10) during both the years of study.

Bohra and Kumar (2015) reported that, hand transplanting gave highest gross returns (60591 Rs ha^{-1}), net returns (37108 Rs ha^{-1}) and B: C ratio (2.58) as compared to direct seeding of sprouted rice seeds by drum seeder (53182 Rs ha^{-1}, 31990 Rs ha^{-1} and 2.51) on two years pooled basis.

2.2 Effect of different weed management practices on *Kharif* rice

2.2.1 Effect on growth attributes

Raman *et al.* (2007) conducted a field experiment during *Kharif* 2005 and 2006 at Acharya N. G. Ranga Agricultural University (AP) and observed that, pre emergence application of Oxadiargyl @ 80 g a.i. ha^{-1} recorded the highest plant height (85.3 cm) and No. of tillers clump^{-1} (7.5) as compared to post emergence application of Almix @ 4 g a.i. ha^{-1} (80.5 cm and 4.1). However, weedy check recorded the lowest plant height (75.2 cm) and tillers clump^{-1} (3.7).

Mohan *et al.* (2010) conducted a field experiment during *Kharif* 2005 at Zonal Agricultural Research Station, Mandya (Karnataka) and observed that HW at 20 and 40 DAS recorded the highest plant height (22.1 cm), No. of tillers m^{-2} (22.1) and dry matter production hill^{-1} (51 g) as compared to remaining treatments. Weedy check recorded the lowest growth attributes of direct seeded rice crop.

Kumar *et al.* (2012) conducted field trial during *Kharif* 2006 and 2007 and observed that two HW at 20 and 40 DAS significantly increased plant height (30.7 and 32.8 cm) and No. of tillers m^{-1} (52.2 and 57.4) at 30 DAS. However, weedy check produced less number of plant height (19.9 and 21.4 cm) and No. of tillers m^{-1} (29.8 and 31.1) at 30 DAS during both the years.

Verma *et al.* (2013) conducted a field experiment at Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut (UP) and found that, the post emergence application of Almix @ 4 g a.i. ha^{-1} recorded the highest plant height (97.97 cm), No. of tillers m^{-2} (277.66) and dry matter accumulation (1073 g m^{-2}) as compared to weedy check which recorded the lowest growth attributes of rice.

Chauhan *et al.* (2013) conducted a field experiment at Research Farm of JNKVV, Jabalpur during *Kharif* 2011 and concluded that two hand weedings at 20 and 40 DAT recorded the highest plant height (76.6 cm) and number of effective tillers (185.2 m^{-2}) followed by post-emergence application of Chlorimuron-ethyl (72.2 cm and 169.8 m^{-2}) and unweeded control (70.1 cm and 144.2 m^{-2}).

Madhukumar *et al.* (2013) conducted a field trial during *Kharif* 2010 at Main Research Station, Hebbal, University of Agricultural Sciences, Bangalore and observed that 2 hand weedings at 20 and 40 DAS produced the highest plant height (84.30 cm), No. of productive tillers (21.30 hill^{-1}) and dry matter production (62.90 g hill^{-1}) over Pyrazosulfuron ethyl (PE) @ 25 g a.i. ha^{-1} followed by Chlorimuron-ethyl + Metsulfuron-methyl (POE) @ 4 g a.i. ha^{-1} (82.90 cm, 21.00 hill^{-1} and 56.30 g hill^{-1}).

Kumar *et al.* (2013) conducted research at Bihar Agricultural University, Sabour, Bihar during *Kharif*

2011 and 2012 and stated that two HW at 20 and 40 DAT poduced higher plant height (116.2 cm) followed by Oxadiargyl (PE) alone (111.3 cm) and weedy check recorded (108.2 cm) during both the years.

Yadav *et al.* (2014) conducted a field trial at Banaras Hindu University, Varanasi, Uttar Pradesh during *Kharif* 2012. They observed that two hand weedings recorded significantly higher values of plant height (53.1 cm), number of tillers m^{-2} (287.1) and dry matter accumulation (53.4 g running m^{-1}) followed by Oxadiagryl (PE) + Almix (POE) + 1 HW (49.2 cm, 227.5 and 35.3 g running m^{-1}).

Singh and Singh (2014) undertaken a field study during 2008 and 2009 at Institute of Agricultural Sciences, BHU, Varanasi (UP). They reported that two HW at 20 and 40 DAS produced higher plant height (96.0 and 99.7 cm), tillers (44.2 and 44.8 m row^{-1}) and dry matter production (978 and 1001 g m^{-1} row) of dry direct-seeded rice followed by Pendimethalin (PE) + Almix (POE) + 1 HW at 40 DAS and weedy check.

Kumar *et al.* (2014) conducted a field experiment at Agriculture College and Research Institute, Killikulam, Tamil Nadu and concluded that pre-emergence application of Oxadiargyl 80% WP @ 70 g a.i. ha^{-1} + 1 hand weeding at 35 DAT produced more No. of tillers m^{-2} (460) and dry matter production (13060 kg ha^{-1}) from transplanted rice as compared to unweeded control (260 m^{-2} and 7404 kg ha^{-1}).

Shendage (2015) conducted field research at Agronomy Farm, College of Agriculture, Dapoli (MS) during *Kharif* 2015 and concluded that hand weedings at 30, 60 and 90 DAS recorded the highest growth attributes *viz.,* plant height (95.37 cm), No. of tillers running meter^{-1} (65.67) and dry matter accumulation running meter^{-1} (180.39 g) in drilled rice than pre-emergence application of Oxadiargyl + post-emergence application of Bispyribac-Na (92.66 cm, 60 and 143.99 g running meter^{-1}).

Kikon and Gohain (2016) conducted field experiments during *Kharif* 2009 and 2010 at SASRD, NU, Medziphema Campus, Nagaland and reported that two hand weedings at 20 and 40 DAS was found to be superior in recording the highest plant height (139.19 and 142.73 cm), number of tillers (354.73 and 359.21 m^{-2}) and plant dry weight (1602.10 and 1654.66 g m^{-2}) followed by pre-emergence application of butachlor @ 1.5 kg ha^{-1} + 1 HW at 40 DAS (128.46 and 133.39 cm, 306.81 and 270.33 m^{-2}, 1486.08 and 1530.46 g m^{-2}) as compared to unweeded control.

Sreelakshmi *et al.* (2016) conducted a field trial at Agriculture College, Madurai, Tamil Nadu during *Rabi* 2012-13. They reoported that maximum plant height (101.7 cm), No. of tillers m^{-2} (337.2) and plant dry matter (3.93 t ha^{-1}) in hand weeding at 25 and 45 DAT and was significantly superior to rest of the treatments.

Control plot recorded the lowest growth attributes of transplanted rice (69.2 cm, 228.0 m^{-2} and 2.02 t ha^{-1}).

Kumar *et al.* (2017) undertaken the study during *Kharif* 2014 at Student's Farm of CCSHAU, College of Agriculture, Kaul, Hisar. Resultts revealed that weed free treatment recorded maximum plant height (104.2 cm), number of tillers (305 m^{-2}) and dry matter accumulation (964 g m^{-2}) followed by Oxadiargyl 100 g ha^{-1} (PE) + Bispyribac-Na 25 g ha^{-1} (POE) and weedy check which recorded the lowest growth attributes of transplanted rice as compared to other treatments.

Singh *et al.* (2017) undertaken a field experiment for two years during *Kharif* 2012 and 2013 at Banaras Hindu University, Varanasi, Uttar Pradesh and reported that Oxadiargyl @ 90 g ha^{-1} (PE) + Bispyribac-Na @ 25 g ha^{-1} (POE) recorded maximum plant height (94.2 and 91.4 cm), tillers (58.1 and 57.0 m row^{-1}) and plant biomass (93.8 and 92.5 g m^{-1} row) followed by Pendimethalin @ 1.0 kg ha^{-1} (PE) and weedy check.

2.2.2 Effect on yield attributes and yield

Yadav and Singh (2006) reported maximum yield attributes such as grains panicle^{-1} (104.42), test weight (24.42 g) and grain yield (55.46 q ha^{-1}) with two hand weedings than one hand weeding + herbicide (103.71, 24.38 g and 43.77 q ha^{-1}, respectively), due to better weed control by two hand weedings in rice on silty loam soils of Faizabad, Uttar Pradesh.

Raman *et al.* (2007) concluded that, pre emergence application of Oxadiargyl @ 80 g a.i. ha^{-1} recorded the highest panicle length (19.9 cm), test weight (20.8 g), grain (2.09 t ha^{-1}) and straw (4.11 t ha^{-1}) yield as compared to post emergence application of Almix @ 4 g a.i. ha^{-1} (17.0 cm, 19.2 g, 1.58 and 3.23 t ha^{-1}). However, weedy check recorded the lowest yield attributes and yield of rice crop.

Dixit and Varshney (2008) conducted a field experiment on direct seeded rice during rainy seasons of 2001 and 2002 at National Research Centre for Weed Science, Jabalpur (MP). They found that weed free recorded more number of panicles m^{-2} (256.5 and 230.4), test weight (24.4 and 25.1 g) and grain yield (2876 and 1890 kg ha^{-1}) as compared to post emergence application of Almix @ 4 g a.i. ha^{-1} (237 and 213, 24.2 and 24.4 g, 2388 and 1400 kg ha^{-1}) during both the years.

Mohan *et al.* (2010) reported that two hand weedings at 20 and 40 DAS recorded more grain (5562 kg ha^{-1}) and straw yield of rice (6400 kg ha^{-1}) as compared to weedy check plot (3452 and 4214 kg ha^{-1}) during *Kharif* 2005.

Kumar *et al.* (2010) stated that weed free recorded more number of panicles m^{-2} (238.1 and 240.3), 1000 grain weight (2.18 and 2.23 g) and grain yield (4662 and 4745 kg ha^{-1}) over post-emergence application of

Metasulfuron methyl + chlorimuron ethyl + 1 HW (223.4 and 225.9 m^{-2}, 1.82 and 1.90 g, 4054 and 4166 kg ha^{-1}).

Pal *et al.* (2012) conducted a field experiment during *Kharif* season of 2008 and 2009 at Bidhan Chandra Krishi Viswavidyalaya, West Bengal. Results revealed that the highest rice grain yield (3.7 t ha^{-1}) was recorded in hand weeded plot which was statistically at par with Almix @ 4 g a.i. ha^{-1} (2.7 t ha^{-1}). Lowest grain (2.1 t ha^{-1}) yield of rice was observed in untreated check which was due to high weed density and biomass.

Rawat *et al.* (2012) carried out an experiment at Jawaharlal Nehru Kirshi Vishwa Vidyalaya, Jabalpur (MP) during *Kharif* season of 2010 and reported that the maximum grain yield of rice (4.85 t ha^{-1}) recorded in two hand weedings at 20 and 40 DAS and the lowest (1.62 t ha^{-1}) under weedy check.

Murthy *et al.* (2012) carried out a field experiment during *Kharif* 2007 and 2008 at Acharya N. G. Ranga Agricultural University, (AP). They showed that hand weeding twice at 20 and 40 DAS recorded more number of grains panicle^{-1} (170 and 168) and 1000 grain weight (24.11 and 23.84 g) as compared to pre-emergence application of Oxadiargyl @ 0.07 kg ha^{-2} + 1 hand weeding at 40 DAS (165 and 163, 23.93 and 23.67 g) and unweeded check recorded the lowest yield attributes (81 and 79, 23.25 and 22.96 g) in direct seeded rice during both the years.

Prakash *et al.* (2013) conducted a field trial during *Kharif* 2008 and 2009 at ARS, Kota, Rajasthan. Results revealed that hand weeding at 20 and 40 DAT produced

more No. of panicles m^{-2} (368 and 388), panicle weight (3.92 and 3.92 g) and grain yield (6.43 and 6.02 t ha^{-1}) as compared to unweeded control (268 and 278 m^{-2}, 2.91 and 2.85 g, 4.16 and 4.05 t ha^{-1}) during both the years in transplanred rice.

Verma *et al.* (2013) reported that, two HW at 20 and 40 DAT recorded the highest panicle length (23.31 cm), No. of filled grains $panicle^{-1}$ (131), test weight (23.86 g), grain (53.54 q ha^{-1}) and straw yield (71.54 q ha^{-1}) followed by post emergence application of Almix @ 4 g a.i. ha^{-1} recorded, panicle length (20.95 cm), No. of filled grains $panicle^{-1}$ (121.22), test weight (23.56 g), grain (48.98 q ha^{-1}) and straw yield (68.01 q ha^{-1}). The lowest yield attributes of transplanted rice were recorded in weedy check.

Murthy and Reddy (2013) conducted field experiment during *Kharif* 2007 and 2008 at Acharya N. G. Ranga Agricultural University, Andhra Pradesh and observed that, HW at 20 and 40 DAS produced the highest No. of panicles m^{-2} (183 and 180), No. of filled grains $panicle^{-1}$ (156 and 152), grain (5761 and 5595 kg ha^{-1}) and straw (9401and 8981 kg ha^{-1}) yield followed by pre emergence application of Oxadiargyl @ 0.007 kg a.i. ha^{-1} + 1 HW at 40 DAS (179 and 176 m^{-2}, 150 and 146, 5561 and 5392 kg ha^{-1}, 9025 and 8731 kg ha^{-1}, respectively) during both the years.

Mishra *et al.* (2013) conducted research at Puri district of Odisha during *Kharif* 2010. Results revealed

that pre-emergence application of Oxadiargyl gave the highest grain (4.24 t ha^{-1}) and straw yield (5.10 t ha^{-1}) of rice as compared to post emergence application of Chloromuron-ethyl + Metsulfuron-methyl recorded the lowest grain (3.42 t ha^{-1}) and straw yield (4.31 t ha^{-1}).

Naseeruddin and Subramanyam (2013) conducted a field investigation during *Kharif* 2012 at Acharya N. G. Ranga Agricultural University, Tirupathi, (AP) and reported that among the weed management practices, HW twice at 20 and 40 DAS recorded significantly higher yield attributes, *viz.,* No. of panicles m^{-2}, No. of filled grains panicle^{-1}, No. of grains panicle^{-1}, test weight and grain yield of drum seeded rice over pre emergence application of Oxadiargyl @ 75 g ha^{-1} + post-emergence application of Bispyribac-Na in respect to all the above yield attributes and yield.

Chauhan *et al.* (2013) indicated that two hand weedings at 20 and 40 DAT produced heigher grains panicle^{-1} (162.7), 1000 grain weight (24.9 g), grain and straw yield (5.9 and 10.6 t ha^{-1}) of transplanted rice over Chlorimuron-ethyl (POE) and control plot.

Veeraputhiran and Balasubramanian (2013) conducted field experiments at Agricultural College and Research Institute, Tamil Nadu during *Kharif* 2010 and 2011. They concluded that two HW at 20 and 40 DAT recorded the highest No. of panicles m^{-2} (401 and 291), panicle length (24.2 and 23.4 cm) and grain yield (6.69

and 6.45 t ha^{-1}) of transplanted rice as compared to unweeded check during both the years.

Madhukumar *et al.* (2013) stated that two hand weedings at 20 and 40 DAS recorded the highest grain and straw yield (4074 and 4928 kg ha^{-1}) than Pyrazosulfuron ethyl (PE) @ 25 g a.i. ha^{-1} followed by Chlorimuron-ethyl + Metsulfuron-methyl (POE) @ 4 g a.i. ha^{-1} (3696 and 4565 kg ha^{-1}) and unweeded check recorded the lowest grain and straw yield of direct seeded rice (339 and 462 kg ha^{-1}).

Singh and Paikra (2014) conducted a field experiment at the Instructional cum Research Farm, IGKV, Raipur during *Kharif* season of 2011 and reported that two hand weedings recorded the highest grain and straw yield (5.54 and 6.74 t ha^{-1}) of rice as compared to remaining weed management practices. The minimum grain and straw yield was observed under control plot (2.44 and 4.33 t ha^{-1}).

Yadav *et al* (2014) reported that two hand weedings recorded the highest test weight (25.0 g), grain and straw yield (7.20 and 8.74 t ha^{-1}) of direct seeded rice followed by Oxadiagryl (PE) + Metsulfuron-methyl + Chlorimuron- ethyl (POE) + 1 HW (22.0 g, 6.05 and 8.12 t ha^{-1}). Weedy check recorded the lowest yield of rice crop as compared to remaining treatments.

Upasani and Barla (2014) conducted a field trial at Birsa Agricultural University, Ranchi and concluded that two HW at 20 and 40 DAS recorded the highest grain

(3807 kg ha^{-1}) and straw yield (5936 kg ha^{-1}) of *Kharif* rice as compared to other weed management practices.

Maheswari *et al.* (2015) conducted a field experiment at Agricultural College Farm, Bapatla during *Kharif* 2013. Result revealed that among the herbicide treatments, number of productive tillers m^{-2} (248), number of grains panicle^{-1} (163) and the highest grain yield (5433 kg ha^{-1}) was obtained with two hand weedings at 20 and 40 DAT as compared to Oxadiagryl (PE) @ 100 g ha^{-1} + 2,4-D @ 0.8 kg ha^{-1} (236 m^{-2}, 154 and 5133 kg ha^{-1}) and weedy check (195 m^{-2}, 112 and 3433 kg ha^{-1}, respectively) in transplanted rice.

Kikon and Gohain (2016) conducted field research during *Kharif* 2009 and 2010 and concluded that two hand weedings at 20 and 40 DAS recorded the highest panicle weight (6.26 and 6.90 g), No. of filled grains panicle^{-1} (201 and 215), 1000 grain weight (29.13 and 29.64 g) and grain yield (3.42 and 3.57 t ha^{-1}) over pre-emergence application of Butachlor @ 1.5 kg ha^{-1} + 1 HW at 40 DAS and unweeded control.

Chakraborti *et al.* (2017) revealed that, the pre-emergence application of Pendimethalin @ 1.0 kg ha^{-1} + 1 hand weeding at 30 DAS produced more No. of panicles m^{-2} (324.17 and 335.10), No. of filled grains panicle^{-1} (65.23 and 69.66) and grain yield (3.30 3.59 t ha^{-1}) compared to Fenoxaprop-p-ethyl @ 60 g ha^{-1} + Almix @ 4 g ha^{-1} (182.93 and 168.85 m^{-2}, 49.15 and 51.81, 1.89 and 1.98 t ha^{-1}, respectively) during *Kharif*

2013 and 2014. Weedy check produced the lowest yield attributes and yield of direct seeded rice.

Kumar *et al.* (2017) conducted a field experiment during *Kharif* 2016 at Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, (UP) to find out the impact of different herbicides on weed flora, yield and economics of transplanted rice (*Oryza sativa* L.). Results revealed that, the highest grain (47.88 q ha^{-1}) and straw (71.82 q ha^{-1}) yield was found in two hand weedings followed by pre-emergence application of Oxidiargyl + 1 HW (39.76 and 63.24 q ha^{-1}). Weedy check recorded the lowest grain and straw yield of rice.

Singh and Singh (2017) carried out a field experiment during *Kharif* 2010 at Crop Research Centre of GBPUAT, Pantnagar, Uttarakhand and showed that two hand weedings at 20 and 40 DAS recorded more number of panicles m^{-2} (165), test weight (25.26 g), grain and straw yield (32.63 and 54.01 q ha^{-1}) over pre-emergence appication of Cyhalofopbutyl + post-emergence application of Almix (115 m^{-2}, 23.44 g, 15.36 and 38.01 q ha^{-1}), respectively.

2.2.3 Effect on weed density

Singh *et al.* (2004) conducted a field trial during rainy seasons of 2000 and 2001 at the Crop Research Centre of G. B. P. University of Agriculture and Technology, Pantnagar. They stated that weed free treatment recorded the lowest weed density (6 m^{-2}) and

dry weight of weeds (0.75 g m^{-2}) followed by Butachlor (PE) +1 HW and Butachlor (PE) + Almix. Weedy check recorded the highest density and dry weight of weeds in *Kharif* rice.

Subramanyam *et al.* (2007) observed that Oxadiargyl 75 g ha^{-1} supplimented with 1 hand weeding at 40 DAT recorded less weed dry weight (3.83 g m^{-2}) and higher rice grain yield over herbicide application alone and on par with hand weeding twice at 20 and 40 DAT.

Sharma *et al.* (2007) reported that, among weed management practices, dry weight of weeds at two hand weedings at 20 and 40 DAS (6.4 g m^{-2}) and pre emergence application of Butachlor @ 1.5 kg a.i. ha^{-1} combined with one hand weeding at 30 DAS (6.8 g m^{-2}) were at par with each other and significantly superior over unweeded control (21.4 g m^{-2}) in direct sown rice.

Ramana *et al.* (2007) observed that, Oxadiargyl (PE) @ 75 g ha^{-1} recorded the lowest weed index (13.5%) followed by Almix (POE) @ 4 g a.i. ha^{-1} (34.9%). Weedy check recorded the highest weed index (62.6%) as compared to remaining treatments.

Dixit and Varshney (2008) conducted a field experiment on direct seeded rice during rainy season and reported that weed free check recorded less dry weight of weeds and the highest weed control efficiency as compared to post emergence application of Almix @ 4 g a.i. ha^{-1}. However, weedy check recorded maximum dry weight of weeds.

Singh *et al.* (2008) conducted field research during the years 2002-03 and 2003-04 at Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) and observed that pre-emergence application of Oxadiargyl @ 0.08 kg ha^{-1} recorded minimum dry matter of weeds (13.31 and 14.79 g m^{-2}) as compared to weedy check (37.07 and 38.71 g m^{-2}) during both the years.

Kiran and Subramanyam (2010) stated that, the lowest density and dry weight of sedge weeds was recorded with two HW at 20 and 40 DAT (15.66 m^{-2} and 7.97 g m^{-2}) which was comparable with Oxadiargyl (PE) + Bispyribac-Na (POE) (26.00 m^{-2} and 12.60 g m^{-2}) in transplanted rice during *Rabi* 2009.

Mohan *et al.* (2010) concluded that, two hand weedings at 20 and 40 DAS recorded the minimum dry weight of weeds 0.25 m^{-2} at harvest (3.9 g) and weedy check recorded the maximum dry weight of weeds (9.6 g) in direct seeded rice.

Akbar *et al.* (2011) reported from Faisalabad (Pakistan) that hand weeding was more effective in decreasing weed density and dry weight under direct seeded rice and increasing weed control efficiency and rice yield than chemical weed control method.

Murthy *et al.* (2012) conducted an experiment for water and weed management practices in aerobic rice during *Kharif* 2007 and 2008 and reported that hand weeding twice at 20 and 40 DAS recorded the lowest weed density (37.87 and 55.57 m^{-2}) and the highest

weed control efficiency (86.94 and 84.83%) as compared to pre-emergence application of Oxadiargyl @ 0.07 kg ha^{-2} + 1 hand weeding at 40 DAS (49.34 and 76.34 m^{-2}, 81.76 and 79.28%). Unweeded check recorded the highest weed density (272.12 and 294.21 m^{-2}) during both the years.

Kumar *et al.* (2012) concluded that, two HW at 20 and 40 DAS significantly reduced the density of weeds (3.43 and 2.97 m^{-2}), weed dry weight (2.27 and 0.30 g m^{-2}) and recorded the highest weed control efficiency (88 and 90%) during both the years in rice crop as compared to other weed management practices.

Pal *et al.* (2012) conducted field experiment during *Kharif* season of 2008 and 2009. Observed, the lowest weed index (27.03%) under post emergence application of Almix @ 4 g a.i. ha^{-1} as compared to untreated check (473.24%).

Madhukumar *et al.* (2013) conducted a field trial during *Kharif* 2010-11 and reported the lowest weed density and dry weight of weeds under treatment two HW at 20 and 40 DAS (1.93 m^{-2} and 2.28 g m^{-2}) followed by Pyrazosulfuron ethyl (PE) @ 25 g a.i. ha^{-1} + Chlorimuron-ethyl + Metsulfuron-methyl (POE) @ 4 g a.i. ha^{-1} (2.10 m^{-2} and 2.39 g m^{-2}) and unweeded check (2.41 m^{-2} and 6.58 g m^{-2}), respectively in direct seeded rice.

Verma *et al.* (2013) revealed that, two HW at 20 and 40 DAT recorded the lowest number of grasses, sedges and BLW weeds, less dry matter accumulation

and the highest weed control efficiency (100%) as compared to remaining treatments. The highest weed population and dry weight were recorded under unweeded control.

Mishra *et al.* (2013) conducted a field research during *Kharif* 2010 and observed that the pre emergence application of Oxadiargyl recorded minimum weed count m^{-2} (34.6), weed dry matter (18.5 g) and the highest weed control efficiency (81%) as compared to post emergence application of Chloromuron-ethyl + Metsulfuron-methyl (21.7 m^{-2}, 26.1 g and 71%).

Naseeruddin and Subramanyam (2013) reported the lowest density (2.79 m^{-2}) and dry weight of total weeds (6.28 g m^{-2}) with higher weed control efficiency (94%) with two HW at 20 and 40 DAS in drum seeded rice. The next best treatment was the pre-emergence application of Oxadiargyl @ 75 g ha^{-1} + post emergence application of azimsulfuron @ 30 g ha^{-1}, which was at par with pre-emergence application of Oxadiargyl alone @ 75 g ha^{-1} in reducing the total density and dry weight of weeds.

Veeraputhiran and Balasubramanian (2013) indicated that the two HW at 20 and 40 DAT recorded minimum weed count m^{-2} (2.06 and 4.14), dry weight of weeds (22.62 and 11.34 g), weed index (6.30 and 5.57%) and maximum weed control efficiency (93.6 and 96.4%) under transplanted rice as compared to unweeded check during both the years.

Chauhan *et al.* (2013) observed that two hand weedings at 20 and 40 DAT recorded minimum weed density and dry weight of grassy (0.77 m^{-2} and 0.71 g m^{-2}), sedges (0.71 m^{-2} and 0.71 g m^{-2}) and broad leaved weeds (1.08 m^{-2} and 1.22 g m^{-2}) as compared to unweeded control (6.22 and 3.80 g m^{-2} grassy, 5.94 and 4.26 g m^{-2} sedges, 12.64 and 11.87 g m^{-2} BLW weeds), respectively in transplanted rice.

Prakash *et al.* (2013) indicated that hand weeding twice at 20 and 40 DAT recorded minimum weed density (5 and 6 m^{-2}) and dry weight of weeds (6.26 and 9.25 g m^{-2}) as compared to unweeded control (68 and 72 m^{-2}, 76.36 and 88.66 g m^{-2}) during *Kharif* 2008 and 2009 in transplanred rice.

Kumar *et al.* (2013) showed that, two HW at 20 and 40 DAT recorded minimum weed population (5.39 m^{-2}) and dry weight of weeds (1.59 g m^{-2}) at 60 DAS followed by Oxadiargyl (PE) alone (7.84 m^{-2} and 2.44 g m^{-2}). Weedy check recorded 14.64 m^{-2} and 4.75 g m^{-2} weed population and dry weight of weeds, respectively during both the seasons of *Kharif* 2011 and 2012 in transplanted rice.

Singh and Paikra (2014) conducted a field experiment during *Kharif* 2011. Results revealed that two HW recorded the lowest weed density (4.17 m^{-2}) and dry weight of weeds (3.95 g m^{-2}) followed by Almix (POE) @ 20% WP (7.52 and 8.05 g m^{-2}) and Oxadiargyl (PE) @ 80% WP (8.65 and 8.84 g m^{-2}). However, unweeded

control recorded the highest weed density (14.06 m^{-2}) and dry weight of weeds (11.87 g m^{-2}).

Yadav *et al.* (2014) observed that two hand weedings recorded minimum weed density (5.7 m^{-2}) and weed biomass (14.3 g m^{-2}) in direct seeded rice as compared to Oxadiagryl (PE) + Almix (POE) + 1 HW (7.4 m^{-2} and 18.0 g m^{-2}) and weedy check recorded maximum weed density and weed biomass as compared to other treatments.

Kumar *et al.* (2014) reported that, two hand weedings at 15 and 35 DAT recorded the lowest weed density (5.57 m^{-2}) and weed dry matter production (6.10 g m^{-2}) in transplanted rice and the highest weed index (11.76%) and weed control efficiency (91.85%) as compared to pre-emergence application of Oxadiargyl 80% WP @ 70 g a.i. ha^{-1} + 1 hand weeding at 35 DAT (5.92 m^{-2}, 6.28 g m^{-2} and 8.82%, 90.80%), respectively.

Nayak *et al.* (2014) conducted a field experiment at the Agricultural College Farm, Bapatla on sandy loam soil during *Kharif* 2012. Results indicated that hand weedings at 20 and 40 DAS recorded the lowest weed density (33.3 m^{-2}) and the highest weed control efficiency (42.7%) as copmared to other weed management practices. Weedy check recorded the highest weed density (124.9 m^{-2}).

Singh and Singh (2014) conducted a field study during 2008 and 2009 and stated that two HW at 20 and 40 DAS recorded minimum dry weight of weeds (7.83

and 7.48 g m^{-2}) and maximum weed control efficiency (62.6 and 63.9%) in direct seeded rice as compared to weedy check (11.9 and 11.7 g m^{-2}) during both the years.

Ramachandra *et al.* (2014) conducted a field experiment at ZARS, V. C. Farm, Mandya, Karnataka during rainy seasons of 2009 and 2010. The results indicated that among different weed management practices, hand weeding twice at 20 and 40 DAT recorded the lowest weed biomass (11.97 g m^{-2}) as compared to unweeded control (26.53 g m^{-2}).

Maheswari *et al.* (2015) conducted research during *Kharif* 2013 and reported that two hand weedings at 20 and 40 DAT recorded the lowest weed density (6.00 m^{-2}) and weed dry weight (2.32 g m^{-2}) followed by Oxadiagryl (PE) @ 100 g ha^{-1} + 2, 4-D @ 0.8 kg ha^{-1} (7.40 m^{-2} and 2.59 g m^{-2}). Weedy check recorded the highest weed density and dry weight of weeds (17.03 m^{-2} and 6.76 g m^{-2}), respectively in transplanted rice.

