Efficacy and Economics of Weed Management Strategies in Aerobic Rice (*Oryza sativa* L.)

by

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THESIS

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2014

DECLARATION

I, hereby declare that this thesis entitled "**Efficacy and Economics of Weed Management Strategies in Aerobic Rice** (*Oryza sativa* L.)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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LIST OF ABBREVIATIONS

a.i	-	Active ingredient
B:C ratio	-	Benefit Cost Ratio
BLW	-	Broad Leaved Weeds
CD (0.05)	-	Critical difference at 5 % level
cm	-	Centimetre
DAS	-	Days after sowing
day^{-1}	-	Per day
et al.	-	Co-workers/ Co-authors
Fig.	-	Figure
g	-	Gram
$g\ m^{-2}$	-	Gram per square metre
ha	-	Hectare
HI	-	Harvest index
HW	-	Hand weeding
$hill^{-1}$	-	per hill
i.e.	-	that is
K	-	Potassium
KAU	-	Kerala Agricultural University
kg	-	Kilogram
$kg\ ha^{-1}$	-	Kilogram per hectare
LAI	-	Leaf area index
m	-	Metre

m^{-2}	-	per square metre
MOP	-	Muriate of Potash
MSL	-	mean sea level
N	-	Nitrogen
NS	-	Not significant
P	-	Phosphorus
plant $^{-1}$	-	per plant
panicle^{-1}	-	per panicle
pH	-	Negative logarithm of hydrogen ion concentration
RH	-	Relative humidity
Rs. ha^{-1}	-	Rupees per hectare
Rs. Re^{-1}	-	Returns per rupee
S	-	Significant
SEm	-	Standard error of mean
sp.	-	Species
t ha^{-1}	-	Tonnes per hectare
viz.	-	Namely
WCE	-	Weed Control Efficiency

LIST OF SYMBOLS

%	-	per cent
°C	-	Degree Celsius
@	-	at the rate of

INTRODUCTION

1. INTRODUCTION

Rice (*Oryza sativa* L.) has shaped the culture, diets and economies of millions of people. For more than half of the humanity "rice is life". Rice, the only food crop to acquire two years designated as "International" in its honour, forms the staple food for more than half of the world's population. Hamilton (2003) describes the integral and vital role of rice as follows: "a key tenet of rice culture is that rice is a sacred food divinely given to humans that uniquely sustains the human body in a way that no other food can."

Rice production is challenged by the increasing food demand and threatened by the declining water availability. The demand for rice continues to grow and is projected to increase by more than 50 per cent over the next few decades (Zeigler, 2012). Rice is widely grown under flooded conditions for better establishment and easy weed control. However, the declining water and labour availability is a major hurdle for sustaining the traditional flood irrigated rice ecosystem (Anwar *et al.*, 2010). In Asia, it is predicted that 17 m ha of rice areas may be subjected to "physical water scarcity" and 22 m ha to "economic water scarcity" by 2025 (Bouman and Tuong, 2001). Therefore it is no longer feasible to flood rice fields for ensuring better crop establishment and weed control (Johnson and Mortimer, 2005).

Among different water-saving approaches, aerobic rice cultivation has come up with huge success in different parts of the world. Aerobic rice, growing rice in non-saturated and non-puddled aerobic soil, is a promising water-wise technique of rice cultivation under the context of ever-mounting water scarcity (Anwar *et al.*, 2011). It is a new concept of rice culture to decrease water requirements in rice production and is highly suitable for irrigated lowland rice with insufficient rainfall and favorable uplands with access to supplementary irrigation (Amudha et *al.*, 2009). It can save as much as 50 per cent of irrigation water in comparison with lowland rice. It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers aiming at high yields (Wang *et al*., 2002).

Aerobic rice is specifically developed, combining drought tolerance of upland rice and yield potential of lowland rice. Therefore, it is “improved upland rice" in terms of yield potential, and "improved lowland rice" in terms of drought tolerance. These varieties have the ability to maintain rapid growth in soils with moisture content at or below field capacity, and can produce yields of 4-6 t ha^{-1} with a moderate application of fertilizers under such soil moisture conditions.

Aerobic rice is targeted to water-short areas where there is irrigation but where the water supply is insufficient for growing lowland rice and to the rainfed areas where rainfall is sufficient to frequently bring the soil water content close to field capacity. These areas can be uplands, upper slopes and lowlands in a toposequence (Bouman, 2007). The rice varieties for aerobic cultivation are designed to be high yielding, input responsive and weed competitive to obtain high yields under aerobic soil conditions. Futher, they are better adapted to intensified management with moderate input use than the traditional upland rice, which has low harvest index and is prone to lodging when fertilized (Atlin *et al*., 2006).

Weeds are perceived to be the most severe constraint to the direct-seeded aerobic rice as compared to transplanted rice, because of many reasons – land is exposed during initial crop growth stages, aerobic soil conditions, dry tillage practice, lack of standing water column and alternate wetting and drying which make the conditions more conducive for germination and growth of weeds (Madhukumar *et al.,* 2013). The conditions prevailing in aerobic soil are highly conducive for germination and growth of weeds which result in higher weed population coupled with greater yield loss (Mahajan *et al.,* 2009). Uncontrolled weeds reduce the grain yield of aerobic rice by 75.8 per cent (Singh *et al*., 2005). Thus weeds are the most severe constraints to aerobic rice production and timely weed management is crucial in increasing the productivity of aerobic rice (Rao *et al*., 2007).

Different weed control practices have been evaluated to minimize the weed pressure in different systems of rice cultivation (Chauhan *et al*., 2010). Hand weeding is easy and environment friendly but it is tedious and highly labour intensive. The labour requirement for weeding is a major impediment to the adoption of water saving aerobic rice and for increasing the productivity of traditional upland rice based cropping systems (Zhao *et al*., 2006). Herbicides are considered to be an alternative or supplement to hand weeding (Singh *et al*., 2006).

Mechanical weed control suppressed weeds and increased grain yield in direct seeded rice (Rao *et al*., 2007). Akbar *et al*. (2011) observed that mechanical hoeing was equally effective as hand weeding for weed management in aerobic rice. Alizadeh (2011) obtained the highest weeding efficiency with power weeder as compared against conical weeder, rotary weeder and hand weeding. Mulching with rice straw resulted in effective weed control and improved the agronomic traits. Mulching with crop residues was observed to control weeds effectively in dry seeded rice (Khaliq *et al*., 2011). Devasinghe *et al*. (2011) observed that application of rice straw mulch @ 4 t ha^{-1} was effective in weed management under direct seeded rice.

In Kerala, the area under rice has been declining, especially during the *puncha* season (summer crop), as evidenced by the decrease in area from 55258 ha in2000-01 to 47290 ha in 2011-12 (FIB, 2014). One of the main causes for this is water shortage. Aerobic rice cultivation has been reported to be a viable option to combat this water shortage. PTB 52 (Aiswarya) and MO 16 (Uma) (high yielding varieties released from KAU) were identified to possess good adaptiveness to aerobic condition (Jinsy *et al*., 2014).

Aerobic rice is gaining popularity day by day as a water-wise technology. But this technology is impeded by high weed pressure because of dry tillage and aerobic conditions, and hence weed management has been a challenge for this promising technology. Integrated weed management offers most practical and cost effective means of reducing weed competitions in aerobic rice.

Keeping the above in view, a study was undertaken to assess the efficacy and economic feasibility of different weed management practices in aerobic rice, with the following objectives:

- To assess the extent of yield loss due to weeds in aerobic rice.
- To assess the most suitable weed management strategy for aerobic rice.
- To study the economic feasibility of different weed management strategies in aerobic rice.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Aerobic rice refers to growing of rice varieties in non-puddled and non-flooded condition. It is a new method of cultivating rice that requires less water than conventional low land rice. It entails the growing of rice in aerobic soil, with the use of external inputs such as supplementary irrigation and fertilizers besides aiming at high yields. In this method, land is brought to fine tilth under dry condition, the seeds are dibbled in definite row proportion with wider spacing and soil moisture regime is maintained almost around field capacity. With this method about 60 to 70 per cent of irrigation water is observed to be saved (Shanmuganathan, 2006). Weed infestation and competition is more severe in direct seeded aerobic rice as compared to transplanted rice, because of the reasons *viz*., land is exposed during initial crop growth stages, aerobic soil conditions, dry tillage practices and alternate wetting and drying make the conditions more conducive for the germination and growth of weeds. Therefore, in this study, entitled "Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)", an attempt has been made to evaluate different weed management strategies in aerobic rice so as to find a suitable method. The research works done on the weed management in aerobic rice are reviewed in this chapter. Since the research work done on the varietal effect under aerobic rice culture is very limited, relevant literature on other varieties also reviewed.

2.1 AEROBIC RICE

Aerobic systems are subjected to much higher weed pressure than conventional puddled transplanting systems (Balasubramanian and Hill, 2002; Rao *et al*., 2007) in which weeds are suppressed by standing water and by transplanted rice seedlings which have an advantage over germinating weed seedlings (Moody, 1983). On the other hand, aerobic soil dry-tillage and alternate wetting and drying conditions are conducive to the germination and growth of weeds, causing grain yield losses of 50 per cent to 91 per cent (Elliot *et al*., 1984; Fujisaka *et al*., 1994., Rao *et al*., 2007).

Thus weeds are one of the severe constraints in aerobic rice production, and timely weed management is crucial to increase the productivity of aerobic rice (Rao *et al*., 2007). Direct seeded aerobic rice is highly infested with grasses, broad leaved weeds and sedges.

Unlike transplanted rice, early and timely weed control is essential in aerobic rice; otherwise the yield loss is to an extent of 82 per cent due to crop weed competition (Thimmegowda, 2006). Chauhan and Johnson (2011a) also suggested that it is beneficial to control weeds in aerobic rice within eight weeks of sowing.

Yield reduction due to weeds is more critical in direct seeded rice than in transplanted rice (Karim *et al*., 2004). In dry seeded aerobic rice, relative yield loss caused by weeds is as high as 50-91 per cent (Rao *et al*., 2007), while in transplanted rice, yield loss has been estimated to be only 13 per cent (Azmi, 1992). Among the rice ecosystems, yield losses are the highest in aerobic rice (Balasubramanian and Hill, 2002). Season-long weed competition in direct seeded aerobic rice may cause yield reduction up to 80 per cent (Sunil *et al*., 2010). In extreme cases, weed infestation may cause complete failure of aerobic rice (Jayadeva *et al*., 2011). Thus direct seeded aerobic rice is highly vulnerable to weeds compared with other rice ecosystems (Anwar *et al*., 2011).

2.1.1 Weed Flora in Direct Seeded Aerobic Rice

Damage on growth and yield caused by weeds depend on weed species and their densities.

Verma *et al*. (2004) observed that in direct seeded rice, *Echinochloa crussgalli, Echinochloa colona, Elusine indica, Eclipta alba, Ludwigia parrillora, Cyperus iria, Cyperus difformis* and *Fimbristylis miliacea* were the major weed species. In dry seeded rice, *Echinochloa colona* (30.8 per cent), *Echinochloa crussgalli*

(15.8 per cent), *Ischaemum rugosum* (26.4 per cent), *Commelina diffusa* (7.6 per cent) and others (8.9 per cent) were the dominating weed species (Bahar and Singh, 2004)

Chauhan and Abugho (2013) observed that in dry seeded rice, cleome (*Cleome rutidospermum* Dc.), bermuda grass (*Cynodon dactylon* L.), purple nutsedge (*Cyperus rotundus* L.), crow foot grass [*Dactyloctenium aegypticum* (L.) Willd.], southern crab grass [*Digitaria ciliaris* (Retz.) Koel.], jungle rice [*Echinochloa colona* (L.) Link], goosegrass [*Eleusine indica* (L.) Gaertn.], chinese sprangletop [*Leptochloa chinensis* (L.) Nees], common purslane (*Portulaca oleracea* L.) and horse purslane (*Trianthema portulacastrum* L.) were the major weeds.

Singh *et al*. (2005) observed that in direct seeded rice, *Echinochloa crussgalli, Echinochloa colona, Leptochloa chinensis, Cyperus rotundus, Cyperus difformis, Fimbristylis dichotoma, Commelina benghalensis* and *Cyanotis axillaris* were the dominating weed flora.

Saha *et al*. (2005) revealed that in rainfed upland rice, *Cynodon dactylon, Eragrostis gangeticum, Setaria glauca, Dactyloctenium aegypticum, Cyperus rotundus, Cyperus iria, Cyperus compressus, Fimbristylis miliaceae, Oldenlandia corymbosa, Ludwigia parviflora, Borreria hispida, Desmodium triflorum, Scoparia dulcis, Sida rhombifolia, Phyllanthus niruri, Alysicarpus vaginalis, Cleome viscosa* etc were the major weed flora.

Mishra and Singh (2007) observed that in irrigated direct seeded rice, *Echinochloa colona, Commelina sp, Cyperus difformis* etc were the major weed flora. In irrigated direct seeded rice, *Echinochloa crussgalli, Echinochloa colonum, Elusine indica, Cynodon dactylon, Eclipta alba, Commelina benghalensis, Amaranthus viridis, Trianthema portulacastrum, Cyperus rotundus, Cyperus iria, Fimbristylis miliaceae* were the most commonly present weed flora (Singh and Tripathi, 2007).

2.2 WEED MANAGEMENT IN AEROBIC RICE

Weeds by virtue of their wider adaptability and faster growth dominate the crops habitat and reduce the yield potential (Raju and Reddy, 1992). Weeds are the foremost biotic barrier in enhancing yield of direct seeded rice and the yield losses due to weeds vary from 5 per cent to even complete failure of crop (Kolhe, 1989). High weed infestation in direct seeded rice causing severe reduction in grain yield is the major constraint for low productivity (Kalia and Bindra, 1996).