Shendage (2015) reported that hand weedings at 30, 60 and 90 DAS recorded minimum dry weight of weeds (1.50 q ha^{-1}) and maximum weed control efficiency (92.78%) than the pre-emergence application of Oxadiargyl + post emergence application of Bispyribac-Na (8.22 q ha^{-1} and 60.48%). The weedy check recorded maximum dry weight of weeds (20.80 q ha^{-1}) in drilled rice.

Kikon and Gohain (2016) carried out field research during *Kharif* 2009 and 2010. Results revealed that 2

HW at 20 and 40 DAS recorded the lowest weed density (10.38 and 9.58 m^{-2}), dry weight of weeds (41.13 and 36.88 g m^{-2}) and the highest weed control effieciency (92.57 and 94.64%) followed by Butachlor (PE) @ 1.5 kg ha^{-1} + 1 HW at 40 DAS (11.11 and 10.37 m^{-2}, 47.21 and 43.52 g m^{-2}, 88.81 and 90.61%), respectively during both the years. Weed density and dry weight of weeds were recorded to be significantly the highest under unweeded control throughout the crop season.

Sreelakshmi *et al.* (2016) reoported that two hand weedings at 25 and 45 DAT recorded the lowest weed density (6.08 m^{-2}) and dry weight of weeds (8.66 g m^{-2}) as compared to other treatmnets. Control plot recorded more weed density (17.65 m^{-2}) and dry weight of weeds (32.21 g m^{-2}) in transplanted rice.

Samant (2016) carried out the study through front line demonstration during *Kharif* 2010 in the Baragaunia village of Angul district in Odisha and stated that, the lowest dry weed biomass was found in pre-emergence application of Oxadiagryl @ 90 g a.i. ha^{-1} at 2 DAS with one hand weeding at 30 DAS (81.43 g m^{-2}) and the highest weed control efficiency (72.46%) where as farmers practice recorded the dry weed biomass (105.72 g m^{-2}) and WCE (64.25%) and weedy check recorded the highest dry weed biomass (295.68 g m^{-2}).

Kumar *et al.* (2017) conducted field experiment during *Kharif* 2016 and concluded that two hand weedings recorded the lowest weed density (3.30 m^{-2})

followed by Oxidiargyl + 1 hand weeding (4.78 m^{-2}). Weedy check (9.81 m^{-2}) recoreded the highest weed density in transplanted rice as compared to remaining treatments.

Singh and Singh (2017) conducted the field experiment during *Kharif* 2010 and reported that two hand weedings at 20 and 40 DAS recorded the lowest weed population (16 m^{-2}) and dry weight of weeds (87.4 g m^{-2}) as compared to remaining treatments. Weedy check recorded the highest weed population (40 m^{-2}) and dry weight of weeds (589 g m^{-2}).

Chakraborti *et al.* (2017) conducted field experiment during *Kharif* seasons 2013 and 2014. They obersved that pre-emergence application of Pendimethalin at 1.0 kg ha^{-1} + 1 hand weeding at 30 DAS recorded the lowest dry weight of weeds (61.33 and 50.10 g m^{-2}) and the highest weed control efficiency (75.62 and 79.95%) compared to Fenoxaprop-p-ethyl at 60 g ha^{-1} + Almix at 4 g ha^{-1} (139.08 and 128.02 g m^{-2}, 44.71 and 48.76%), respectively during both the years of study.

Bhatt *et al.* (2017) carried out field trial during *Kharif* 2013 and 2014 at Professor Jayashankar Telangana State Agricultural University, Hyderabad. They stated that hand weeding twice at 25 and 45 DAT recorded minimum weed dry matter at harvest (6.39 and 6.34 g m^{-2}) in transplanted rice than Pretilachlor (PE) at

3 DAT + Almix (POE) at 25 DAT (7.07 and 6.84 g m^{-2}) and weedy check (13.50 and 13.87 g m^{-2}), respectively.

2.2.4 Effect on quality and uptake of nutrients

Sawant (2003) conducted a field experiment at Agronomy Farm, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli (MS) during *Kharif* 2002 and observed that, the Butachlor (PE) with 1 hand weeding recorded significantly higher protein (7.50%) content than the rest of the treatments under study. However, weedy check (5.81%) recorded significantly lower protein content in rice grain than the remaining treatments.

Verma *et al.* (2013) concluded that, two HW at 20 and 40 DAT recorded the highest uptake of nutrients by rice (84.47, 23.99 and 91.98 NPK kg ha^{-1}) and the lowest uptake of nutrients by weeds as compared to post emergence application of Almix @ 4 g a.i. ha^{-1} (77.00, 18.95 and 85.65 NPK kg ha^{-1}). However, weedy check recorded the highest uptake of nutrients by weeds and the lowest uptake of nutrients by rice (51.99, 15.23 and 61.15 NPK kg ha^{-1}).

Murthy and Reddy (2013) reported from their two years study that among the weed management practices, HW at 20 and 40 DAS recorded the highest N, P and K uptake by crop and was comparable with pre-emergence application of Oxadiargyl @ 0.007 kg a.i. ha^{-1} + 1 HW at 40 DAS. The lowest uptake of N, P and K by weeds was recorded with HW at 20 and 40 DAS, which was in parity with pre-emergence application of Oxadiargyl @ 0.007 kg a.i. ha^{-1} + 1 HW at 40 DAS. The

lowest uptake of these nutrients by crop was recorded with unweeded check during both the years of study.

Nayak *et al.* (2014) conducted a field trial on sandy loam soil during *Kharif* 2012 and observed that hand weedings at 20 and 40 DAS recorded the highest uptake of nutrients by rice (139.1, 74.2 and 132.4 NPK kg ha^{-1}) and weedy check recorded the lowest uptake of nutrients (85.8 45.3 76.5 NPK kg ha^{-1}), respectively.

Islam and Kalita (2015) conducted a field experiment at Farmer's Fields of Puthimari village Meghalaya, India during *Kharif* 2010 and 2011 and concluded that, two hand weedings at 20 and 40 DAT recorded the lowest uptake of N, P and K (1.25, 0.29 and 1.20 kg ha^{-1}) by weeds as compared to unweeded control (9.86, 3.34 and 10.22 NPK kg ha^{-1}).

Shendage (2015) conducted field research during *Kharif* 2015 at Dapoli (MS) and stated that, hand weeding at 30, 60 and 90 DAS recorded maximum total uptake of nutrients by rice (86.41, 24.67 and 76.00 NPK kg ha^{-1}) and minimum by weeds (3.67, 1.67 and 9.67 NPK kg ha^{-1}) in drilled rice as compared to pre-emergence application of Oxadiargyl + post emergence application of Bispyribac-Na (64.86, 14.78 and 62.33 NPK kg ha^{-1} by crop and 23.33, 10.67 and 18.33 NPK kg ha^{-1} by weeds).

2.2.5 Economics

Ramana *et al.* (2007) from their field experiment revealed that, the highest net returns (4210 Rs ha^{-1}) and

B: C ratio (1.37) were observed in rice treated with Oxadiargyl (PE) @ 80 g a.i. ha^{-1} followed by Almix (POE) @ 4 g a.i. ha^{-1} (505 Rs ha^{-1} and 1.04), respectively.

Kiran and Subramanyam (2010) observed the highest B: C ratio from Oxadiargyl (PE) 75 g ha^{-1} + Bispyribac (POE) 30 g ha^{-1} (3.06), which was at par with HW twice at 20 and 40 DAT (3.04) and Oxadiargyl (PE) 75 g ha^{-1} (2.81), due to reduced cost of weeding and increased grain and straw yields in sequential application of herbicides. Weedy check recorded the lowest B: C ratio (2.39) as compared to remaining treatments.

Verma *et al.* (2013) reported the highest gross returns (69757.92 Rs. ha^{-1}), net returns (47578.27 Rs. ha^{-1}) and the lowest B: C ratio (2.10) under two HW at 20 and 40 DAT and the lowest gross returns (64070.45 Rs. ha^{-1}), net returns (45165.77 Rs. ha^{-1}) and the highest B: C ratio (2.34) under post emergence application of Almix @ 4 g a.i. ha^{-1}. Weedy check recorded the lowest gross returns, net returns and B: C ratio from the rice crop.

Murthy and Reddy (2013) revealed from their two years study that HW at 20 and 40 DAS resulted in the highest gross and net returns which were comparable with pre-emergence application of Oxadiargyl @ 0.007 kg a.i. ha^{-1} + 1 HW at 40 DAS but pre-emergence application of Oxadiargyl @ 0.007 kg a.i. ha^{-1} + 1 HW at 40 DAS recorded the highest B: C ratio (4.99 and 4.75) as compared to HW at 20 and 40 DAS (4.80 and 4.58)

during both the years. The poorest performance of rice was recorded with unweeded check.

Mishra *et al.* (2013) conducted field research during *Kharif* 2010 and registered the highest B: C ratio of rice from pre-emergence application of Oxadiargyl (2.59) followed by post emergence application of Chloromuron-ethyl + Metsulfuron-methyl (2.39).

Naseeruddin and Subramanyam (2013) indicated that the highest net returns (68766 Rs. ha^{-1}) and B: C ratio (3.30) were realized with pre-emergence application of Oxadiargyl @ 75 g ha^{-1} + Azimsulfuron (POE) @ 30 g ha^{-1}, which were comparable with two hand weedings at 20 and 40 DAS (23699 Rs. ha^{-1} and 1.91) and both of them were significantly higher over rest of the weed management practices.

Ramachandra *et al* (2014) showed that, pooled data of two years indicated the highest gross returns (93177 Rs. ha^{-1}), net returns (57578 Rs. ha^{-1}) and B: C ratio (1.67) recorded under 2 HW at 20 and 40 DAT over weedy check (63666, 31167 Rs. ha^{-1} and 0.95) in transplanted *Kharif* rice.

Kumar *et al.* (2014) from their field experiment concluded that, higher net returns (57104 Rs. ha^{-1}) and B: C ratio (3.19) were achieved with pre-emergence application of Oxadiargyl 80% WP @ 70 g a.i. ha^{-1} + 1 hand weeding at 35 DAT as compared to 2 HW at 15 and 35 DAT (52720 Rs. ha^{-1} and 2.90). Unweeded control

recorded the lowest net returns and B: C ratio (Rs. 23085 ha^{-1} and 2.01) from transplanted rice.

Results of the study conducted by Maheswari *et al.* (2015) revealed that two hand weedings at 20 and 40 DAT gave the highest gross returns (85939 Rs. ha^{-1}), net returns (46039 Rs. ha^{-1}) and the lowest B: C ratio (1.15) because hand weeding is expensive due to high labour cost as compared to Oxadiagryl (PE) @ 100 g ha^{-1} + 2,4-D @ 0.8 kg ha^{-1} (80904, 52499 Rs. ha^{-1} and 1.84) and weedy check (55839, 30939 Rs. ha^{-1} and 1.24), respectively in transplanted rice.

Kumar *et al.* (2017) conducted field experiment during *Kharif* 2016 and observed that two hand weedings gave the highest gross returns (88338 Rs. ha^{-1}), net returns (47102 Rs. ha^{-1}) and B: C ratio (2.14) followed by Oxidiargyl (PE) + 1 HW (74257 Rs. ha^{-1}, 34520 Rs. ha^{-1} and 1.86).

Chakraborti *et al.* (2017) from their experiment revealed that the highest gross returns (50055 and 52143 Rs. ha^{-1}) were obtained from hand weedings at 15, 30 and 45 DAS followed by Pendimethalin (PE) at 1.0 kg ha^{-1} + 1 hand weeding at 30 DAS (47989 and 52122 Rs. ha^{-1}) and Fenoxaprop-p-ethyl (PE) at 60 g ha^{-1} + Almix (POE) at 4 g ha^{-1} (28399 and 29677 Rs. ha^{-1}), respectively during *Kharif* 2013 and 2014. Weedy check gave the lowest gross and net returns from direct seeded rice.

Kumar *et al.* (2017) showed that, the highest gross income (135951 Rs. ha^{-1}), net income (30149 Rs. ha^{-1}) and B: C ratio (1.28) with weed free check followed by Oxadiargyl (PE) + Bispyribac-Na (131895, 41340 Rs. ha^{-1} and 1.46).

Bhatt *et al.* (2017) carried out an investigation during *Kharif* 2013 and 2014 and observed that hand weeding twice at 25 and 45 DAT recorded the highest gross (102277 and 109721 Rs. ha^{-1}) and net returns (62278 and 68721 Rs. ha^{-1}) from transplanted rice as compared to Pretilachlor (PE) at 3 DAT + Almix (POE) at 25 DAT (98322 and 105832, 60833 and 67654 Rs. ha^{-1}, respectively) during both the years of study.

2.3 Interaction effect between establishment methods and weed management practices on *Kharif* rice

2.3.1 Effect on growth attributes

Mandal *et al.* (2013) carried out field experiment during *Kharif* 2008 and 2009 at the farmer's field at village Binuria, West Bengal, India and found that SRI method recorded the highest plant height (149.7 cm) and No. of effective tillers (230.8 m^{-2}) followed by conventional transplanting (148.6 cm and 228.1 m^{-2}) and drum seeding (147 cm and 203.4 m^{-2}). In weed management practices, weed free check recorded more plant height (144.7 cm) and No. of effective tillers (248.7 m^{-2}) as compared to post emergence application of Almix @ 4 g a.i. ha^{-1} (146.8 cm and 210.9 m^{-2}).

Raj *et al.* (2013) conducted a field experiment at Rice Research Station, Moncompu, Kerala during *Kharif* 2012 and concluded that, the manual transplanting with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAT recorded the highest plant height (94.9 cm) and tillers m^{-2} (326) than broadcasting of sprouted seeds with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAS (92.3 cm and 296 m^{-2}).

Hassan and Upasani (2015) conducted a field experiment at Agronomical Research Farm of Birsa Agricultural University, Ranchi during rainy season of 2009. From their studies they reported that SRI method of rice establishment along with two HW at 25 and 40 DAS/DAT recorded the highest plant height (92.17 cm) and number of tillers (236 m^{-2}) as compared to transplanting (89.09 cm and 235 m^{-2}), drum seeding (88.24 cm and 235 m^{-2}) and broadcasting (87.26 cm and 212 m^{-2}) methods of rice establishment and other weed management practices, respectively.

Kikon and Gohain (2016) conducted field experiments during *Kharif* 2009 and 2010. They reported that broadcasting method along with 2 HW at 20 and 40 DAS recorded the highest plant height, number of tillers and dry weight of plant as compaed to remaining treatments during both the years.

Tadepalli and Singh (2017) conducted a field experiment at Crop Research Farm, Department of

Agronomy, SHUATS, Allahabad, (UP) during *Kharif* 2016 and concluded that transplanting with two hand weedings at 15 and 30 DAS recorded the highest plant height (102 cm), No. of tillers hill^{-1} (26) and dry weight hill^{-1} (74.82 g) as compared to broadcasting of sprouted rice seeds with two hand weedings at 15 and 30 DAS (101.9 cm, 16 and 67.61 g).

2.3.2 Effect on yield attributes and yield

The results of the field experiment conducted during *Kharif* 2003 and 2004. Results revealed that, the transplantig with two hand weedings at 30 and 60 DAT produced higher number of rice grains panicle^{-1} (133.5), test weight (28.7 g) and grain yield (4303 kg ha^{-1}) followed by sowing of pre-germinated seeds on puddled soil (109.2, 28.7 g and 3675 kg ha^{-1}) and dry seeding after conventional tillage (96.3, 28.4 g and 2663 kg ha^{-1}), respectively during both the years of study (Singh *et al.* 2005).

Baloch *et al.* (2006) conducted field trial at the Agricultural Research Institute, Dera, NWFP, Pakistan during 2002 and 2003. They observed that, the transplanting method produced more number of panicles m^{-2} (363.25 and 425.81) and grain yield (5.78 and 8.54 t ha^{-1}) during both the years as compared to drum seeding. Significantly higher number of panicles (381.50 and 512.25 m^{-2}) and grain yield (4.78 and 6.53 t ha^{-1}) was found in hand weeding during both the years.

The lowest number of panicles and grain yield of rice was produced in weedy check.

Hassan *et al.* (2010) conducted a field experiment during *Kharif* 2008 and 2009. Results revealed that, the interaction of rice establishment and weed control methods was found to be significant with respect to grain yield. Transplanting associated with two hand weedings produced maximum and significantly higher grain yield (3794 kg ha^{-1}) of rice over all other combinations of rice establishment and weed control methods except transplanting with Pyrazosulfuron + mechanical weeding (4244 kg ha^{-1}).

Shan *et al.* (2012) reported that transplanting method proved superior over drum seeded rice. Among the weed management practices, Butachlor (PE) @ 1.5 kg a.i. ha^{-1} + Almix (POE) @ 4.0 g a.i. ha^{-1}) proved to be superior over other weed management practices with respect to grain yield and yield attributes. Maximum grain yield and weed control efficiency were recorded in transplanted rice with the application of Butachlor (PE) @ 1.5 kg a.i. ha^{-1} a + Almix (POE) @ 4.0 g a.i. ha^{-1}.

Mandal *et al.* (2013) reported that, the number of filled grains (97.8), test weight (22.87), grain (3.23 t ha^{-1}) and straw (9.52 t ha^{-1}) yield of rice were the highest and significantly superior under SRI method over conventional transplanting and drum seeding which were at par with each other. Among the weed management practices weed free check registered

significantly higher yield attributes over other treatments.

Raj *et al.* (2013) results revealed that, the manual transplanting with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAT recorded the highest grain and straw yield of rice (5131 and 9135 kg ha^{-1}) as compared to broadcasting of sprouted seeds with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAS (4566 and 8505 kg ha^{-1}). Drum seeding recorded the lowest yield of rice during *Kharif* 2012.

Parameswari and Srinivas (2014) conducted a field experiment during *Kharif* season of 2010 and 2011. Study revealed that, the higher grain (4265 and 4438 kg ha^{-1}) and straw (5364 and 5697 kg ha^{-1}) yield of rice was obtained under SRI method along with two HW at 20 and 40 DAT as compared to direct sowing of sprouted seeds under puddled condition (3894 and 4075, 4948 and 5300 kg ha^{-1}), respectively during both the years.

Talla and Jena (2014) conducted a field study during *Kharif* 2011 at Agronomy Research Farm, Central Research Station, Orissa and concluded that, SRI method recorded the highest grain and straw yield (5.02 and 5.85 t ha^{-1}) of rice followed by transplanting (4.36 and 5.41 t ha^{-1}) and drum seeding (4.03 and 4.98 t ha^{-1}) methods, respectively. Among weed management practices, HW twice at 20 and 40 DAS/DAT recorded

significantly higher grain and straw yield (4.53 and 5.44 t ha^{-1}) as compared to pre-emergence application of Pyrazosulfuron ethyl @ 20 g ha^{-1} (4.18 and 4.87 t ha^{-1}). Weedy check recorded the lowest yield of rice as compared to other treatments.

Kumar *et al.* (2014) conducted a field trial during *Kharif* 2007 to find out the suitable crop establishment method and weed management practice in rice and concluded that, the number of effective tillers (297.98 m^{-2}), number of grain panicle^{-1} (143.84), grain (3711 kg ha^{-1}) and straw yield (5808 kg ha^{-1}) produced higher under broadcast in puddled condition and among weed management practices, weed free recorded higher number of productive tillers (361.37 m^{-2}), number of grains panicle^{-1} (162.48), grain and straw yield (4238 and 6573 kg ha^{-1}), respectively as compared to other etablishment methods and weed management practices.

Kunnathadi *et al.* (2014) conducted a field research at Pattambi, Kerala during *Kharif* 2007 and 2008. Results revealed that SRI with pre-emergence herbicide + 1 hand weeding at 30 DAT produced more number of productive tillers hill^{-1} (23.5), panicle length (20.4 cm), number of filled grains (82) and straw yield (2.29 t ha^{-1}) of transplanted rice as compared to conventional system with pre-emergence herbicide + 1 hand weeding at 30 DAT (10.3, 18.7 cm, 81.9 and 2.04 t ha^{-1}), respectively based on pooled mean of two years.

Hassan and Upasani (2015) found that the transplanting method of rice establishment recorded higher rice grain yield (3925 kg ha^{-1}) as well as straw yield (6454 kg ha^{-1}). It also recorded higher effective tillers m^{-2} (236), panicle length (21.15 cm) and number of filled grain panicle^{-1} (68) as compared to rice grown under drum seeded and broadcast methods, respectively. Among weed control methods two HW at 25 and 40 DAS/DAT recorded the highest yield and yield attributes of rice crop as compared to other methods.

Islam and Kalita (2015) conducted a field experiment at farmer's field of Puthimari village Meghalaya, India during 2010 and 2011 in the *Kharif* season. The pooled data of two years revealed that significantly higher grain and straw yield of 5.63 and 7.97 t ha^{-1}, respectively was obtained in SRI method which was statistically similar to conventional rice culture (CRC). Among the weed management practices, significantly higher grain and straw yield was obtained with HW twice at 20 and 40 DAT (5.89 and 8.26 t ha^{-1}) which was similar to Butachlor (PE) @ 1.5 kg a.i. ha^{-1} at 3 DAT + cono-weeding at 20 DAT (5.78 and 7.97 t ha^{-1}) but remained superior over unweeded control.

Tadepalli and Singh (2017) conducted a field trial during *Kharif* 2016. Results revealed that transplanting with two hand weedings at 15 and 30 DAS/DAT recorded the highest No. of grains panicle^{-1} (202), grain and straw

yield (6118 and 7526 kg ha^{-1}) of rice as compared to broadcasting of sprouted seeds with two hand weedings at 15 and 30 DAS/DAT (161, 4928 and 6456 kg ha^{-1}), respectively.

Paliwal *et al.* (2017) conducted research at Crop Research Centre of G. B. Pant University of Agriculture and Technology, Pantnagar during *Kharif* 2015 and 2016. Results indicated that conventional transplanted rice with recommended herbicide + 1 hand weeding recorded more number of panicles m^{-2}, No. of grains panicle^{-1}, 1000 grain weight, grain and straw yield as compared to other establishment methods and weed management practices.

Singh *et al.* (2017) undertaken a field experiment for two years during *Kharif* 2012 and 2013 and reported that weed free check produced maximum grain (5.44 and 5.23 t ha^{-1}) and straw (7.52 and 7.33 t ha^{-1}) yield of direct seeded rice compared to Oxadiargyl (PE) @ 90 g ha^{-1} + Bispyribac-Na (POE) @ 25 g ha^{-1} (3.91 and 3.74 t ha^{-1}, 6.21 and 6.05 t ha^{-1}), respectively.

2.3.3 Effect on weed density

Singh *et al.* (2005) conducted a field experiment during *Kharif* 2003 and 2004 and observed that, conventional transplanting with two hand weedings at 30 and 60 DAS/DAT recorded lowest dry weight of weeds (1.00 g m^{-2}) as compared to wet seeded (4.03 g m^{-2}) and dry seeded (4.81 g m^{-2}) rice.

Baloch *et al.* (2006) reported that, transplanted rice produced lower weed population (5.18 and 7.56 m^{-2}) and dry weight of weeds at 90 DAS (18.93 and 66.68 g m^{-2}) than direct seeding (9.31 and 15.18 m^{-2}, 58.50 and 249.43 g m^{-2}) during either year of study. Similarly, hand weeding showed significantly lower weed density and dry weight of weeds in transplanted (4.12 and 5.50 g m^{-2}) as well as direct seeded rice (13.25 and 87.25 g m^{-2}), respectively as compared to other treatments during either cropping season.

Mandal *et al.* (2013) reported that among rice establishment methods, SRI had the lowest weed population (2.65 m^{-2}) and dry weight of weeds (3.23 g m^{-2}) and drum seeding had the highest weed population (3.84 m^{-2}) and dry weight of weeds (4.73 g m^{-2}). Treatment weed free check, recorded the lowest weed population, dry weight of weeds and the highest weed control efficiency (0.71 m^{-2}, 0.71 g m^{-2} and 100%) at 60 DAS/DAT, respectively.

Raj *et al.* (2013) concluded that, manual transplanting with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAT recorded the lowest dry weight of weeds at 60 and 90 DAS/DAT (20.38 and 53.82 g m^{-2}) as compared to broadcasting of sprouted seeds with pre-emergence application of pyrazosulfuron ethyl 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAS (46.42 and 66.25 g m^{-2}), respectively.

Parameswari and Srinivas (2014) conducted a field experiment during *Kharif* season of 2010 and 2011 at College of Agriculture, Rajendranagar, Hyderabad and reported that the total weed density and dry weight of weeds were higher (43.49 m^{-2} and 39.47 g m^{-2}) in direct sowing of sprouted seeds under puddled condition as compared to transplanting (33.73 m^{-2} and 32.20 g m^{-2}) and SRI (37.67 m^{-2} and 33.67 g m^{-2}) methods which might be due to failure to maintain flooded conditions in rice field. Among the weed management practices HW twice at 20 and 40 DAS in direct seeded rice, transplanted rice and in SRI method recorded significantly lower weed count (29.31 and 25.65 m^{-2}) and weedy weight (11.25 and 8.74 g m^{-2}) as compared to other treatments.

Kunnathadi *et al.* (2014) from their field study carried out during *Kharif* 2007 and 2008 in the lateritic sandy clay loam soils and indicated that, SRI with pre-emergence herbicide followed by 1 hand weeding at 30 DAT recorded the lowest weed density (11.27 m^{-2}) and dry weight of weeds (5.13 g m^{-2}) in transplanted rice as copmared to other treatment combinations.

Islam and Kalita (2015) conducted a field research at farmer's fields in the years 2010 and 2011 during *Kharif* season and observed that, SRI method with two hand weedings at 20 and 40 DAT recorded the lowest weed biomass (16.1 g m^{-2}) in transplanted rice over SRI method with control plot (28.6 g m^{-2}).

Hassan and Upasani (2015) carried out field research during *Kharif* 2009. Results revealed that the direct seeded and drum seeded rice registered higher weed population and weed dry matter at 30 and 60 DAS/DAT as compared to SRI and transplanted methods due to puddling situation. Hand weeding recorded the highest weed control efficiency and the lowest weed index as compared to other weed management methods.

Kumar *et al.* (2017) from their field experiment conducted during *Kharif* 2016 and reported that, the interaction between establishment methods and weed management practices was significant for density of grasses, sedges and broad leaved weeds at 60 DAS/DAT. The lowest density of grasses, sedges and broad leaved weeds was recorded with transplanted rice in combination with pre-emergence application of Pretilachlor + HW at 20 and 40 DAS/DAT which was significantly superior over hand weeding at 20 and 40 DAS/DAT.

Tadepalli and Singh (2017) conducted a field research during *Kharif* 2016 and revealed that, transplanting with two hand weedings recorded the lowest weed density (5.0 m^{-2}) and weed dry weight (1.78 g m^{-2}) over broadcasting of sprouted rice seeds with two hand weedings (6.0 m^{-2} and 1.98 g m^{-2}), respectivel as compared to remaning treatments.

2.3.4 Effect on quality and uptake of nutrients

Parameswari and Srinivas (2014) conducted field trial during *Kharif* 2010 and 2011 and found that, the nutrient uptake by rice grain (62.84 and 65.44, 12.40 and 12.92, 12.13 and 12.65 NPK kg ha^{-1}) in transplanting and SRI method (59.96 and 62.38, 11.96 and 12.44, 12.13 and 12.65 NPK kg ha^{-1}, respectively during both the years were significantly higher as compared to direct seeded rice (sprouted seeds) under puddled condition (54.27 and 56.77, 10.19 and 10.66, 10.01 and 10.48 NPK kg ha^{-1}, respectively). Among weed management practices, HW twice at 20 and 40 DAS recorded significantly higher uptake of nitrogen (80.35 and 83.96 kg ha^{-1}) phosphorus (16.07 and 16.79 kg ha^{-1}) and potassium (15.51 and 16.21 kg ha^{-1}) as compared to remaining treatments under study and nutrients removal by weeds in direct seeded rice (sprouted seeds) under puddled condition was significantly higher as compared to transplanting and SRI method during both the years.

Talla and Jena (2014) observed that maximum uptake of nutrients was recorded in SRI method (63.34 and 25.48 kg ha^{-1} of N, 17.24 and 5.55 kg ha^{-1} of P, 13.08 and 101.03 kg ha^{-1} of K in grain and straw, respectively) followed by transplanting, drum seeding and line sowing. In weed management practices, two HW at 20 and 40 DAS/DAT recorded higher uptake of nutrients (54.84 and 21.74 kg ha^{-1} of N, 13.59 and 4.34 kg ha^{-1} of P, 10.42 and 90.22 kg ha^{-1} of K in grain and

straw, respectively) as compared to other treatments. Minimum removal of nutrients by rice grain and straw was observed in weedy check.

Kunnathadi *et al.* (2014) conducted research during *Kharif* 2007 and 2008 and observed that conventional transplanting with two hand weedings at 20 and 40 DAT recorded the lowest uptake of N, P and K by weeds (1.19, 0.25 and 0.71 NPK kg ha^{-1}) in transpalnted rice as compared to other establishment methods and weed management practices during both the years of study.

Islam and Kalita (2015) showed that, the maximum total uptake of N (110.41 kg ha^{-1}), P (25.21 kg ha^{-1}) and K (49.27 kg ha^{-1}) by rice was recorded in SRI method with hand weeding twice at 20 and 40 DAT. Among establishment methods SRI left significantly the highest amount of available N, P and K (257, 9.24 and 268 kg ha^{-1}, respectively) in soil over conventional rice culture and in weed management methods, hand weeding twice at 20 and 40 DAT reocrded higher available N, P and K (264, 9.55 and 283 kg ha^{-1}, respectively) in soil after harvest of rice crop as compared to other treatments.