Direct seeded rice under rainfed upland situation is prone to severe weed infestation than other situations due to aerobic soil conditions and optimum temperatures (Moorthy, 1997). The effect of weed menace is more pronounced as the weeds and rice crop start their growth together (Mutanal *et al*., 1998 and Singh *et al*., 1998). Weed emergence was the highest during 30 days of crop growth (84.6 per cent) in dry seeded rice (Bahar and Singh, 2004). Though there are several advantages under direct seeding, various production obstacles are also encountered and heavy weed infestation is the major one (Singh *et al*., 2005).

Aerobic soil conditions and dry tillage practices, besides alternate wetting and drying conditions are conducive for germination and growth of highly competitive weeds, which cause grain yield losses of 50-91 per cent (Singh *et al*., 2006). Hence it is apparent that rice yield can be maximized in direct dry seeded rice with timely seeding, provided weeds are adequately controlled.

2.2.1 Loss Due to Weeds in Aerobic Rice

Weed competition is one of the prime constraints that restrain the productivity of upland rice and the yield losses caused by weeds vary from 50-60 per cent and even sometimes complete failure of the crop is a common feature (Singh and Mani, 1981). Weeds are perceived to be the most severe constraint to the upland aerobic rice production than the conventional production systems, in which weeds are suppressed by standing water and transplanted rice seedlings have a head start over germinating weed seedlings. Nowadays, water scarcity threatens the sustainability of irrigated rice ecosystems and it may no longer be feasible for farmers to undertake wet cultivation and flood fields to ensure good crop establishment and control weeds (Johnson and Mortimer, 2005).

Weed infestation depending up on the situation moderately to severely limit the production of direct seeded aerobic rice. The extent of weed menace is more serious in direct seeded aerobic rice than lowland rice mainly due to variations in hydrology and reduction in rice grain yield is ranging from 5 to 100 per cent (Singh *et al.*, 2002). Direct seeded upland rice suffers more from weed problem and consequently yield reduction compared to transplanted rice (Saini, 2005). The extent of decline in the yield of upland rice due to weeds has been reported from 87.5 to 94.0 per cent (Bhan and Mishra, 1993; Saxena, 1990) and 5-100 per cent (Kolhe, 1989). Weed competition lowers the crop yield in rainfed lowland rice to the tune of 74 per cent (Nyarko and De Datta, 1991) and upland rice by 37-79 per cent (Umrani, 1995). Weeds were reported to reduce rice yields by 12 to 98 per cent, depending on type of method of rice establishment. Rice yield losses due to uncontrolled weed growth and weed competition were least (12 per cent) in transplanted rice (Singh *et al.*, 2005) and highest in aerobic direct- seeded rice on a furrow-irrigated raised-bed systems (Singh *et al.*, 2008) and in dry-seeded rice sown without tillage (Singh *et al.*, 2005).

2.2.2 Critical Period of Crop Weed Competition

Critical period of weed competition is the period before and after which weed growth does not affect crop yield (Zimdahl, 1999). The critical period of weed competition is longer (15 to 45 DAS) for direct- seeded rice (Singh *et al.*, 2008). In aerobic rice cultivation, weed free condition during the initial crop growth period (up to 35 DAS) is critical which has the potential to reduce grain yield drastically

(Rajakumar *et al.*, 2010). For higher yield of spring rice, crop should be kept weed-free during 40 to 120 days (Pandey *et al.*, 2003). First 30 to 60 days after sowing is considered as critical period for crop-weed competition in case of rainfed lowland rice (Moorthy and Saha, 2005). In rice, weed free period of 30 days is required to avoid the significant loss in rice yield due to weeds (Sharma, 2007).

2.2.3 Weed Competition for Nutrients

The greatest weed pressure and crop–weed competition occur in upland and aerobic rice (Rao *et al.*, 2007). Weed infestation depleted the soil by 24.7 kg nitrogen, 5.8 kg phosphorus and 63.4 kg potassium ha^{-1} in one season (Sharma, 2007). Ramachandiran *et al.* (2012) reported that nutrient depletion by weeds in unweeded condition of aerobic rice showed higher removal of 19.77, 5.28, 16.20 kg N, P, and K ha^{-1} respectively. They also stated that the nutrient uptake by rice in unweeded check was very much reduced by 25.75, 4.13, 35.68 kg NPK ha^{-1} respectively compared to farmers practice of hand weeding twice.

2.2.4 Nutrient Uptake by Weeds

Nanjappa and Krishnamurthy (1980) observed the maximum removal of nutrients by weeds in unweeded control (42 kg N, 22.15 kg P_2O_5 and 56.04 kg K_2O ha^{-1}), whereas minimum was in the weed free plot (27.83, 13.25 and 24.0 kg N, P_2O_5 and K_2O ha^{-1} respectively).

Weed control measures greatly influence the uptake of nutrients by crops and associated weeds. Weeds remove 19.4 to13.7 kg N, 1.5 to 1.8 kg P and 17.4 to 33.7 kg K per hectare from the soil and uptake of N, P and K by rice crop was proportional to WCE (Moorthy and Mitra, 1991).

Kumari (1991) revealed that the maximum removal of NPK by weeds was recorded under unweeded check (70.23, 31.72 and 92.04 kg NPK ha^{-1}) and lowest is recorded under weed free check.

Chandrakar and Chandrakar (1992) reported that in direct sown upland rice nutrient loss was to the tune of 86.5, 12.4 and 134.5 kg N, P and K ha^{-1} respectively under weedy check and loss was reduced to 4.7, 0.7 and 6.9 kg N, P and K ha^{-1}, respectively with two hand weeding at 30 and 50 DAS.

Moorthy and Mana (1993) reported that in direct seeded upland drilled rice highest depletion of nitrogen by weeds was noticed in unweeded check (26.29 kg ha^{-1}). Madhu (1994) observed that, unweeded check recorded significantly higher nutrient removal by weeds (90, 60 and 90 kg N, P_2O_5 and K_2O ha^{-1} respectively) as compared to other weed control treatments.

Geetha (2002) found that in upland rice the nutrient uptake by weed was higher in weedy check (26.3, 35.7 and 35.0 per cent N, P and K). Among single weed species *Echinochloa* followed by *Cyperus* sp. recorded higher uptake of NPK (10.2, 22.3 and 19.5 per cent NPK and 7.9, 11.0 and 15.5 per cent NPK, respectively).

Singh *et al.* (2003) observed that in direct seeded rice, uptake of nutrients by weeds was higher in weedy check condition (34.8, 15.6 and 42.3 kg N, P and K ha^{-1}). Among other weed control treatments hand weeding at 20 and 40 DAS recorded higher nutrient uptake by the crop (4.5, 1.9 and 5.2 kg N, P and K ha^{-1} respectively)

2.2.5 Nutrient Uptake by Crop

Kumari (1991) reported that weed free check recorded maximum N uptake (92.75 and 85.25 kg ha^{-1}), P uptake (47.96 and 44.98 kg ha^{-1}) and K uptake (117.60 and 119.33 kg ha^{-1}) by crops. This was followed by hand weeding at 25 and 45 DAS (86.01, 87.16 and 44.50, 42.89 and 111.17, 107.80 kg NPK ha^{-1}, respectively) as compared to unweeded check (13.19, 15.61 and 6.21, 6.38 and 13.60, 17.67 kg N, P and K ha^{-1}, respectively).

Sahai and Bhan (1992) revealed that weeds competed severely with the direct sown rice for nitrogen supply and the competition started early in the season. Maximum removal of nitrogen from the soil was observed at 60 DAS (127.3 kg N ha^{-1}). The maximum uptake of nitrogen by the crop (150.9 kg ha^{-1}) was observed on 90 th day of growth, in the weed free plots.

2.3 WEED MANAGEMENT PRACTICES

2.3.1 Methods of Weed Control in Direct Seeded Aerobic Rice

There are various methods to control weeds in aerobic rice and each method has its own merits and demerits. The choice of any weed control method will depends largely on its effectiveness and economics.

2.3.2 Effect of Chemical Weed Control in Direct Seeded Aerobic Rice

Among the agronomic requirements to improve the yield levels of aerobic rice timely weed control plays an important role. Traditional methods of weed management are widely adopted for control of weeds in aerobic rice. These practices are tedious, time consuming, labour intensive, costly and not possible to practice over an extensive area. Further, due to labour scarcity and high labour wages traditional weed management practices are being impracticable.

Herbicides are considered as an alternative or supplement to hand weeding. The development of new improved herbicides for dry seeded rice is also needed (Gupta *et al.*, 2003; Singh *et al.*, 2006). Several pre- emergent herbicides, including butachlor, oxyfluorfen, pendimethalin, thiobencarb, oxadiazon and nitrofen alone or supplemented with hand weeding, have been reported to provide a fair degree of weed control (Estorninos and Moody, 1988; Janiya and Moody, 1988; Moorthy and Manna, 1993; Pellerin and Webster, 2004).

Kathiresan and Manoharan (2002) reported that integrated weed control with pre-emergence herbicides coupled with one hand weeding proved better weed control strategy in dealing with effective, timely and economic weed suppression (Wibawa *et al.*, 2010).

Application of weedicides effectively suppresses the weeds and provides the direct seeded rice, an environment free from weeds (Gitsopoulo and Williams, 2004). But herbicide options for weed control in direct seeded rice differ according to the method of crop establishment because the performance of herbicides varies in relation to water regimes (Rao *et al.*, 2007).

Chemical weed control in direct seeded rice has gained importance because of higher intensity of weeds coupled with the non availability of labour for control of weeds in time and its higher cost. Herbicides although may not control weeds as effective as hand weeding frequently offers the most practical, effective and economical means of reducing weed problems, crop losses and production cost. (De Datta and Herdt, 1983).

2.3.2.1 Effect of Oxyfluorfen on Weed Management in Rice

Oxyfluorfen is a diphenyl-ether herbicide used for broad spectrum pre- and post-emergent control of weeds in field crops. Oxyfluorfen targets a specific enzyme, protoporphyrinogen oxidase, in the chlorophyll biosynthetic pathway. Oxyfluorfen at 0.1 kg ha^{-1} as pre-emergence most effectively controlled all types of weeds and recorded lowest dry weight of weeds (Gosh and Singh, 1986). Singh *et al.* (2005) reported that *Panicum maximum* population was reduced most effectively by oxyfluorfen application. Pre-emergence application of oxyfluorfen 23.5 per cent EC at 400 g ha^{-1} recorded lower weed density, dry weight and higher WCE at 20 and 40 DAS in rice (ARWR, 2011).

Application of oxyfluorfen at 0.125 kg ha^{-1} registered the highest leaf area Index, dry matter accumulation, number of productive tillers and grain yield in rice (Kathiresan and Manoharan, 2002). The benefit: cost ratio was more in integration of weed management practices- oxyfluorfen at 0.20 kg ha^{-1} + hand weeding (Laskar *et al*., 2005).

Prakash (1994) reported that in direct seeded puddled rice, pre-emergence application of oxyfluorfen at 0.25 kg ha^{-1} recorded lower weed count (3.6 m^{2}) and lower weed dry weight (5.0 g m^2) and higher grain yield (5100 kg ha^{-1}). In upland drilled rice, pre-emergent application of oxyfluorfen @ 0.37 kg ha^{-1} resulted in lower weed population (40.5 m^2) and lower weed dry weight (60.3 g m^2) and higher grain yield (2181 kg ha^{-1}) (Pardkar *et al*.,1997).

Angiras and Sharma (1998) reported that in direct seeded upland rice, pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} resulted in lower weed count (29.82 m^2), weed dry weight (55.9 g m^2) and higher grain yield (26.34 q ha^{-1}). Pre-emergence application of oxyfluorfen @ 0.2 kg ha^{-1} resulted in lower weed biomass (8.08 g m^2) and higher grain yield (13.35 q ha^{-1}) in direct seeded upland rice (Porwal, 1999).

Singh *et al*. (2005) revealed that pre-emergence application of oxyfluorfen @ 0.25 kg ha^{-1} resulted in lower weed count (14.7 m^2), weed dry weight (4.4 g m^2) and higher grain yield (4.3 t ha^{-1}) in direct seeded rice. In direct seeded rice, pre-emergence application of oxyfluorfen at 0.2 kg ha^{-1} resulted in lower weed dry weight and higher grain yield (Rao *et al*., 2007). Application of oxyfluorfen at 0.125 kg ha^{-1} + hand weeding recorded lower weed population (17.6 m^2), weed dry weight (12.2 g m^2) and higher grain yield (5345 kg ha^{-1}) in direct sown rice (Kathiresan and Manoharan,2002).

2.3.2.2 Effect of Pretilachlor on Weed Management in Rice

Pretilachlor is a selective herbicide introduced for the control of broad leaved weeds and sedges in direct seeded rice (Vidotto *et al.*, 2004). Mode of action of pretilachlor is by inhibition of cell division and protein synthesis.

Application of pretilachlor at 0.75 g a.i ha^{-1} as pre-emergence proved to be very effective in reducing weed dry matter and increasing grain yield significantly as compared to unweeded check (Ghuman *et al.*, 2008). Application of pretilachlor at 0.75 g a.i ha^{-1} showed better control of weeds at early stages of crop growth which coincided with critical period of crop-weed competition (Lakshmi *et al.*, 2006). Pre-emergence application of pretilachlor + safener at 500 g a.i ha^{-1} effectively controlled grassy weeds (Singh *et al.*, 2008).

Pretilachlor at 0.75 kg a.i ha^{-1} significantly reduced the total weed population and weed dry matter production resulting in higher weed control efficiency (Payman and Singh, 2008). Pretilachlor at 0.45 kg a.i ha^{-1} as pre-emergence along with one hand weeding at 30 to 35 DAS registered higher weed control efficiency (Arunvenkatesh and Velayatham, 2010). Islam *et al.* (2000) compared hand weeding with different herbicides and found that Pretilachlor (500 g a.i ha^{-1}) was the most successful herbicide with higher yield and cost-benefit ratio.

It was observed that in aerobic rice, the grain yield could be increased by 5.5 to 10.4 times and the straw yield by 2.0 to 3.4 times when weeds were effectively controlled. This may be attributed to enhanced availability of nutrients, soil moisture and other resources due to effective weed control by herbicides during early stages as reported by Singh *et al.* (2005). Among herbicides, pretilachlor + safener was found to be efficient in reducing population of sedges and broad- leaved weeds.

Pre-emergence application of pretilachlor + safener at 0.45 kg ha^{-1} followed by one hand weeding at 45 DAS was resulted in significantly higher grain yield in direct sown rice due to better control of weeds, leading to lesser nutrient removal by weeds and higher uptake of nutrients by rice (Parthipan *et al*., 2013).

2.3.3 Effect of Straw Mulching in Rice

New approaches of using rice straw for controlling weeds in different crops, indicated that rice straw can be used for mulching, which benefits in preventing weed growth as well as supplies organic matter for N-fixation by heterotrophic N-fixing microorganisms (Mendoza and Samson 1999).

Thus, use of rice straw as manure as well as mulch for suppressing the weed growth due to its allelopathic potential can be a good approach to reduce the herbicide load. Application of rice straw mulch at the time of crop establishment in direct seeded rice results in suppressing growth and development of a wide range of weeds (Devasinghe *et al*., 2011).

The crop residue present on the soil surface can influence weed and crop growth (Chauhan 2012, Chauhan and Mahajan 2012, Chauhan and Abugho 2013, Chauhan *et al*. 2012).

2.3.4 Effect of Mechanical Weeding in Rice

Mechanical weed control suppressed the weeds and increased grain yield in direct seeded rice (Rao *et al*., 2007). Mechanization of the intra row weed control would not only lower the direct costs for hand weeding but also release time and labour to be used elsewhere in the production. Inter row weeds can be removed by ordinary inter row cultivation relatively easily although intra row weeds constitute a major challenge (Melander *et al*., 2005).

Mechanical weeding at 15 and 30 DAS using finger weeder and wheel hoe supplemented with one hand weeding gave effective and economical weed control (Moorthy and Mishra, 2004). Mechanical hoeing resulted in significant increase

(25.1 per cent) in grain yield over control despite lower percentage inhibition in total weed density and dry weight over control compared with the other weed control treatments. This may be due to the enhanced nutrient availability due to soil stirring during mechanical hoeing (Arif *et al.*, 2004).

Mechanical weeding produced minimum density and dry weight of weeds at early growth stages. The effective control of weeds through use of weeder was also reported by Nair *et al.* (2002). Mechanical weeding becomes difficult due to increased occurrence of weeds at inter hill spaces in later stages of rice. Inter row hoeing controls weeds growing in the inter row area almost completely under favourable circumstances, whereas those growing in the intra row area are only partly controlled.

Rotary hoeing is most effective just before or shortly after weeds emerge (Oriade and Forcella, 1999). Small weeds are more easily uprooted and desiccated compared to larger and more established weeds. Rotary hoe is an effective implement for managing weed populations in poorly competitive cropping systems. Efficacy depends on careful timing of rotary hoeing relative to weed emergence and weather conditions. Multiple passes are required when weather conditions inhibit rapid desiccation of seedling following rotary hoeing (Boyd and Brennan, 2006).

2.3.5 Effect of Hand Weeding in Rice

Hand weeding is the traditional method of weed management in rice cultivation. Amongst several weed management techniques practiced in rice cultivation, manual weeding appears to be the most effective method by keeping the crop under near-weed free situation for a considerable period of time (Ghosh, 2005). Though manual weeding is the general practice adopted by the farmers, it is becoming, more and more cost prohibitive and caused drudgery (Saha *et al.*, 2005).

Hand weeding is the most common and effective method of weed control in rice but is becoming difficult and uneconomical day by day due to high wages and non availability of labours at peak period of farm operation (Singh *et al.*, 1999). It is generally not a very efficient method.

Hand weeding at 20 and 40 DAS recorded the maximum rice grain yield (Laskar *et al.*, 2005). According to Lakshmi *et al.* (2006) hand weeding twice on 20 and 40 DAS was found to be superior weed control in dry sown rice. They also recorded higher crop growth parameters, yield attributing characters, grain yield (5444 kg ha^{-1}) and straw yield (5759 kg ha^{-1}) in dry sown rice. The highest grain yield was recorded with two hand weedings (Singh *et al.*, 2005). Two hand weedings, one as early as possible (10-15 days after sowing) and the second 25-50 days later were generally sufficient in upland rice (Sharma, 2007).

Highest weed control efficiency of 65.52 per cent was recorded with two hand weedings at 30 and 45DAS (Payman and Singh, 2008). Keeping the rice fields weed free exclusively by manual weeding may not be feasible because of high cost, more time and other difficulties involved (Kandaswamy, 1999).

Amongst several weed management techniques practiced in rice cultivation, manual weeding appears to be the most effective method by keeping the crop under near-weed free situation for a considerable period of time (Ghosh, 2005).

Though manual weeding is the general practice adopted by the farmers, it is becoming more and more cost prohibitive and causes drudgery (Saha *et al.,* 2005). It was observed that grain yield was significantly lower in dry seeded rice where only hand weedings were done because of early crop-weed competition rather than application of pre-emergence application of herbicide supplemented with hand weedings (Singh *et al.*, 2005).

It is to be noted that time consumption for hand weeding varies according to weed density and the success of preceding weed control measures (Melander *et al.*, 2005).

Highest reduction in total weed density and total dry weed in hand weeding over the weedy check was possible with the involvement of the intense labour and frequency of the weeding *i.e.* three times during the growing season (Rao *et al.*, 2007). Plant height and leaf area index (LAI) were lowest in weedy check and maximum in two hand weedings on 25 and 45 DAS (Singh *et al.*, 2008). Hand weeding twice resulted in lower weed density and dry weight compared to herbicide application and untreated control.

In upland direct seeded rice, hand weeding at 20 and 40 DAS recorded lower weed count and weed dry weight and higher grain yield (21.25 q ha^{-1}) (Moorthy and Saha, 2005). In upland direct seeded rice hand weeding twice at 20 and 40 DAS recorded lower weed dry weight (0.09 t ha^{-1}) and higher WCE (94.6per cent) and higher grain yield (3.1 t ha^{-1}) (Moorthy and Saha, 2005).

Singh *et al.* (2006) revealed that, hand weeding at 25 and 50 DAS recorded lower weed population (12.25 m^2), lower weed dry weight (91.6 g m^2) and higher grain yield (3.2 t ha^{-1}). In direct seeded rice under rainfall condition all the weed control methods reduced weed growth significantly over unweeded control. WCE was highest (71.25 per cent) with power weeder followed by hand weeding thrice (70.55per cent) (Viren *et al.*, 2005).

2.4 EFFECT OF WEED MANAGEMENT ON ECONOMICS OF AEROBIC RICE.

Hand weeding is time consuming, expensive and tedious though much effective. Under the present situation of unavailability of labourers and high wages, manual weed control is not possible. Hence, chemical weed control appears to hold a great promise in dealing with effective, timely and economic weed suppression

(Wibawa *et al*., 2010). Despite high weed control efficiency, manual weeding is not cost-effective, while chemical weed control are highly efficient and economic as well. The benefit: cost ratio was more in chemical weed control using oxyfluorfen at 0.20 kg ha^{-1} + hand weeding (Laskar *et al*., 2005).

From this brief review it can be concluded that weeds pose a greater problem in aerobic rice cultivation. The yield loss in aerobic rice is very large and it varies to a greater extent depending on the type of weed flora, intensity of weeds and management practices. The management of weeds by adopting suitable weed management methods is very important in managing weed problem under aerobic condition.

With this background a field study was conducted to find out the effective and economical weed management practice for the management of weeds in aerobic rice.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigation entitled "Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)" was undertaken, primarily to identify the most suitable method for managing weed problem in aerobic rice. The materials used and the methods adopted in the conduct of the experiment are presented in this chapter.

3.1 EXPERIMENTAL SITE

The experiment was conducted at the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram of the Kerala Agricultural University. It is located at 8° 25' "44.49" N latitude and 76° 59' "14.97" E longitude and at an altitude of 29 m above mean sea level.

3.1.1 Soil

Soil samples were collected prior to the experiment from 0-15 cm depth and a composite sample was used for the determination of the physico-chemical properties. The data on the mechanical composition and chemical nature of the soil of the experimental site are presented in Tables 1 and 2 respectively. The chemical properties of the soil were rated as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2011)

The soil of the experimental site was sandy clay loam, acidic in reaction, high in organic carbon, medium in available nitrogen, high in available phosphorus and medium in available potassium status

Table 1. Mechanical composition of the soil of the experiment site

Sl.No.	Fractions	Content in soil (%)	Method adopted
1	Coarse sand	45.55	Bouyoucos Hydrometer Method (Bouyoucos, 1962)
2	Fine sand	12.20	
3	Silt	9.05	
4	Clay	33.20	

Textural class: Sandy clay loam.

Table 2. Chemical properties of the soil of the experimental site

Sl. No.	Fractions	Content	Method adopted
1	Soil reaction (pH)	5.1	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
2	CEC (cmol kg^{-1})	13.6	Ammonium saturation using neutral normal ammonium acetate (Jackson, 1973)
3	Organic carbon (%)	1.02	Walkley and Black's rapid titration (Jackson, 1973)
4	Available N (kg ha^{-1})	526.8	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg ha^{-1})	26.2	Bray colorimetric method (Jackson, 1973)
6	Available K (kg ha^{-1})	186.3	Ammonium acetate method (Jackson, 1973)

3.1.2 Climate and Season

The experimental site experiences warm humid tropical climate. The experiment was conducted during the summer season (*puncha*), *i.e.*, January to May 2013. The data on the weekly mean temperature, relative humidity, rainfall, and bright sun shine hours recorded during the cropping period were collected from the Class B Agromet Observatory attached to the Department of Agricultural Meteorology, College of Agriculture, Vellayani. The data are presented in Appendix-I and illustrated graphically in Figure 1. The mean, maximum temperature ranged between 33.3°C to 30°C and minimum temperature ranged between 26.1°C to 20.8°C. While the mean, maximum relative humidity ranged from 84.8 per cent to 96.4 per cent, the minimum relative humidity ranged from 67.4 per cent to 81.7 per cent. A total rainfall of 134.9 mm was recorded during the cropping period.

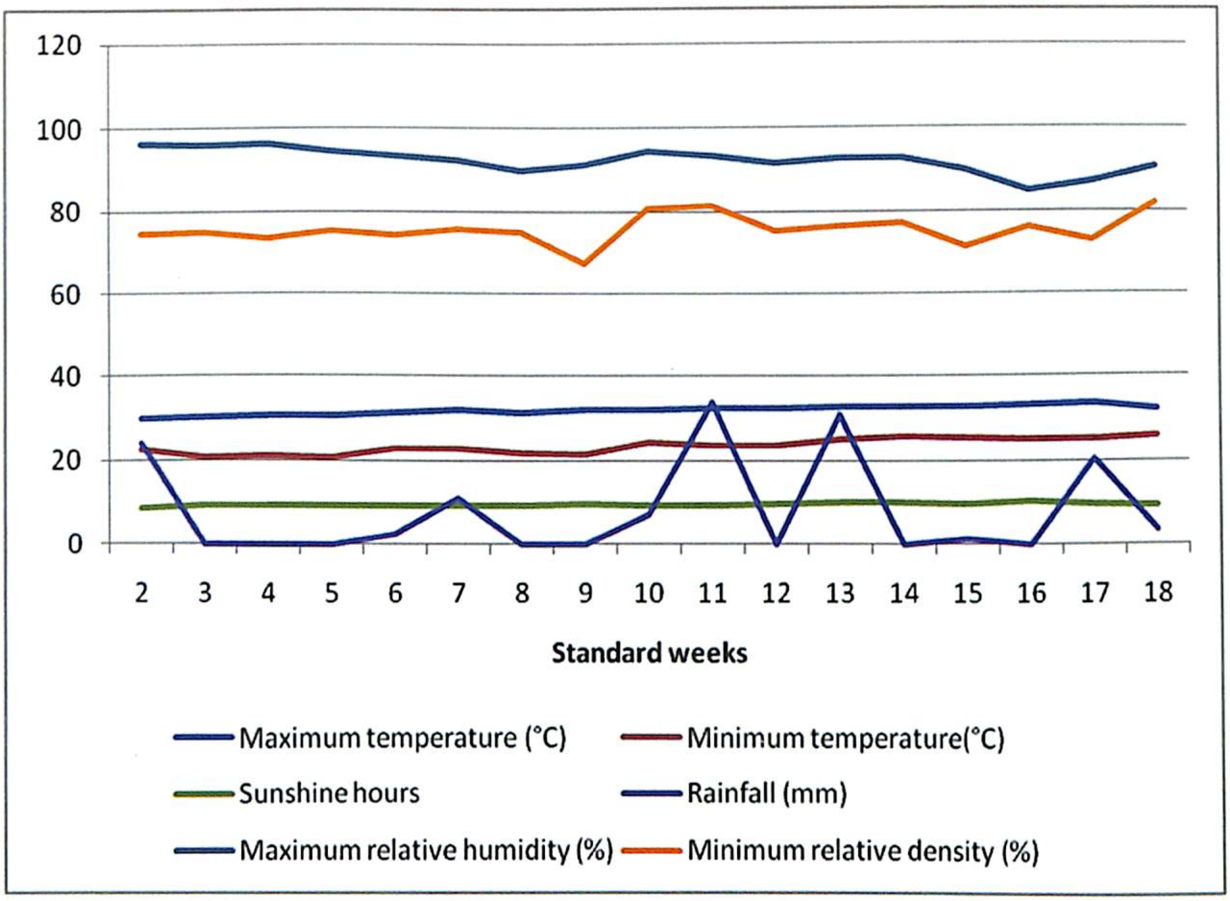


Figure 1. Weather data during the cropping period (January to May 2013)

3.1.3 Cropping History of the Field

The area was previously under a bulk crop of cassava.