Hassan and Upasani (2015) carried out field experiment during rainy season of 2009 and reported that maximum removal of nutrients by weeds was observed under drum seeded rice (11.72, 1.91 and 16.27 NPK kg ha^{-1}) followed by transplanting (10.37, 1.69 and 14.38 NPK kg ha^{-1}) and SRI method (9.08, 1.48 and 12.60

NPK kg ha^{-1}), respectively. In weed management practices, two HW at 25 and 30 DAS/DAT recoded minimum uptake of nutrients by weeds (4.65, 0.76 and 6.46 NPK kg ha^{-1}) as compared to weedy check.

2.3.5 Economics

Raj *et al.* (2013) conducted a field trial during *Kharif* 2012 to study the effect of different establishment techniques on yield and economics of rice cultivation and observed that, the manual transplanting with Pyrazosulfuron ethyl (PE) 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAT gave the highest gross returns (96362 Rs. ha^{-1}), net returns (63302 Rs. ha^{-1}) and the lowest B: C ratio (2.92) as compared to broadcasting of sprouted seeds with Pyrazosulfuron ethyl (PE) 10% WP @ 20 g a.i. ha^{-1} + 1 HW at 40 DAS (86127, 56777 Rs. ha^{-1} and 2.93), respectively.

Kunnathadi *et al.* (2014) indicated that, conventional transplanting (CT) with pre-emergence herbicide + 1 hand weeding at 30 DAT gave more net returns (4433 Rs. ha^{-1}) and B: C ratio (1.12) from transplanted rice over CT with two hand weedings at 20 and 40 DAT (677 Rs. ha^{-1} and 1.02) respectively, during both the years.

Tadepalli and Singh (2017) conducted a field trial during *Kharif* 2016. They found that transplanting with two hand weedings gave the highest gross returns (107440 Rs. ha^{-1}), net returns (Rs. 79751 ha^{-1}) and B: C ratio (2.88) over broadcasting of sprouted rice seeds

with two hand weedings (87320, 54054 Rs. ha^{-1} and 1.62).

Paliwal *et al.* (2017) conducted research during *Kharif* 2015 and 2016 and repoted that conventional transplanted rice gave higher gross returns (101644 and 104133 Rs. ha^{-1}), net returns (66000 and 67488 Rs. ha^{-1}) and B: C ratio (1.8 and 1.8) than direct seeded rice. Among weed management practices, recommended herbicide + 1 hand weeding gave higher gross returns (105811 and 109212 Rs. ha^{-1}), net returns (75422 and 78112 Rs. ha^{-1}) and B: C (2.6 and 2.6) ratio as compared to unweeded control.

CHAPTER III

MATERIALS AND METHODS

The present investigation "Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods" was conducted at Agronomy Farm, College of Agriculture, Dapoli during *Kharif* season of 2016 and 2017. The details of the material used and the methodology employed throughout the course of investigation are presented in this chapter.

3.1 Selection of experimental site

The field experiment was laid out in plot No. 24 of 'B' block of Agronomy Farm, College of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri during *Kharif* season of 2016 and 2017. The selection of the site was considered on the basis of suitability of the land for the cultivation of rice.

3.2 Soil

The topography of experimental plot was uniform and levelled. The plot was well drained.

The representative soil samples collected from 0 to 30 cm soil depth at random from 10 spots covering the entire experimental area before laying out an experiment were mixed thoroughly and a composite sample was analysed for various physico-chemical properties. The data pertaining to these parameters and techniques used for determination of these properties are presented in Table 1.

The soil analysis (Table 1) indicated that the soil of the experimental plot was sandy clay loam in texture, low in available nitrogen, phosphorus and potassium, moderately high in organic carbon and slightly acidic in reaction. It was lateritic in nature and reddish brown in colour.

Table 1. Initial physico-chemical properties of soil from the experimental field

Particulars	Values	Methods used
A) Mechanical analysis		
i) Sand (%)	50.19	Bouyoucos hydrometer (Jackson, 1973)
ii) Silt (%)	22.16	
iii) Clay (%)	27.65	
iv) Textural class	Sandy clay loam	Using textural triangle given by ISSS
B) Chemical analysis		
v) Soil pH (1:2.5)	5.80	Potentiometric method (Jackson, 1973)
vi) EC (dSm^{-1})	0.063	
vii) Organic carbon (%)	0.94	Walkey and Black's wet method (Black, 1965)
viii) Available N (kg ha^{-1})	216.12	Alkaline permanganate method (Subbaih and Asija, 1956)
ix) Available P_2O_5 (kg ha^{-1})	9.22	Bray's method (Bray's and Kurtz, 1945)
x) Available K_2O (kg ha^{-1})	205.75	Flame photometer (Jackson, 1973)
C) Physical properties		
xi) Bulk density (g cc^{-1})	1.55	Clod coating method (Black, 1965)
xii) Particle density (g cc^{-1})	2.64	Pycnometer method (Black, 1965)
xiii) Porosity (%)	36.55	Keen box method (Piper, 1956)

3.3 Climate and weather conditions

Geographically Agronomy Farm, College of Agriculture, Dapoli is situated at $17^0.45'$ N latitude and $73^0.1'$ E longitude having altitude of 250 meters above the mean sea level.

Climatologically, this area falls under subtropical region with mean annual precipitation of 3500 mm, which is generally received from June to October in 95 to 110 days. Weather data

was recorded at the meteorological observatory of Agronomy Farm, College of Agriculture, Dapoli from 23th Met. Week to 41th Met. Week (4 June to 14 October) during year 2016 and 2017. These weekly meteorological observations are presented in Table 2 and graphically depicted in Fig. 1 and 2.

The meteorological observations presented in Table 2 revealed that, the climatic conditions were moderate during both the years. The mean maximum temperatures ranged from 27.0^{0}C to 34.0^{0}C and 27.4^{0}C to 31.8^{0}C and mean minimum temperatures from 21.4^{0}C to 24.9^{0}C and 22.7^{0}C to 25.2^{0}C during the crop season in the years 2016 and 2017, respectively. The mean temperature variation was more or less same during both the years.

The relative humidity during entire crop season of 2016 ranged from 91 to 99 per cent during morning and 70 to 95 per cent during afternoon, respectively. Whereas, during 2017 the corresponding values of relative humidity ranged between 86 to 98 per cent and 73 to 91 per cent, respectively. The data indicated that the mean relative humidity during morning hours (RH-I) and afternoon hours (RH-II) was higher during 2016 as compared to 2017.

During the crop growth period, an amount of 4492.8 and 3568.4 mm of rainfall in 100 and 105 days was received during 2016 and 2017, respectively. The higher rainfall during 2016 resulted in reducing weed density due to anaerobic conditions, as compared to 2017.

A glance at the solar radiation in terms of bright sunshine hours during the crop seasons of both the years revealed that, during 2016 there was more cloud cover as compared to 2017. The total hours of bright sunshine during crop growth period of 2016 were 39.3 hours as against 51.1 hours during 2017. The bright sunshine hours during 2016 and 2017 ranged from 0.0 to 5.8 hours and 0.7 to 6.2 hours, respectively.

Table 2. Meteorological data recorded during the crop growth period (*Kharif* 2016 and 2017)

Met. Week (No.)	Period	Temperature (°C)				Relative humidity (%)				Rainfall (mm)		No. of Rainy days		Sunshine (hrs/day)	
		Max.		Min.		RH-I		RH-II							
		2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
23	04.06 - 10.06	34.0	31.8	24.8	24.1	91	93	70	73	40.0	293.8	2.0	6.0	3.2	5.4
24	11.06 - 17.06	31.4	29.5	24.9	24.1	91	92	76	77	93.5	259.6	5.0	4.0	4.7	2.1
25	18.06 - 24.06	29.6	30.4	23.1	25.2	98	86	93	80	298.7	67.0	7.0	6.0	1.4	6.2
26	25.06 - 01.07	27.2	29.5	22.6	24.5	98	90	97	87	792.5	411.5	7.0	7.0	0.0	1.4
27	02.07 - 08.07	28.5	29.5	23.6	24.3	94	93	92	86	462.6	140.0	7.0	7.0	0.2	4.1
28	09.07 - 15.07	28.4	29.1	23.3	23.8	95	92	89	84	256.8	244.0	7.0	7.0	1.4	2.0
29	16.07 - 22.07	27.3	27.4	22.4	23.9	99	95	95	91	403.0	519.6	7.0	7.0	0.6	0.7
30	23.07 - 29.07	28.8	28.5	22.4	24.7	98	90	85	85	268.0	123.6	6.0	7.0	0.7	0.7
31	30.07 - 05.08	27.6	29.0	22.7	23.9	97	94	94	87	481.5	142.6	7.0	7.0	0.6	4.2
32	06.08 - 12.08	27.7	29.1	23.6	23.9	94	95	92	81	182.7	99.2	7.0	7.0	0.4	2.9
33	13.08 - 19.08	29.3	29.1	24.3	23.9	91	95	84	81	39.0	40.8	4.0	6.0	1.8	2.3
34	20.08 - 26.08	28.9	28.6	23.4	23.5	95	96	87	87	73.6	171.0	6.0	6.0	2.0	1.2
35	27.08 - 02.09	28.4	28.2	22.6	23.6	95	95	88	87	138.4	195.4	7.0	7.0	1.1	1.0
36	03.09 - 09.09	29.4	30.1	21.6	23.2	94	95	72	85	36.9	53.2	3.0	2.0	5.3	5.4
37	10.09 - 16.09	29.9	31.3	22.2	23.9	93	96	82	80	55.8	85.4	2.0	4.0	3.3	5.1
38	17.09 - 23.09	27.0	27.5	22.5	22.7	98	98	94	91	582.4	565.6	7.0	5.0	1.0	1.1
39	24.09 - 30.09	29.1	30.1	22.6	22.7	96	94	82	83	88.1	31.4	2.0	3.0	3.5	4.2
40	01.10 - 07.10	27.7	31.7	21.4	23.2	97	95	83	85	189.1	19.7	6.0	3.0	2.4	2.1
41	08.10 - 14.10	30.4	30.3	22.3	23.6	94	96	83	82	10.2	105.0	1.0	4.0	5.8	2.0
Mean/ Total		**29.0**	**29.5**	**23.0**	**23.8**	**95.3**	**93.7**	**86.2**	**83.7**	**4492.8**	**3568.4**	**100**	**105**	**39.3**	**51.1**

3.4 Cropping history of the experimental plot

The cropping sequence followed on the experimental plot for previous four years of the experimentation up to the completion of the experiment is presented in Table 3.

Table 3. Cropping history of the experimental plot

Year	**Season**	
	Kharif	***Rabi***
2011-12	Rice	Cowpea
2012-13	Rice	Cowpea
2013-14	Rice	Wal
2014-15	Rice	Fallow
2015-16	Rice (Experimental crop)	Fallow
2016-17	Rice (Experimental crop)	-

3.5 Experimental details

1.	Crop	: Rice
2.	Variety	: Ratnagiri-1
3.	Experimental design	: Strip plot design
4.	No. of replications	: Three
5.	Total No. of plots	: 75
6.	Spacing	: Drum seeder-22.5 cm between rows SRI method-25 cm X 25 cm Conventional transplanting-20 cm X 15 cm
7.	Gross plot size	: 4.5 m X 3.6 m
8.	Net plot size	: 4.20 m X 3.15 m, For M_1, M_2 and M_3 4.00 m X 3.10 m, For M_4 4.20 m X 3.20 m, For M_5
9.	RDF	: 100:50:50 $N:P_2O_5:K_2O$ Kg ha^{-1}
10.	Season	: *Kharif,* 2016 and 2017

3.6 Treatment details

The field experiment was laid out in a strip plot design comprising of twenty five treatment combinations replicated thrice. The horizontal strips comprised five rice establishment methods and vertical strips consisted five weed management practices. The treatment details along with the symbols used in the layout plan are as hereunder.

Treatments	Symbols used
A) Horizontal strips: (Rice establishment methods)	
1. Sowing of dry seeds by drum seeder at onset of monsoon	$\mathbf{M_1}$
2. Sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field	$\mathbf{M_2}$
3. Broadcasting of sprouted seeds (*Rahu)* on puddled field	$\mathbf{M_3}$
4. SRI (System of Rice Intensification) method	$\mathbf{M_4}$
5. Conventional transplanting	$\mathbf{M_5}$
B) Vertical strips: (Weed management practices)	
1. Need based hand weedings (2 HW at 20/30 and 40/60 DAS/DAT)	$\mathbf{W_1}$
2. Pre-emergence application of Oxadiargyl 80 WP @ 100 g ha^{-1} + 1 hand weeding at 20/30 DAS/DAT	$\mathbf{W_2}$
3. Pre-emergence application of Oxadiargyl 80 WP @ 100 g ha^{-1} + 1 hand weeding at 40/60 DAS/DAT	$\mathbf{W_3}$
4. Pre-emergence application of Oxadiargyl 80 WP @ 100 g ha^{-1} + post-emergence application of Almix 20 WP @ 4 g ha^{-1}	$\mathbf{W_4}$
5. Unweeded control	$\mathbf{W_5}$

3.7 Plan of layout

The experiment was conducted at the same site during both the seasons without changing the randomisation of the treatments. The plan of layout is depicted in Fig. 3.

3.8 Cultural operations

The schedule of the cultural operations carried out in the experimental field during years 2016 and 2017 is presented in Table 4.

3.8.1 Preparatory tillage

Ploughing of the experimental field was done with a tractor-operated plough followed by one operation by tractor drawn rotavator for clod crushing and bringing the soil in fine tilth. After clod crushing, planking was done to bring the field into level.

3.8.2 Layout of the experimental plot

Experiment was laid out after the field preparation in strip plot design. There were three replications and 25 plots in each replication. The rice establishment methods were alloted in horizontal strips and weed management practices were assigned in vertical strips of the replication by using random number table.

3.8.3 Seed material

The truthful seed of long bold seeded early rice variety, Ratnagiri-1 was used in the present investigation. The seed material was obtained from Department of Agronomy, College of Agriculture, Dapoli. The duration of variety is 110 to 115 days and it is a cross between I. R. 8 X Ratnagiri-24 released by Dr. B.S.K.K.V., Dapoli in the year 1986.

3.8.4 Seed treatment

Seeds were treated with thiram @ 3 g kg^{-1} of seeds, before sowing in order to protect the crop against seed and soil born fungal diseases.

3.8.5 Raising of seedlings

3.8.5.1 For conventional transplanting

The soil was ploughed twice by tractor drawn plough and peg tooth cultivator and subsequently brought under fine tilth. The raised beds of 10 m length, 1 m breadth and 10 cm height were prepared.

Then well decomposed FYM @ 100 kg 100 sq. m^{-1} was spread and mixed with soil over the beds. Urea was applied @ 1 kg 100 sq. m^{-1} at the time of sowing. The fungicide treated seeds of rice variety Ratnagiri-1 were sown in line at 8-10 cm apart parallel to width and at 2-3 cm depth. Seed germination started from third day of sowing and it was completed by the fifth day. Top dressing with urea @ 1 kg 100 sq. m^{-1} area was done 15 days after sowing. The need based plant protection and weed control measures were carried out in the nursery.

3.8.5.2 For SRI method

The seedlings were raised by modified mat nursery. Beds were prepared by using plastic sheet of 1.5 m width. Plastic paper was spread on the soil. Boundaries of the paper were raised up to 5-6 cm height with half of bricks. Then silt and FYM mixture of 1:1 proportion was spread on the plastic paper. Seeds were first soaked in water for 24 hours and kept in moist gunny bag for 24 hours. Sprouted seeds were sown on the bed and covered with silt. Beds were watered as and when required. Seedlings became ready for transplanting within 12 days.

3.8.6 Drum seeding of dry seeds

In this treatment fungicide treated seeds were sown in the field by using manually operated four coulter drum seeder at about 3 to 5 cm depth with a row spacing of 22.5 cm. After sowing, the seeds were covered with soil.

3.8.7 Drum seeding and broadcasting of sprouted seeds

In case of sowing of sprouted seeds (*Rahu*) by drum seeder and broadcasting of sprouted seeds (*Rahu*) on puddled field the fungicide treated seeds were first soaked in water for 24 hours and kept in moist gunny bag for 24 hours. The sprouted seeds were sown in the field by using manually operated four coulter drum seeder at about 3 to 5 cm depth with the row spacing of 22.5 cm on puddled field. In broadcasting method sprouted seeds were spread on the puddled field.

3.8.8 Transplanting of seedlings

Twenty one days old seedlings were transplanted at the spacing of 20 cm X 15 cm for conventional transplanting. In SRI method healthy and vigorous seedlings were uprooted 12 days after sowing. While uprooting the seedlings cares were taken that the roots of seedlings were not disturbed. One seedling was transplanted hill^{-1} at a spacing 25 cm X 25 cm.

3.8.9 FYM and fertilizer application

Uniform application of FYM @ 7.5 t ha^{-1} was made after preparation of experimental layout. The crop was fertilized with 100 kg N, 50 kg P_2O_5 and 50 kg K_2O hectare^{-1}. At the time of sowing/transplanting of rice seeds/seedlings, 40 kg N and full dose of P_2O_5 and K_2O was applied as basal dose. Top dressing of 40 kg N was made at 30 days after sowing/transplanting (tillering stage) and remaining 20 kg at 60 days after sowing/transplanting (panicle initiation stage).

3.8.10 Gap filling and thinning

Gap filling and thinning was done on 10 day after sowing/transplanting, during both the years in order to maintain the uniform plant population in the experimental area.

3.8.11 Weed management

Weed management practices in rice established by different methods were followed as per the treatments. Two hand weedings were carried out at 20/30 and 40/60 DAS/DAT as per the treatments and spraying of herbicides *i.e.* Oxadiargyl 80 WP @ 100 g ha^{-1} and Almix (Chlorimuron + Metasulfuron) 20 WP @ 4 g ha^{-1} was done as a pre emergence and post emergence, respectively as per the treatments.

The details regarding chemistry of herbicides which are used in the experiment are as hereunder.

Sr. No.	Chemical name	Trade names	Chemical formulae	Mode of action of herbicide
1.	Oxadiargyl (PE)	Topstar	$C_{15}H_{14}Cl_2N_2O_3$	Inhibition of proto-porphyrinogen oxidase (PPO)
2.	Chlorimuron + Metasulfuron (POE)	Almix	$C_{13}H_{11}ClN_4O_6$	Inhibits aceto-lactate synthase, which regulates plant growth

3.8.12 Plant protection measures

Since the seeds were treated with thiram before sowing, the crop was free from fungal diseases throughout growth period. The crab attack was observed at an early growth stage which was controlled by the application of poison baits prepared by mixing phorate 10 G. in cooked rice.

3.8.13 Harvesting and threshing

The rice crop was harvested at physiological maturity. Single border row of the gross plots was removed first to eliminate border effect. Harvesting was done with '*Vaibhav*' sickle close to the ground by employing manual labours.

The harvested produce was kept in respective plots for sun drying. Plot wise threshing was done 2-3 days after sun drying. Grains were separated by winnowing and plot wise rice grain and straw yield was recorded by weighing the produce. Harvesting, threshing, winnowing and drying dates of both the years are given in Table 4.

Table 4. Schedule of field operations carried out in the experimental plot

Sr. No.	Field operations	Freq-uency	Dates of operation 2016	2017
A) Nursery preparation				
1.	Tractor ploughing	1	25-05-16	24-05-17
2.	Clod crushing by tractor drawn rotavator	1	30-05-16	28-05-17
3.	Planking with tractor	1	01-06-16	30-05-17
4.	Stubble picking and preparation of nursery beds	1	02-06-16	03-06-17
5.	Manuring of nursery beds	1	06-06-16	05-06-17
6.	Application of basal dose of fertilizers on nursery beds	1	10-06-16	07-06-17
7.	Sowing of dry and sprouted seeds in nursery beds for conventional transplanting and SRI method	1	10-06-16	07-06-17
8.	Top dressing of urea to nursery beds	1	16-06-16	13-06-17
B) Preparation of experimental field				
1.	Tractor ploughing	1	25-05-16	24-05-17
2.	Clod crushing by tractor drawn rotavator	1	30-05-16	28-05-17
3.	Levelling and planking with tractor	1	01-06-16	30-05-17
4.	layout of the experimental plot	1	04-06-16	01-07-17
5.	Application of FYM	1	06-06-16	05-06-17
6.	Puddling for drum seeding and broadcasting of sprouted seeds	1	11-06-16	08-06-17
7.	Puddling for SRI and conventional transplanting methods and uprooting of seedlings	1	24-06-16 30-06-16	18-06-17 28-06-17
C) Sowing/transplanting and basal dose application				
1.	Application of basal dose of fertilizers and sowing of dry seeds by drum seeder	1	10-06-16	07-06-17
2.	Seeds soaked in water for drum seeding and broadcasting of sprouted seeds *(Rahu)*	1	10-06-16	07-06-17
3.	Application of basal dose of fertilizers and sowing of sprouted seeds *(Rahu)* by drum seeder and broadcasting	1	12-06-16	9-06-17
4.	Application of basal dose of fertilizers and transplanting of rice by SRI and conventional methods	1	22-06-16 01-07-16	19-06-17 29-06-17

D) Weed management practices as per the treatments				
1.	Hand weeding at 20/30 and 40/60 DAS/DAT			
	M_1- Drum seeding of dry seeds	2	30-06-16 20-07-16	27-06-17 17-07-17
	M_2 and M_3- Drum seeding and broadcasting of sprouted seeds	2	02-07-16 22-07-16	29-06-17 19-07-17
	M_4- SRI method	2	22-07-16 22-08-16	19-07-17 19-08-17
	M_5- Conventional transplanting	2	01-08-16 01-09-16	29-07-17 29-08-17
2.	Spraying of Oxadiargyl (PE) and Almix (POE)			
	M_1- Drum seeding of dry seeds	2	13-06-16 05-07-16	09-06-17 03-07-17
	M_2 and M_3- Drum seeding and broadcasting of sprouted seeds	2	15-06-16 07-07-16	11-06-17 05-07-17
	M_4- SRI method	2	24-06-16 17-07-16	21-06-17 14-07-17
	M_5- Conventional transplanting	2	03-07-16 25-07-16	01-07-17 24-07-17
E) Gap filling/Thinning				
	M_1- Drum seeding of dry seeds	1	20-06-16	18-06-17
	M_2 and M_3- Drum seeding and broadcasting of sprouted seeds	1	22-06-16	20-06-17
	M_4 and M_5- SRI and conventional transplanting methods	1	09-07-16	06-07-17
F) Top dressing				
1.	Second dose of N (40%) at tillering stage	1	15-07-16 01-08-16	12-07-17 29-07-17
2.	Third dose of N (20%) at panicle initiation stage	1	15-08-16 30-08-16	12-08-17 29-08-17
G) Plant protection measures				
1.	Application of poison baits for crab control	2	27-06-16 20-07-16	20-06-17 27-07-17
H) Harvesting and threshing				
	M_1- Drum seeding of dry seeds	1	05-10-16 06-10-16	02-10-17 03-10-17
	M_2 and M_3- Drum seeding and broadcasting of sprouted seeds	1	08-10-16 10-10-16	06-10-17 08-10-17
	M_4 and M_5- SRI and conventional transplanting methods	1	12-10-16 14-10-16	09-10-17 11-10-17
I) Winnowing and drying		1	15-10-16 19-10-16	12-10-17 16-10-17
J) Weighing of grains and straw		1	20-10-16 26-10-16	17-10-17 24-10-17

3.9 Biometric observations

For studying the effect of various treatments on growth and development of rice, biometric observations *viz.*, plant height, number of functional leaves, number of tillers and dry matter accumulation of plants were recorded at a regular interval of 30 days throughout the life period of the crop. These are presented in Table 5.

3.9.1 Sampling technique

For recording biometric observations, five plants in direct seeded plots and five hills in transplanted plots were selected randomly from each net plot. The selected plants and plant hills from the each net plot were labelled and marked by fixing pegs.

3.9.2 Pre harvest studies

3.9.2.1 Plant population

The plant population m^{-2} was recorded at 20 DAS/DAT and at harvest from randomly thrown four quadrates each of 0.25 m^{-2} from each net plot and number of plants in direct seeded plots and number of hills in transplanted plots were counted. By adding values of four spots, plant population m^{-2} was recorded.

3.9.2.2 Plant height (cm)

Plant height was measured from base of the plant, *i.e.* from ground level to the base of fully opened leaf and thereafter up to the base of the panicles at reproductive stage.

3.9.2.3 Number of functional leaves m^{-2}

The total number of functional leaves m^{-2} was recorded periodically from randomly thrown four quadrates each of 0.25 m^{-2} from each net plot and it was summed.

Table 5. Biometric observations studied during the crop growth period and after harvest of rice

Sr. No.	Particulars	Freq.	Days after sowing / Transplanting
A.	**Pre harvest studies**		
	1) Plant population	2	20 DAS/DAT and at harvest
	2) Plant height (cm) 3) Number of functional leaves m^{-2} 4) Number of tillers m^{-2} 5) Dry matter accumulation m^{-2} (g)	4 4 4 4	30, 60, 90 DAS and at harvest
B.	**Post harvest studies**		
	1) Number of panicles m^{-2} 2) Length of panicle (cm) 3) Weight $panicle^{-1}$ (g) 4) Number of filled grains $panicle^{-1}$ 5) Number of unfilled grains $panicle^{-1}$ 6) Test weight (1000 grain weight) 7) Grain yield (q ha^{-1}) 8) Straw yield (q ha^{-1})	1 1 1 1 1 1 1 1	At harvest
C.	**Weed studies**		
	1) Number of grassy, sedges and broad leaved weeds m^{-2}	3	20/30, 40/60 DAS/DAT and at harvest
	2) Total dry weight of weeds (q ha^{-1}) 3) Weed index (%) 4) Weed control efficiency (%)	1 1 1	At harvest
D.	**Chemical analysis**		
	Soil analysis: Available N, P and K (kg ha^{-1})	2	Before and After harvest
	Plant analysis: 1) N, P and K content and their uptake in grain and straw 2) N, P and K content and their uptake in weeds	1 1	After harvest
	Quality studies: Protein content in grains (%)	1	After harvest
E.	**Economics**		
	1) Cost of cultivation (Rs. ha^{-1}) 2) Gross returns (Rs. ha^{-1}) 3) Net returns (Rs. ha^{-1}) 4) B: C ratio		

3.9.2.4 Number of tillers m^{-2}

The total number of tillers m^{-2} was recorded periodically from randomly thrown four quadrates each of 0.25 m^{-2} from each net plot and it was summed.

3.9.2.5 Dry matter accumulation m^{-2} (g)

For dry matter studies, two plants from direct sown plots and two plant hills from transplanted plots randomly selected from sample rows were used for recording periodical dry matter accumulation m^{-2}.

The plants and plant hills were uprooted and their roots were removed. The aerial plant parts were chopped and put in a brown paper bag. The samples were dried in thermostatically controlled oven at a temperature of 50-60^{0} C till their constant weights were obtained. The dry matter m^{-2} was worked out by multiplying the oven dry weight of plant^{-1} and hill^{-1} by number of plants and plant hills m^{-2}.

3.9.3 Post harvest studies

3.9.3.1 Number of panicles m^{-2}

The total number of panicles m^{-2} was recorded at harvest from randomly thrown four quadrates each of 0.25 m^{-2} from each net plot and the values were summed to report as number of panicles m^{-2}.

3.9.3.2 Length of panicle (cm)

Length of randomly selected five panicles from each net plot was measured from the base of whorl *i.e.* peduncle up to the tip of the panicle and average length of panicle was worked out.

3.9.3.3 Weight panicle^{-1} (g)

Weight panicle^{-1} was recorded from the five panicles used for measuring length and counting number of filled grains panicle^{-1} and average weight panicle^{-1} was worked out.

3.9.3.4 Number of filled grains panicle^{-1}

The number of filled grains was counted from five panicles selected for measuring length from each net plot and average number was worked out.

3.9.3.5 Number of unfilled grains panicle^{-1}

The number of unfilled grains was counted from the five panicles selected for measuring length from each net plot and average number was worked out.

3.9.3.6 Test weight (1000 grain weight)

A representative sample of grains was taken from the total produce of each net plot, 1000 grains were counted and weight was recorded as per the treatments.

3.9.3.7 Grain yield (q ha^{-1})

The grain yield obtained after threshing the produce from each net plot was sun dried for about 3-4 days, the weight was recorded and converted into q ha^{-1}.

3.9.3.8 Straw yield (q ha^{-1})

The straw yield was recorded by weighing air dried straw remained after threshing the produce from each net plot and the values were converted on hectare basis.

3.9.4 Weed studies

Density of weeds occurring in the net plot was calculated by quantitative method. For this, a quadrant having an area of 0.25 m^2 was thrown randomly in a net plot at four spots. By adding values of four spots, weeds m^{-2} was recorded. The weeds present in the quadrant were grouped as grassy, sedges and broad leaved weeds.

3.9.4.1 Weed count (m^{-2})

Species wise weed count was taken by counting the weeds within the 0.25 m^{-2} quadrant. First weed count was taken at 20/30 DAS/DAT. The second and third weed counts were taken at 40/60 DAS/DAT and at harvest.

3.9.4.2 Total dry weight of weeds (q ha^{-1})

The weeds from each net plot were cut close to the ground immediately after harvest of crop and kept in the same plot for sun drying up to five days. Then all the weeds from each net plot were collected and their weights were recorded. The dry weight obtained per net plot was converted on hectare basis.

3.9.4.3 Square root transformation

In weed studies, observations of weed population and their dry weight were recorded at 20/30, 40/60 DAS/DAT and at harvest. The values of these observations under different weed management treatments were either zero or very meagre.