3.2 MATERIALS

3.2.1 Crop and Variety

The rice varieties selected for the experiment were PTB 52 (Aiswarya) and MAS 946-1 (Sharada). The variety, PTB 52 (Aiswarya) was selected based on the results of a previous study conducted by Jinsy *et al.* (2013), who observed that the rice variety PTB 52 (Aiswarya) was well adapted to aerobic conditions in the lowlands of southern Kerala. MAS 946-1(Sharada) is the first aerobic rice variety released in 2007, from the University of Agricultural Sciences, Bengaluru. The important varietal characters are given in Table 3.

Table 3. Important characters of rice varieties chosen for the study

Characteristics	Rice variety	
	PTB 52 (Aiswarya)	MAS 946-1 (Sharada)
Released from	RARS, Pattambi	UAS, Bengaluru
Duration (days)	120-125	105-110
Grain type	Long, bold	Medium, slender
Bran colour	Red	White
Stress tolerance	Resistant to sheath blight, blast, and BPH	Drought and blast disease tolerant
Special characters	Exhibits good adaptation to aerobic conditions	First aerobic rice variety, suitable for dry sowing

3.2.1.1 Source of Seed Material

The seeds of Aiswarya were obtained from Cropping Systems Research Centre, Karamana, Thiruvanathapuram, Kerala and seeds of MAS 946-1 from University of Agricultural Sciences, Bengaluru.

3.2.2 Herbicides

The herbicides used for the study were oxyfluorfen and pretilachlor. The important characteristics of these herbicides are presented in Table.4

Table 4. Technical information of herbicides

Common Name	**Oxyfluorfen**	**Pretilachlor**
Trade name	Goal	Ramfit
Chemical name	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4 (trifluoromethyl) benzene	2-chloro-N-(2,6-diethylphenyl)-N-(2-propoxyethyl) acetamide
Chemical family	Diphenyl ether herbicide	Chloroacetanalide
Mode of action	Cell membrane destroyer	Inhibition of cell division and protein synthesis
Formulation	23.5 % EC	23.5 % EC
Molecular weight	361.72 g/mole	311.9 g/mole
Physical state, colour, odour	Crystalline solid, orange to deep red brown, odourless	Liquid, colourless, odourless
Acute oral toxicity LD_{50} (Rats)	> 5000 mg/kg	> 6099 mg/kg
Acute dermal toxicity LD_{50} (Rats)	> 2000 mg/kg	> 3100 mg/kg
Manufacturer	Dow Agro Sciences	Sree Ramcides Chemicals Pvt. Ltd.
Cost (Rs.)	190 / 100 ml	135 / 250 ml

3.2.3 Weeders

A cycle hoe and a power weeder were tested for their weed control efficiency (Plate 2 and 3). The cycle hoe developed by the Engineering Division of the Central Research Institute for Dryland Agriculture; Hyderabad is a hand wheel with three tynes. The power weeder used for the study was Microtiller MB – 25H (four stroke OHV Honda GX 25; 1.1 HP petrol engine; four rotating tynes; approximately 10kg weight; field capacity of 1ha in 10 hours).

3.2.4 Straw Mulch

Paddy straw was used as mulching material @ 4 t ha^{-1}. The paddy straw used for the study was analysed and has a C/N ratio of 72:1.

3.2.5 Manures and Fertilizers

Well decomposed dry cow dung containing 0.55 per cent N, 0.23 per cent P_2O_5 and 0.46 per cent K_2O was used as the organic manure source. N, P and K were applied as urea (46 per cent N), rajphos (20 per cent P_2O_5) and muriate of potash (60 per cent K_2O) respectively.

3.3 METHODS

3.3.1 Design and Layout

The efficacy of seven weed management practices was evaluated with the variety PTB 52 (Aiswarya). It was compared against MAS 946-1, maintained weed free by hand weeding. The experiment was laid out in randomized block design (RBD) with eight treatments replicated thrice.

The details of the layout are given below.

Design	: Randomized Block Design (RBD)
Treatments	: 7+1
Replications	: 3
Plot size	: 5 m x 4 m
Spacing	: 20 cm x 10 cm
Variety	: PTB 52 (Aiswarya), MAS 946-1 (Sharada)
Season	: Summer, 2012-13

Plate 1. General view of the experimental field

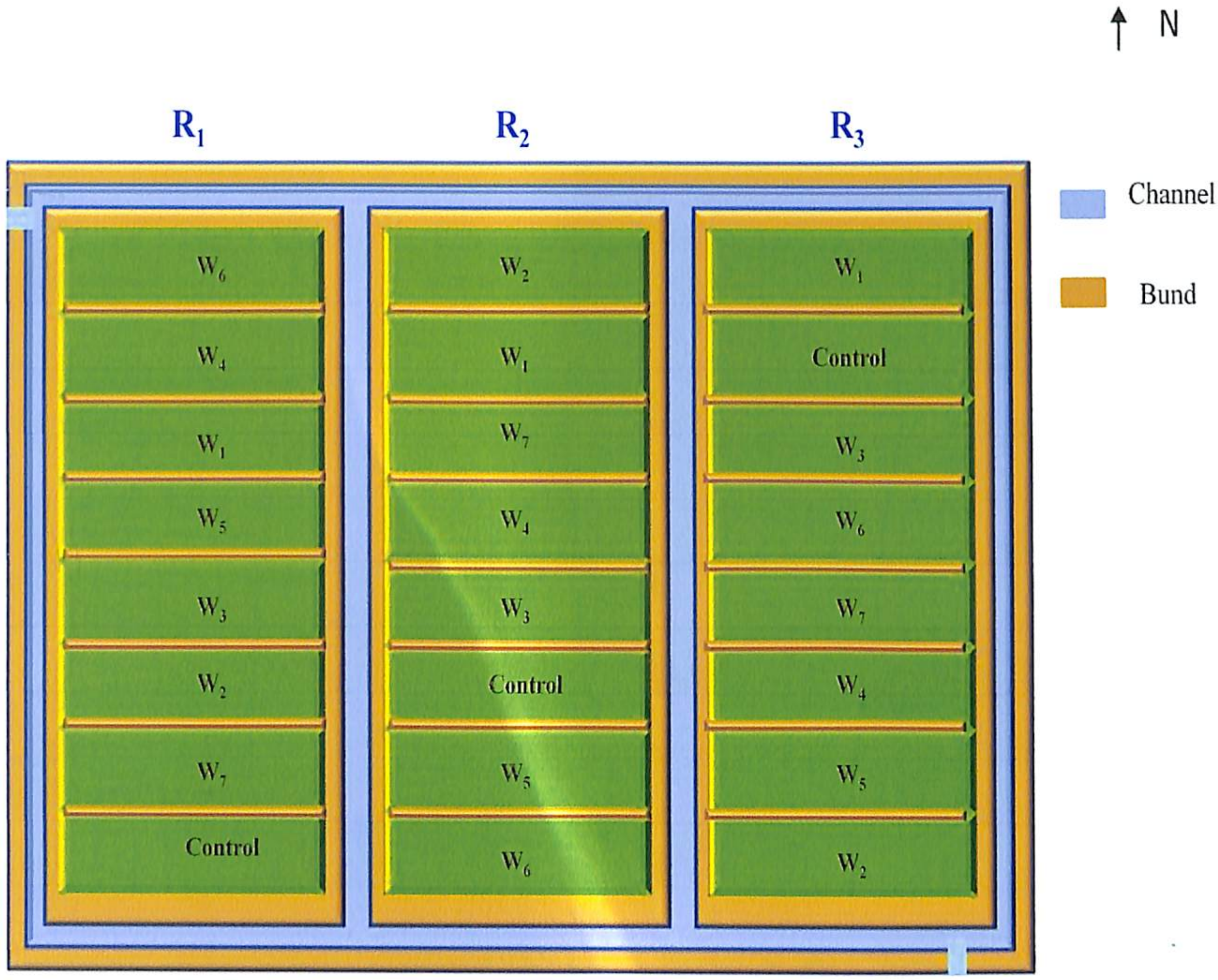


Figure 2. Lay out of the experimental field

3.3.1.1 Treatments

W_1 : Hand weeding (15, 30, 45 DAS)

W_2 : Mechanical weeding with cycle hoe

W_3 : Weeding with power weeder

W_4 : Mulching with straw

W_5 : Oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS

W_6 : Pretilachlor @ 0.75 kg a.i ha^{-1}+ hand weeding at 20 DAS

W_7 : Weedy check

Control (C):

MAS 946 – 1: weed-free up to 45 DAS (Hand weeding at 15, 30 and 45 DAS)

3.3.2 Crop Management

All cultural practices except weed management were carried out as per the Package of Practices Recommendations of Kerala Agricultural University (KAU, 2011).

3.3.2.1 Main Field Preparation

The experimental area was ploughed twice, levelled and weeds and stubbles were removed. The plots were laid out in to three blocks with eight plots each. The plots were separated with bunds of 30 cm height and width. Irrigation and drainage channels of 50 cm width were provided alternatively between the rows.

3.3.3.2 Seeds and Sowing

Seeds were soaked for 24 hours and the pre-germinated seeds were dibbled on the next day at a spacing of 20 cm x 10 cm.

3.3.3.3 Straw Mulching

Straw mulching was done (as per the treatments) at 15 DAS @ 4 t ha^{-1}.

Plate 2. Mechanical weeding with cycle hoe

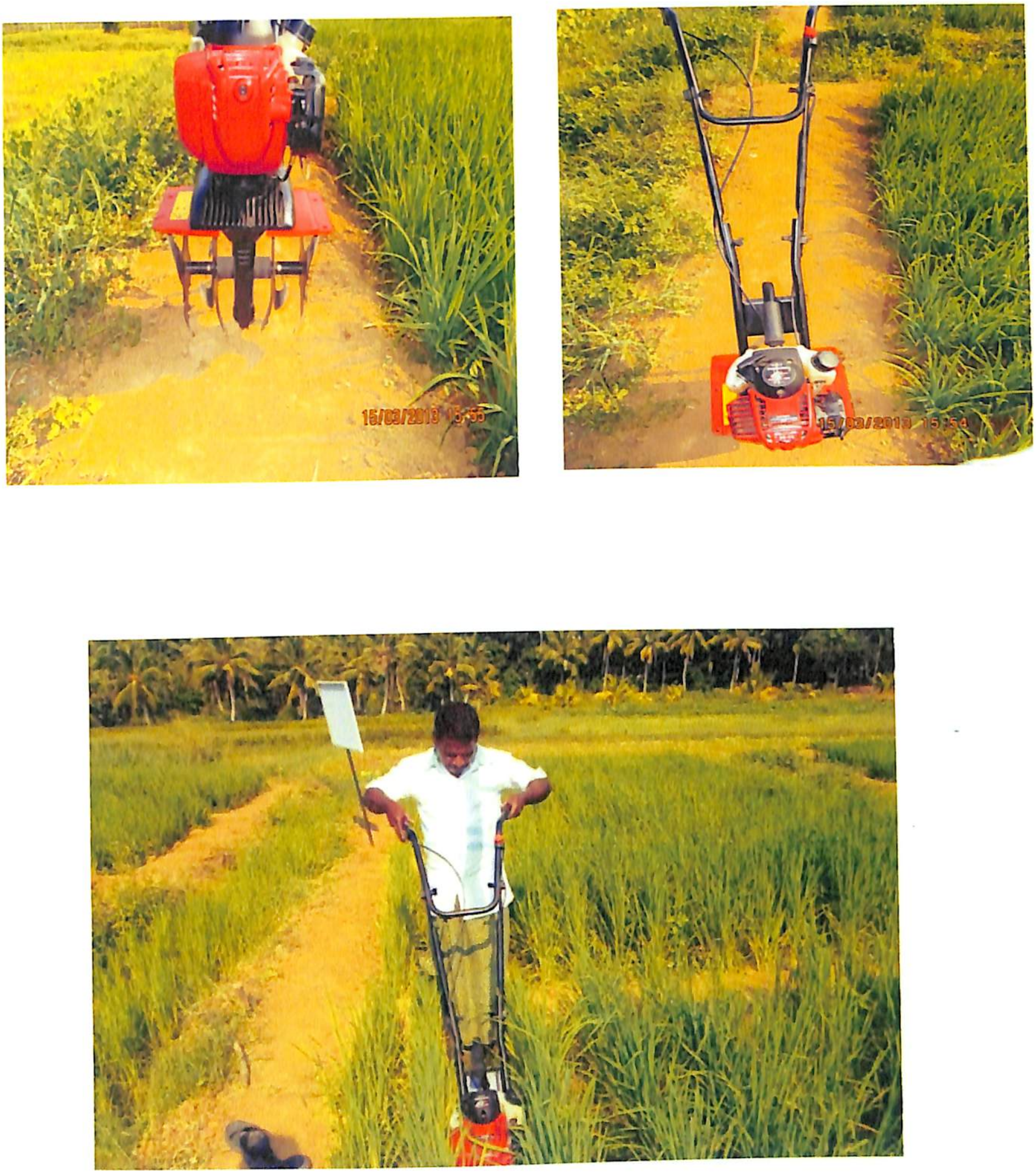


Plate 3. Mechanical weeding with power weeder

Plate 4. Straw mulching

3.3.3.4 Application of Manures and Fertilizers

Well decomposed dry cow dung was applied to all the plots @ 5 t ha^{-1} at the time of land preparation. A nutrient recommendation of 90:45:45 kg NPK ha^{-1} was adopted uniformly for all the plots. Urea, rajphos and muriate of potash were applied to supply N, P_2O_5 and K_2O respectively. The entire dose of P, one- third N and half K were applied basally, 10 days after sowing. The remaining N and K_2O were applied in two splits, one-third N at tillering and one-third N and half K at 7 days prior to PI stage (KAU, 2011). Uniform seed germination was observed. However, gap filling and thinning were done two weeks after sowing for uniform plant population, maintaining two seedlings per hill.

3.3.3.5 Irrigation

The soil moisture was maintained at field capacity uniformly in all the treatments. Irrigation was given once in two days till the panicle initiation (PI) stage. From the PI stage onwards daily irrigation was given. One week prior to harvest, irrigation was stopped for ensuring uniform maturity of the grains.

3.3.3.6 Herbicide Application

Herbicides were applied as per the treatments. Oxyfluorfen (@ 0.15 kg a.i ha^{-1}) and pretilachlor (@ 0.75 kg a.i ha^{-1}) were applied as pre-emergent herbicides, 3 DAS.

3.3.3.7 Plant Protection

No major incidence of pests and diseases were noted.

3.3.3.8 Harvest

The net plot area was harvested, threshed, winnowed and dried separately. The weight of grains and straw from individual plots were recorded and expressed in kg ha^{-1} on dry weight basis.

3.4 OBSERVATIONS

3.4.1 Observation on Weeds

3.4.1.1 Weed Composition

Weeds from the experimental area were identified and recorded.

3.4.1.2 Absolute Density (Ad)

Absolute weed density was recorded by placing 25cm x 25 cm quadrate at random in four sites in each plot and the mean value was recorded. The weeds were categorized into grasses, broadleaved weeds and sedges. The absolute density was recorded at 20, 40 and 60 DAS using the formula suggested by Philips (1959).

Ad = Total number of weeds of a given species m^{-2}

3.4.1.3 Relative Density (Rd)

Relative density (Rd) of grasses, broadleaved weeds and sedges were worked out separately at 20, 40 and 60 DAS using the formula put forward by Philips (1959).

$$Rd = \frac{\text{Absolute density of a species x100}}{\text{Total absolute density of all species}}$$

3.4.1.4 Absolute Frequency (Af)

Absolute frequency was computed at 20, 40 and 60 DAS according to the equation developed by Philips (1959). Absolute weed frequency of grasses, broadleaved weeds and sedges were recorded separately.

$$Af = \frac{\text{Number of quadrates in which a given species occured x 100}}{\text{Total number of quadrates used}}$$

3.4.1.5 Relative Frequency (Rf)

The computation of relative weed frequency was done at 20, 40 and 60 DAS, separately for grasses, broad-leaved weeds and sedges using the relationship developed by Philips (1959)

$$Rf = \frac{\text{Absolute frequency of a species x 100}}{\text{Total of absolute frequencies of all species}}$$

3.4.1.6 Importance value (IV)

Importance Value was obtained by adding the relative density (Rd) and relative frequency (Rf) of a given species (Kent and Coker, 1992).

Importance value (IV) = Relative density (Rd) + Relative frequency (Rf)

3.4.1.7 Summed Dominance Ratio (SDR)

Summed Dominance Ratio (SDR) was worked out at 20, 40 and 60 DAS according to the equation developed by Sen (1981). Summed dominance ratio of grasses, broadleaved weeds and sedges were worked out separately.

$$\text{SDR} = \frac{\text{Relative density} + \text{Relative frequency}}{2}$$

3.4.1.8 Weed Dry Matter Production

Weed dry weight was recorded at 20, 40, 60 DAS and at harvest. Weed samples were collected from the area left aside for taking destructive samples. Weeds coming inside the quadrate were pulled out carefully with roots intact, washed, dried under shade and then oven dried at 80 ± 5^0C to a constant weight. The dry weight was expressed as weed dry matter production in g m^{-2}.

3.4.1.9 Weed Control Efficiency (WCE)

Weed control efficiency was calculated by adopting the formula suggested by Mani and Gautham (1973).

$$WCE = \frac{WDWC - WDWT \times 100}{WDWC}$$

where,

WCE – weed control efficiency

WDWC – weed dry weight in unweeded (control) plot

WDWT – Weed dry weight in treated plot

3.4.1.10 Weed Index (WI)

Weed index was calculated according to the equation suggested by Gill and Vijayakumar (1969).

$$WI = \frac{X - Y \times 100}{Y}$$

where,

WI – Weed Index

X – Yield from weed free plot

Y – Yield from treatment plot

3.4.2 Observation on Crop

3.4.2.1 Crop Growth Characters

3.4.2.1.1 Plant Height

Plant height was recorded at 20, 40, 60 DAS and at harvest. Height of six randomly selected plants from the net plot area was measured from the base of the plant to the tip of the longest leaf or the tip of the longest ear head whichever was taller and the average was recorded in centimeters.

3.4.2.1.2 Number of Tillers Hill^{-1}

The number of tillers per hill was worked out from six randomly selected hills at 20, 40, 60 DAS and at harvest.

3.4.2.1.3 Leaf Area Index (LAI)

Leaf area index was calculated at 20, 40, 60 DAS and at harvest. Six sample hills were selected and the maximum width (w) and length (l) of all the leaves of the middlemost tiller of each hill was measured and leaf area index was calculated according to the method developed by Yoshida *et al*. (1976).

Leaf area of a single leaf = l x w x k, where k is the adjustment factor (0.75 at seedling stage, maximum tillering, panicle initiation and flowering and 0.67 at harvest stage).

$$\text{LAI} = \frac{\text{Sum of leaf area / hill of 6 sample hill (cm}^2\text{) x 100}}{\text{Area of land covered by the 6 sample hills (cm}^2\text{)}}$$

3.4.2.1.4 Dry Matter Production

From each plot six sample hills were uprooted at harvest. They were washed, dried in shade and later in a hot air oven till constant weights were attained. Dry weights of the plants were expressed as dry matter production in t ha^{-1}.

3.4.2.2 Yield Attributes and Yield

3.4.2.2.1 Number of Productive Tillers m^{-2}

At harvest, the number of productive tillers was counted from the six randomly selected hills in the net plot area and was expressed as number of productive tillers m^{-2}

3.4.2.2.2 Number of Spikelets per Panicle

Number of spikelets per panicle was found out by counting the grains from the six randomly selected panicles from each plot.

3.4.2.2.3 Number of Filled Grains per Panicle

Number of filled grains in the six panicles, collected randomly from the net plot was counted and the mean value was expressed as the number of grains per panicle.

3.4.2.2.4 Sterility Percentage

Sterility percentage was worked out using the following relationship

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

3.4.2.2.5 Thousand Grain Weight

One thousand grains were counted from the cleaned and dried produce from the net plot area of each plot and the weight of the grains was recorded in grams.

3.4.2.2.6 Grain Yield

The net plot area was harvested individually, threshed, winnowed, dried and weight was recorded and expressed in kg ha^{-1}.

3.4.2.2.7 Straw Yield

The straw obtained from net plot area was dried in sun, weighed and expressed in kg ha^{-1}.

3.4.2.2.8 Harvest Index (HI)

Harvest index was worked out using the following formula suggested by Donald and Hamblin (1976).

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

3.5 CHEMICAL ANALYSIS

3.5.1 Soil Analysis

Composite soil samples, collected before the start of the experiment were analysed to determine the soil reaction, organic carbon, available nitrogen, and phosphorus and potassium status of the soil. The physical composition of the soil was also determined. After the harvest of the crop, soil samples were taken from each plot separately and analysed for available nutrient status.

3.5.1.1 Available Nitrogen

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956).

3.5.1.2 Available Phosphorus

Available phosphorus content of the soil was determined by Dickman and Brays molybdenum blue method. Bray No.1 reagent was used for extraction (Jackson, 1973).

3.5.1.3 Available Potassium

Available potassium content of the soil was determined using neutral normal ammonium acetate extract and estimated using the EEL Flame Photometer (Jackson, 1973).

3.5.2 Plant Analysis

The weed samples collected at 20, 40 and 60 DAS and harvest and the crop plant samples collected at harvest were analysed for their total N, P and K contents. The grains were analysed separately for total nitrogen content. The samples were dried in an electric hot air oven to constant weight, ground and sieved through a 0.5 mm sieve. The required quantity of samples were weighed out accurately in an electronic balance, subjected to acid extraction and analysed.

3.5.2.1 Total Nitrogen Content

Total nitrogen content was estimated by modified microkjheldal method (Jackson, 1973).

3.5.2.2 Total Phosphorus Content

Total phosphorus content was found out using Vanadomolybdo phosphoric yellow colour method (Jackson, 1973).

3.5.2.3 Total Potassium Content

Total potassium content in plant was determined using EEL Flame Photometer (Jackson, 1973).

3.5.3 Uptake of Nutrients

The N, P and K uptake of weeds (20, 40 and 60 DAS and harvest) and crop was calculated as the product of nutrient content and the respective plant dry weight and expressed as kg ha^{-1}.

3.6 ECONOMIC ANALYSIS

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

3.6.1 Cost of Cultivation

Cost of cultivation was worked out for all treatments.

3.6.2 Net Income

Net income was computed using the formula,

Net income (Rs. ha^{-1}) = Gross income – Cost of cultivation

3.6.3 Benefit Cost Ratio (BCR)

Benefit cost ratio was computed using the formula,

$$BCR = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.6.4 Net Returns per Rupee Invested on Weed Management

Net returns per rupee invested on weed management was computed using the formula,

$$\frac{\text{Gross returns - Cost of cultivation excluding that for weed management}}{\text{Cost incurred for weed management}}$$

3.7 STATISTICAL ANALYSIS

The data generated from the experiment were statistically analysed using Analysis of Variance techniques (ANOVA) as applied to Randomized Block Design described by Cochran and Cox (1965). The data which required transformation were appropriately transformed and analyzed. The treatment versus control comparison is denoted as ‘S’ when significant and ‘NS’ when not significant. In the case of data which did not fall in agreement with the others, statistical analysis was done excluding that.

RESULTS

4. RESULTS

The experiment entitled" Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)" was taken up at the Instructional farm, College of Agriculture, Vellayani, Thiruvananthapuram, during January, 2013 to May, 2014. The main objective of the study was to assess the extent of yield loss due to weeds in aerobic rice, to assess the most suitable weed management strategy for aerobic rice and to study the economic feasibility. The results of the experiment are presented in this chapter.

4.1 OBSERVATION ON WEEDS

4.1.1 Weed Composition

The different weed species found in the experimental field during the study were collected, identified and classified into grasses, sedges and broadleaved weeds. The results are presented in the Table 5.

4.1.2 Absolute Density

4.1.2.1 Absolute Density of Grasses

Data on absolute density of grasses at 20, 40 and 60 DAS is presented in the Table 6.

The data indicated that the density of grassy weeds were less when compared with broad leaved weeds and sedges. At 20 DAS and 40 DAS, the effect of weed management practices on the absolute density of grasses was not significant. At 60 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded the lowest density of grasses followed by the hand weeding treatment of the variety Aiswarya (W_1) and the hand weeded control (MAS 946-1). Among the different weed management practices the highest grass density was recorded in the treatment W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS).

Table 5. Major weed composition observed in the experimental field

Common Name	Scientific name	Family
Broad leaved weeds		
Spider weed	*Cleome rutidospermum* Dc.	Capparidaceae
Goat weed	*Ageratum conyzoides* (L.)	Asteraceae
Desert horsepurslane	*Trianthema portulacastrum* (L.)	Aizoceae
Indian pennywort	*Centella asiatica* (L.)	Apiaceae
Spreading day flower	*Commelina jacobi* C.E.C.Fisch	Commelinaceae
Indian madder	*Oldenlandia umbellata* (L.)	Rubiaceae
Melochia	*Melochia nodiflora* Sw.	Sterculiaceae
Sedges		
Purple net sedge	*Cyperus rotundus* (L.)	Cyperaceae
Globe finger rush	*Fimbristylis miliacea* (L.) Vahl	Cyperaceae
Grasses		
Bermuda grass	*Cynodon dactylon* (L.)	Poaceae
Ginger grass	*Panicum repens* (L.)	Poaceae

4.1.2.2 Absolute Density of Broadleaved Weeds

Data on absolute density of broadleaved weeds at 20, 40 and 60 DAS is presented in the Table 7.

The absolute density of broadleaved weeds was significantly influenced by the weed management practices on all the crop growth stages. At 20 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) registered lowest absolute density of broadleaved weeds and it was on par with W_4 (straw mulching) and W_2 (mechanical weeding with cycle hoe). At 40 DAS, the lowest density of broadleaved weeds was recorded by W_1 (hand weeding at 15, 30, 45 DAS) and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS), W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and W_2 (mechanical weeding with cycle hoe). At 60 DAS, the lowest density of broadleaved weeds was found in the control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS), W_2 (mechanical weeding with cycle hoe) and W_1 (hand weeding (15, 30, 45 DAS). At 20, 40 and 60 DAS, the highest absolute density of broadleaved weeds was found in the weedy check.

4.1.2.3 Absolute Density of Sedges

Data on absolute density of grasses at 20, 40 and 60 DAS is presented in the Table 8.

At 20 DAS, the effect of weed management practices on the absolute density of sedges was found to be not significant. At 40 DAS, the lowest absolute density of sedges was recorded from control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS), W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS), W_1 (hand weeding at 15, 30, 45 DAS) and W_4 (straw mulching). At 60 DAS, lowest density of sedges was observed in W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and it was on par with W_1

(hand weeding 15, 30, 45 DAS) and control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

4.1.2.4 Total Weed Density

Data on total weed density at 20, 40 and 60 DAS is presented in the Table 9. The total weed density was significantly influenced by the weed management practices at all the stages. At 20 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded lowest total weed density and it was on par with W_1 (hand weeding 15, 30, 45 DAS). At 40 DAS control recorded lowest total weed density and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). At 60 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded lowest total weed density and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and W_1 (hand weeding 15, 30, 45 DAS). Among the different weed management practices W_4 (straw mulching) and W_3 (mechanical weeding with power weeder) were found to be least effective with higher weed density. Weedy check recorded significantly higher number of weeds all throughout the growth stages.

4.1.3 Relative Density

4.1.3.1 Relative Density of Grasses

Data on relative density of grasses at 20, 40 and 60 DAS is presented in the Table 10.

At 20 DAS relative density of grasses was not significant. At 40 DAS the relative density of grasses recorded by W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). At 60 DAS lowest relative density was recorded by W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + HW at 20 DAS).