Therefore, for the convenience of statistical analysis, data were converted into square root transformation by using the following formula for the values ranging from 0 to 10 (Anonymous 2012).

Square root transformation = $\sqrt{X + 0.5}$

Where,

X = The observational value ranging from 0 to 10. When the value of observation was more than 10, the actual square root of respective value was considered for square root transformation.

3.9.4.4 Weed index (%)

The weed index is the reduction in crop yield due to presence of weeds in comparison with weed free check that was calculated by using following formula.

$$\text{Weed index (WI)} = \frac{X - Y}{X} \times 100$$

Where,

X = Yield from weed free plot.

Y = Yield from treatment plot for which WI is to be worked out.

3.9.4.5 Weed control efficiency (%)

The weed control efficiency was calculated as the percentage reduction in density and growth of weeds in case of the treatments under study compared to the control treatment and calculated by using following formula.

$$\text{Weed control efficiency (WCE)} = \frac{W_0 - W_t}{W_0} \times 100$$

Where,

W_0 = Total dry weight of weeds from unweeded plot.

W_t = Total dry weight of weeds from treated plot

3.9.5 Chemical studies

3.9.5.1 Soil analysis

The availability of nutrients in soil was determined before (Initial- as described under 3.2) and after harvest of rice during both the years. The soil samples were collected from 0-30 cm depth from each individual plot after harvest of rice for determination of post harvest soil fertility in terms of available N, P and K. The samples were dried and then sieved through 2 mm size sieve. The initial soil sample was analysed for different physico-chemical properties. The soil samples collected after harvest of rice crop were used for determination of available nitrogen, phosphorus and potassium.

3.9.5.2 Plant analysis

Nitrogen, phosphorus and potassium content in plant components *i.e.* grain and straw were determined separately after harvest of rice. The dry matter accumulation in grain and straw at harvest was considered to calculate uptake of the nutrients (kg ha^{-1}) in the respective treatments during individual years.

3.9.6 Uptake studies

3.9.6.1 Nitrogen content in grain and straw (%)

Nitrogen content in rice grain and straw was determined by modified Microkjeldahl's method (Tandon, 1993).

3.9.6.2 Nitrogen accumulation in grain and straw (kg ha^{-1})

From the respective percentage figure, nitrogen accumulation in grain and straw was calculated by multiplying the grain and straw production $hectare^{-1}$ at harvest.

3.9.6.3 Total nitrogen uptake (kg ha^{-1})

It was calculated by addition of nitrogen accumulation in grain and straw recorded as per the treatments.

3.9.6.4 Phosphorus content in grain and straw (%)

Phosphorus content in grain and straw was determined by Ammonium molybdovanadate method (Tandon, 1993).

3.9.6.5 Phosphorus accumulation in grain and straw (kg ha^{-1})

This was determined separately from grain and straw from their respective percentage values with the help of grain and straw yield $hectare^{-1}$ at harvest.

3.9.6.6 Total phosphorus uptake (kg ha^{-1})

It was calculated by addition of phosphorus uptake in grain and straw of respective treatments.

3.9.6.7 Potassium content in grain and straw (%)

Potassium content in grain and straw was determined with the help of Flame photometer (Jackson 1973).

3.9.6.8 Potassium accumulation in grain and straw (kg ha^{-1})

It was calculated by multiplying grain and straw yield with respective percentage figure.

3.9.6.9 Total potassium uptake (kg ha^{-1})

It was calculated by addition of potassium accumulation in grain and straw of respective treatments.

3.9.7 Nutrient removal by weeds

The weeds at harvest were used to analyse for nutrient content. Composite weed samples from each net plot were taken for analysis of nitrogen, phosphorus and potassium contents. The total dry matter produced by weeds at harvest was considered to calculate the nutrient removal by weeds (kg ha^{-1}) in the respective treatment during the individual years. This was done as per the methods and procedures described for the estimation of contents and uptake of N, P and K in rice crop.

3.9.8 Quality studies (Protein content in grain)

Protein content was considered as the important quality attribute. Quality of grain was studied by working out the protein percentage in the grain. The nitrogen content in the grain was multiplied by a factor 6.25 (Subbaiah and Asija, 1956) to work out the protein content in the rice grain from the respective treatment.

Per cent protein = ‘N’ percentage x 6.25

3.9.9 Economics of the treatments

On the basis of the results obtained from the field experiment the economics was worked out. The gross income ha^{-1} was calculated on the basis of cost of grain and straw and their yield from the respective treatments.

The prevailing market prices for grain and straw were considered. The cost of cultivation of crop under individual treatment was worked out by taking into accounts the cost of all inputs.

3.10 Statistical analysis

The experimental data pertaining to each character were analysed statistically by using the technique of ‘Analysis of Variance’ for strip plot design and significance was tested by ‘F’ test (Panse and Sukhatme, 1967). Standard error of means (S.Em.) and critical differences (C.D.) were worked out for each character studied to evaluate difference between the treatments and interaction effects at 5% level of significance. Graphical illustrations of the data have also been presented at relevant places in the text. The two years data of grain and straw yield have been used for pooled analysis and to draw the relevant conclusions.

CHAPTER IV

EXPERIMENTAL FINDINGS

The results of the field experiment entitled “Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods” conducted during the years 2016 and 2017 are presented in this chapter. The experimental findings are presented under following headings.

4.1 Plant population

4.2 Crop growth and development studies

4.3 Yield contributing characters

4.4 Yield studies

4.5 Weed studies

4.6 Nutrient content, uptake and quality study of rice

4.7 Nutrient content and uptake by weeds

4.8 Nutrient status of soil after harvest of rice

4.9 Economics

4.1 Plant population

The mean number of plants and plant hills m^{-2} as influenced by different treatments at 20 DAS/DAT and at harvest are presented in Table 6.

Effect of establishment methods

The plant population m^{-2} was influenced significantly due to different crop establishment methods at 20 DAS/DAT as well as at harvest during both the years.

Sowing of sprouted seeds by drum seeder on puddled field recorded significantly higher plant population as compared to other establishment methods. Broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder recorded statistically identical and significantly higher plant population over conventional transplanting and SRI method. Significantly the lowest plant population was observed under SRI method followed by conventional transplanting during both the years.

Table 6. Mean number of plants and plant hills m^{-2} as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	**20 DAS/DAT**		**At harvest**	
	2016	**2017**	**2016**	**2017**
Establishment methods				
M$_1$: Sowing of dry seeds by drum seeder	144.27	144.20	136.53	136.20
M$_2$: Sowing of sprouted seeds by drum seeder	145.67	145.27	137.33	137.00
M$_3$: Broadcasting of sprouted seeds	144.40	144.27	136.73	136.40
M$_4$: SRI method	15.88	15.70	12.31	12.30
M$_5$: Conventional transplanting	32.96	32.77	29.99	29.91
S.Em. ±	0.23	0.15	0.22	0.24
C.D. at 5%	0.77	0.50	0.73	0.79
Weed management practices				
W$_1$: Two hand weedings	97.86	97.80	92.16	91.94
W$_2$: Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT	97.85	97.78	91.59	91.39
W$_3$: Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT	97.12	96.99	90.78	90.51
W$_4$: Oxadiargyl (PE) + Almix (POE)	95.57	95.43	89.91	89.70
W$_5$: Unweeded control	94.76	94.20	88.47	88.27
S.Em. ±	0.30	0.26	0.11	0.15
C.D. at 5%	NS	NS	NS	NS
Interaction effect				

S.Em. ±	1.44	1.28	0.60	0.62
C.D. at 5%	NS	NS	NS	NS
General mean	96.63	96.44	90.58	90.36

Effect of weed management practices

It is seen from the data presented in Table 6 that the number of plants and plant hills m^{-2} were not affected significantly by the different weed management practices at 20 DAS/DAT and at harvest during both the years of experimentation.

Interaction effect

The interaction effects between establishment methods and weed management practices on plant population at 20 DAS/DAT and at harvest were found to be non-significant during both the years.

4.2 Crop growth and development studies

The results obtained from different treatments on growth and development parameters *viz.*, plant height, number of functional leaves m^{-2}, number of tillers m^{-2} and dry matter accumulation m^{-2} of rice at various growth stages have been presented here.

4.2.1 Plant height (cm)

Data pertaining to the plant height of rice as influenced by different treatments at various crop growth stages are presented in Table 7 and depicted in Fig 4.

It was noticed that the mean plant height was more during *Kharif* 2016 as compared to *Kharif* 2017. Data clearly revealed that the plant height increased with increase in the age of crop and was maximum at harvest, during both the years.

Effect of establishment methods

It is seen from the data presented in Table 7 that Sowing of sprouted seeds by drum seeder on puddled field recorded significantly higher plant height over broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder at 30 DAS during both the years barring plant height recorded under broadcasting of sprouted seeds on puddled field at 30 DAS during both the years and at harvest during 2016. Thus, sowing of dry seeds by drum seeder recorded significantly the lowest plant height from 60 DAS to harvest during both the years except plant height observed under broadcasting of sprouted seeds on puddled field at 60 DAS during 2017.

Table 7. Mean plant height (cm) of rice as influenced by different treatments at 30, 60, 90 DAS and at harvest during *Kharif* 2016 and 2017

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods								
M_1: Sowing of dry seeds by drum seeder	12.16	11.99	34.74	34.03	66.38	65.35	67.55	65.97
M_2: Sowing of sprouted seeds by drum seeder	13.18	13.15	37.17	35.54	70.94	69.47	72.10	70.95
M_3: Broadcasting of sprouted seeds	12.99	12.96	35.92	34.85	69.47	67.03	70.69	69.69
M_4: SRI method	11.30	11.24	44.50	44.37	73.73	73.43	80.52	79.90
M_5: Conventional transplanting	11.05	11.04	42.97	42.35	72.40	72.21	78.58	77.86
S.Em. ±	0.11	0.07	0.22	0.41	0.40	0.29	0.58	0.27
C.D. at 5%	0.35	0.22	0.72	1.34	1.31	0.95	1.90	0.89
Weed management practices								
W_1: Two hand weedings	12.46	12.43	42.68	41.84	74.17	73.23	78.49	76.70
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	12.44	12.38	40.75	40.12	72.33	71.63	75.59	74.65
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	12.42	12.41	39.75	38.67	71.07	69.92	74.14	73.31

W_4: Oxadiargyl (PE) + Almix (POE)	12.12	11.95	37.38	36.71	69.29	67.98	72.02	71.33
W_5: Unweeded control	11.24	11.20	34.74	33.80	66.07	64.74	69.20	68.37
S.Em. ±	0.17	0.07	0.16	0.15	0.18	0.28	0.38	0.20
C.D. at 5%	0.56	0.24	0.52	0.50	0.58	0.90	1.24	0.65
Interaction effect								
S.Em. ±	0.51	0.56	1.01	1.02	0.61	0.57	1.35	0.76
C.D. at 5%	NS	NS	2.90	2.94	NS	NS	NS	NS
General mean	12.14	12.07	39.06	38.23	70.59	69.50	73.89	72.87

SRI method recorded maximum and significantly higher plant height from 60 DAS to harvest during both the years as compared to rest of the rice establishment methods. Conventional transplanting produced significantly taller plants from 60 DAS to harvest as compared to remaining establishment methods except SRI method during both the years. However, at 30 DAS SRI and conventional transplanting methods recorded significantly lower plant height during both the years as compared to other establishment methods.

Effect of weed management practices

Weed management treatments *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), integration of pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3), combination of sprays of Oxadiargyl as pre-emergence and Almix as post emergence (W_4) and unweeded control (W_5) differed significantly from one another in descending order, respectively in recording the plant height from 60 DAS to harvest during both the years. During early growth stage of the crop (30 DAS) weed management practices produced more or less identical and significantly taller plants than unweeded control during both the years of experimentation.

Interaction effect

The interaction effects between establishment methods and weed management practices were found to be significant at 60 DAS during both the years.

In general, all weed management practices (Table 8) followed for SRI and conventional transplanting recorded higher plant height as compared to observed in other establishment methods. The rice establishment methods without any weed management (unweeded control) recorded lower plant height. Hand weeding alone, pre-emergence and post emergence herbicidal sprays or their integration produced more or less similar height of rice plants established by sowing of dry and sprouted seeds.

Table 8. Interaction effects between establishment methods and weed management practices on plant height (cm) at 60 DAS during *Kharif* 2016 and 2017

	Plant height (cm)									
	2016					2017				
	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5
W_1	38.70	40.28	39.21	48.80	46.40	38.07	38.74	38.17	48.67	45.53
W_2	37.00	39.10	38.27	45.19	44.21	36.50	37.27	37.16	45.19	44.47
W_3	36.20	39.10	37.32	43.90	42.23	35.63	36.56	36.13	43.37	41.67
W_4	32.27	35.30	34.06	43.33	41.93	31.74	34.07	33.60	43.33	40.80
W_5	29.51	32.09	30.73	41.30	40.10	28.20	31.09	29.17	41.30	39.27
S.Em.	1.01					1.02				
C.D.	2.90					2.94				

Two hand weedings carried out in SRI method at 30 and 60 DAT (M_4W_1) produced significantly the tallest plants as compared to rest of the treatment combinations during both the years except two hand weedings carried out in conventional transplanting at 30 and 60 DAT (M_5W_1) during 2016.

4.2.2 Number of functional leaves m^{-2}

Data pertaining to mean number of functional leaves m^{-2} as influenced by different treatments at different crop growth stages are presented in Table 9 and depicted in Fig. 5.

It is evident from the data that, the number of functional leaves with the advancement in the age up to 60 DAS and thereafter showed decline at senescence stage during both the years of experimentation. The count was low at lag phase and it was higher during log phase.

Effect of establishment methods

At 30 DAS sowing of sprouted seeds by drum seeder recorded significantly more number of functional leaves m^{-2} followed by broadcasting of sprouted seeds and sowing of dry seeds by drum seeder over rest of the treatments during both the years.

Table 9. Mean number of functional leaves m^{-2} of rice as influenced by different treatments at 30, 60, 90 DAS and at harvest during *Kharif* 2016 and 2017

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods								
M_1: Sowing of dry seeds by drum seeder	572.40	571.53	1426.47	1425.67	1348.47	1346.60	1175.53	1173.93
M_2: Sowing of sprouted seeds by drum seeder	589.00	587.87	1494.00	1492.40	1401.47	1399.27	1205.27	1204.33
M_3: Broadcasting of sprouted seeds	586.93	584.87	1445.20	1443.87	1371.60	1369.80	1188.93	1188.40
M_4: SRI method	307.27	306.53	1449.20	1448.60	1377.40	1378.00	1199.60	1200.07
M_5: Conventional transplanting	338.13	337.47	1524.20	1522.53	1439.80	1438.47	1223.53	1222.93
S.Em. ±	0.40	0.37	0.42	0.22	0.79	0.57	0.50	0.37
C.D. at 5%	1.31	1.20	1.36	0.71	2.56	1.87	1.62	1.20
Weed management practices								
W_1: Two hand weedings	482.40	481.67	1475.07	1474.07	1400.13	1398.73	1208.07	1207.20
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	481.33	480.60	1472.20	1471.27	1394.80	1393.27	1202.27	1202.00
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	479.60	478.73	1468.67	1467.87	1389.60	1388.40	1198.33	1197.80

W_4: Oxadiargyl (PE) + Almix (POE)	478.47	477.47	1463.60	1462.53	1380.40	1379.33	1194.40	1193.93
W_5: Unweeded control	471.93	469.80	1459.53	1457.33	1373.80	1372.40	1189.80	1188.73
S.Em. ±	0.26	0.31	0.38	0.35	0.63	0.41	0.49	0.35
C.D. at 5%	0.85	1.02	1.25	1.13	2.05	1.35	1.59	1.14
Interaction effect								
S.Em. ±	2.29	2.25	1.06	1.63	1.77	1.75	1.89	1.74
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS
General mean	478.75	477.65	1467.81	1466.61	1387.75	1386.43	1198.57	1197.93

From 60 DAS to harvest conventional transplanting recorded significantly more number of functional leaves m^{-2} followed by sowing of sprouted seeds by drum seeder and SRI method over rest of the treatments during both the years. Sowing of dry seeds by drum seeder recorded significantly the lowest number of leaves over all the treatments during both the years of experimentation.

Effect of weed management practices

All weed management practices recorded significantly more number of functional leaves m^{-2} as compared to unweeded control at all growth stages of crop during both the years. Weed management treatments *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3) and pre-emergence application of Oxadiargyl + post emergence application of Almix (W_4) also differed significantly from one another in descending order at all growth stages during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices were found to be non-significant with respect to number of functional leaves m^{-2} at all the growth stages of rice during *Kharif* 2016 and 2017.

4.2.3 Number of tillers m^{-2}

Data pertaining to mean number of tillers m^{-2} as influenced periodically by different treatments are summarized in Table 10 and graphically shown in Fig. 6.

The data indicated that, the number of tillers m^{-2} increased with increase in age of the crop up to 60 DAS. Thereafter, there was gradual decrease due to mortality of late tillers during both the years. The number of tillers m^{-2} was slightly higher during *Kharif* 2016 as compared to *Kharif* 2017.

Table 10. Mean number of tillers m^{-2} of rice as influenced by different treatments at 30, 60, 90 DAS and at harvest during *Kharif* 2016 and 2017

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods								
M$_1$: Sowing of dry seeds by drum seeder	190.13	189.13	280.13	279.67	275.93	274.60	271.93	270.40
M$_2$: Sowing of sprouted seeds by drum seeder	194.47	194.00	293.40	291.80	286.07	284.27	281.60	280.53
M$_3$: Broadcasting of sprouted seeds	193.93	192.80	284.00	283.13	281.80	280.33	275.47	274.53
M$_4$: SRI method	101.47	102.13	285.47	285.13	283.20	284.13	280.87	281.40
M$_5$: Conventional transplanting	112.67	111.40	300.40	299.97	292.80	292.27	286.13	285.13
S.Em. ±	0.60	0.39	0.59	0.51	0.32	0.35	0.33	0.32
C.D. at 5%	1.95	1.28	1.92	1.68	1.05	1.16	1.06	1.03
Weed management practices								
W$_1$: Two hand weedings	161.80	161.00	296.13	294.73	290.00	289.47	284.13	283.60
W$_2$: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	159.93	159.40	292.20	291.73	287.47	286.47	282.40	281.67
W$_3$: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	159.20	158.93	288.67	288.40	284.33	283.33	279.53	279.00

W_4: Oxadiargyl (PE) + Almix (POE)	157.07	156.27	285.80	285.60	281.40	280.60	276.60	275.93
W_5: Unweeded control	154.67	153.87	280.60	279.23	276.60	275.73	273.33	271.80
S.Em. ±	0.54	0.53	0.53	0.58	0.26	0.36	0.17	0.24
C.D. at 5%	1.78	1.75	1.72	1.90	0.84	1.17	0.55	0.77
Interaction effect								
S.Em. ±	1.40	1.38	2.75	3.36	1.93	1.84	1.57	1.47
C.D. at 5%	NS	NS	NS	NS	5.56	5.30	NS	NS
General mean	158.53	157.89	288.68	287.94	283.96	283.12	279.20	278.40

Effect of establishment methods

Data from Table 10 implies that, the establishment methods significantly influenced the mean number of tillers m^{-2} throughout the growth period of crop. Sowing of sprouted seeds by drum seeder on puddled field responded well and recorded significantly higher number of tillers m^{-2} at 30 DAS over sowing of dry seeds by drum seeder, conventional transplanting and SRI method. However, broadcasting of sprouted seeds on puddled field was at par with sowing of sprouted seeds by drum seeder at 30 DAS during both the years. From 60 DAS to harvest conventional transplanting recorded significantly higher number of tillers m^{-2} as compared to other establishment methods. At 90 DAS sowing of sprouted seeds by drum seeder and SRI method were at par during 2017 and at harvest during both the years. Sowing of dry seeds by drum seeder recorded significantly the lower number of tillers m^{-2} as compared to other establishment methods during both the years of experimentation.

Effect of weed management practices

Data furnished in Table 10 showed that, at all the stages of crop growth, two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly more number of tillers m^{-2} as compared to other weed management practices except application of Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT at 30 DAS during 2017. Application of Oxadiargyl (PE) integrated with 1 HW either at 20/30 DAS/DAT (W_2) or 40/60 DAS/DAT (W_3) were at par with each other and significantly superior over pre-emergence application of Oxadiargyl + post emergence application of Almix (W_4) and unweeded control (W_5) at initial growth stage (30 DAS) during both the years.

Interaction effect

The interactions between establishment methods and weed management practices were found to be significant at 90 DAS during both the years.

Table 11. Interaction effects between establishment methods and weed management practices on number of tillers m^{-2} at 90 DAS during *Kharif* 2016 and 2017

	Number of tillers m^{-2}									
	2016					2017				
	M$_1$	**M$_2$**	**M$_3$**	**M$_4$**	**M$_5$**	**M$_1$**	**M$_2$**	**M$_3$**	**M$_4$**	**M$_5$**
W$_1$	280.00	292.00	287.00	289.00	302.00	279.00	290.33	285.33	291.00	301.67
W$_2$	278.33	289.00	286.00	285.00	299.00	276.33	287.00	284.67	286.33	298.00
W$_3$	276.00	286.67	284.00	283.00	292.00	274.67	284.67	282.33	283.67	291.33
W$_4$	274.33	285.00	279.00	281.33	287.33	273.67	283.33	277.33	281.67	287.00
W$_5$	271.00	277.67	273.00	277.67	283.67	269.33	276.00	272.00	278.00	283.33
S.Em.	1.93					1.84				
C.D.	5.56					5.30				

At 90 DAS two hand weedings at 30 and 60 DAT carried out in rice established by conventional transplanting (M_5W_1) recorded maximum and significantly higher number of tillers m^{-2} as compared to other treatment combinations except pre-emergence application of Oxadiargyl + 1 HW at 30 DAT carried out in conventional transplanting (M_5W_2) during both the years of experimentation. Combination of unweeded control with all rice establishment methods recorded significantly lower number of tillers m^{-2} as compared to other treatment combinations during both the years.

4.2.4 Dry matter accumulation (g) m^{-2}

Periodical data pertaining to dry matter accumulation m^{-2} are presented in Table 12 and graphically depicted in Fig. 7. In general, the dry matter accumulation m^{-2} increased with increase in the age of the crop and it was maximum at harvest. During all the growth stages, as well as at harvest dry matter production was higher during *Kharif* 2016 than *Kharif* 2017 under all the treatments.

Effect of establishment methods

The mean dry matter accumulation m^{-2} was significantly higher in sowing of sprouted seeds by drum seeder over rest of the treatments except broadcasting of sprouted seeds on puddled field at 30 DAS during both the years. At 60 and 90 DAS conventional transplanting recorded significantly higher values of dry matter accumulation m^{-2} as compared to remaining establishment methods except SRI method at 90 DAS during 2017. At harvest SRI method recorded significantly higher dry matter accumulation m^{-2} than other establishment methods during both the years. Sowing of dry seeds by drum seeder recorded significantly lower dry matter accumulation m^{-2} from 60 DAS to harvest during both the years of experimentation.

Effect of weed management practices

Among weed management practices, two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher dry matter accumulation m^{-2} at 30, 60, 90 DAS and at harvest over rest of the treatments except Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) at 60 DAS during 2016. Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) remained at par with Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3) and both the treatments recorded significantly higher dry matter accumulation m^{-2} over pre and post emergence application of Oxadiargyl + Almix (W_4) at 60 DAS during 2016. Unweeded control (W_5) recorded significantly lower dry matter accumulation m^{-2} as compared to other weed management practices.

Interaction effect

Interaction effects between establishment methods and weed management practices were found to be significant at 90 DAS during both the years.

The data presented in Table 13 revealed that, the rice crop established by conventional transplanting with two hand weedings carried out at 30 and 60 DAT (M_5W_1) produced significantly higher dry matter accumulation (g) m^{-2} at 90 DAS during 2016 and two hand weedings carried out at 30 and 60 DAT in SRI method (M_4W_1) recorded significantly higher dry matter accumulation (g) m^{-2} at 90

Table 12. Mean dry matter accumulation (g) m^{-2} of rice as influenced by different treatments at 30, 60, 90 DAS and at harvest during *Kharif* 2016 and 2017

Treatments	30 DAS		60 DAS		90 DAS		At harvest	
	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods								
M_1: Sowing of dry seeds by drum seeder	282.91	281.67	369.85	366.54	433.80	429.47	534.53	521.73
M_2: Sowing of sprouted seeds by drum seeder	285.97	285.18	391.95	386.03	480.53	477.40	600.94	585.07
M_3: Broadcasting of sprouted seeds	284.80	283.99	380.85	374.71	464.13	460.60	571.03	558.68
M_4: SRI method	196.95	196.28	388.26	380.05	502.27	500.33	633.84	620.73
M_5: Conventional transplanting	208.10	206.83	400.88	396.35	504.34	501.41	624.60	611.67
S.Em. ±	0.36	0.45	0.67	0.38	0.61	0.64	0.94	0.63
C.D. at 5%	1.17	1.47	2.20	1.25	2.00	2.09	3.08	2.06
Weed management practices								
W_1: Two hand weedings	254.32	253.64	392.54	385.85	491.34	488.74	622.76	610.93
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	252.88	251.92	389.71	383.79	484.47	481.73	607.88	595.87
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	251.67	250.78	387.12	381.91	477.00	473.80	598.53	584.07

W_4: Oxadiargyl (PE) + Almix (POE)	250.57	249.79	383.38	379.22	471.33	468.00	580.50	567.34
W_5: Unweeded control	249.29	247.83	379.03	372.92	460.93	456.93	555.27	539.67
S.Em. ±	0.16	0.28	0.97	0.32	1.15	1.00	1.20	0.78
C.D. at 5%	0.51	0.91	3.15	1.04	3.74	3.26	3.93	2.54
Interaction effect								
S.Em. ±	0.54	0.90	4.60	3.83	3.27	3.37	7.95	8.69
C.D. at 5%	NS	NS	NS	NS	9.41	9.71	NS	NS
General mean	251.75	250.79	386.36	380.74	477.01	473.84	592.99	579.58

DAS during 2017 over rest of the treatment combinations and remained at par with each other during both the years of study.

Table 13. Interaction effect of establishment methods and weed management practices on dry matter accumulation m^{-2} at 90 DAS during *Kharif* 2016 and 2017

	Dry matter accumulation m^{-2}									
	2016					2017				
	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5
W_1	447.67	495.33	472.33	520.00	521.37	442.33	492.00	469.67	520.00	519.70
W_2	443.33	485.33	471.00	511.33	511.33	441.00	483.33	468.00	506.67	509.67
W_3	435.67	478.33	466.00	503.00	502.00	431.33	474.33	462.00	501.33	500.00
W_4	429.67	476.33	459.00	494.67	497.00	424.00	471.67	456.00	493.00	495.33
W_5	412.67	467.33	452.33	482.33	490.00	408.67	465.67	447.33	480.67	482.33
S.Em	3.27					3.37				
C.D.	9.41					9.71				

4.3 Yield contributing characters

Data regarding yield contributing characters *viz*., number of panicles m^{-2}, length of panicle (cm), weight panicle^{-1} (g), number of filled grains panicle^{-1}, number of unfilled grains panicle^{-1} and test weight (g) as affected by the various treatments are presented in Table 14 and 15.

4.3.1 Number of panicles m^{-2}

The data pertaining to mean number of panicles m^{-2} of rice as influenced by different treatments are presented in Table 14 and graphically depicted in Fig. 8. The mean number of panicles m^{-2} was 279.20 and 278.40 during the years 2016 and 2017, respectively.

Effect of establishment methods

Conventional transplanting produced significantly the highest number of panicles m^{-2} over rest of the rice establishment methods during both the years. Sowing of sprouted seeds by drum seeder and SRI method remained at par with each other and produced significantly higher number of panicles m^{-2} than broadcasting of sprouted seeds on puddled field during both the years. Broadcasting of sprouted seeds on puddled field recorded significantly higher m^{-2} panicle count as compared to sowing of dry seeds by drum seeder during both the years of experimentation.

Effect of weed management practices

All weed management practices *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl + Almix (W_4) produced significantly more number of panicles m^{-2} than unweeded control (W_5). The treatment W_2 and W_3 produced significantly more number of panicles m^{-2} over rest of the treatments.

Interaction effect

The interaction effects between establishment methods and weed management practices were found to be non-significant with respect to number of panicles m^{-2} in rice during both the years.

4.3.2 Length of panicle (cm)

The data pertaining to length of panicle (cm) of rice as influenced by different treatments are presented in Table 14 and graphically depicted in Fig. 9. The mean length of panicle was 21.87 and 21.80 cm during the years 2016 and 2017, respectively. The length of panicle was slightly higher during *Kharif* 2016 as compared to *Kharif* 2017.

Effect of establishment methods

SRI and conventional transplanting rice establishment methods produced statistically identical and significantly longer panicles over rest of the establishment methods. Sowing of dry seeds by drum seeder recorded significantly the lowest panicle length as compared to remaining rice establishment methods. Sowing of sprouted seeds either by drum seeder or broadcasting on puddled field did not differ significantly in recording the panicle length.