Table 6. Effect of weed management practices on the absolute density of grasses, number m^{-2}

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	2.96 (1.99)
W_2:MW with cycle hoe	4.00 (2.00)	1.99 (1.73)	5.91 (2.63)
W_3:MW with power weeder	4.37 (2.09)	1.92 (1.71)	7.01 (2.83)
W_4:Straw mulching	0	1.19 (1.48)	7.24 (2.87)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	0.90 (1.38)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	3.31 (1.82)	4.48 (2.34)	14.21 (3.90)
W_7:Weedy check	10.67	11.33	19.33
Control: MAS 946-1 (HW)	0	2.31 (1.82)	2.96 (1.99)
SEm (±)	0.230	0.186	0.175
CD (0.05)	NS	NS	0.538
Treatment *Vs* Control	NS	NS	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 7. Effect of weed management practices on the absolute density of broadleaved weeds, number m^{-2}

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	24.00	5.67	13.00
W_2:MW with cycle hoe	21.00	14.67	11.33
W_3:MW with power weeder	28.67	19.67	32.67
W_4:Straw mulching	16.67	27.33	33.33
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	14.67	13.33	10.67
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	24.00	20.67	26.67
W_7:Weedy check	68.33	117.33	140.67
Control: MAS 946-1 (HW)	26.00	7.00	10.00
SEm (±)	2.409	3.226	3.359
CD (0.05)	7.427	9.946	10.357
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 8. Effect of weed management practices on the absolute density of sedges, number m^{-2}

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	3.93 (2.22)	7.12 (2.85)	5.96 (2.64)
W_2:MW with cycle hoe	7.94 (2.99)	10.29 (3.36)	10.90 (3.45)
W_3:MW with power weeder	8.54 (3.09)	19.88 (4.57)	14.84 (3.98)
W_4:Straw mulching	0	7.53 (2.92)	11.75 (3.57)
W_5:OF@ 0.15 kg a.i ha^{-1} + HW	0	3.45 (2.11)	5.96 (2.64)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	1.22 (1.49)	5.60 (2.57)	10.22 (3.35)
W_7:Weedy check	17.67	38	44.33
Control: MAS 946-1 (HW)	0	2.96 (1.99)	8.92 (3.15)
SEm (±)	0.414	0.416	0.257
CD (0.05)	NS	1.281	0.792
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 9. Effect of weed management practices on total weed density, number m^{-2}

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	28.67	15.33	23.00
W_2:MW with cycle hoe	33.00	24.00	44.67
W_3:MW with power weeder	39.00	42.33	55.67
W_4:Straw mulching	16.67	36.33	53.67
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	14.67	17.67	18.67
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	28.67	31.33	37.33
W_7:Weedy check	96.67	173.00	198.00
Control: MAS 946-1 (HW)	26.00	12.00	23.00
SEm (±)	1.889	6.687	2.709
CD(0.05)	5.824	21.168	8.351
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

4.1.3.2 Relative Density of Broadleaved Weeds

Data on relative density of broadleaved weeds at 20, 40 and 60 DAS are presented in the Table 11.

At 20 DAS, relative density of broadleaved weeds was lowest in W_2 (mechanical weeding with cycle hoe). At 40 DAS, W_1 (hand weeding 15, 30, 45 DAS) recorded the lowest relative density of broadleaved weeds. At 60 DAS, lowest relative density of broadleaved weeds was recorded by control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

4.1.3.3 Relative Density of Sedges

Data on relative density of sedges at 20, 40 and 60 DAS is presented in the Table 12.

At 20 and 40 DAS the effect of weed management practices on the relative density of sedges was not significant. At 60 DAS, among the different weed management practices lowest relative density of sedges was found in W_4 (straw mulching) and it was on par with W_1, W_2 and W_3.

4.1.4 Absolute Frequency

4.1.4.1 Absolute Frequency of Grasses

The data on absolute frequency of grass weeds at 20, 40 and 60 DAS is given in the Table 13.

At 20 DAS absolute frequency of sedges was not significantly different among the different weed management practices. At 40 DAS absolute frequency of grasses was zero in W_1 and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). At 60 DAS W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + HW at 20 DAS) recorded lowest absolute frequency of grasses and it was on par with W_1 (hand weeding 15, 30, 45 DAS), W_2, W_3, W_4, W_5 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

Table 10. Effect of weed management practices on the relative density of grasses, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	13.14 (3.76)
W_2:MW with cycle hoe	12.18 (3.49)	8.55 (3.09)	13.22 (3.77)
W_3:MW with power weeder	11.16 (3.34)	4.71 (2.39)	12.54 (3.68)
W_4:Straw mulching	0	3.28 (2.07)	14.29 (3.91)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	5.10 (2.47)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	11.56 (3.40)	15.00 (4.00)	38.31 (6.27)
W_7:Weedy check	11.09 (3.33)	18.80 (4.45)	9.69 (3.27)
Control: MAS 946-1 (HW)	0	6.51 (2.74)	12.61 (3.69)
SEm (±)	0.184	0.346	0.341
CD (0.05)	NS	1.092	1.037
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 11. Effect of weed management practices on the relative density of broadleaved weeds, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	83.81	35.24	55.95 (7.48)
W_2:MW with cycle hoe	63.73	61.51	59.59 (7.72)
W_3:MW with power weeder	68.49	46.82	58.82 (7.67)
W_4:Straw mulching	100.00	75.37	59.75 (7.73)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	100.00	77.16	53.29 (7.30)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	83.59	64.35	30.36 (5.51)
W_7:Weedy check	70.79	67.85	70.89 (8.42)
Control: MAS 946-1 (HW)	100.00	56.99	41.86 (6.47)
SEm (±)	3.724	5.411	0.254
CD (0.05)	11.322	16.455	0.775
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 12. Effect of weed management practices on the relative density of sedges, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	12.47 (3.67)	25.42 (5.14)	30.43
W_2:MW with cycle hoe	23.90 (4.99)	29.47 (5.52)	26.77
W_3:MW with power weeder	19.98 (4.58)	48.28 (7.02)	28.52
W_4:Straw mulching	0	20.53 (4.64)	25.67
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	16.98 (4.24)	39.73
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	4.02 (2.24)	18.27 (4.39)	30.84
W_7:Weedy check	18.01 (4.36)	64.61 (8.10)	19.26
Control: MAS 946-1 (HW)	0	23.80 (4.98)	44.74
SEm (±)	0.728	0.648	4.213
CD (0.05)	NS	1.969	12.810
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 13. Effect of weed management practices on the absolute frequency of grasses

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	43.16 (6.57)
W_2:MW with cycle hoe	33.33	33.34 (5.86)	43.16 (6.57)
W_3:MW with power weeder	44.44	33.34 (5.86)	43.16 (6.57)
W_4:Straw mulching	0	16.98 (4.24)	43.16 (6.57)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	33.29 (5.77)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	0	54.35 (7.44)	77.08 (8.78)
W_7:Weedy check	44.44	76.97 (8.83)	100 (10.00)
Control: MAS 946-1 (HW)	0	33.34 (5.86)	43.16 (6.57)
SEm (±)	6.414	0.832	0.710
CD(0.05)	NS	2.626	2.159
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Weedy check recorded highest absolute frequency and it was on par with W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS).

4.1.4.2 Absolute Frequency of Broadleaved Weeds

Data on absolute frequency of broadleaved weeds at 20, 40 and 60 DAS are presented in the Table 14.

At 20 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded lowest absolute frequency of broadleaved weeds and it was on par with W_1 (hand weeding 15, 30, 45 DAS). At 40 DAS W_1 (hand weeding 15, 30, 45 DAS) and control (MAS 946-1: hand weeding at 15, 30, 45 DAS) recorded lowest absolute frequency of broadleaved weeds and it was on par with W_2, W_3 and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). Weedy check recorded highest absolute frequency and it was on par with W_4 (straw mulching). At 60 DAS W_1 (hand weeding 15, 30, 45 DAS) recorded lowest absolute frequency and it was on par with W_2, W_5, W_6 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS). Weedy check recorded the highest absolute frequency.

4.1.4.3 Absolute Frequency of Sedges

Data on absolute frequency of sedges at 20, 40 and 60 DAS are presented in the Table 15.

At 20 DAS absolute frequency of sedges was not significantly different among the different weed management practices. At 40 DAS W_5 recorded lowest absolute frequency of sedges and it was on par with W_2 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS). Weedy check recorded highest absolute frequency. At 60 DAS W_5 recorded lowest absolute frequency of sedges and it was on par with W_1 (hand weeding at 15, 30, 45 DAS), W_2, W_4, W_6 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

Table 14. Effect of weed management practices on the absolute frequency of broadleaved weeds

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	42.16 (6.57)	33.33 (5.86)	33.29 (5.77)
W_2:MW with cycle hoe	99 (10.00)	43.22 (6.65)	54.32 (7.37)
W_3:MW with power weeder	99 (10.00)	43.22 (6.65)	77.08 (8.78)
W_4:Straw mulching	53.32 (7.37)	76.96 (8.83)	88.17 (9.39)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	32.29 (5.77)	43.22 (6.65)	43.16 (6.57)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	65.74 (8.17)	51.70 (7.26)	43.16 (6.57)
W_7:Weedy check	99 (10.00)	100.00 (10.05)	100.00(10.00)
Control: MAS 946-1 (HW)	65.74 (8.17)	33.33 (5.86)	43.16 (6.57)
SEm (±)	0.383	0.700	0.585
CD(0.05)	1.165	2.130	1.780
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 15. Effect of weed management practices on the absolute frequency of sedges

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	16.97 (4.24)	43.22 (6.65)	43.16 (6.57)
W_2:MW with cycle hoe	43.22 (6.65)	33.34 (5.86)	54.32 (7.37)
W_3:MW with power weeder	43.22 (6.65)	43.22 (6.65)	77.08 (8.78)
W_4:Straw mulching	0	76.97 (8.83)	54.32 (7.37)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	16.98 (4.24)	33.29 (5.77)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	16.98 (4.24)	43.22 (6.65)	43.16 (6.57)
W_7:Weedy check	88.11 (9.44)	100.00 (10.05)	100 (10.00)
Control: MAS 946-1 (HW)	0	33.34 (5.86)	54.32 (7.37)
SEm (±)	1.272	0.788	0.686
CD(0.05)	NS	2.395	2.086
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

4.1.5 Relative Frequency

4.1.5.1 Relative Frequency of Grasses

The data on relative frequency of grasses at 20, 40 and 60 DAS is given in the Table 16.

At 20, 40 and 60 DAS the relative frequency of grasses was not significantly different among the different weed management practices.

4.1.5.2 Relative Frequency of Broadleaved Weeds

The data on relative frequency of broadleaved weeds at 20, 40 and 60 DAS is given in the Table 17.

At 20 DAS the relative frequency of broadleaved weeds was highest in W_4 (straw mulching). At 40 and 60 DAS the relative frequency of broadleaved weeds had no significant difference between the different weed management practices.

4.1.5.3 Relative Frequency of Sedges

The data on relative frequency of sedges at 20, 40 and 60 DAS is given in the Table 18.

The relative frequency was zero in W_4, W_5 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS) at 20 DAS. At 40 and 60 DAS the relative frequency of sedges had no significant difference between the different weed management practices.

4.1.6 Summed Dominance Ratio

4.1.6.1 Summed Dominance Ratio of Grasses

The data on summed dominance ratio of grasses at 20, 40 and 60 DAS is given in the Table 19.

At 20 and 40 DAS there was no significant difference between the summed dominance ratio of different weed management practices. At 60 DAS W_5 recorded the lowest summed dominance ratio and it was on par with the remaining treatment.

4.1.6.2 Summed Dominance Ratio of Broadleaved Weeds

The data on summed dominance ratio of broadleaved weeds at 20, 40 and 60 DAS is given in the Table 20.

At 20, 40 and 60 DAS the effect was significant but did not follow any specific pattern.

4.1.6.3 Summed Dominance Ratio of Sedges

The data on summed dominance ratio of sedges at 20, 40 and 60 DAS is given in the Table 21.

At 20, 40 and 60 DAS the effect of the different weed management practices on the summed dominance ratio of sedges was not significant.

4.1.7 Importance Value

4.1.7.1 Importance Value of Grasses

The data on Importance valve of grasses at 20, 40 and 60 DAS is presented in the Table 22.

At 20, 40 and 60 DAS the effect of the different weed management practices on the importance value of grasses was not significant.

4.1.7.2 Importance Value of Broadleaved Weeds

The data on Importance valve of broadleaved weeds at 20, 40 and 60 DAS is presented in the Table 23.

Table 16. Effect of weed management practices on the relative frequency of grasses, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	35.55
W_2:MW with cycle hoe	18.84 (4.34)	31.47 (5.61)	28.33
W_3:MW with power weeder	0	29.49 (5.43)	22.54
W_4:Straw mulching	0	11.49 (3.39)	23.33
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	33.33
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	22.85 (4.78)	36.36 (6.03)	47.78
W_7:Weedy check	18.40 (4.29)	28.62 (5.35)	33.33
Control: MAS 946-1 (HW)	0	34.34 (5.86)	30.00
SEm (±)	0.221	0.615	5.035
CD(0.05)	NS	NS	NS
Treatment *Vs* Control	NS	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 17. Effect of weed management practices on the relative frequency of broadleaved weeds, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	58.06 (7.62)	38.89	28.89
W_2:MW with cycle hoe	56.55 (7.52)	38.89	36.67
W_3:MW with power weeder	53.14 (7.29)	35.55	38.73
W_4:Straw mulching	100 (10.00)	43.33	46.67
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	64.80 (8.05)	44.44	44.43
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	69.39 (8.33)	33.33	26.11
W_7:Weedy check	43.16 (6.57)	36.11	33.33
Control: MAS 946-1 (HW)	58.68 (7.66)	33.33	30.00
SEm (±)	0.600	4.412	5.683
CD(0.05)	1.827	NS	NS
Treatment *Vs* Control	S	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 18. Effect of weed management practices on the relative frequency of sedges, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	33.29 (5.77)	50.00	35.55
W_2:MW with cycle hoe	24.11 (4.91)	30.55	35.00
W_3:MW with power weeder	22.85 (4.78)	35.55	38.72
W_4:Straw mulching	0	43.33	30.00
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	27.78	33.33
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	30.47 (5.52)	30.56	26.11
W_7:Weedy check	37.82 (6.15)	36.11	33.33
Control: MAS 946-1 (HW)	0	33.33	40.00
SEm (±)	0.243	7.634	5.214
CD(0.05)	0.797	NS	NS
Treatment *Vs* Control	S	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 19. Effect of weed management practices on the summed dominance ratio of grasses

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	7.06 (2.84)	0	23.70 (4.97)
W_2:MW with cycle hoe	11.53(3.54)	19.43 (4.52)	56.00 (7.55)
W_3:MW with power weeder	15.89 (4.11)	16.72 (4.21)	53.17 (7.36)
W_4:Straw mulching	0	7.00 (2.83)	31.26 (5.68)
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	11.18 (3.49)
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	3.97 (2.23)	25.32 (5.13)	58.14 (7.69)
W_7:Weedy check	11.32 (3.51)	18.18 (4.38)	60.31 (7.83)
Control: MAS 946-1 (HW)	2.49 (1.87)	24.70 (5.07)	45.10 (6.79)
SEm (±)	1.021	0.521	4.088
CD(0.05)	NS	NS	12.431
Treatment *Vs* Control	NS	NS	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 20. Effect of weed management practices on the summed dominance ratio of broad leaved weeds

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	62.32	31.77	33.74
W_2:MW with cycle hoe	62.08	50.42	38.51
W_3:MW with power weeder	61.81	41.19	36.27
W_4:Straw mulching	100.00	51.23	47.28
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	75.57	51.55	49.23
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	82.29	48.85	25.69
W_7:Weedy check	50.93	52.54	52.15
Control: MAS 946-1 (HW)	69.54	45.36	36.22
SEm (±)	8.925	3.747	4.296
CD(0.05)	27.139	11.395	13.065
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 21. Effect of weed management practices on the summed dominance ratio of sedges

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	17.66 (4.32)	61.57 (7.91)	41.45
W_2:MW with cycle hoe	22.33 (4.83)	29.92 (5.56)	41.26
W_3:MW with power weeder	17.23 (4.27)	41.90 (6.55)	49.27
W_4:Straw mulching	0	38.56 (6.29)	37.24
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	18.72 (4.44)	36.53
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	8.48 (3.08)	26.88 (5.28)	31.07
W_7:Weedy check	29.91 (5.56)	42.16 (6.57)	36.21
Control: MAS 946-1 (HW)	0	29.91 (5.56)	42.38
SEm (±)	1.015	0.754	4.752
CD(0.05)	NS	NS	NS
Treatment *Vs* Control	NS	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 22. Effect of weed management practices on the importance value of grasses

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	42.93
W_2:MW with cycle hoe	23.16	39.07	48.76
W_3:MW with power weeder	32.46	33.68	45.08
W_4:Straw mulching	0	17.42	54.30
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	43.30
W_6:PC@ 0.75 kg a.i ha^{-1} + HW	0	52.11	64.71
W_7:Weedy check	22.92	37.06	53.86
Control: MAS 946-1 (HW)	0	49.52	42.80
SEm (±)	3.159	7.826	4.755
CD(0.05)	NS	NS	NS
Treatment *Vs* Control	NS	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 23. Effect of weed management practices on the importance value of broad leaved weeds

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	124.63	63.55	67.48
W_2:MW with cycle hoe	124.15	100.83	77.02
W_3:MW with power weeder	123.58	82.37	72.52
W_4:Straw mulching	200.00	102.46	94.56
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	151.13	104.62	98.45
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	154.59	97.69	51.39
W_7:Weedy check	104.67	105.07	104.30
Control: MAS 946-1 (HW)	139.08	90.71	72.44
SEm (±)	18.555	7.416	8.593
CD(0.05)	NS	22.551	26.131
Treatment *Vs* Control	NS	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 24. Effect of weed management practices on the importance value of sedges

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	34.16 (5.93)	124.00	82.91
W_2:MW with cycle hoe	41.12 (6.49)	60.09	82.54
W_3:MW with power weeder	34.40 (5.95)	83.94	98.55
W_4:Straw mulching	0	80.12	74.48
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	81.89	73.06
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	16.31 (4.16)	58.66	62.21
W_7:Weedy check	59.68 (7.79)	84.63	74.42
Control: MAS 946-1 (HW)	0	60.09	84.75
SEm (±)	1.502	13.227	9.505
CD(0.05)	NS	NS	NS
Treatment *Vs* Control	NS	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor
Figures in parentheses denote transformed values

Table 25. Effect of weed management practices on dry matter production, g m^{-2} of grasses

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0	0	1.24
W_2:MW with cycle hoe	0.26	0.93(1.39)	2.61
W_3:MW with power weeder	0.24	0.79(1.34)	2.13
W_4:Straw mulching	0	0.42(1.19)	1.32
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0	0.67
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	0	2.72(1.93)	5.60
W_7:Weedy check	0.80	3.40(5.92)	9.02
Control: MAS 946-1 (HW)	0	0.32(1.15)	1.33
SEm (±)	0.054	0.093	0.206
CD(0.05)	0.216	0.302	0.635
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor
Figures in parentheses denote transformed values

At 20 DAS the effect of the different weed management practices on the importance value of broadleaved weeds was not significant. At 40 and 60 DAS the effect was significant but did not follow any specific pattern.

4.1.7.3 Importance Value of sedges

The data on Importance valve of sedges at 20, 40 and 60 DAS is presented in the Table 24.

At 20, 40 and 60 DAS the effect of the different weed management practices on the importance value of sedges was not significant.

4.1.8 Weed Drymatter Production

4.1.8.1 Weed Drymatter Production of Grasses

The data on drymatter production of grasses at 20, 40 and 60 DAS is presented in the Table 25.

At 20 DAS zero drymatter production of grassy weeds were recorded by W_1 (hand weeding 15, 30, 45 DAS), W_4 (straw mulching), W_5, W_6 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At 40 DAS zero drymatter production of weeds was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and W_1. At 60 DAS lowest drymatter production of weeds was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and it was on par with W_1 (hand weeding 15, 30, 45 DAS). At all the growth stages weedy check recorded highest drymatter production.

4.1.8.2 Weed Drymatter Production of Broadleaved Weeds

The data on drymatter production of broadleaved weeds at 20, 40 and 60 DAS is presented in the Table 26.

At 20 DAS lowest drymatter production of weeds was recorded by W_5 and it was on par with W_4 (straw mulching). At 40 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded lowest weed drymatter production and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At 60 DAS lowest drymatter production of weeds was recorded by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). At all the growth stages weedy check recorded highest drymatter production.

4.1.8.3 Weed Drymatter Production of Sedges

The data on drymatter production of sedges at 20, 40 and 60 DAS is presented in the Table 27.

At 20 DAS W_4 (straw mulching), W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and control recorded zero weed drymatter production. At 40 DAS and 60 DAS, lowest drymatter production was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS). At all the growth stages weedy check recorded highest drymatter production.

4.1.8.4 Total Weed Drymatter Production

The data on total drymatter production of weeds at 20, 40 and 60 DAS is presented in the Table 28.

At 20 DAS lowest drymatter production of weeds was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and it was on par with W_4 (straw mulching). At 40 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded lowest weed drymatter production and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At 60 DAS lowest drymatter production was recorded W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and it was on par

Table 26. Effect of weed management practices on dry matter production, g m^{-2} of broad leaved weeds

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	1.08	0.46(1.21)	2.34
W_2:MW with cycle hoe	1.65	6.39(2.72)	4.77
W_3:MW with power weeder	1.96	5.76(2.60)	5.22
W_4:Straw mulching	0.39	4.66(2.38)	5.19
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0.38	0.46(1.21)	2.70
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	2.08	13.06(3.75)	6.33
W_7:Weedy check	7.27	23.06	23.27
Control: MAS 946-1 (HW)	1.76	0.56(1.25)	1.78
SEm (±)	0.134	0.159	0.302
CD(0.05)	0.412	0.491	0.929
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 27. Effect of weed management practices on dry matter production, g m^{-2} of sedges

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	0.54(1.24)	2.14	3.94
W_2:MW with cycle hoe	1.59(1.61)	1.71	5.47
W_3:MW with power weeder	1.46(1.57)	2.06	6.24
W_4:Straw mulching	0	1.34	4.20
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0	0.54	2.17
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	0.18(1.09)	1.31	4.44
W_7:Weedy check	6.18(2.68)	8.93	20.42
Control: MAS 946-1 (HW)	0	1.19	4.13
SEm (±)	0.073	0.195	0.139
CD(0.05)	0.235	0.601	0.985
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Figures in parentheses denote transformed values

Table 28. Effect of weed management practices on total weed dry matter production, g m^{-2}

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	1.66	3.35	7.52
W_2:MW with cycle hoe	3.51	5.36	12.86
W_3:MW with power weeder	3.67	5.47	13.61
W_4:Straw mulching	0.39	4.18	10.71
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0.38	1.01	5.54
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	2.28	7.83	16.37
W_7:Weedy check	14.26	37.97	52.71
Control: MAS 946-1 (HW)	1.05	2.75	7.24
SEm (±)	0.265	0.729	0.582
CD(0.05)	0.818	2.249	1.793
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 29. Effect of weed management on weed control efficiency of grasses, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	85.43	94.73	86.15
W_2:MW with cycle hoe	73.99	88.19	71.09
W_3:MW with power weeder	76.21	88.71	76.38
W_4:Straw mulching	100	89.68	85.32
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	100	97.92	92.42
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	96.81	83.79	37.84
W_7:Weedy check	-	-	-
Control: MAS 946-1 (HW)	93.60	94.56	85.09
SEm (±)	1.456	0.582	2.027
CD(0.05)	4.490	1.796	6.250
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

with control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At all the growth stages observed weedy check recorded highest drymatter production.

4.1.9 Weed Control Efficiency

4.1.9.1 Weed Control Efficiency of Grasses

The data on weed control efficiency of grasses at 20, 40 and 60 DAS is presented in the Table 29.

At 20 DAS, the treatments W_4 (straw mulching) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency than the remaining treatments. At 40 DAS and 60 DAS W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly high weed control efficiency than the remaining treatments. Lowest weed control efficiency was recorded by W_6 at these two stages.

4.1.9.2 Weed Control Efficiency of Broadleaved Weeds

The data on weed control efficiency of broadleaved weeds at 20, 40 and 60 DAS is presented in the Table 30.

At 20 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency and it was on par with W_4 (straw mulching). At 40 DAS, W_5 recorded significantly higher weed control efficiency. At 60 DAS, control recorded higher weed control efficiency and it was on par with W_1 (hand weeding 15, 30, 45 DAS).

4.1.9.3 Weed Control Efficiency of sedges

The data on weed control efficiency of sedges at 20, 40 and 60 DAS is presented in the Table 31.

At 20 DAS, the treatments W_4 (straw mulching) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency than the remaining treatments. Lowest weed control efficiency was recorded by W_2. At 40 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) registered maximum weed control efficiency and W_1 registered lowest weed control efficiency. At 60 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) registered maximum weed control efficiency and W_3 registered lowest weed control efficiency.

4.1.9.4 Total Weed Control Efficiency

The data on total weed control efficiency of weeds at 20, 40 and 60 DAS is presented in the Table 32.

At 20 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency and it was on par with W_4. At 40 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency and it was on par with W_1 and control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At 60 DAS also W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) recorded significantly higher weed control efficiency and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

4.1.10 Weed Index

The results are presented in Table 33. The lowest weed index was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS) and it was on par with W_2 (mechanical weeding with cycle hoe). The next lowest weed index was observed for W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS) and it was on par with W_3 (mechanical weeding with power weeder) and W_4 (straw mulching). Weedy check recorded the highest weed index of 45.46 per cent.

Table 30. Effect of weed management on weed control efficiency broadleaved weeds, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	85.21	94.73	89.89
W_2:MW with cycle hoe	77.41	88.19	79.48
W_3:MW with power weeder	72.66	88.71	77.58
W_4:Straw mulching	94.53	89.68	77.75
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	95.09	97.92	88.44
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	70.97	83.79	72.80
W_7:Weedy check	-	-	-
Control: MAS 946-1 (HW)	75.74	94.56	92.44
SEm (±)	2.189	0.583	1.289
CD(0.05)	6.747	1.796	3.974
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 31. Effect of weed management on weed control efficiency of sedges, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	85.43	76.14	80.58
W_2:MW with cycle hoe	73.99	80.73	72.60
W_3:MW with power weeder	76.21	76.82	69.09
W_4:Straw mulching	100	85.21	79.43
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	100	94.01	89.24
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	96.81	85.46	77.95
W_7:Weedy check	-	-	-
Control: MAS 946-1 (HW)	93.60	86.81	79.58
SEm (±)	1.574	2.274	1.692
CD(0.05)	4.855	7.012	5.219
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 32. Effect of weed management practices on total weed control efficiency, per cent

Treatments	20 DAS	40 DAS	60 DAS
W_1:Hand weeding (HW)	88.48	91.12	85.71
W_2:MW with cycle hoe	75.37	85.84	75.57
W_3:MW with power weeder	74.09	85.64	74.16
W_4:Straw mulching	97.52	88.82	81.60
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	97.42	97.29	89.43
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	83.93	79.48	68.92
W_7:Weedy check	-	-	-
Control: MAS 946-1 (HW)	85.60	92.73	86.22
SEm (±)	1.545	0.866	1.028
CD(0.05)	4.762	2.731	3.170
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 33. Effect of weed management practices on weed index, per cent

Treatments	Weed index
W_1:Hand weeding (HW)	-
W_2:MW with cycle hoe	11.37
W_3:MW with power weeder	24.99
W_4:Straw mulching	26.39
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	8.85
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	22.97
W_7:Weedy check	45.46
Control: MAS 946-1 (HW)	-
SEm (±)	2.558
CD (0.05)	8.358
Treatment *Vs* Control	-

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

4.2 OBSERVATIONS ON CROP

4.2.1 Growth and Growth Attributes

4.2.1.1 Plant Height

The results on the effect of weed management practices on plant height at different stages of growth are presented in Table 34.