Table 14. Number of panicles m^{-2}, length of panicle (cm) and weight $panicle^{-1}$ (g) of rice as influenced by different treatments at harvest during *Kharif* 2016 and 2017

Treatments	No. of panicles m^{-2}		Length of panicle (cm)		Weight $panicle^{-1}$ (g)	
	2016	2017	2016	2017	2016	2017
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	271.93	270.40	20.08	20.00	3.06	3.03
M_2: Sowing of sprouted seeds by drum seeder	281.60	280.53	21.41	21.29	3.38	3.23
M_3: Broadcasting of sprouted seeds	275.47	274.53	21.21	21.08	3.29	3.17
M_4: SRI method	280.87	281.40	23.61	23.61	3.57	3.48
M_5: Conventional transplanting	286.13	285.13	23.05	23.01	3.49	3.38
S.Em. ±	0.33	0.32	0.26	0.22	0.03	0.02
C.D. at 5%	1.06	1.03	0.83	0.71	0.06	0.07
Weed management practices						
W_1: Two hand weedings	284.13	283.60	23.68	23.65	3.63	3.52
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	282.40	281.67	22.57	22.51	3.49	3.39
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	279.53	279.00	22.08	21.86	3.39	3.27

W_4: Oxadiargyl (PE) + Almix (POE)	276.60	275.93	21.10	21.09	3.21	3.11
W_5: Unweeded control	273.33	271.80	19.92	19.89	3.06	2.99
S.Em. ±	0.17	0.24	0.19	0.24	0.02	0.01
C.D. at 5%	0.55	0.77	0.63	0.77	0.07	0.04
Interaction effect						
S.Em. ±	1.57	1.47	0.29	0.41	0.05	0.06
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	279.20	278.40	21.87	21.80	3.36	3.26

Effect of weed management practices

Unweeded control produced significantly the shortest and two hand weedings at 20/30 and 40/60 DAS/DAT produced significantly the longest panicles over rest of the establishment methods during both the years. Integration of pre-emergence herbicidal spray with hand weeding at different growth stages were found to be identical and significantly superior than combination of pre and post emergence herbicidal sprays in recording the panicle length.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to length of rice panicles (cm) were found to be non-significant in rice during both the years.

4.3.3 Weight panicle^{-1} (g)

The data pertaining to weight panicle^{-1} (g) of rice are presented in Table 14 and graphically depicted in Fig. 10. The mean weight panicle^{-1} was 3.36 and 3.26 g during the years 2016 and 2017, respectively.

Effect of establishment methods

The data presented in Table 14, indicated that various rice establishment methods *viz.,* SRI, conventional transplanting, sowing of sprouted seeds by drum seeder, broadcasting of sprouted seeds and sowing of dry seeds by drum seeder differed significantly from one another in descending order in recording weight panicle^{-1} during both the years barring sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds in 2017.

Effect of weed management practices

It is evident from the data presented in Table 14 that during both the years of study weed management practices produced significantly heavy weight panicle^{-1} than unweeded control. Two hand weedings at 20/30 and 40/60 DAS/DAT recorded maximum and significantly higher panicle weight over rest of the treatments. Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3) produced significantly lighter and heavier panicles than Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) and pre and post emergence application of Oxadiargyl + Almix (W_4), respectively during both the years of study.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to weight panicle^{-1} (g) were found to be non-significant in rice during both the years.

4.3.4 Number of filled grains panicle^{-1}

It is seen from the data presented in Table 15 and graphically depicted in Fig. 11 that the number of filled grains panicle^{-1} was significantly influenced due to different crop establishment methods and weed management practices during both the years of experimentation.

The mean number of filled grains panicle^{-1} was 107.91 and 106.96 during the years 2016 and 2017, respectively.

Effect of establishment methods

Transplanting of rice significantly increased the number of filled grains panicle^{-1} as compared to sowing of dry or sprouted seeds. Rice seedlings transplanted by SRI method recorded significantly higher count of filled grains panicle^{-1} than conventional transplanting. Further, broadcasting of sprouted seeds on puddled field recorded significantly higher and lower filled grains panicle^{-1} as compared to sowing of dry seeds by drum seeder and sowing of sprouted seeds by drum seeder on puddled field, respectively during both the years.

Effect of weed management practices

Weed management practices produced significantly higher number of filled grains panicle^{-1} than unweeded control (W_5) during

Table 15. Number of filled grains panicle^{-1}, number of unfilled grains panicle^{-1} and test weight (g) of rice as influenced by different treatments at harvest during *Kharif* 2016 and 2017

Treatments	No. of filled grains panicle^{-1}		No. of unfilled grains panicle^{-1}		Test weight (g) (1000 grain weight)	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	101.00	100.07	24.00	24.80	28.11	28.04
M_2: Sowing of sprouted seeds by drum seeder	106.00	105.40	20.13	20.67	29.55	29.49
M_3: Broadcasting of sprouted seeds	104.47	103.07	21.67	21.87	29.08	29.06
M_4: SRI method	114.60	114.13	16.00	16.07	30.68	30.68
M_5: Conventional transplanting	113.47	112.13	17.73	17.67	30.11	30.04
S.Em. ±	0.21	0.34	0.37	0.39	0.15	0.12
C.D. at 5%	0.68	1.12	1.19	1.27	0.48	0.41
Weed management practices						
W_1: Two hand weedings	110.93	110.07	16.93	16.93	30.98	30.90
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	109.73	108.80	18.67	18.80	30.11	30.05

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	108.27	107.40	19.67	20.07	29.79	29.77
W_4: Oxadiargyl (PE) + Almix (POE)	106.73	105.60	21.73	22.07	28.64	28.63
W_5: Unweeded control	103.87	102.93	22.53	23.20	28.01	27.95
S.Em. ±	0.38	0.11	0.33	0.29	0.16	0.13
C.D. at 5%	1.25	0.36	1.06	0.94	0.51	0.43
Interaction effect						
S.Em. ±	1.09	1.16	0.77	0.74	0.45	0.43
C.D. at 5%	3.15	3.33	NS	NS	NS	NS
General mean	107.91	106.96	19.91	20.21	29.51	29.46

both the years of study. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher number of filled grains panicle^{-1} over rest of the weed management practices except integration of pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) during 2016. Integration of pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly higher and lower count of filled grains panicle^{-1} than W_4 and W_2, respectively.

Interaction effect

The interaction effects between establishment methods and weed management practices on number of filled grains panicle^{-1} were found to be significant during both the years.

Table 16. Interaction effect between establishment methods and weed management practices on number of filled grains panicle^{-1} during *Kharif* 2016 and 2017

	Number of filled grains panicle^{-1}									
	2016					2017				
	M_1	M_2	M_3	M_4	M_5	M_1	M_2	M_3	M_4	M_5
W_1	104.00	110.67	106.00	118.00	116.00	104.33	108.00	106.00	116.33	115.67
W_2	102.00	108.00	106.33	117.00	115.33	102.33	107.33	106.00	115.33	113.00
W_3	101.00	106.00	106.67	115.00	112.67	102.00	105.33	102.67	115.00	112.00
W_4	100.00	105.33	102.67	113.00	112.67	98.67	104.33	101.00	113.00	111.00
W_5	98.00	100.00	100.67	110.00	110.67	93.00	102.00	99.67	111.00	109.00
S.Em.	1.09					1.16				
C.D.	3.15					3.33				

The integration of pre-emergence application of Oxadiargyl with 1 HW at 30 DAT carried out in SRI (M_4W_2) and conventional transplanting (M_5W_2) methods recorded comparable number of filled grains panicle^{-1} as compared to 2 hand weedings carried out at 30 and 60 DAT (M_4W_1 and M_5W_1) as well as integration of Oxadiargyl (PE) with 1 HW at 60 DAT (M_4W_3) in SRI method. Other treatment combinations recorded lower number of filled grains panicle^{-1} during both the years.

4.3.5 Number of unfilled grains panicle^{-1}

The data pertaining to number of unfilled grains panicle^{-1} of rice as influenced by different treatments are presented in Table 15 and graphically depicted in Fig. 12. The mean number of unfilled grains panicle^{-1} was 19.91 and 20.21 during 2016 and 2017, respectively. More number of chaffy grains was produced during the year 2017 as compared to 2016.

Effect of establishment methods

The SRI method of planting recorded significantly the lowest number of unfilled grains panicle^{-1} followed by conventional transplanting, sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds during both the years. Sowing of dry seeds by drum seeder recorded significantly more number of unfilled grains panicle^{-1} as compared to other establishment methods.

Effect of weed management practices

Unweeded control produced significantly the highest number of unfilled grains panicle^{-1} as compared to cultural, chemical and integrated weed management methods. Two hand weedings at 20/30 and 40/60 DAS/DAT recorded significantly lowest number of unfilled grains panicle^{-1} over other weed management practices during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to number of unfilled grains panicle^{-1} were found to be non-significant in rice during both the years.

4.3.6 Test weight (g)

The test weight (1000 grain weight) was significantly influenced by different treatments. The data are presented in Table 15 and graphically depicted in Fig. 13. The mean test weight was 29.51 and 29.46 g during the years 2016 and 2017, respectively.

Effect of establishment methods

Significantly the highest test weight of rice grains was recorded in SRI method over rest of the establishment methods of rice. Further, conventional transplanting recorded significantly higher test weight as compared to sowing of dry or sprouted seeds. Sowing of sprouted seeds by drum seeder produced heavier grains over broadcasting of sprouted seeds and sowing of dry seeds. Sowing of dry seeds by drum seeder recorded significantly the lowest test weight of rice during both the years.

Effect of weed management practices

Weed management practices recorded significantly higher test weight of rice grains than unweeded control (W_5). Among weed management practices two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly the highest test weight of rice over rest of the weed management practices. Integration of pre-emergence application Oxadiargyl either with HW at 20/30 DAS/DAT (W_2) or HW at 40/60 DAS/DAT (W_3) remained at par and both weed management practices recorded significantly higher test weight than combined application of pre and post emergence herbicides (W_4) during both the years.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to test weight (g) were found to be non-significant in rice during both the years.

4.4 Yield studies

Data pertaining to grain and straw yield (q ha^{-1}) of rice as influenced by different treatments are presented in Table 17 and graphically depicted in Fig. 14 and 15.

4.4.1 Grain yield (q ha^{-1})

The data presented in Table 17 revealed that, the mean grain yield of rice was 40.47, 39.29 and 39.88 q ha^{-1} during 2016, 2017 and in two years pooled data, respectively. The grain yield was rather more in 2016 as compared to 2017.

Effect of establishment methods

The grain yield of rice was significantly influenced due to different establishment methods during both the years as well as in pooled data over the years.

The grain yield of rice was significantly higher when it was grown by transplanting the seedlings by SRI method or conventional transplanting as compared to sowing of either dry or sprouted seeds. System of Rice Intensification method produced maximum and significantly higher grain yield of rice as compared to rest of the rice establishment methods during both the years as well as in pooled data. Sowing of sprouted seeds by drum seeder on puddled field recorded significantly higher grain yield of rice as compared to broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder during individual years and in pooled data. Further, broadcasting of sprouted seeds on puddled field produced significantly higher grain yield of rice than sowing of dry seeds by drum seeder.

On the basis of pooled data, the mean increase in grain yield recorded under broadcasting of sprouted seeds on puddled field, sowing of sprouted seeds by drum seeder on puddled field, conventional transplanting and SRI method over sowing of dry seeds by drum seeder were 4.06, 6.57, 15.18 and 17.77 per cent, respectively.

Effect of weed management practices

Different methods of weed management significantly increased the grain yield of rice over unweeded control (W_5) during both the years as well as in pooled data.

Table 17. Grain and straw yield (q ha^{-1}) of rice as influenced by different treatments during *Kharif* 2016, 2017 and in pooled data

Treatments	Grain yield (q ha^{-1})			Straw yield (q ha^{-1})		
	2016	2017	Pooled	2016	2017	Pooled
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	37.54	35.82	36.68	53.58	52.25	52.92
M_2: Sowing of sprouted seeds by drum seeder	39.55	38.62	39.09	60.15	58.60	59.38
M_3: Broadcasting of sprouted seeds	38.61	37.73	38.17	57.19	55.79	56.49
M_4: SRI method	43.85	42.56	43.20	63.69	62.18	62.94
M_5: Conventional transplanting	42.80	41.71	42.25	62.49	61.15	61.82
S.Em. ±	0.11	0.20	0.13	0.40	0.36	0.37
C.D. at 5%	0.37	0.65	0.41	1.31	1.16	1.18
Weed management practices						
W_1: Two hand weedings	42.93	41.98	42.45	62.24	61.07	61.65
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	41.79	40.62	41.20	60.85	59.57	60.21
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	40.87	39.68	40.27	59.91	58.54	59.22

W_4: Oxadiargyl (PE) + Almix (POE)	39.10	38.10	38.60	58.13	56.87	57.50
W_5: Unweeded control	37.67	36.05	36.86	55.97	53.93	54.95
S.Em. ±	0.15	0.17	0.13	0.23	0.21	0.22
C.D. at 5%	0.48	0.50	0.42	0.74	0.69	0.70
Interaction effect						
S.Em. ±	0.35	0.59	0.42	0.53	0.61	0.44
C.D. at 5%	NS	NS	1.21	NS	NS	NS
General mean	40.47	39.29	39.88	59.42	57.99	58.71

Among weed management practices, two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) significantly increased the grain yield of rice as compared to integration of Oxadiargyl (PE) with 1 HW either at 20/30 DAS/DAT (W_2) or 40/60 DAS/DAT (W_3) during both the years and in pooled analysis. Application of Oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT (W_2) recorded significantly higher grain yield over the integration of Oxadiargyl (PE) and 1 HW at 40/60 DAS/DAT (W_3) as well as pre and post emergence application of Oxadiargyl and Almix (W_4), respectively. Further, W_3 produced higher grain yield of rice than W_4. The magnitude of increase in grain yield recorded due to W_4, W_3, W_2 and W_1 over W_5 on pooled basis was 4.72, 9.25, 11.77 and 15.16 per cent, respectively.

Interaction effect

The interaction effects between establishment methods and weed management practices were found to be non-significant during individual years. However, in pooled analysis the differences became discernible and significant (Table 18).

Table 18. Interaction effects between establishment methods and weed management practices on grain yield (q ha^{-1}) of rice in pooled mean

	Grain yield (q ha^{-1})				
	Pooled mean				
	M_1	**M_2**	**M_3**	**M_4**	**M_5**
W_1	39.34	42.07	40.62	45.68	44.56
W_2	37.77	39.68	39.75	44.77	44.05
W_3	37.20	39.27	38.28	43.82	42.80
W_4	36.00	37.63	36.96	41.63	40.77
W_5	33.08	36.78	35.24	40.12	39.08
S.Em.	0.42				
C.D.	1.21				

Weed management practices significantly increased the grain yield of rice established by different methods over unweeded control except combined application of Oxadiargyl as pre and Almix as post emergence in the rice established by sowing of sprouted seeds through drum seeder on puddled field (M_2W_4).

Two hand weedings at 30 and 60 DAT carried out in SRI method (M_4W_1) produced maximum and significantly higher grain yield over rest of the treatment combinations barring two hand weedings at 30 and 60 DAT carried out in conventional transplanting (M_5W_1) and integration of pre-emergence application of Oxadiargyl with 1 HW at 30 DAT carried out in SRI method (M_4W_2). Further, integration of Oxadiargyl (PE) with 1 HW at 30 DAT in SRI method (M_4W_2) recorded statistically identical grain yield to that of M_4W_1, M_5W_1, M_5W_2 and M_4W_3 treatment combinations and significantly higher over rest of the treatment combinations, suggesting that integrated weed management in SRI and conventional transplanting is equally effective to manual hand weeding.

Pre-emergence application of Oxadiargyl with 1 HW at 20 DAS carried out in rice established by sowing of sprouted seeds by drum seeder (M_2W_2) and broadcasting of sprouted seeds on puddled field (M_3W_2) recorded significantly higher rice grain yield over rest of the treatment combinations comprising integrated or herbicidal weed management in direct seeded rice. The remaining treatment combinations recorded more or less similar grain yield of rice.

4.4.2 Straw yield (q ha^{-1})

The data presented in Table 17 revealed that, the mean straw yield of rice was 59.42, 57.99 and 58.71 q ha^{-1} during 2016, 2017 and in pooled data, respectively. The straw yield was slightly more during *Kharif* 2016 as compared to *Kharif* 2017.

Effect of establishment methods

SRI and conventional transplanting methods remained at par and both the methods produced significantly higher straw yield over sowing of dry and sprouted seeds. Sowing of sprouted seeds by drum seeder on puddled field recorded significantly higher straw yield as compared to broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder. Sowing of dry seeds by drum seeder recorded significantly lower straw yield as compared to other establishment methods during both the years of experimentation as well as in pooled data.

Effect of weed management practices

All the weed management treatments produced significantly higher straw yield of rice than unweeded control (W_5) during both the years and in pooled data. Weed management practices *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), integration of pre-emergence application of Oxadiargyl either with HW at 20/30 DAS/DAT (W_2) or HW at 40/60 DAS/DAT (W_3) and combined application of Oxadiargyl (PE) and Almix (POE) herbicides (W_4) differed significantly from one another in descending order, respectively during both the years of experimentation and in the pooled analysis.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to straw yield (q ha^{-1}) of rice were found to be non-significant during both the years of study and in pooled data.

4.5 Weed studies

Weed density of grasses, sedges and broad leaved weeds were taken periodically at 20/30, 40/60 DAS/DAT and at harvest during the years 2016 and 2017. Similarly, dry weight of weeds at harvest of crop was also recorded.

Further, weed index and weed control efficiency were calculated during both the years of experimentation. Dominant weed flora recorded during *Kharif* 2016 and 2017 is given in Table 19.

Table 19. Dominant weeds observed in the *Kharif* rice crop

Sr. No.	Botanical name	Family	Common name
A) Grassy weeds			
1	*Echinochloa colona*	Poaceae	Pakhad
2	*Echinochloa glabrescens*	Poaceae	Pakhad
3	*Ischaemum globosa*	Poaceae	Dhur

B) Sedges			
1	*Cyperus iria*	Cyperaceae	Lavala
2	*Cyperus difformis*	Cyperaceae	Lavala
C) Broad leaved weeds			
1	*Celosia argentea*	Amaranthaceae	Cocks comb
2	*Mimosa pudica*	Leguminaceae	Lajaloo
3	*Alternanthera sessilis*	Amaranthaceae	Reshim kata
4	*Ageratum conyzoides*	Asteraceae	Osadi
5	*Ludwigia octovalvis*	Onagraceae	Kadu Chinch

4.5.1 Number of grassy weeds m^{-2}

Data pertaining to the mean number of grassy weeds in rice as affected by various treatments at 20/30, 40/60 DAS/DAT and at harvest are presented in Table 20 and graphically depicted in Fig. 16.

The mean density of grasses m^{-2} at harvest was 5.39 and 5.40 during *Kharif* 2016 and 2017, respectively.

Effect of establishment methods

Sowing of dry seeds by drum seeder recorded significantly higher count of grassy weeds m^{-2} over rest of the establishment methods throughout the crop growth period during both the years of study. SRI and conventional transplanting methods remained at par and both these methods recorded significantly lower count of grassy weeds m^{-2} as compared to sowing of sprouted seeds, throughout the crop growth period except 20/30 DAS/DAT and at harvest during both the years. Sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds were at par with each other at all the growth stages.

Table 20. Mean number of grassy weeds m^{-2} as influenced by different treatments at 20/30, 40/60 DAS/DAT and at harvest during *Kharif* 2016 and 2017

Treatments	20/30 DAS/DAT		40/60 DAS/DAT		At harvest	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	3.78 (23.20)	3.81 (23.73)	5.12 (41.20)	5.14 (41.40)	7.15 (56.67)	7.17 (56.87)
M_2: Sowing of sprouted seeds by drum seeder	2.93 (11.40)	2.97 (11.73)	3.26 (15.53)	3.28 (15.60)	4.99 (26.80)	5.00 (26.87)
M_3: Broadcasting of sprouted seeds	2.98 (11.87)	3.00 (12.07)	3.30 (15.93)	3.31 (16.00)	5.00 (26.80)	5.01 (26.93)
M_4: SRI method	2.80 (10.33)	2.85 (10.73)	3.12 (14.00)	3.13 (14.20)	4.90 (25.67)	4.89 (25.60)
M_5: Conventional transplanting	2.80 (10.33)	2.84 (10.60)	3.15 (14.33)	3.15 (14.40)	4.92 (25.80)	4.92(25.73)
S.Em. ±	0.14	0.15	0.04	0.03	0.18	0.17
C.D. at 5%	0.44	0.47	0.12	0.11	0.57	0.55
Weed management practices						
W_1: Two hand weedings	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	3.82 (14.40)	3.83 (14.47)
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.71 (0.00)	0.71 (0.00)	3.73 (14.13)	3.74 (14.27)	4.60 (21.93)	4.60 (22.00)
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	4.50 (20.93)	4.54 (21.47)	0.71 (0.00)	0.71 (0.00)	4.02 (15.87)	4.03 (15.93)

W_4: Oxadiargyl (PE) + Almix (POE)	4.12 (17.27)	4.18 (17.80)	5.58 (32.53)	5.60 (32.87)	6.52 (43.20)	6.51 (43.07)
W_5: Unweeded control	5.27 (28.93)	5.33 (29.60)	7.23 (54.33)	7.24 (54.47)	8.00 (66.33)	8.01 (66.53)
S.Em. ±	0.21	0.20	0.03	0.04	0.16	0.15
C.D. at 5%	0.70	0.66	0.11	0.13	0.51	0.50
Interaction effect						
S.Em. ±	0.61	0.60	0.85	0.84	0.42	0.44
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	3.06 (13.43)	3.09 (13.77)	3.59 (20.20)	3.60 (20.32)	5.39 (32.35)	5.40 (32.40)

Note: Transformed values ($Y=\sqrt{X+0.5}$); Figures in parentheses are means of original values.

Effect of weed management practices

All weed management practices recorded significantly lower number of grassy weeds m^{-2} as compared to unweeded control (W_5) during both the years. Similarly, application of pre and post emergence herbicides (W_4) recorded significantly higher count of grassy weeds m^{-2} as compared to W_1, W_2 and W_3 throughout the crop growth period except 20/30 DAS/DAT during both the years.

The weed count was taken at 20/30 and 40/60 DAS/DAT after adoption of treatments therefore, the treatments *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), integration of pre-emergence application of Oxadiargyl either with HW at 20/30 DAS/DAT (W_2) or HW at 40/60 DAS/DAT (W_3) involving hand weedings did not record any weed count after hand weeding therefore, there is no any significance in comparing the weed count as influenced by these treatments. At harvest W_3 recorded significantly higher and lower grassy weed count m^{-2} than W_1 and W_2, respectively.

Interaction effect

The interaction effects between establishment methods and weed management practices on number grassy weeds m^{-2} were found to be non-significant during *Kharif* 2016 and 2017.

4.5.2 Number of sedges weeds m^{-2}

Data pertaining to the mean number of sedges weeds in rice as affected by various treatments at 20/30, 40/60 DAS/DAT and at harvest are presented in Table 21 and graphically depicted in Fig. 17.

The mean density of sedges weeds m^{-2} was 5.25 and 5.33 during *Kharif* 2016 and 2017 at harvest, respectively.

Effect of establishment methods

Sowing of dry seeds by drum seeder recorded maximum and significantly higher number of sedges weeds m^{-2} throughout the crop growth period during both the years of experimentation over rest of the rice establishment methods.

Table 21. Mean number of sedges weeds m^{-2} as influenced by different treatments at 20/30, 40/60 DAS/DAT and at harvest during *Kharif* 2016 and 2017

Treatments	20/30 DAS/DAT		40/60 DAS/DAT		At harvest	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Establishment methods						
M$_1$: Sowing of dry seeds by drum seeder	1.79 (3.87)	1.80 (3.93)	1.82 (3.87)	1.84 (3.90)	6.91 (51.47)	6.95 (51.87)
M$_2$: Sowing of sprouted seeds by drum seeder	1.20 (1.13)	1.21 (1.17)	1.45 (2.13)	1.46 (2.17)	4.84 (24.97)	4.96 (25.90)
M$_3$: Broadcasting of sprouted seeds	1.22 (1.20)	1.22 (1.20)	1.48 (2.20)	1.49 (2.23)	4.85 (25.00)	4.94 (25.73)
M$_4$: SRI method	1.20 (1.13)	1.20 (1.13)	1.43 (2.07)	1.43 (2.07)	4.84 (24.93)	4.90 (25.40)
M$_5$: Conventional transplanting	1.20 (1.13)	1.21 (1.17)	1.46 (2.13)	1.46 (2.13)	4.83 (24.93)	4.92 (25.67)
S.Em. ±	0.05	0.06	0.07	0.05	0.08	0.11
C.D. at 5%	0.18	0.20	0.22	0.16	0.27	0.37
Weed management practices						
W$_1$: Two hand weedings	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	3.87 (14.80)	4.07 (16.27)
W$_2$: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.71 (0.00)	0.71 (0.00)	1.75 (2.73)	1.76 (2.77)	4.56 (21.60)	4.56 (21.60)
W$_3$: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	1.72 (2.87)	1.73 (2.87)	0.71 (0.00)	0.71 (0.00)	3.88 (14.87)	4.09 (16.47)

W_4: Oxadiargyl (PE) + Almix (POE)	1.57 (2.27)	1.58 (2.27)	1.82 (2.93)	1.84 (2.97)	6.24 (39.50)	6.25 (39.63)
W_5: Unweeded control	1.91 (3.33)	1.93 (3.47)	2.66 (6.73)	2.67 (6.77)	7.71 (60.53)	7.72 (60.60)
S.Em. ±	0.09	0.07	0.05	0.04	0.11	0.12
C.D. at 5%	0.29	0.24	0.17	0.14	0.36	0.40
Interaction effect						
S.Em. ±	0.29	0.30	0.20	0.19	0.37	0.40
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	1.32 (1.69)	1.33 (1.72)	1.53 (2.48)	1.54 (2.50)	5.25 (30.26)	5.33 (30.91)

Note: Transformed values ($Y=\sqrt{X+0.5}$); Figures in parentheses are means of original values.

The remaining rice establishment methods did not differ significantly from one another in recording the number of sedges weeds m^{-2} throughout the crop growth period during both the years of study.

Effect of weed management practices

All the weed management practices recorded significantly lower number of sedges weeds m^{-2} as compared to unweeded control (W_5) throughout the crop growth period during both the years.

At 20/30 DAS/DAT pre-emergence application of Oxadiargyl + 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl + Almix (W_4) were at par and both these treatments resulted in significantly higher sedges weeds m^{-2} count as compared to two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) and Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2). Further, W_1 and W_2 were at par with each other.

At 40/60 DAS/DAT among weed management practices W_1 and W_3 remained at par and recorded significantly lower sedges weeds m^{-2} count as compared to W_2 and W_4 however, later two treatments were also at par with each other during both the years. Among weed management practices W_1 and W_3 remained at par and both these treatments recorded significantly lower sedges weeds m^{-2} count than W_2 and W_4 at harvest. The treatment W_2 recorded significantly lower number of sedges weeds m^{-2} than W_4 at harvest during both the years of study.

Interaction effect

All the interaction effects between establishment methods and weed management practices with respect to number of sedges weeds m^{-2} were found to be non-significant in rice during both the years.

4.5.3 Number of broad leaved weeds m^{-2}

Data regarding to the mean number of broad leaved weeds in rice as influenced by various treatments at 20/30, 40/60 DAS/DAT and at harvest are presented in Table 22 and graphically depicted in Fig. 18.

The mean density of broad leaved weeds m^{-2} was 3.90 and 3.92 at harvest during *Kharif* 2016 and 2017, respectively.

Effect of establishment methods

The sowing of dry seeds by drum seeder recorded maximum and significantly higher number of broad leaved weeds m^{-2} at 20/30 DAS/DAT and at harvest during both the years over rest of the rice establishment methods. The remaining rice establishment methods did not differ significantly from one another in recording the number of broad leaved weeds m^{-2} at 20/30 DAS/DAT and at harvest during both the years of study.

Effect of weed management practices

Weed management practices recorded significantly lower number of broad leaved weeds m^{-2} as compared to unweeded control (W_5) throughout the crop growth period during both the years.

At 20/30 DAS/DAT pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl + Almix (W_4) were at par and both these treatments resulted in significantly higher broad leaved weeds m^{-2} count as compared to two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) and Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2). Further, W_1 and W_2 were at par with each other.

At 40/60 DAS/DAT among weed management practices W_1 and W_3 remained at par and recorded significantly lower broad leaved weeds m^{-2} count as compared to W_2 and W_4, the latter two treatments were also at par with each other during both the years. At harvest W_1 and W_3 treatments recorded significantly lower broad leaved weeds m^{-2} count than W_2 and W_4. The treatment W_2 recorded significantly lower number of broad leaved weeds m^{-2} than W_4 at harvest during both the years of study.

Table 22. Mean number of broad leaved weeds m^{-2} as influenced by different treatments at 20/30, 40/60 DAS/DAT and at harvest during *Kharif* 2016 and 2017

Treatments	20/30 DAS/DAT		40/60 DAS/DAT		At harvest	
	2016	2017	2016	2017	2016	2017
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	3.01 (13.40)	3.02 (13.53)	3.33 (17.47)	3.34 (17.57)	4.98 (26.80)	5.00 (26.93)
M_2: Sowing of sprouted seeds by drum seeder	2.14 (5.63)	2.14 (5.63)	2.62 (9.20)	2.62 (9.20)	3.64 (13.80)	3.65 (13.87)
M_3: Broadcasting of sprouted seeds	2.15 (5.67)	2.16 (5.73)	2.65 (9.40)	2.65 (9.40)	3.65 (13.87)	3.66 (13.93)
M_4: SRI method	2.11 (5.43)	2.11 (5.47)	2.61 (9.13)	2.62 (9.20)	3.64 (13.77)	3.64 (13.80)
M_5: Conventional transplanting	2.11 (5.43)	2.11 (5.47)	2.65 (9.47)	2.65 (9.47)	3.60 (13.53)	3.63 (13.67)
S.Em. ±	0.10	0.11	0.21	0.20	0.04	0.03
C.D. at 5%	0.34	0.35	NS	NS	0.14	0.08
Weed management practices						
W_1: Two hand weedings	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	2.77 (7.27)	2.78 (7.33)
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.71 (0.00)	0.71 (0.00)	3.45 (11.53)	3.46 (11.60)	3.63 (12.93)	3.62 (12.87)

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	3.14 (9.43)	3.15 (9.47)	0.71 (0.00)	0.71 (0.00)	2.93 (8.17)	2.94 (8.27)
W_4: Oxadiargyl (PE) + Almix (POE)	2.91 (9.20)	2.92 (9.27)	3.94 (16.20)	3.95 (16.27)	4.40 (19.80)	4.42 (20.00)
W_5: Unweeded control	4.04 (16.93)	4.06 (17.10)	5.05 (26.93)	5.06 (26.97)	5.80 (33.60)	5.81 (33.73)
S.Em. ±	0.16	0.17	0.19	0.20	0.05	0.04
C.D. at 5%	0.51	0.52	0.61	0.63	0.15	0.13
Interaction effect						
S.Em. ±	0.48	0.50	0.52	0.53	0.35	0.37
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	2.30 (7.11)	2.31 (7.17)	2.77 (10.93)	2.78 (10.97)	3.90 (16.35)	3.92 (16.44)

Note: Transformed values ($Y=\sqrt{X+0.5}$); Figures in parentheses are means of original values.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to number of broad leaved weeds m^{-2} were found to be non-significant in rice during *Kharif* 2016 and 2017.

4.5.4 Total dry weight of weeds (q ha^{-1})

Data regarding mean dry weight of weeds (q ha^{-1}) as influenced by different treatments during *Kharif* 2016 and 2017 are presented in Table 23 and graphically depicted in Fig. 19. The mean total dry weight of weeds at harvest was 2.54 and 2.61 q ha^{-1} during *Kharif* 2016 and 2017, respectively.

Effect of establishment methods

It is seen from the data presented in Table 23, that sowing of dry seeds by drum seeder recorded significantly higher dry weight of weeds after harvest of rice as compared to rest of the rice establishment methods during both the years of experimentation. Further, the other rice establishment methods *i.e.* SRI method and conventional transplanting remained at par with each other and sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field in recording the total dry weight of weeds during both the years of study.

Effect of weed management practices

Weed management practices recorded significantly lower dry weight of weeds after harvest of rice as compared to unweeded control (W_5) during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) remained at par with Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and both these methods produced significantly lower weed biomass at harvest than Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) and pre and post emergence application of Oxadiargyl + Almix (W_4). Further, W_2 recorded significantly lower dry weight of weeds than W_4 during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices on total dry weight of weeds (q ha^{-1}) were found to be non-significant at harvest during *Kharif* 2016 and 2017.

4.5.5 Weed index (%)

The data was not statistically analysed. Therefore, the inferences are drawn from the mean values. Data regarding weed index (%) are presented in Table 23 and graphically depicted in Fig. 20.

Effect of weed management practices

Data presented in Table 23 revealed that, the lowest weed index was recorded under Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) followed by Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3), pre and post emergence application of Oxadiargyl + Almix (W_4) and the highest weed index was recorded under unweeded control (W_5) during both the years of study.

4.5.6 Weed control efficiency (%)

The data is not statistically analysed. Therefore, the inferences have been drawn from the mean values. Data regarding weed control efficiency (%) are presented in Table 23 and graphically depicted in Fig. 20.

Effect of weed management practices

Data presented in Table 23 clearly indicated that, two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded the highest weed control efficiency (%) followed by Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3), Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) and the lowest weed control efficiency was recorded under pre and post emergence application of Oxadiargyl + Almix (W_4) during both the years.

Table 23. Total dry weight of weeds (q ha^{-1}) at harvest, weed index (%) and weed control efficiency (%) as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	Dry weight of weeds (q ha^{-1})		Weed index (%)		Weed control efficiency (%)	
	2016	2017	2016	2017	2016	2017
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	3.04 (9.87)	3.07 (10.08)				
M_2: Sowing of sprouted seeds by drum seeder	2.44 (5.89)	2.53 (6.37)				
M_3: Broadcasting of sprouted seeds	2.48 (6.09)	2.56 (6.55)				
M_4: SRI method	2.36 (5.42)	2.43 (5.80)				
M_5: Conventional transplanting	2.39 (5.56)	2.46 (5.98)				
S.Em. ±	0.01	0.03				
C.D. at 5%	0.04	0.08				
Weed management practices						
W_1: Two hand weedings	2.01 (3.56)	2.06 (3.75)	-	-	75.57	75.92
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	2.27 (4.67)	2.32 (4.91)	2.66	3.30	67.65	68.34

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	2.03 (3.63)	2.09 (3.88)	4.82	5.52	74.90	75.11
W_4: Oxadiargyl (PE) + Almix (POE)	2.48 (5.73)	2.54 (6.04)	8.92	9.21	61.32	61.93
W_5: Unweeded control	3.92 (15.25)	4.05 (16.20)	11.77	13.37	-	-
S.Em. ±	0.01	0.03				
C.D. at 5%	0.05	0.09				
Interaction effect						
S.Em. ±	0.23	0.21				
C.D. at 5%	NS	NS				
General mean	2.54 (6.57)	2.61 (6.96)				

Note: Transformed values ($Y=\sqrt{X+0.5}$); Figures in parentheses are means of original values.

4.6 Nutrient content, uptake and quality study of rice

The effect of different treatments on content and uptake of nitrogen, phosphorus and potassium by both the components (grain and straw) of rice are presented here. Similarly, the data on protein content in grain of rice as influenced by various treatments are also presented here.

4.6.1 Nitrogen content in grain and straw (%)

The nitrogen content in grain and straw of rice as influenced by various treatments are presented in Table 24 and graphically depicted in Fig. 21.

Effect of establishment methods

SRI method recorded maximum and significantly higher N content in grain and straw of rice over rest of the establishment methods except N content in rice straw under conventional transplanting during both the years. Conventional transplanting significantly increased N content in grain and straw as compared to remaining establishment methods except N content in straw of rice sown by sprouted seeds using drum seeder. Significantly the lowest N content was observed in rice when dry seeds were sown through drum seeder. Sowing of sprouted seeds either by drum seeder or broadcasting recorded more or less similar N content in both the components of rice.

Effect of weed management practices

All weed management practices recorded significantly higher N content in grain as well as straw as compared to unweeded control (W_5) during both the years of study. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher N content in grain as well as straw over all other weed management practices except Oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT (W_2) in respect of nitrogen content in rice straw during 2017. Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly higher and lower N content in grain as well as straw than W_4 and W_2, respectively during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to nitrogen content (%) in grain and straw of rice were found to be non-significant during both the years.

4.6.2 Nitrogen uptake by rice (kg ha^{-1})

The data pertaining to the effect of different treatments on N uptake by rice grain, straw and total uptake are presented in Table 24 and graphically depicted in Fig. 22 and 23.

The mean values of nitrogen uptake by rice grain and straw were 46.80 and 45.35, 30.29 and 29.01 kg ha^{-1} during 2016 and 2017, respectively. The values of total uptake of nitrogen by rice grain and straw were 77.08 and 74.36 kg ha^{-1} during 2016 and 2017, respectively.

Effect of establishment methods

Rice transplanted by SRI method significantly increased the nitrogen uptake by grain, straw and their total as compared to rest of the establishment methods. Conventional transplanting recorded significantly higher N uptake by rice grain, straw and their total over sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field. Sowing of dry seeds by drum seeder recorded significantly lower N uptake by rice grain, straw and their total over other establishment methods during both the years.

Effect of weed management practices

Weed management practices recorded significantly higher N uptake in grain, straw and their total as compared to unweeded control (W_5) during both the years.

Table 24. Nitrogen content (%), nitrogen uptake in grain, straw (kg ha^{-1}) and total nitrogen uptake (kg ha^{-1}) by rice as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	N content (%)				N uptake (kg ha^{-1})				Total N uptake (kg ha^{-1})	
	Grain		Straw		Grain		Straw			
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods										
M_1: Sowing of dry seeds by drum seeder	1.123	1.123	0.485	0.484	42.19	40.24	26.06	25.34	68.25	65.58
M_2: Sowing of sprouted seeds by drum seeder	1.146	1.143	0.513	0.504	45.36	44.20	30.89	29.60	76.25	73.79
M_3: Broadcasting of sprouted seeds	1.144	1.141	0.502	0.491	44.20	43.11	28.76	27.42	72.96	70.53
M_4: SRI method	1.183	1.182	0.524	0.512	51.91	50.33	33.41	31.90	85.32	82.23
M_5: Conventional transplanting	1.175	1.171	0.517	0.503	50.31	48.89	32.33	30.80	82.63	79.68
S.Em. ±	0.002	0.001	0.004	0.003	0.16	0.24	0.28	0.27	0.37	0.47
C.D. at 5%	0.006	0.005	0.012	0.010	0.51	0.79	0.92	0.88	1.20	1.55
Weed management practices										
W_1: Two hand weedings	1.176	1.173	0.535	0.525	50.53	49.30	33.35	32.11	83.87	81.41
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	1.166	1.165	0.523	0.513	48.78	47.40	31.86	30.63	80.64	78.02

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	1.156	1.155	0.513	0.507	47.30	45.87	30.80	29.70	78.10	75.57
W_4: Oxadiargyl (PE) + Almix (POE)	1.144	1.143	0.495	0.488	44.78	43.58	28.81	27.80	73.60	71.38
W_5: Unweeded control	1.129	1.125	0.475	0.460	42.59	40.61	26.62	24.83	69.21	65.44
S.Em. ±	0.003	0.002	0.003	0.004	0.21	0.22	0.19	0.30	0.29	0.40
C.D. at 5%	0.007	0.008	0.009	0.013	0.67	0.66	0.63	0.99	0.95	1.32
Interaction effect										
S.Em. ±	0.005	0.008	0.004	0.006	0.46	0.61	0.35	0.54	0.51	0.68
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
General mean	1.154	1.152	0.508	0.499	46.80	45.35	30.29	29.01	77.08	74.36

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher N uptake in grain, straw and their total over all other weed management practices. Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly higher and lower N uptake in grain, straw and their total than pre and post emergence application of Oxadiargyl + Almix (W_4) and Oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT (W_2), respectively during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to nitrogen uptake (kg ha^{-1}) in rice grain, straw and their total were found to be non-significant during both the years.

4.6.3 Phosphorus content in grain and straw (%)

The data on phosphorus content in grain and straw of rice as influenced by different treatments are presented in Table 25 and graphically depicted in Fig. 24.

Effect of establishment methods

Among different establishment methods SRI method recorded maximum and significantly higher phosphorus content in grain as well as straw over other rice establishment methods barring conventional transplanting and sowing of sprouted seeds by drum seeder in respect of P content in rice grains during both the years. Further, SRI and conventional transplanting methods remained at par with each other and sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field in respect of P content in rice straw during both the years of experimentation.

Table 25. Phosphorus content (%), phosphorus uptake in grain, straw (kg ha^{-1}) and total phosphorus uptake (kg ha^{-1}) by rice as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	P content (%)				P uptake (kg ha^{-1})				Total P uptake (kg ha^{-1})	
	Grain		Straw		Grain		Straw			
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods										
M_1: Sowing of dry seeds by drum seeder	0.183	0.177	0.084	0.071	6.89	6.40	4.53	3.74	11.43	10.14
M_2: Sowing of sprouted seeds by drum seeder	0.217	0.210	0.096	0.090	8.60	8.13	5.80	5.31	14.40	13.44
M_3: Broadcasting of sprouted seeds	0.207	0.202	0.098	0.087	8.04	7.65	5.63	4.91	13.67	12.56
M_4: SRI method	0.225	0.217	0.108	0.108	9.91	9.29	6.90	6.75	16.81	16.04
M_5: Conventional transplanting	0.219	0.213	0.100	0.100	9.41	8.91	6.27	6.15	15.69	15.06
S.Em. ±	0.003	0.004	0.003	0.002	0.10	0.13	0.20	0.16	0.19	0.27
C.D. at 5%	0.009	0.012	0.009	0.008	0.31	0.43	0.64	0.52	0.63	0.88
Weed management practices										
W_1: Two hand weedings	0.234	0.228	0.114	0.109	10.08	9.60	7.12	6.67	17.20	16.27
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.222	0.215	0.104	0.099	9.31	8.75	6.35	5.96	15.65	14.71

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	0.212	0.207	0.099	0.096	8.68	8.25	5.95	5.66	14.63	13.91
W_4: Oxadiargyl (PE) + Almix (POE)	0.201	0.195	0.091	0.084	7.87	7.44	5.29	4.84	13.17	12.27
W_5: Unweeded control	0.183	0.175	0.079	0.068	6.92	6.35	4.43	3.72	11.35	10.06
S.Em. ±	0.002	0.003	0.003	0.002	0.07	0.08	0.16	0.15	0.18	0.20
C.D. at 5%	0.007	0.006	0.009	0.008	0.23	0.24	0.53	0.49	0.59	0.65
Interaction effect										
S.Em. ±	0.005	0.006	0.004	0.005	0.15	0.20	0.24	0.22	0.24	0.27
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
General mean	0.210	0.204	0.097	0.091	8.57	8.08	5.83	5.37	14.40	13.45

Effect of weed management practices

Unweeded control (W_5) recorded significantly lower phosphorus content in grain and straw as compared to other weed management practices during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher P content in grain and straw over all other weed management practices. Pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) remained at par with pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) in respect of P content in rice straw during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to phosphorus content (%) in grain and straw of rice were found to be non-significant during both the years.

4.6.4 Phosphorus uptake by rice (kg ha^{-1})

The data regarding phosphorus uptake by rice grain, straw and their total as influenced by various treatments are presented in Table 25 and graphically depicted in Fig. 25 and 26.

The mean values of P uptake by rice grain and straw were 8.57 and 8.08, 5.83 and 5.37 kg ha^{-1} during 2016 and 2017, respectively. The values of total uptake of P by rice grain and straw were 14.40 and 13.45 kg ha^{-1} during 2016 and 2017, respectively.

Effect of establishment methods

The uptake of P by rice grain, straw and their total were affected significantly due to different establishment methods in both the seasons. SRI method significantly increased P uptake by grain, straw and their total as compared to remaining establishment methods except conventional transplanting in respect of P uptake in rice grain and straw during 2017 and 2016.

Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field during both the seasons in respect of P uptake in rice straw. Sowing of dry seeds by drum seeder recorded significantly lower uptake of P by grain, straw and their total over other treatments during both the years.

Effect of weed management practices

All weed management practices recorded significantly higher uptake of P by rice grain and straw as well as total uptake as compared to unweeded control (W_5) during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher P uptake in grain, straw and total P uptake over remaining weed management practices. Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) remained at par with Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and recorded significantly higher P uptake in grain, straw and their total than pre and post emergence application of Oxadiargyl and Almix (W_4), respectively during both the years.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to phosphorus uptake (kg ha^{-1}) in rice grain, straw and total P uptake were found to be non-significant during both the years.

4.6.5 Potassium content in grain and straw (%)

The data regarding K content in grain and straw as affected due to various treatments are presented in Table 26 and graphically depicted in Fig. 27.

Effect of establishment methods

The K content in grain and straw of rice was statistically identical under SRI and conventional transplanting methods and significantly higher over remaining establishment methods. Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field in respect of K content in rice grain and straw during both the years. The K content in grain and straw of rice grown by sowing of dry seeds using drum seeder was minimum and significantly lower as compared to rest of the rice establishment methods during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly the lowest K content in grain and straw as compared to other weed management practices during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher K content in grain and straw over all other weed management practices. Pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) remained at par with pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) in respect of K content in rice grain during both the years.

Interaction effect

Interaction effects between establishment methods and weed management practices in respect of potassium content (%) in grain and straw of rice were found to be non-significant during both the years.

4.6.6 Potassium uptake by rice (kg ha^{-1})

Data regarding K uptake by rice grain, straw and their total as influenced by various treatments are presented in Table 26 and graphically depicted in Fig. 28 and 29.

The mean uptake values of K by rice grain and straw were 8.28 and 7.82, 69.33 and 67.32 kg ha^{-1} during 2016 and 2017, respectively. The total mean uptake values of K by rice crop were 77.61 and 75.14 kg ha^{-1} during 2016 and 2017, respectively.

Table 26. Potassium content (%), potassium uptake in grain, straw (kg ha^{-1}) and total potassium uptake (kg ha^{-1}) by rice as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	K content (%)				K uptake (kg ha^{-1})				Total K uptake (kg ha^{-1})	
	Grain		Straw		Grain		Straw			
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Establishment methods										
M$_1$: Sowing of dry seeds by drum seeder	0.176	0.169	1.139	1.133	6.64	6.11	61.04	59.21	67.68	65.32
M$_2$: Sowing of sprouted seeds by drum seeder	0.204	0.203	1.167	1.159	8.09	7.85	70.22	67.94	78.31	75.80
M$_3$: Broadcasting of sprouted seeds	0.200	0.199	1.170	1.163	7.75	7.53	66.94	64.90	74.69	72.43
M$_4$: SRI method	0.221	0.210	1.181	1.176	9.70	8.98	75.23	73.17	84.93	82.14
M$_5$: Conventional transplanting	0.215	0.207	1.171	1.166	9.21	8.66	73.23	71.36	82.44	80.02
S.Em. ±	0.005	0.002	0.002	0.003	0.17	0.05	0.49	0.41	0.50	0.43
C.D. at 5%	0.015	0.006	0.008	0.009	0.54	0.17	1.60	1.34	1.63	1.40
Weed management practices										
W$_1$: Two hand weedings	0.226	0.220	1.187	1.183	9.73	9.26	73.91	72.32	83.64	81.58
W$_2$: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.213	0.209	1.175	1.171	8.94	8.55	71.53	69.79	80.47	78.33

W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	0.206	0.202	1.167	1.165	8.44	8.05	69.98	68.23	78.42	76.29
W_4: Oxadiargyl (PE) + Almix (POE)	0.195	0.183	1.154	1.144	7.64	6.97	67.12	65.09	74.77	72.07
W_5: Unweeded control	0.175	0.173	1.145	1.133	6.65	6.29	64.11	61.15	70.76	67.45
S.Em. ±	0.002	0.003	0.004	0.002	0.09	0.08	0.29	0.26	0.31	0.30
C.D. at 5%	0.008	0.007	0.005	0.007	0.30	0.33	0.96	0.85	1.02	0.98
Interaction effect										
S.Em. ±	0.004	0.005	0.003	0.005	0.15	0.24	0.63	0.79	0.58	0.83
C.D. at 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
General mean	0.203	0.197	1.165	1.159	8.28	7.82	69.33	67.32	77.61	75.14

Effect of establishment methods

The uptake of K by rice grain, straw and total uptake was maximum and significantly higher under SRI method except conventional transplanting during 2016 in respect of K uptake in rice grains. Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field during 2016 in respect of K uptake in rice grains. Sowing of dry seeds by drum seeder recorded significantly lower uptake of K by grain, straw and total K uptake than other establishment methods during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly lower uptake of K by rice grain and straw as well as total uptake as compared to weed management practices during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher K uptake in grain, straw and their total over remaining weed management practices. Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly higher and lower K uptake in grain, straw and their total than pre and post emergence application of Oxadiargyl + Almix (W_4) and Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2), respectively during both the years.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to potassium uptake (kg ha^{-1}) in rice grain, straw and their total were found to be non-significant during both the years.

4.6.7 Quality study (Protein content in rice grain)

The data regarding protein content (%) in grain as affected by various treatments are presented in Table 27 and graphically depicted in Fig. 30. The mean protein content in rice grain was 7.21 and 7.20 per cent, during 2016 and 2017 crop seasons, respectively.

Effect of establishment methods

The protein content in rice grain was significantly influenced under various establishment methods. SRI and conventional transplanting methods recorded identical and significantly higher protein content in grain during both the years as compared to other establishment methods. Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field during both the years and recorded significantly higher protein content in rice grain than sowing of dry seeds by drum seeder during both the years of study.

Table 27. Protein content (%) in rice grain as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	Protein content (%)	
	2016	**2017**
Establishment methods		
M_1: Sowing of dry seeds by drum seeder	7.02	7.02
M_2: Sowing of sprouted seeds by drum seeder	7.16	7.15
M_3: Broadcasting of sprouted seeds	7.15	7.13
M_4: SRI method	7.40	7.39
M_5: Conventional transplanting	7.34	7.32
S.Em. ±	0.01	0.03
C.D. at 5%	0.03	0.02
Weed management practices		
W_1: Two hand weedings	7.35	7.33
W_2: Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT	7.29	7.28
W_3: Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT	7.23	7.22
W_4: Oxadiargyl (PE) + Almix (POE)	7.15	7.14
W_5: Unweeded control	7.06	7.03
S.Em. ±	0.01	0.02
C.D. at 5%	0.04	0.05
Interaction effect		
S.Em. ±	0.03	0.05
C.D. at 5%	NS	NS

General mean	7.21	7.20

Effect of weed management practices

Unweeded control (W_5) recorded significantly lower protein content in rice grain as compared to other weed management methods during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher protein content in rice grain over other weed management practices except Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) during 2017. Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly higher and lower protein content in rice grain than the pre and post emergence application of Oxadiargyl + Almix (W_4) and Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) during both the seasons.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to protein content in rice grain (%) were found to be non-significant during both the years.

4.7 Nutrient content and uptake by weeds

Data regarding nutrient content (%) and uptake of nitrogen, phosphorous and potassium (Kg ha^{-1}) by weeds as influenced by different treatments.

4.7.1 Nutrient content in weeds (%)

The data regarding nutrient content (%) in weeds are presented in Table 28 and graphically depicted in Fig. 31.

4.7.1.1 Nitrogen content in weeds (%)

Data pertaining to nitrogen content in weeds as influenced by different treatments during 2016 and 2017 are presented in Table 28. The mean nitrogen content in weeds was 0.899 and 0.906 per cent during 2016 and 2017, respectively.

Table 28. Nitrogen, phosphorus and potassium content (%) in weeds as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	N content (%)		P content (%)		K content (%)	
	2016	2017	2016	2017	2016	2017
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	0.970	0.976	0.263	0.271	0.827	0.830
M_2: Sowing of sprouted seeds by drum seeder	0.889	0.898	0.245	0.247	0.770	0.773
M_3: Broadcasting of sprouted seeds	0.886	0.896	0.251	0.255	0.785	0.785
M_4: SRI method	0.869	0.877	0.239	0.240	0.747	0.756
M_5: Conventional transplanting	0.880	0.884	0.240	0.242	0.759	0.767
S.Em. ±	0.018	0.019	0.002	0.004	0.005	0.006
C.D. at 5%	0.060	0.063	0.007	0.009	0.015	0.017
Weed management practices						
W_1: Two hand weedings	0.818	0.828	0.209	0.215	0.718	0.726
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	0.835	0.840	0.227	0.229	0.741	0.743
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	0.846	0.853	0.241	0.245	0.753	0.758

W_4: Oxadiargyl (PE) + Almix (POE)	0.876	0.881	0.262	0.265	0.797	0.798
W_5: Unweeded control	1.119	1.129	0.297	0.301	0.878	0.886
S.Em. ±	0.019	0.018	0.002	0.003	0.006	0.007
C.D. at 5%	0.062	0.060	0.006	0.009	0.020	0.022
Interaction effect						
S.Em. ±	0.054	0.056	0.009	0.010	0.015	0.018
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	0.899	0.906	0.247	0.251	0.777	0.782

Effect of establishment methods

Sowing of dry seeds by drum seeder recorded maximum and significantly higher N content in weeds over other establishment methods. The remaining rice establishment methods *i.e.* SRI, conventional transplanting, sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field remained at par with each other during both the years of experimentation.

Effect of weed management practices

All weed management practices *i.e.* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) remained at par and recorded significantly lower N content in weeds as compared to unweeded control (W_5) during both the years of study.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to nitrogen content (%) in weeds were found to be non-significant during both the years.

4.7.1.2 Phosphorus content in weeds (%)

The data on phosphorus content in weeds as influenced by different treatments are presented in Table 28. The mean phosphorus content in weeds was 0.247 and 0.251 per cent during 2016 and 2017, respectively.

Effect of establishment methods

Among different establishment methods sowing of dry seeds by drum seeder recorded maximum and significantly higher phosphorus content in weeds over rest of the rice establishment methods during both the years. SRI method, conventional transplanting and sowing of sprouted seeds by drum seeder remained at par with one another and recorded significantly lower phosphorus content in weeds than broadcasting of sprouted seeds on puddled field during both the years of study. SRI method recorded significantly lower phosphorus content in weeds as compared to other rice establishment methods during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher phosphorus content in weeds as compared to other weed management practices during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly lower P content in weeds over all other weed management practices. Pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) recorded significantly lower and higher phosphorus content in weeds than pre and post emergence application of Oxadiargyl + Almix (W_4) and Oxadiargyl (PE) along with 1 HW at 20/30 DAS/DAT (W_2), respectively during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices with respect to phosphorus content (%) in weeds were found to be non-significant during both the years.

4.7.1.3 Potassium content in weeds (%)

The data regarding K content in weeds as affected due to various treatments are presented in Table 28. The mean potassium content in weeds was 0.777 and 0.782 per cent during 2016 and 2017, respectively.

Effect of establishment methods

The K content in weeds was significantly higher under sowing of dry seeds by drum seeder over remaining establishment methods. SRI and conventional transplanting methods remained at par with each other and recorded significantly lower K content in weeds than sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field these two methods remained at par with each other during both the years and recorded significantly higher K content in weeds as compared to rest of the rice establishment methods except sowing of dry seeds by drum seeder during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly the highest K content in weeds as compared to other weed management practices during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly the lowest K content in weeds over all other weed management practices. Pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) remained at par with pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) during both the years. Pre and post emergence application of Oxadiargyl and Almix (W_4) recorded significantly higher K content in weeds as compared to W_1, W_2 and W_3 during both the years.

Interaction effect

Interaction effects between establishment methods and weed management practices with respect to potassium content (%) in weeds were found to be non-significant during both the years.

4.7.2 Nutrient uptake by weeds (Kg ha^{-1})

The data regarding nutrient uptake (Kg ha^{-1}) by weeds are presented in Table 29 and graphically depicted in Fig. 32.

4.7.2.1 Nitrogen uptake by weeds (Kg ha^{-1})

The data pertaining to the effect of different treatments on total uptake of nitrogen (Kg ha^{-1}) by weeds are presented in Table 29. The mean values of total uptake of nitrogen (Kg ha^{-1}) by weeds were 6.52 and 6.95 kg ha^{-1} in 2016 and 2017, respectively.

Effect of establishment methods

The uptake of N by weeds was maximum and significantly higher under sowing of dry seeds by drum seeder as compared to other establishment methods during both the years. The remaining establishment methods *viz.,* SRI, conventional transplanting, sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field remained at par with one another and recorded significantly lower uptake of N by weeds than sowing of dry seeds by drum seeder during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher uptake of N by weeds as compared to other weed management treatments during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) and Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) recorded minimum and significantly lower N uptake by weeds and remained at par with each other during both the years. Pre and post emergence application of Oxadiargyl and Almix (W_4) recorded significantly higher uptake of N by weeds as compared to other weed management treatments except unweeded control (W_5) during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices did not reach the level of significance in case of nitrogen uptake by weeds during both the years.

4.7.2.2 Phosphorus uptake by weeds (Kg ha^{-1})

The data regarding effect of different treatments on total uptake of phosphorus (Kg ha^{-1}) by weeds are presented in Table 29. The mean values of total uptake of phosphorus (Kg ha^{-1}) by weeds were 1.77 and 1.90 kg ha^{-1} in 2016 and 2017, respectively.

Effect of establishment methods

Sowing of dry seeds by drum seeder recorded maximum and significantly higher phosphorus uptake by weeds as compared to other establishment methods. SRI and conventional transplanting methods recorded significantly lower uptake of P by weeds and remained at par with each other during both the years. Sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field recorded significantly lower phosphorus uptake by weeds than sowing of dry seeds by drum seeder during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher phosphorus uptake by weeds as compared to other weed management practices during both the years. The treatment W_1 *i.e.* two hand weedings at 20/30 and 40/60 DAS/DAT was at par with Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) during 2017 and recorded significantly lower phosphorus uptake by weeds as compared to rest of the treatments. Pre-emergence application Oxadiargyl with 1 HW at 20/30 DAS/DAT (W_2) recorded significantly lower P uptake by weeds than pre and post emergence application of Oxadiargyl + Almix (W_4) during both the years.

Interaction effect

The interaction effects between establishment methods and weed management practices did not reach the level of significance in case of phosphorus uptake by weeds during both the years.

4.7.2.3 Potassium uptake by weeds (Kg ha^{-1})

The data pertaining to the effect of different treatments on total uptake of potassium (Kg ha^{-1}) by weeds are presented in Table 29. The mean values of total uptake of potassium (Kg ha^{-1}) by weeds were 5.07 and 5.43 kg ha^{-1} in 2016 and 2017, respectively.

Table 29. Nitrogen, phosphorus and potassium uptake (kg ha^{-1}) by weeds as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	N uptake (kg ha^{-1})		P uptake (kg ha^{-1})		K uptake (kg ha^{-1})	
	2016	2017	2016	2017	2016	2017
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	11.08	11.37	2.89	3.04	7.70	7.95
M_2: Sowing of sprouted seeds by drum seeder	5.57	6.09	1.52	1.67	4.47	4.83
M_3: Broadcasting of sprouted seeds	5.75	6.26	1.65	1.79	4.64	5.04
M_4: SRI method	5.00	5.39	1.37	1.46	4.02	4.34
M_5: Conventional transplanting	5.18	5.62	1.41	1.52	4.54	4.98
S.Em. ±	0.42	0.39	0.02	0.04	0.05	0.08
C.D. at 5%	1.38	1.28	0.07	0.13	0.15	0.27
Weed management practices						
W_1: Two hand weedings	2.92	3.11	0.75	0.81	2.65	2.80
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	3.91	4.13	1.07	1.13	3.53	3.74
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	3.08	3.32	0.88	0.96	2.92	3.12

W_4: Oxadiargyl (PE) + Almix (POE)	5.03	5.35	1.51	1.62	5.06	5.39
W_5: Unweeded control	17.64	18.83	4.63	4.98	11.20	12.11
S.Em. ±	0.44	0.36	0.03	0.05	0.10	0.15
C.D. at 5%	1.42	1.19	0.11	0.16	0.32	0.49
Interaction effect						
S.Em. ±	3.93	3.78	0.89	0.90	1.46	1.37
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	6.52	6.95	1.77	1.90	5.07	5.43

Effect of establishment methods

The uptake of potassium by weeds was maximum and significantly higher under sowing of dry seeds by drum seeder as compared to other establishment methods during both the years. SRI method of rice transplanting recorded significantly lower uptake of K by weeds over remaining establishment methods. Conventional transplanting recorded higher and lower uptake of K by weeds than sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field and these two treatments remained at par with each other during 2017.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher uptake of K by weeds as compared to other weed management treatments during both the years. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded minimum and significantly lower K uptake by weeds over other weed management practices except pre-emergence application of Oxadiargyl with 1 HW at 40/60 DAS/DAT (W_3) during both the years. Integration of pre-emergence application of Oxadiargyl with 1 HW at 20/30 DAS/DAT (W_2) recorded significantly lower K uptake by weeds than pre and post emergence application of Oxadiargyl and Almix (W_4) during both the years of study.

Interaction effect

The interaction effects between establishment methods and weed management practices did not reach the level of significance in case of potassium uptake by weeds during both the years.

4.8 Nutrient status of soil after harvest of rice

The effect of different treatments on available N, P and K (kg ha^{-1}) status of soil after harvest of rice are presented in Table 30 and graphically depicted in Fig. 33 to 35.

4.8.1 Soil available nitrogen (kg ha^{-1})

The data on soil available N after harvest of rice as influenced by various treatments are presented in Table 30.

The mean values of available N content in soil after harvest of rice were 231.20 and 231.67 kg ha^{-1} during 2016 and 2017, respectively. The soil available N after harvest of experimental crop, in general, showed slight increase during successive years as well as over initial level of 216.12 kg ha^{-1}.

Effect of establishment methods

The soil available N determined after harvest of rice was more compared to initial levels during both the years.

The soil available N measured after harvest of rice was significantly higher when the crop was established by sowing of dry seeds by drum seeder as compared to other establishment methods. Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field during 2017 and recorded significantly higher available N as compared to SRI and conventional transplanting methods. Further, SRI and conventional transplanting methods remained at par with each other during both the years.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher available N in soil as compared to other weed management practices during both the years. All the weed management practices *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) differed significantly with one another in descending order in recording available N during both the years.

Table 30. Available nitrogen, phosphorus and potassium content (kg ha^{-1}) in soil after harvest of rice as influenced by different treatments during *Kharif* 2016 and 2017

Treatments	Available N (kg ha^{-1})		Available P_2O_5 (kg ha^{-1})		Available K_2O (kg ha^{-1})	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	233.53	234.13	13.00	13.13	211.53	211.73
M_2: Sowing of sprouted seeds by drum seeder	231.20	232.07	12.20	12.40	209.53	209.53
M_3: Broadcasting of sprouted seeds	232.94	233.21	12.80	12.87	209.80	209.93
M_4: SRI method	228.90	228.90	11.60	11.73	209.33	209.33
M_5: Conventional transplanting	229.43	230.03	12.07	12.13	209.33	209.40
S.Em. ±	0.50	0.49	0.24	0.28	0.43	0.44
C.D. at 5%	1.61	1.59	0.77	0.90	1.41	1.40
Weed management practices						
W_1: Two hand weedings	218.97	219.83	9.40	9.47	205.80	205.80
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	223.67	223.67	10.60	10.80	207.60	207.67
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	226.40	226.40	11.80	11.87	209.27	209.40

W_4: Oxadiargyl (PE) + Almix (POE)	234.00	234.93	13.20	13.33	211.53	211.60
W_5: Unweeded control	252.97	253.51	16.67	16.80	215.33	215.47
S.Em. ±	0.30	0.38	0.18	0.19	0.39	0.34
C.D. at 5%	0.99	1.24	0.59	0.61	1.26	1.10
Interaction effect						
S.Em. ±	1.26	1.55	0.39	0.53	1.39	1.38
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	231.20	231.67	12.33	12.45	209.91	209.99
Initial value	216.12		9.22		205.75	

Interaction effect

The interaction between establishment methods and weed management practices failed to exhibit any significant effect on available N after harvest of rice during both the years.

4.8.2 Soil available phosphorus (kg ha^{-1})

The data on soil available P after harvest of rice as affected by different treatments are presented in Table 30.

The mean available P_2O_5 in soil after harvest of rice was 12.33 and 12.45 kg ha^{-1} in 2016 and 2017, respectively indicating the improvement in available P_2O_5 over initial level (9.22 kg ha^{-1}) during both the years of experimentation.

Effect of establishment methods

The available P status of soil was improved after harvest of rice as compared to initial P level during both the years.

The soil available P_2O_5 observed after harvest of rice was maximum and significantly higher when the crop was established by sowing of dry seeds through drum seeder as compared to other establishment methods. Sowing of sprouted seeds by drum seeder remained at par with broadcasting of sprouted seeds on puddled field during both the years and recorded significantly higher available P_2O_5 as compared to SRI and conventional transplanting methods, however, later two methods were at par with each other during both the years.

Effect of weed management practices

The available P_2O_5 in soil estimated after harvest of rice was significantly higher under unweeded control (W_5) as compared to other weed management practices during both the years. Weed management practices *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), pre-emergence application of Oxadiargyl either with HW at 20/30 DAS/DAT (W_2) or HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) differed significantly with one another in descending order in recording available P_2O_5 during both the years.

Interaction effect

The interaction between establishment methods and weed management practices failed to exhibit any significant effect on available P_2O_5 after harvest of rice during both the years.

4.8.3 Soil available potassium (kg ha^{-1})

The data on soil available K after harvest of rice as influenced by various treatments are presented in Table 30.

The mean figures of available K_2O content of soil measured after harvest of rice were 209.91 and 209.99 kg ha^{-1} during 2016 and 2017, respectively. In general, there was a little rise in soil available K_2O over the initial level (205.75 kg ha^{-1}) during both the years.

Effect of establishment methods

The soil available K_2O determined after harvest of rice was more as compared to initial levels during both the years.

The soil available K_2O measured after harvest of rice was maximum and significantly higher when the crop was established by sowing of dry seeds by drum seeder as compared to other establishment methods. However, remaining establishment methods *viz.,* SRI method, conventional transplanting, sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds on puddled field remained at par with each other during both the years of study.

Effect of weed management practices

Unweeded control (W_5) recorded significantly higher available K_2O in soil as compared to weed management practices carried out in rice during both the years. All the weed management practices *viz.,* two hand weedings at 20/30 and 40/60 DAS/DAT (W_1), Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) differed significantly with one another in descending order in recording available K_2O during both the years.

Interaction effect

The interaction between establishment methods and weed management practices failed to exhibit any significant effect on available K_2O after harvest of rice during both the years.

4.9 Economics

4.9.1 Economics of the treatments

Data regarding economics of rice cultivation as affected by different treatments are presented in Table 31 and 32.

4.9.1.1 Gross returns (Rs. ha^{-1})

The data pertaining to gross returns from rice as influenced by various treatments are presented in Table 31.

The mean gross returns from rice were Rs. 71995, 70496 and 71246 ha^{-1} during 2016, 2017 and in pooled analysis, respectively.

Effect of establishment methods

Maximum and significantly higher gross returns were obtained from the rice established by SRI method as compared to rest of the establishment methods followed by conventional transplanting, sowing of sprouted seeds by drum seeder, broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder in descending order during both the years as well as in pooled analysis. Sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds remained at par with each other during 2017. Sowing of dry seeds by drum seeder realized significantly the lowest gross returns during both the years as well as in pooled data.

Table 31. Cost of cultivation and gross returns (Rs. ha^{-1}) from rice as influenced by different treatments

Treatments	Cost of cultivation (Rs. ha^{-1})			Gross returns (Rs. ha^{-1})		
	2016	**2017**	**Pooled**	**2016**	**2017**	**Pooled**
Establishment methods						
M$_1$: Sowing of dry seeds by drum seeder	60858	60836	60847	66651	63840	65245
M$_2$: Sowing of sprouted seeds by drum seeder	62534	62317	62425	70965	69257	70111
M$_3$: Broadcasting of sprouted seeds	61965	61635	61800	68960	67353	68157
M$_4$: SRI method	70872	70596	70734	78070	75851	76960
M$_5$: Conventional transplanting	71958	71688	71823	75330	74312	74821
S.Em. ±	97	137	94	286	337	255
C.D. at 5%	318	446	305	934	1101	832
Weed management practices						
W$_1$: Two hand weedings	68321	68196	68258	76136	74791	75464
W$_2$: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	66860	66525	66692	74433	72438	73436
W$_3$: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	66846	66439	66643	72873	70823	71848
W$_4$: Oxadiargyl (PE) + Almix (POE)	63767	63477	63622	69882	68076	68979

W_5: Unweeded control	62392	62434	62413	66652	64485	65569
S.Em. ±	91	139	77	356	245	267
C.D. at 5%	295	454	251	1162	799	869
Interaction effect						
S.Em. ±	1025	813	891	987	874	753
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	65637	65414	65526	71995	70496	71246

Effect of weed management practices

Unweeded control (W_5) recorded the lowest gross returns from *Kharif* rice as compared to other weed management methods during both the years and in pooled data. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher gross returns followed by Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2), Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) in descending order during both the seasons as well as in pooled analysis. The treatment W_1 remained at par with W_2 during 2017.

Interaction effect

Interaction effects were found to be non-significant during both the years of study and in pooled mean.

4.9.1.2 Net returns (Rs. ha^{-1})

The data regarding net returns from *Kharif* rice as influenced by various treatments are presented in Table 32.

The mean net returns from rice were Rs. 6358, 4708 and 5533 ha^{-1} during 2016, 2017 and in pooled analysis, respectively.

Effect of establishment methods

Sowing of sprouted seeds by drum seeder recorded significantly higher net returns from *Kharif* rice as compared to rest of the establishment methods during both the years and in pooled data indicating that it can be an alternative method of rice establishment to SRI and conventional transplanting methods so as to overcome the problems of scarcity of labours due to increased industrialization and urbanization as well as high wage rates.

SRI method of rice establishment and broadcasting of sprouted seeds on puddled field remained at par with each other and recorded significantly higher net returns during both the seasons as well as in pooled analysis as compared to remaining establishment methods showing that the higher rice grain and straw yields obtained in SRI method did not compensate the expenditure required for transplanting of seedlings in SRI method.

Conventional transplanting recorded significantly the lowest net returns from rice as compared to other establishment methods during both the years and in pooled analysis due to higher cost of transplanting involved in conventional transplanting which was not recovered by higher yields.

Effect of weed management practices

It is seen from the data presented in Table 32 that unweeded control (W_5) recorded significantly the lowest net returns from rice as compared to other weed management methods during both the years as well as in pooled data. Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher net returns over remaining weed management methods except Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) during 2016 and in pooled analysis indicating that pre-emergence herbicidal spray with 1 HW at tillering stage was as effective as 2 HW at tillering and panicle initiation stages, in controlling the weeds in *Kharif* rice established by different methods. Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) were at par with each other during both the seasons as well as in pooled analysis.

Interaction effect

Interaction effects were found to be non-significant during both the years of study and in pooled data.

4.9.1.3 Benefit to cost ratio

The data on benefit to cost ratio as influenced by various treatments are presented in Table 32. It is evident from the data that the mean values of benefit to cost ratio from rice were 1.098, 1.072 and 1.085 during 2016, 2017 and in pooled analysis, respectively.

Table 32. Net returns (Rs. ha^{-1}) and benefit to cost ratio from rice as influenced by different treatments

Treatments	Net returns (Rs. ha^{-1})			B: C ratio		
	2016	2017	Pooled	2016	2017	Pooled
Establishment methods						
M_1: Sowing of dry seeds by drum seeder	5793	3005	4399	1.096	1.049	1.073
M_2: Sowing of sprouted seeds by drum seeder	8431	6940	7686	1.134	1.111	1.123
M_3: Broadcasting of sprouted seeds	6996	5719	6357	1.112	1.092	1.102
M_4: SRI method	7198	5254	6226	1.101	1.074	1.087
M_5: Conventional transplanting	3372	2624	2998	1.046	1.036	1.041
S.Em. ±	271	339	239	0.004	0.005	0.004
C.D. at 5%	883	1105	778	0.012	0.017	0.011
Weed management practices						
W_1: Two hand weedings	7815	6595	7205	1.116	1.098	1.107
W_2: Oxadiargyl (PE) +1 HW at 20/30 DAS/DAT	7573	5914	6743	1.114	1.089	1.102
W_3: Oxadiargyl (PE) +1 HW at 40/60 DAS/DAT	6026	4384	5205	1.091	1.067	1.079
W_4: Oxadiargyl (PE) + Almix (POE)	6115	4599	5357	1.098	1.075	1.086

W_5: Unweeded control	4260	2051	3155	1.071	1.033	1.052
S.Em. ±	357	196	227	0.005	0.003	0.003
C.D. at 5%	1163	639	739	0.018	0.010	0.012
Interaction effect						
S.Em. ±	1405	1052	1037	0.023	0.017	0.020
C.D. at 5%	NS	NS	NS	NS	NS	NS
General mean	6358	4708	5533	1.098	1.072	1.085

Effect of establishment methods

Among different establishment methods sowing of sprouted seeds by drum seeder recorded significantly higher benefit to cost ratio from *Kharif* rice as compared to rest of the establishment methods during both the years and in pooled data. SRI method of rice establishment remained at par with broadcasting of sprouted seeds on puddled field during 2016 and recorded significantly higher benefit to cost ratio over remaining establishment methods. Sowing of dry seeds by drum seeder recorded significantly the lowest benefit to cost ratio as compared to other establishment methods except conventional transplanting during both the seasons as well as in pooled analysis.

Effect of weed management practices

Unweeded control (W_5) recorded significantly the lowest benefit to cost ratio from rice as compared to other weed management practices during both the years as well as in pooled data.

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher benefit to cost ratio over remaining weed management methods except Oxadiargyl (PE) with 1 HW at 20/30 DAS/DAT (W_2) during both the seasons as well as in pooled analysis confirming the results obtained in case of net returns. Pre and post emergence application of Oxadiargyl + Almix (W_4) recorded significantly higher benefit to cost ratio than Oxadiargyl (PE) with 1 HW at 40/60 DAS/DAT (W_3) and both these treatments remained at par with each other during both the seasons as well as in pooled analysis.

Interaction effect

Interaction effects were found to be non-significant during both the years of study and in pooled analysis.

4.9.2 Economics of treatment combinations

The data on economics of treatment combinations of rice are presented in Table 33.

Data revealed that the maximum net profit of Rs. 11336, 10043 and 10690 ha^{-1} was obtained when rice crop was established by sowing of sprouted seeds by drum seeder with two hand weedings carried out at 20 and 40 DAS over the remaining treatment combinations followed by the combination of broadcasting of sprouted seeds on puddled field with two hand weedings carried out at 20 and 40 DAS (Rs. 9212, 7556 and 8384 ha^{-1}) and sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field with pre-emergence application of Oxadiargyl along with 1 HW at 20 DAS (Rs. 8710, 6777 and 7744 ha^{-1}) over the remaining treatment combinations during 2016, 2017 and in pooled data, respectively.

The highest B: C ratio (1.176, 1.156 and 1.166) was obtained when rice crop was established by sowing of sprouted seeds by drum seeder with two hand weedings carried out at 20 and 40 DAS followed by the combination of crop established by broadcasting of sprouted seeds on puddled field with two hand weedings carried out at 20 and 40 DAS (1.143, 1.118 and 1.131) and sowing of sprouted seeds (*Rahu*) using drum seeder on puddled field with pre-emergence application of Oxadiargyl + 1 HW carried out at 20 DAS (1.137, 1.107 and 1.122) over the remaining treatment combinations during 2016, 2017 and in pooled mean, respectively.

Thus, rice crop established by sowing of sprouted seeds by drum seeder with two hand weedings carried out at 20 and 40 DAS or pre-emergence application of Oxadiargyl + 1 HW carried out at 20 DAS (M_2W_1 and M_2W_2) recorded higher net returns and B: C ratios from *Kharif* rice as compared to other treatment combinations during both the years as well as in pooled data.

Table 33. Economics of the rice cultivation as influenced by different treatment combinations

Treatment combinations	Cost of cultivation ($Rs.\ ha^{-1}$)			Gross returns ($Rs.\ ha^{-1}$)			Net returns ($Rs.\ ha^{-1}$)			B: C Ratio		
	2016	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**	**2016**	**2017**	**Pooled**
M_1W_1	65863	65626	65745	70552	69126	69839	4689	3500	4095	1.071	1.053	1.062
M_1W_2	62637	61804	62221	68756	65695	67226	6119	3891	5005	1.098	1.063	1.080
M_1W_3	62544	62073	62308	67473	64643	66058	4929	2571	3750	1.079	1.041	1.060
M_1W_4	57729	57447	57588	64722	63031	63877	6993	5584	6289	1.121	1.097	1.109
M_1W_5	55516	55229	56373	61750	56705	59228	6233	1476	2855	1.112	1.026	1.052
M_2W_1	64529	64270	64400	75865	74314	75089	11336	10043	10690	1.176	1.156	1.166
M_2W_2	63568	63581	63574	72278	70358	71318	8710	6777	7744	1.137	1.107	1.122
M_2W_3	63168	62922	63045	71217	69705	70461	8049	6783	7416	1.127	1.108	1.118
M_2W_4	60616	60294	60455	68722	66792	67757	8106	6498	7302	1.134	1.108	1.121
M_2W_5	60789	60517	60653	66744	65117	65931	5956	4599	5277	1.098	1.076	1.087
M_3W_1	64337	64006	64172	73549	70896	72556	9212	7556	8384	1.143	1.118	1.131
M_3W_2	63014	62665	62840	71793	79695	70744	8779	7031	7905	1.139	1.112	1.126
M_3W_3	63028	62422	62725	69213	67572	68392	6184	5150	5667	1.098	1.083	1.090

M_3W_4	60431	60303	60367	66448	65682	66065	6018	5379	5698	1.100	1.089	1.094
M_3W_5	59012	58777	58895	63799	62255	63027	4787	3478	4132	1.081	1.060	1.070
M_4W_1	72802	72995	72899	82034	80209	81122	9232	7214	8223	1.127	1.099	1.113
M_4W_2	71989	71705	71847	80351	78807	79579	8362	7102	7732	1.116	1.099	1.108
M_4W_3	72212	71883	72048	79029	77052	78041	6817	5169	5993	1.094	1.072	1.083
M_4W_4	69494	69139	69316	75537	73410	74474	6044	4271	5157	1.087	1.062	1.074
M_4W_5	67864	67260	67562	73399	69775	71587	5535	2515	4025	1.082	1.037	1.059
M_5W_1	74072	74083	74078	78680	78745	78713	4608	4662	4635	1.062	1.063	1.063
M_5W_2	73093	72868	72981	78986	77637	78311	5893	4768	5330	1.081	1.065	1.073
M_5W_3	73278	72898	73088	77432	75143	76288	4154	2245	3199	1.057	1.031	1.044
M_5W_4	70567	70202	70384	73982	71462	72722	3416	1260	2338	1.048	1.018	1.033
M_5W_5	68780	68386	68583	69908	68572	69240	1128	0186	657	1.016	1.002	1.009

CHAPTER V

DISCUSSION

The results of the present investigation have been reported in the previous chapter. This chapter deals with the probable reasons for the variations observed in different growth and development parameters, yield attributes and yield, weed density, nutrient content and their uptake, soil fertility and economics as a result of the imposition of treatments and substantiate them, wherever possible, with the available references from the literature in order to establish the effect and cause relationship. The entire chapter has been divided for the sake of convenience in to following sub heads.

5.1 Soil, weather and crop growth

5.2 Effect of establishment methods

5.3 Effect of weed management practices

5.4 Interaction effect between establishment methods and weed management practices

5.5 Economics of treatment combinations

5.1 Soil, weather and crop growth

Before going into discussion of the present investigation, it is important to discuss the weather conditions to which the crop was exposed and the soil conditions on which it was grown.

The analysis of the initial soil sample indicated that the soil of experimental plot was sandy clay loam in texture, moderately high in organic carbon, low in available nitrogen, phosphorus, potassium and slightly acidic in reaction (Table 1). It was lateritic in nature and reddish brown in colour. The soil was levelled, well drained and uniform in depth. Thus, the soil was suitable for growing rice in *Kharif* season. Among the various factors responsible for affecting the growth and yield performance of crop, the weather conditions play a key role. The various weather parameters pertaining to *Kharif*, 2016 and 2017 crop seasons are presented in Table 2.

The data on growth and development parameters, yield contributory characters and yield of rice showed higher values during the first year as compared to the second year of study, although the differences were of little magnitude. This could be attributed to the comparatively high rainfall and its better distribution during 2016 as compared to 2017 (Table 2) which in turn might have influenced the overall growth and development of the crop.

The meteorological data (Table 2) showed that the total rainfall received during *Kharif* season was 4492.8 and 3568.4 mm in 100 and 105 rainy days in 2016 and 2017, respectively. The total rainfall received in *Kharif* 2016 was high and its distribution was better than *Kharif* 2017. The mean maximum temperatures ranged from 27.0^{0}C to 34.0^{0}C and 27.4^{0}C to 31.8^{0}C and mean minimum temperatures from 21.4^{0}C to 24.9^{0}C and 22.7^{0}C to 25.2^{0}C during the crop season in the years 2016 and 2017, respectively. The relative humidity during entire crop season of 2016 ranged from 91 to 99 per cent during morning and 70 to 95 per cent during afternoon, respectively. During 2017 the corresponding values of relative humidity ranged between 86 to 98 per cent and 73 to 91 per cent, respectively.

The meteorological data revealed that the weather was, by and large, congenial for the growth and development of *Kharif* rice without incidence of any major pests or diseases during both the years. Thus, the observed differences were mainly due to treatment effects.

5.2 Effect of establishment methods

5.2.1 Plant population

The number of plants and plant hills m^{-2} of rice counted at 20 DAS/DAT and at harvest (Table 6) differed significantly due to various crop establishment methods. The number of plants in a unit area mainly depends on the establishment methods. In the present investigation the rice crop was established by various methods with different spacings, therefore, the plant population was varied as per the establishment method. Direct seeded methods recorded significantly higher plant population as compared to transplanted methods because of closer spacing between plant to plant.

5.2.2 Growth parameters

It is evident from the data presented in previous chapter (Table 7 to 13) that a marked effect of crop establishment methods was observed on growth characters of rice throughout the crop growth period. At initial growth stage (30 DAS) sowing of sprouted seeds (*Rahu*) by drum seeder recorded significantly higher plant height as compared to other establishment methods. Similar findings were also reported by Dhebe (2009).

At 60, 90 DAS and at harvest SRI and conventional transplanting methods of crop establishment significantly increased the plant height during both the years. The tallest plants under SRI might be due to optimum plant population and square geometry which led to availability of more growth resources to plants. The increased height in SRI was due to open plant structure giving more coverage to the ground area. Further, the lower angle of inclination of leaves in case of SRI results in more spread than other establishment methods (Thakur *et al.* 2011). The transplanting of younger seedlings in SRI method which might have established quickly in the field and started growing at faster might be attributed to higher plant height (Krishna *et al.* 2008). Similar results were also reported by Kumar (2015).

At 30 DAS sowing of sprouted seeds (*Rahu*) by drum seeder recorded significantly higher plant height, maximum number of functional leaves m^{-2}, tillers m^{-2} and higher dry matter accumulation (g) m^{-2} as compared to other establishment methods. It may be due to more number of mother plants m^{-2} under direct seeding at initial stage as compared to transplanting. Similar findings have been reported by Gill *et al.* (2006) and Sharma *et al.* (2015).

From 60 DAS to harvest, conventional transplanting recorded significantly maximum number of functional leaves m^{-2}, tillers m^{-2} and higher dry matter accumulation (g) m^{-2} during both the years. The increased growth parameters may be attributed to the fact that each individual plant hill in transplanting method got the advantage of more available and liberal nutrients, space, solar radiation and other growth resources available to the plant due to less competition of lower plant population. The other possible reason of high dry matter accumulation in transplanting method may be traced to the significant increase in morphological parameters which are responsible for the photosynthetic capacity of the plant there by increasing the biological yield. Similar findings were also reported by Dhebe (2009) and Bhowmick *et al.* (2013).

5.2.3 Yield attributes and yield

The main objective of agronomist is to increase the economic yield which is grain yield in case of rice. The grain yield per unit area in rice is a function of yield attributes of an individual plant *viz.*, length of panicle (cm), weight panicle^{-1} (g), number of filled grains panicle^{-1}, test weight (g) and ultimately the grain yield (q ha^{-1}) obtained from the crop. The results revealed that SRI method of transplanting remained at par with conventional transplanting in some of these yield contributing characters and significantly improved the yield attributes (Table 14 to 16) and thereby grain yield ha^{-1} over sowing of sprouted seeds by drum seeder on puddled field, broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder during both the years as well as in pooled data. However, sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds were at par with each other in recording the some yield attributes of rice crop.

The increase in yield attributes and grain yield in SRI method (Table 17) might be due to square geometry of hills with wider spacing and planting of single seedling hill^{-1} which reduced the above and below ground competition, enhanced solar radiation interception and nutrient uptake (Mohanty *et al.* 2014). Increased grain yield under SRI is mainly due to the synergistic effects of modification in the cultivation practices such as use of young seedlings, limited irrigation and frequent loosening of the top soil to stimulate aerobic soil conditions (Kumar 2015). Bhowmick *et al.* (2013) obtained comparatively lower yields under normal transplanting due to gradual degeneration of rice roots with the progress of crop growth stages due to continuous submergence. The higher yield realized with SRI method might be due to the use of younger seedlings, which preserved a potential for more tillering and rooting. The increase in the grain yield of SRI method may be attributed to large root volume, profuse and strong tillers with big panicles, more and well filled spikelets with higher grain weight (Satyanarayana and Babu, 2004). Similar findings were recorded by Jayadeva *et al.* (2008).

Conventional transplanting recorded more number of panicles m^{-2} as compared to SRI method. This might be due to closer spacing between plant to plant and higher plant population per unit area (Bommayasamy *et al.* 2010). Number of unfilled grains panicle^{-1} was found to be maximum under sowing of dry seeds by drum seeder. It was probably due to intra-species weed competition and more weedy competition in terms of higher density and growth of weeds. Transplanted methods recorded minimum number of unfilled grains panicle^{-1}. Similar findings were also reported by Dhebe (2009).

SRI method of transplanting recorded maximum straw yield (Table 17) and remained at par with conventional transplanting during both the years as well as in pooled analysis. This is attributed to the fact that the roots of rice plants might have least competition under wider spacing so that growth is stimulated by sunlight and more space for canopy expansion that increased the straw yield in SRI and conventional transplanting methods. These findings are in conformity with earlier reports by Geethalaxmi *et al.* (2011) and Thakur *et al.* (2011).

Thus, the results clearly showed that SRI method of establishment was superior followed by conventional transplanting and sowing of sprouted seeds by drum seeder for obtaining higher grain and straw yield ha^{-1} from *Kharif* rice.

5.2.4 Weed studies

SRI, conventional transplanting, sowing of sprouted seeds by drum seeder on puddled field and broadcasting of sprouted seeds on puddled field remained at par with one another and recorded significantly lower weed count and dry weight of weeds as compared to sowing of dry seeds by drum seeder (Table 20 to 23) during all the growth stages of crop. This might be due to the puddling practice in which pre-germinated weed seeds were buried in the field and flooded condition in field reduced grassy and broad leaved weeds. Sowing of dry seeds by drum seeder recorded higher number of weeds m^{-2} and their dry weight (q ha^{-1}) which might be due to non-submergence of crop in the initial stages, crop and weeds germinated simultaneously and competition among them existed for growth resources. These results are in conformity with Subramanayam *et al.* (2007).

5.2.5 Nutrient content, uptake and quality study of rice

SRI method and conventional transplanting recorded almost identical and significantly higher N, P and K content in grain and straw of rice over sowing of sprouted seeds by drum seeder on puddled field, broadcasting of sprouted seeds on puddled field and sowing of dry seeds by drum seeder (Table 24 to 26). This might be due to the fact that the crop absorbed proportionately higher amount of N, P and K due to their higher availability under comparatively lower plant population and less competition among the plants for growth resources. Similar findings have been reported by Dhebe (2009) and Thakur *et al.* (2011).

The highest N, P and K uptake by grain, straw and total uptake was recorded under SRI method and was at par with conventional transplanting. This might be due to proliferate root system in SRI method that increased the uptake of nutrients from deeper layer. Jayashree and Reddy (2003) has reported better control of weeds and favourable conditions for crop growth resulted in higher nutrient uptake by crop in SRI method. Uptake of nutrients (N, P and K) by crop is a function of the nutrient content in the plant and the dry matter accumulation per unit area. Better environment available around the eco-rhizosphere as a result of thorough pulverization of soil under a film of water and transplanting of rice seedlings aged about 12 and 21 days in such an ideal environment might have enabled the crop to absorb native as well as applied nutrients incessantly to give an early lead to the growth of individual plants as well as higher nutrient content that resulted in higher nutrient uptake. Similar findings were also reported by Dhebe (2009) and Kanthi *et al.* (2014).

The protein content (Table 27) in rice grain followed the same trend as nitrogen content by grain because protein content is computed by multiplying N content with the factor 6.25. Thus, the results resembled to that of N content during both the years.

5.2.6 Nutrient content and uptake by weeds

Nutrient (N, P and K) removal by weeds in direct seeded rice was significantly higher as compared to transplanted rice. Sowing of dry seeds by drum seeder recorded the highest content and uptake of nutrients by weeds over broadcasting of sprouted seeds, sowing of sprouted seeds by drum seeder, conventional transplanting and SRI method (Table 28 and 29). This could be due to the reason that the crop could not suppress the weeds initially due to poor establishment which resulted in more depletion of nutrients by weeds. Similar results have been reported by Shan *et al.* (2012).

In crop establishment methods the highest removal of N, P and K by weeds in direct seeded rice was due to the reason that weed growth was faster than crop in drum seeding and absorbed added nutrients more rapidly in larger quantities than crop. The results are in accordance with the findings of Revathi *et al.* (2012).

5.2.7 Post harvest soil fertility

The available N, P_2O_5 and K_2O content of soil determined after harvest of rice were influenced significantly due to different establishment methods. The soil available N, P_2O_5 and K_2O after harvest of rice were maximum and significantly higher when crop was established by sowing of dry seeds by drum seeder as compared to broadcasting of sprouted seeds, sowing of sprouted seeds by drum seeder, conventional transplanting and SRI method in descending order, respectively (Table 30).

SRI method left significantly the lowest amount of available N, P_2O_5 and K_2O content in soil and remained at par with conventional transplanting during both the years. This is due to higher uptake of nutrients in SRI method. However, there was, in general more or less improvement in available status of all these nutrients under all the establishment methods after harvest of crop over their initial levels, indicating sustainability in soil fertility after harvest of crop grown by different establishment methods. These results are in agreement with those reported by Kanthi *et al.* (2014) and Islam and Kalita (2015).

5.2.8 Economics

The study on the economic feasibility (Table 31 and 32) of different crop establishment methods in rice revealed that the highest gross returns was recorded under SRI method followed by conventional transplanting, sowing of sprouted seeds by drum seeder, broadcasting of sprouted seeds and sowing of dry seeds by drum seeder during both the years as well as in pooled data. This was mainly because of higher yields obtained in SRI method as compared to other establishment methods which led to more gross returns from *Kharif* rice. The results corroborate earlier findings of Singh *et al.* (2008) and Chapagain *et al.* (2011).

Sowing of sprouted seeds by drum seeder on puddled field gave significantly higher net returns and benefit to cost ratio from *Kharif* rice during both the seasons as well as in pooled data. Further, SRI method and broadcasting of sprouted seeds on puddled field remained at par with each other. Conventional transplanting recorded significantly the lowest net returns and benefit to cost ratio from *Kharif* rice during both the years as well as in pooled analysis. The economics clearly indicated that though the grain and straw yield of rice was significantly higher due to SRI and conventional transplanting, higher yields did not compensate the expenditure incurred for transplanting of seedlings in both the methods. The results in accordance with the findings of Singh *et al.* (2008), Dhebe (2009) and Chapagain *et al.* (2011).

5.3 Effect of weed management practices

5.3.1 Plant population

The number of plants m^{-2} of rice counted at 20 DAS/DAT and at harvest (Table 6) did not differ significantly due to different weed management practices imposed during the investigation. This indicated that the plant population was uniform in the crop throughout its life cycle. Therefore, the variations observed in different growth, yield attributes and yield of the crop in the present investigation were entirely due to imposition of different weed management practices only.

5.3.2 Growth parameters

It is evident from the data presented in previous chapter (Table 7 to 13) that the remarkable influence of different weed management practices on growth characters of rice was not observed during earlier growth period which coincided with the lag phase. However, a marked effect on growth parameters was observed during log growth phase that coincided with grand growth period. During log phase, growth parameters of rice, *viz.*, plant height, number of functional leaves m^{-2}, number of tillers m^{-2} and dry matter accumulation (g) m^{-2} recorded maximum under two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) over rest of the weed management practices during both the years. This might be due to the better environment provided for the full development of the canopy as a result of an effective weed control achieved by two hand weedings at early stage of crop weed competition (Sreelakshmi *et al.* 2016). Rawat *et al.*

(2012) reported in his findings that, the crop under weed free plots attained lush growth due to elimination of weeds from inter and intra row spaces besides better aeration due to manipulation of surface soil and thus more spaces, water, light and nutrients were available for the better growth and development, which was resulted into superior growth of crop.

Integration of pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) remained at par with each other in some of these growth parameters of rice. This showed that the pre-emergence application of selective herbicide was found to be most effective in controlling weeds during initial growth period and 1 manual weeding has taken due care for managing weeds in later growth stage of the crop. Similar findings were also reported by Shan *et al.* (2012) and Kanthi *et al.* (2014). Unweeded control (W_5) recorded the lowest growth parameters due to maximum crop weed competition. The results are similar to the findings of Mohan *et al.* (2010).

5.3.3 Yield attributes and yield

The grain yield of rice per unit area is contributed by yield attributes *viz.*, number of panicles m^{-2}, length of panicle (cm), weight panicle^{-1} (g), number of filled grains panicle^{-1}, test weight (g) and ultimately the grain and straw yield (q ha^{-1}) obtained from the crop. The results revealed that all the yield attributes (Table 14 to 16) of rice recorded maximum under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) as compared to remaining weed management practices during both the years. This might be due to effective control of all the categories of weeds during critical period of crop weed competition, which led to increased growth resources and better translocation of photosynthates from source to sink (Dharminder *et al.* 2012). Similar results were also reported by Kumar and Sharma (2005) and Prakasha *et al.* (2012). Further, Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (W_2) and Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (W_3) were at par with each other in recording some of the yield attributes of rice.

The lowest and highest number of unfilled grains panicle^{-1} was recorded under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) and unweeded control (W_5), respectively. This might be due to the effective suppression of weed growth throughout the critical period of crop weed competition might have enabled the rice crop to bear promising architecture of yield attributes and higher grain filling percentage in treated plots as compared to untreated plots. Similar findings were also reported by Ramana *et al.* (2007).

Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher grain yield (Table 17) over rest of the weed management practices during both the years as well as in pooled analysis. The increase in grain yield was mainly due to effective weed control *i.e.* reduction in weed density and weed dry weight at early stage of crop weed competition. The similar findings were also reported by Kathirvelan and Vaiyapuri (2003). The weedy check recorded significantly lower grain yield. This was mainly due to heavy infestation of weeds in this treatment during the crop growth period. Reduced grain yield in weedy check and increased grain yield in weed management plots could be associated with the significant reduction in population and dry weight of weeds, thereby resulting in higher uptake of nutrients by the crop (Dixit and Varshney *et al.* 2008).

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher straw yield (Table 17) over rest of the weed management practices during both the years as well as in pooled analysis. This might be due to less crop weed competition in treated plots. Similar findings were also reported by Kumar and Kumar (2005), Singh (2008) and Dhiman and Singh (2005). Weed free plot produced more straw yield than unweeded control due to significantly better vegetative growth of crop in weed free environment and thereby increase in straw yield of rice. Similar results were also reported by Kathirvelan and Vaiyapuri (2003), Mohan *et al.* (2010) and Verma *et al.* (2013).

5.3.4 Weed studies

The weed density (m^{-2}) and total dry weight of weeds ($q\ ha^{-1}$) was minimum and significantly lower (Table 20 to 23) under two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) followed by integration of pre-emergence application of Oxadiargyl along with 1 HW either at 20/30 DAS/DAT (W_2) or at 40/60 DAS/DAT (W_3) during both the years. Unweeded control (W_5) recorded significantly the highest weed density and total dry weight of weeds as compared to rest of the treatments throughout the crop growth period. This might be due to the differential weed density and their growth observed under different weed management practices as per their efficiencies. The results resemble the findings of Rekha *et al.* (2002), Sanjay *et al.* (2006), Prakash *et al.* (2013), Raj *et al.* (2013), Rajiv *et al.* (2013) and Sharma *et al.* (2015).

Pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) recorded the lowest weed index (Table 23) followed by Oxadiargyl (PE) along with 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4). Unweeded control (W_5) recorded the highest weed index as compared to other weed management practices during both the years. This might be due to the control of weeds at germination phase by the pre-emergence application of herbicides and significant reduction at later growth stage as late germinating weeds were removed by hand weeding. The results were in agreement with the findings of Saha and Rao (2010) and Mohan *et al.* (2010).

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded the highest weed control efficiency (Table 23) which was closely followed by pre-emergence application of Oxadiargyl along with 1 HW at 40/60 DAS/DAT (W_3), Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) and pre and post emergence application of Oxadiargyl + Almix (W_4). This may be due to effective suppression of weed growth at the early stages by pre-emergence herbicides, followed by hand weeding at later stage of crop growth. Similar result was registered by Ramana *et al.* (2007).

5.3.5 Nutrient content, uptake and quality study of rice

The data presented in Table 24 to 26 revealed that two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher N, P and K content in grain and straw of rice over integration of pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl + Almix (W_4) during both the years. In general, effective weed control recorded higher N, P and K content in crop. This may be because of weed free environments have made more nutrients available to crop. These findings corroborate the reports of Verma *et al.* (2013) and Talla and Jena (2014).

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly higher N, P and K uptake by grain and straw of rice over rest of weed management practices. The pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) remained at par with each other in recording P uptake by straw of rice during both the years. Higher nutrient uptake is due to better control of weeds leading to lower depletion of nutrients by weeds and higher nutrient uptake by rice due to higher biomass production of the crop. The results are in conformity with the findings of Sanjay *et al.* (2006). Unweeded control registered significantly the lowest nutrient uptake by crop due to low grain and straw yield. Similar findings were also reported by Kumar and Kumar (2005) and Singh (2017).

The protein content (Table 27) of rice grain increased significantly under two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) over rest of the treatments. This increase in protein content could be attributed to increased concentration of nitrogen in grain of rice under this weed management treatment. Increase in protein content may be due to the higher amount of nitrogen absorbed by the crop. These results are similar to those reported by Sawant (2003), Dhebe (2009) and Shendage (2015).

5.3.6 Nutrient content and uptake by weeds

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly lower removal of nitrogen, phosphorus and potassium by weeds (Table 28 and 29) as compared to pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) and pre and post emergence application of Oxadiargyl and Almix (W_4) during both the years. This may be due to control of broad spectrum of weeds in turn resulted in lower biomass accumulation of weeds. The findings of the present study are in conformity with the results obtained by Jacob and Syriac (2005).

Unweeded control (W_5) recorded significantly higher nitrogen, phosphorus and potassium removal by weeds as compared to other treatments during two years of experimental study because the weeds usually grow faster than crop plant and thus absorb mineral nutrients quicker, resulting in inadequate supply of nutrients to the crop plants. Similar results were reported by Puniya *et al.* (2007) and Sharma *et al.* (2007).

5.3.7 Post harvest soil fertility

The available N, P_2O_5 and K_2O content of soil (Table 30) after harvest of rice were influenced significantly due to different weed management practices. The soil available N, P_2O_5 and K_2O after harvest of rice were maximum and significantly higher under unweeded control (W_5) as compared to rest of the weed management practices.

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) left significantly the lowest amount of available N, P_2O_5 and K_2O content in soil after harvest of rice during both the years. However, there was, in general more or less improvement in available status of all these nutrients under all the weed management practices after harvest of crop over their initial levels, indicating the overall improvement in soil fertility after harvest of crop. These results are in agreement with those reported by Bhat *et al.* (2005), Islam and Kalita (2015) and Shendage (2015).

5.3.8 Economics

Two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher net returns and B: C ratio from *Kharif* rice (Table 31 and 32) except pre-emergence application of Oxadiargyl + 1 HW at 20/30 DAS/DAT (W_2) during both the years as well as in pooled data showing that pre-emergence application of Oxadiargyl + 1 HW at 20/30 DAS/DAT (tillering stage) was equally effective with 2 HW at tillering (20/30 DAS/DAT) and panicle initiation (40/60 DAS/DAT) stages. Similar findings were also reported by Kumar and Kumar (2005) and Singh (2017).

The poorest performance of rice was recorded under unweeded control (W_5) because of excessive weed density and crop weed competition. The lowest yield recorded under unweeded control has obviously resulted in the poor economic returns. Similar trend of economic returns was reported by Mukherjee and Singh (2005) and Gowda *et al.* (2009).

5.4 Interaction effect between establishment methods and weed management practices

Interaction effects were found to be significant between establishment methods and weed management practices with respect to some of the growth parameters, yield attributes and grain yield of rice during both the years as well as in pooled analysis.

In growth characters, the interaction effects for plant height (cm) at 60 DAS (Table 8) were significant during both the years. Two hand weedings carried out in SRI method at 30 and 60 DAT (M_4W_1) produced significantly the tallest plants as compared to rest of the treatment combinations during both the years except two hand weedings carried out in conventional transplanting at 30 and 60 DAT (M_5W_1) during 2016. The rice establishment methods without any weed management (unweeded control) recorded lower plant height during both the years. The results corroborate the findings of Kumar *et al.* (2012), Mandal *et al.* (2013) and Mohanty *et al.* (2014).

The interactions between establishment methods and weed management practices were found to be significant with respect to number of tillers m^{-2} at 90 DAS (Table 11) during both the years. Two hand weedings carried out at 30 and 60 DAT in rice established by conventional transplanting (M_5W_1) recorded maximum and significantly higher number of tillers m^{-2} as compared to other treatment combinations except pre-emergence application of Oxadiargyl with 1 HW at 30 DAT carried out in conventional transplanting (M_5W_2) during both the years of experimentation. Similar findings have been made by Kumar *et al.* (2014), Parameswari and Srinivas (2014) and Sharma *et al.* (2015).

The dry matter accumulation (g) m^{-2} at 60 DAS (Table 13) showed significant interaction between establishment methods and weed management practices. Two hand weedings at 30 and 60 DAT carried out in rice established by conventional transplanting (M_5W_1) produced significantly higher dry matter accumulation (g) m^{-2} over rest of the treatment combinations except conventional transplanting with spraying of Oxadiargyl (PE) + 1 HW at 20/30 DAS/DAT (M_5W_2), spraying of Oxadiargyl (PE) + 1 HW at 40/60 DAS/DAT (M_5W_3) and pre and post emergence application of Oxadiargyl + Almix (M_5W_4) during both the years. Similar findings were also reported by Kanthi *et al.* (2014), Singh and Paikra (2014) and Paliwal *et al.* (2017).

Regarding yield contributing characters, significant interactions were found between establishment methods and weed management practices in respect to number of filled grains panicle^{-1} (Table 16) during both the years. The integration of pre-emergence application of Oxadiargyl with 1 HW at 30 DAT carried out in SRI (M_4W_2) and conventional transplanting (M_5W_2) methods recorded comparable number of filled grains panicle^{-1} as compared to two hand weedings carried out at 30 and 60 DAT (M_4W_1 and M_5W_1) as well as integration of Oxadiargyl (PE) with 1 HW at 60 DAT (M_4W_3) in SRI method. Similar findings were reported by Mandal *et al.* (2013), Upasani and Barla (2014), Singh and Paikra (2014) and Kumar *et al.* (2014).

The interactions between establishment methods and weed management practices were found to be significant with respect to grain yield (q ha^{-1}) in pooled data (Table 18). Two hand weedings at 30 and 60 DAT carried out in SRI method (M_4W_1) produced maximum and significantly higher grain yield over rest of the treatment combinations barring two hand weedings at 30 and 60 DAT carried out in conventional transplanting and integration of pre-emergence application of Oxadiargyl with 1 HW at 30 DAT carried out in SRI method (M_5W_1 and M_4W_2). It might be due to removal of weeds at critical crop weed competition stages. These results are in accordance with the findings of Jayadeva (2010), Kumar *et al.* (2012), Mandal *et al.* (2013), Talla and Jena (2014), Kumar *et al.* (2014) and Islam and Kalita (2015).

5.5 Economics of treatment combinations

The adoption of any technology by the farmers depends upon its cost effectiveness. The same principle is followed while deciding the establishment methods and weed management practices options for rice. Therefore, while arriving at any conclusion and deriving any inference, a detail economic analysis is must.

On the basis of economic analysis, it is seen that the highest gross returns (Table 33) was obtained when rice crop was established by SRI method with two hand weedings carried out at 30 and 60 DAT (M_4W_1) followed by the combination of SRI method with pre-emergence application of Oxadiargyl along with 1 HW at 30 DAT (M_4W_2) and conventional transplanting with two hand weedings carried out at 30 and 60 DAT (M_5W_1) over the remaining treatment combinations during both the years as well as in pooled data.

The higher net returns and B: C ratio from *Kharif* rice were obtained when rice crop was established by sowing of sprouted seeds (*Rahu*) using drum seeder with two hand weedings carried out at 20 and 40 DAS (M_2W_1) followed by broadcasting of sprouted seeds (*Rahu*) on puddled field with two hand weedings carried out at 20 and 40 DAS (M_3W_1) and sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field with pre-emergence application of Oxadiargyl along with 1 HW at 20 DAS (M_2W_2) as compared to remaining treatment combinations during both the seasons as well as in pooled data.

Thus, economic analysis clearly showed that two hand weedings carried out at 20 and 40 DAS (W_1) or pre-emergence application of Oxadiargyl + 1 HW carried out at 20 DAS (W_2) in *Kharif* rice established by sowing of sprouted seeds (*Rahu*) using drum seeder on puddled field (M_2W_1 and M_2W_2) was found to be most beneficial as compared to other treatment combinations.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The field experiment was conducted on plot No. 24 of 'B' block of Agronomy Department Farm, College of Agriculture, Dapoli. Dist. Ratnagiri during *Kharif* seasons 2016 and 2017 to study the "Weed management in *Kharif* rice (*Oryza sativa* L.) established by different methods".

The analysis of the initial soil sample indicated that the soil of the experimental plot was uniform, levelled and well drained. It was sandy clay loam in texture, low in available nitrogen, phosphorus and potassium, moderately high in organic carbon and slightly acidic in reaction. It was lateritic in nature and reddish brown in colour. Thus, the soil was suitable for growing rice crop in *Kharif* season.

The field experiment was laid out in a strip plot design comprising of twenty five treatment combinations replicated thrice. The horizontal strips comprised five rice establishment methods and vertical strips consisted five weed management practices.

In general, the seasons were favourable for the growth of rice without incidence of any major pests or diseases during both the seasons. The most important findings emerged from the present investigation are summarised hereunder.

Effect of establishment methods

1. The plant population count at 20 DAS/DAT and at harvest was significantly lower under SRI method over rest of the establishment methods followed by conventional transplanting, sowing of dry seeds by drum seeder, broadcasting of sprouted seeds and sowing of sprouted seeds by drum seeder in ascending order during both the years.
2. Sowing of sprouted seeds (*Rahu*) by drum seeder recorded significantly higher growth parameters such as plant height, number of functional leaves m^{-2}, number of tillers m^{-2} and dry matter accumulation m^{-2} at initial growth stage (30 DAS) as compared to other establishment methods during both the years.

3. The tallest plants and higher dry matter accumulation m^{-2} were recorded under SRI method followed by conventional transplanting from 60 DAS to harvest during both the years.

4. The growth characters of rice *viz.,* number of functional leaves m^{-2} and number of tillers m^{-2} were significantly enhanced due to conventional transplanting at all the crop growth stages.

5. The yield attributes *viz.*, panicle length, weight $panicle^{-1}$, number of filled grains $panicle^{-1}$ and test weight increased significantly under SRI method as compared to remaining rice establishment methods during both the years. Conventional transplanting recorded slightly more number of panicles m^{-2} as compared to SRI method during both the years of experimentation.

6. SRI method of rice establishment significantly increased the grain yield ha^{-1} over rest of the establishment methods. Further, conventional transplanting recorded significantly higher grain yield over remaining establishment methods. Sowing of sprouted seeds by drum seeder recorded significantly higher yield over broadcasting of sprouted seeds and sowing of dry seeds by drum seeder during both the years as well as in pooled data. The mean increase in grain yield recorded under broadcasting of sprouted seeds, sowing of sprouted seeds by drum seeder, conventional transplanting and SRI method over sowing of dry seeds by drum seeder were 4.06, 6.57, 15.18 and 17.77 per cent, respectively.

7. SRI method of transplanting recorded the lowest number of grassy, sedges and broad leaved weeds m^{-2} and remained at par with conventional transplanting, sowing of sprouted seeds by drum seeder on puddled field and broadcasting of sprouted seeds on puddled field at all the growth stages of crop during both the seasons.

8. Rice crop established by SRI method recorded significantly the lowest dry weight of weeds (q ha^{-1}) over rest of the treatments except conventional transplanting during both the years. Sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds remained at par with each other and recorded lower dry weight of weeds than sowing of dry seeds by drum seeder during both the years.

9. The nitrogen, phosphorus and potassium content in grain and straw of rice were increased significantly due to SRI method as compared to other

establishment methods except conventional transplanting during both the years of study.

10. SRI method of transplanting significantly increased the total uptake of nitrogen, phosphorus and potassium by grain and straw of rice during both the years.
11. The protein content in rice grain increased significantly in the crop established by SRI method over rest of the establishment methods. Sowing of sprouted seeds by drum seeder and broadcasting of sprouted seeds remained at par with each other during both the years.
12. The nitrogen, phosphorus and potassium content and uptake by weeds was significantly higher under sowing of dry seeds by drum seeder and lower under crop established by SRI method as compared to other establishment methods except conventional transplanting during both the seasons.
13. The available status of N, P_2O_5 and K_2O after harvest of rice were improved under all the establishment methods over their respective initial levels.
14. The available N, P_2O_5 and K_2O after harvest of rice was maximum and significantly higher under sowing of dry seeds by drum seeder and significantly lower under crop established by SRI method. However, conventional transplanting was at par with SRI method during both the years of experimentation.
15. Significantly the highest gross returns were obtained due to SRI method during both the years as well as in pooled data.
16. Significantly the highest net returns and benefit to cost ratio were observed due to sowing of sprouted seeds by drum seeder on puddled field over rest of the establishment methods during both the seasons as well as in pooled data.

Effect of weed management practices

1. Plant population counted at 20 DAS/DAT and at harvest was not affected significantly due to different weed management practices during both the years.
2. Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher values of all the growth parameters of rice, *viz.*, plant height, number of functional leaves m^{-2}, number of tillers m^{-2}

and dry matter accumulation m^{-2} at all the growth stages over rest of the weed management practices during both the years.

3. The yield attributes *viz.*, number of panicles m^{-2}, length of panicle, weight $panicle^{-1}$, number of filled grains $panicle^{-1}$ and test weight increased significantly under two hand weedings at 20/30 and 40/60 DAS/DAT (W_1) as compared to remaining weed management practices during both the years.

4. Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded maximum and significantly higher grain and straw yield ha^{-1} over rest of the weed management treatments during both the seasons as well as in pooled analysis. The magnitude of increase in grain yield recorded due to W_4, W_3, W_2 and W_1 over W_5 on pooled basis was 4.72, 9.25, 11.77 and 15.16 per cent, respectively.

5. Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly the lowest number of grassy, sedges and broad leaved weeds m^{-2} followed by integration of pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) at all the growth stages of crop during both the years.

6. Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) recorded significantly the lowest dry weight of weeds (q ha^{-1}) over rest of the treatments except Oxadiargyl (PE) along with 1 HW at 40/60 DAS/DAT (W_3) during both the years.

7. The lowest weed index was recorded under pre-emergence application of Oxadiargyl + 1 HW at 20/30 DAS/DAT (W_2) whereas the highest weed index was recorded under unweeded control (W_5) during both the years.

8. The highest weed control efficiency was observed under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) which was closely followed by pre-emergence application of Oxadiargyl along with 1 HW at 40/60 DAS/DAT (W_3) during both the seasons.

9. The nitrogen, phosphorus and potassium content in grain and straw of rice were increased significantly under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) as compared to other weed management practices during both the years of study except N content in grain noticed under pre-

emergence application of Oxadiargyl + 1 HW at 20/30 DAS/DAT (W_2) during 2017.

10. Two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) significantly increased the uptake of nitrogen, phosphorus and potassium by grain, straw and total uptake as compared to remaining weed management practices during both the seasons.

11. The protein content in rice grain increased significantly in two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) over rest of the weed management treatments except pre-emergence application of Oxadiargyl + 1 HW carried out at 20/30 DAS/DAT (W_2) during 2017.

12. The nitrogen, phosphorus and potassium content and uptake by weeds was significantly higher under unweeded control (W_5) and lower under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) followed by pre-emergence application of Oxadiargyl along with 1 HW at 20/30 DAS/DAT (W_2) or 1 HW at 40/60 DAS/DAT (W_3) compared to other weed management practices during both the years.

13. The values of available N, P_2O_5 and K_2O after harvest of rice were improved under all the weed management practices over their respective initial levels.

14. The available N, P_2O_5 and K_2O after harvest of rice was maximum and significantly higher under unweeded control (W_5) and significantly lower under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) over rest of the weed management practices during both the years.

15. Significantly the highest gross returns were obtained under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) during both the seasons as well as in pooled data.

16. Maximum and significantly higher net returns and benefit to cost ratio were observed under two hand weedings carried out at 20/30 and 40/60 DAS/DAT (W_1) over rest of the weed management treatments except pre-emergence application of Oxadiargyl + 1 HW carried out at 20/30 DAS/DAT (W_2).

Economics of treatment combinations

Maximum net returns and B: C ratio were observed when rice crop was established by sowing of sprouted seeds (*Rahu*) using drum seeder on puddled field with two hand weedings carried out at 20 and 40 DAS (M_2W_1) or pre-emergence application of Oxadiargyl + 1 HW carried out at 20 DAS (M_2W_2) and broadcasting of sprouted seeds (*Rahu*) on puddled field with two hand weedings carried out at 20 and 40 DAS (M_3W_1) during both the years of experimentation as well as in pooled data.

Conclusions

On the basis of present investigation following broad conclusions can be drawn.

1. The rice crop established by System of Rice Intensification (SRI) method recorded higher yield of *Kharif* rice, however, sowing of sprouted seeds (*Rahu*) by drum seeder on puddled field recorded comparable yield and higher economic returns to that of SRI.

2. Pre-emergence application of Oxadiargyl along with 1 hand weeding carried out at 20/30 DAS/DAT recorded comparable yield and economic returns from *Kharif* rice to that of 2 hand weedings carried out at 20/30 and 40/60 DAS/DAT.

3. Pre-emergence application of Oxadiargyl along with 1 hand weeding carried out at 20 DAS in *Kharif* rice established by sowing of sprouted seeds (*Rahu*) on puddled field using drum seeder gave higher yield and economic returns.

Thus, it can be concluded that to get higher yield and economic returns from *Kharif* rice, the crop be established by sowing of sprouted seeds (*Rahu*) using drum seeder on puddled field with pre-emergence application of Oxadiargyl and 1 hand weeding at 20 DAS.

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* Originals not seen

APPENDIX-I

ABBREVIATIONS USED

a.i.	:	Active ingredient
%	:	Per cent
@	:	At the rate of
:	:	As to
–	:	to
$^{-1}$	:	Per
^{0}	:	Degree
B: C	:	Benefit Cost ratio
cm	:	Centimeter (s)
^{o}C	:	Degree Celsius
C.D. at 5 %	:	Critical Difference at 5% level of significance
DAS	:	Days After Sowing
DAT	:	Days After Transplanting
Dist.	:	District
DSR	:	Direct seeded rice
Dr.	:	Doctor
et al.	:	and others
etc.	:	Excettra
Freq.	:	Frequency
Fig.	:	Figure
Even.	:	Evening
fb	:	Followed by
g	:	gram (s)
ha	:	Hectare
hrs.	:	Hours
HW	:	Hand weeding
i.e.	:	that is
J	:	Journal
K	:	Potassium
K_2O	:	Potassium oxide
Kg	:	Kilogram (s)
lit	:	litre
m	:	meter (s)

m^{-2}	:	Square meter
M.P.	:	Madhya Pradesh
M.S.	:	Maharashtra State
Max.	:	Maximum
Met.	:	Meteorological
Min.	:	Minimum
mm	:	Millimeter (s)
MT	:	Metric Tonne (s)
Morn.	:	Morning
MW	:	Meteorological Week
N	:	Nitrogen
No.	:	Number (s)
N.S.	:	Non- significant
P	:	Phosphorous
PTR	:	Puddled transplanted rice
PE	:	Pre-emergence
POE	:	Post-emergence
P_2O_5	:	Phosphorus pentoxide
q	:	quintal (s)
RDF	:	Recommended Dose of Fertilizers
Rs.	:	Rupee (s)
Sig.	:	Significant
S.Em.	:	Standard Error of mean
sq.m.	:	Square meter
Sr. No.	:	Serial number
t	:	Tone (s)
U.P.	:	Uttar Pradesh
viz.	:	Namley
WP	:	Wettable powder
WCE	:	Weed Control Efficiency
WI	:	Weed Index
Wt.	:	Weight

APPENDIX-II

COST OF INPUTS FOR CALCULATING ECONOMICS OF TREATMENTS

Sr. No.	Particulars	Unit	Rate (Rs.)
1	**Labour wages**		
	a) Male	Rs. day^{-1}	200
	b) Female	Rs. day^{-1}	200
2	**Seed**	Rs. kg^{-1}	35
3	**Tractor**	Rs. hour^{-1}	600
4	**Farm Yard Manure**	Rs. kg^{-1}	1.5
5	**Fertilizers**		
	a) Urea	Rs. kg^{-1}	7.00
	b) Single Super Phosphate	Rs. kg^{-1}	9.00
	c) Murate of potash	Rs. kg^{-1}	18.00
6	**Herbicides**		
	a) Oxadiargyl	Rs. kg^{-1}	8318
	b) Chlorimuron ethyl + Metsulfuron methyl (Almix)	Rs. kg^{-1}	23375
7	**Pesticides**		
	a) Phorate 10%	Rs. kg^{-1}	100
8	**Price of Produce**		
	a) Main produce (Grain)	Rs. qtl^{-1}	1490
	b) By produce (Straw)	Rs. qtl^{-1}	200