Plant height of rice varied significantly with the different weed management strategies tested. At 20 DAS, plant height was significantly higher for W_1 (hand weeding 15, 30 and 45 DAS) and remained at par with W_4 (mulching with straw) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). Plant height recorded at 40 DAS was maximum with W_1 (hand weeding 15, 30, 45 DAS), which was on par with W_2 (mechanical weeding with cycle hoe) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). At 60 DAS, maximum plant height was observed in W_2 (mechanical weeding with cycle hoe) and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). At harvest stage also, maximum height was observed for W_2 (mechanical weeding with cycle hoe) but was on par with W_1 (hand weeding 15, 30, 45 DAS) alone.

The treatments when compared with control, plant height was significantly lower for MAS 946-1 (control) compared to Aiswarya.

4.2.1.2 Number of Tillers per Hill

The results on the effect of weed management practices on plant height at different stages of growth are presented in Table 35.

At 20 DAS, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) recorded maximum tiller number and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and the lowest was

Table 34. Effect of weed management practices on plant height, cm

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	28.29	63.83	86.53	119.67
W_2: MW with cycle hoe	24.34	62.25	87.60	124.33
W_3:MW with power weeder	24.48	48.50	77.90	102.67
W_4:Straw mulching	27.55	44.00	70.26	106.67
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	26.11	59.30	81.50	115.67
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	24.08	52.67	70.03	108.67
W_7:Weedy check	23.80	39.17	66.33	95.00
Control :MAS 946-1 (HW)	21.73	37.82	62.43	89.33
SE m (±)	0.863	2.011	2.098	2.793
CD (0.05)	2.619	6.012	6.365	8.48
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 35. Effect of weed management practices on the number of tillers $hill^{-1}$

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	3.33	6.77	9.70	13.20
W_2: MW with cycle hoe	3.33	6.43	9.53	12.00
W_3:MW with power weeder	2.87	6.13	9.13	11.67
W_4:Straw mulching	3.27	6.00	8.53	11.43
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	3.47	6.77	10.07	13.83
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	3.27	6.53	8.93	12.13
W_7:Weedy check	2.93	4.00	5.23	7.70
Control :MAS 946-1 (HW)	3.40	7.60	13.07	15.77
SE m (±)	0.146	0.259	0.206	0.823
CD (0.05)	0.444	0.786	0.627	2.498
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

recorded for the unweeded plot. At 40 DAS and 60 DAS, maximum tiller number was recorded for control (MAS 946-1: hand weeding at 15, 30, 45 DAS). At harvest maximum tiller number was recorded for control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_5 (Oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS)

The treatments when compared with control, tiller number was significantly higher for control (MAS 946-1) compared to Aiswarya.

4.2.1.3 Leaf Area Index

Leaf area index was recorded at different stages of growth and the results are presented in Table 36.

Weed management practices significantly influenced leaf area index at all growth stages. At 20 DAS W_1 (hand weeding 15, 30, 45 DAS) recorded maximum LAI and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS), W_2 (mechanical weeding with cycle hoe) and W_4 (mulching with straw). At 40 DAS W_1 (hand weeding 15, 30, 45 DAS) recorded maximum LAI and it was on par with W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS) W_2 and W_4. At 60 DAS W_2 (mechanical weeding with cycle hoe) recorded maximum LAI and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and W_1 (hand weeding 15, 30, 45 DAS). At harvest W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) recorded maximum LAI and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS). Weedy check (W_7) recorded lowest LAI at different stages of crop growth.

4.2.1.4 Drymatter Production

The results are presented in Table 38. Drymatter production was recorded at harvest. W_1 (hand weeding 15, 30, 45 DAS) recorded maximum dry matter production and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding

Table 36. Effect of weed management practices on leaf area index

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	2.54	3.51	4.71	3.23
W_2: MW with cycle hoe	2.44	3.32	4.78	3.15
W_3:MW with power weeder	2.17	3.07	4.39	2.93
W_4:Straw mulching	2.54	2.76	4.29	3.19
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	2.50	3.49	4.69	3.83
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	2.26	2.98	4.34	2.54
W_7:Weedy check	1.40	2.39	3.40	2.03
Control :MAS 946-1 (HW)	2.22	3.25	4.37	3.57
SE m (±)	0.089	0.102	0.106	0.133
CD (0.05)	0.270	0.310	0.322	0.403
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

at 20 DAS) and W_2 (Mechanical weeding with cycle hoe). Weedy check (W_7) recorded the lowest drymatter production.

4.2.2 Yield Attributes and Yield

4.2.2.1 Number of Productive Tillers per Square Metre

Number of productive tillers per square metre was significantly influenced by the treatments and the results are presented in Table37.

Highest productive tiller number per square metre (597.17) was recorded by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS). Lowest productive tiller number per square metre was recorded by W_7 (weedy check).

4.2.2.2 Grain Weight per Panicle

The results are presented in Table 37. Maximum grain weight per panicle was recorded by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and it was on par with W_1 (hand weeding 15, 30, 45 DAS). Weedy check (W_7) recorded minimum grain weight per panicle.

4.2.2.3 Number of Spikelets per Panicle

The results are presented in Table 37. Maximum number of spikelets per panicle was recorded by W_1 (hand weeding 15, 30, 45 DAS) and it was on par withW_2 (mechanical weeding with cycle hoe), W_4 (mulching with straw) and W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS). Weedy check (W_7) recorded minimum number of spikelets.

4.2.2.4 Number of Filled Grains per Panicle

The results are presented in Table 37. The maximum number of filled grains per panicle was recorded in W_1 (hand weeding 15, 30, 45 DAS) and it was on par with W_2 (mechanical weeding with cycle hoe), W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS).

4.2.2.5 Sterility Percentage

Data on sterility percentage showed that weed management practices significantly influenced the sterility percentage. The results are presented in Table 38.

The sterility percentage was lowest (10.27) in control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The sterility percentage was maximum (25.24) in the weedy check (W_7).

4.2.2.6 Thousand Grain Weight

The thousand grain weight was found significantly influenced by the weed management practices and the results are presented in Table 38.

W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) recorded the highest thousand grain weight and it was on par with W_1 (hand weeding 15, 30, 45 DAS) and the value was lowest in weedy check (W_7).

4.2.2.7 Grain Yield

The data on grain yield as influenced by the weed management practices are presented in Table 39.

The results indicated that the grain yield was significantly influenced by the various weed management practices. Grain yield recorded was the highest (3889.00 kg ha^{-1}) for W_1 (hand weeding 15, 30, 45 DAS) and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). The lowest yield

(2111.00 kg ha^{-1}) was registered by unweeded check (W_7) which was significantly inferior to all other treatments.

The treatments when compared with the control, grain yield was significantly higher (4944.33 kg ha^{-1}) for control (MAS 946-1) compared to Aiswarya.

4.2.2.8 Straw Yield

The data on straw yield as influenced by the weed management practices are presented in Table 39.

Among all the treatments, highest straw yield (6333.33 kg ha^{-1}) was recorded by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) which was on par with W_1 (hand weeding 15, 30, 45 DAS) followed by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and it was on par with W_2 (mechanical weeding with cycle hoe). The treatments when compared with the control, grain yield was significantly higher (4944.33 kg ha^{-1}) for control (MAS 946-1) compared to Aiswarya.

The lowest straw yield was registered by weedy check (W_7) which was significantly inferior to all the others.

4.2.2.9 Harvest Index (HI)

Harvest index was found significantly influenced by the weed management practices and the results are presented in Table 39.

Harvest index was highest for both W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Weedy check (W_7) recorded the lowest harvest index. The treatments when compared with the control, harvest index was significantly higher for control (MAS 946-1) compared to Aiswarya.

Table 37. Effect of weed management practices on grain weight per panicle, spikelets per panicle, productive tillers and filled grains per panicle

Treatments	Grain weight per panicle (g)	Spikelets per panicle (nos.)	Productive tillers m^{-2} (nos.)	Filled grains per panicle (nos.)
W_1: Hand weeding (HW)	2.19	115.89	547.33	102.00
W_2: MW with cycle hoe	1.95	112.11	488.33	99.55
W_3:MW with power weeder	1.91	91.77	466.83	76.33
W_4:Straw mulching	1.47	103.66	405.67	69.89
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	2.49	112.99	555.00	98.44
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	1.71	104.77	505.67	92.77
W_7:Weedy check	1.44	80.44	288.83	65.56
Control :MAS 946-1 (HW)	1.71	98.89	597.17	89.44
SE m (±)	0.169	5.356	15.968	3.509
CD (0.05)	0.514	16.249	48.439	10.638
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 38. Effect of weed management practices on the sterility percentage, thousand grain weight and dry matter production

Treatments	Sterility (%)	Thousand grain weight (g)	Dry matter production (t ha^{-1})
W_1: Hand weeding (HW)	11.10	22.00	11.53
W_2: MW with cycle hoe	12.45	21.17	11.33
W_3:MW with power weeder	13.44	20.83	9.50
W_4:Straw mulching	13.11	21.83	9.17
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	10.59	24.17	11.23
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	14.13	21.22	9.33
W_7:Weedy check	16.91	18.61	7.33
Control :MAS 946-1 (HW)	10.27	21.23	10.77
SE m (±)	0.564	0.741	0.114
CD (0.05)	1.716	2.249	0.346
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 39. Effect of weed management practices on grain yield, straw yield and harvest index

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
W_1: Hand weeding (HW)	3889.00	6333.33	0.38
W_2: MW with cycle hoe	3333.33	5700.00	0.36
W_3:MW with power weeder	3055.67	5500.13	0.36
W_4:Straw mulching	2944.67	5366.67	0.35
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	3500.00	5822.21	0.38
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	3000.33	5400.00	0.35
W_7:Weedy check	2111.00	4200.33	0.33
Control :MAS 946-1 (HW)	4944.33	6777.79	0.42
SE m (±)	136.626	179.900	0.007
CD (0.05)	414.453	546.997	0.022
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

4.3 CHEMICAL ANALYSIS

4.3.1 NPK uptake by crop

4.3.1.1 Nitrogen Uptake by the Crop

The results are presented in Table 40. Nitrogen uptake by the crop was significantly influenced by the weed management practices. At harvest nitrogen uptake was highest by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) followed by W_1 (hand weeding 15, 30, 45 DAS) and W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). The uptake was lowest under the weedy check (W_7).

4.3.1.2 Phosphorus Uptake by the Crop

The results are presented in Table 40. Phosphorus uptake by the crop was significantly influenced by the weed management practices. At harvest phosphorus uptake was highest by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) followed by W_1 (hand weeding 15, 30, 45 DAS) which was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). The uptake was lowest under the weedy check (W_7)

4.3.1.3 Potassium Uptake by the Crop

The results are presented in Table 40. Potassium uptake by the crop was significantly influenced by the weed management practices. At harvest potassium uptake was highest by control (MAS 946-1: hand weeding at 15, 30, 45 DAS) followed by W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) which was on par with W_1 (hand weeding 15, 30, 45 DAS). The uptake was lowest under the weedy check (W_7).

4.3.2 Nutrient Removal by Weeds

Results obtained at 20, 40, 60 DAS and at harvest.

4.3.2.1 Nitrogen Removal by Weeds

The results are presented in Table 41. Nitrogen removal by the weeds was significantly influenced by the weed management practices at all stages of observation. At 20 DAS nitrogen removal by weeds was lowest for W_4 (mulching with straw) followed by W_1 (hand weeding 15, 30, 45 DAS) and control. At 40 DAS nitrogen removal by weeds was lowest for W_4. At 60 DAS nitrogen removal by weeds was the lowest in control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and it was on par with W_1 (hand weeding 15, 30, 45 DAS). At harvest nitrogen removal by weeds was the lowest in control followed by W_1 (hand weeding 15, 30, 45 DAS). At 20, 40, 60 DAS and harvest, removal of nitrogen by the weeds was significantly higher under weedy check.

4.3.2.2 Phosphorus Removal by Weeds

The results are presented in Table 42. Phosphorus removal by the weeds was significantly influenced by the weed management practices only at 60 DAS. At 60 DAS phosphorus removal by weeds was lowest for control and it was on par with W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and W_1 (hand weeding 15, 30, 45 DAS). The removal of phosphorus by the weeds was significantly higher under weedy check (W_7).

4.3.2.3 Potassium Removal by Weeds

Results obtained at 20, 40, 60 DAS and at harvest are presented in Table 43.

Potassium uptake by weed was significantly influenced by the weed management practices. At 20 DAS, potassium uptake by weed was lowest in W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and it was on par with control, W_1 (hand weeding 15, 30, 45 DAS), W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS) and W_4 (straw mulching). At 40 DAS potassium uptake by weed was lowest in W_5 (oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS) and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and W_1 (hand weeding 15, 30, 45 DAS). At 60 DAS potassium uptake by weed was lowest in W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and it was on par with control (MAS 946-1: hand weeding at 15, 30, 45 DAS) and W_1 (hand weeding 15, 30, 45 DAS). At harvest also the same. At all these stages of crop growth potassium uptake was the highest under weedy check (W_7).

4.3.3 Nutrient Status of Soil after Experiment

The data on nutrient status of the soil after the experiment are presented in Table 44.

There was no significant difference between the treatments on the content of nitrogen, phosphorus and potassium in soil after the experiment.

4.4 ECONOMIC ANALYSIS

Data on economics of various treatments worked out were statistically analysed and presented in Table 45.

4.4.1 Net Income

The data on economics of rice cultivation as influenced by the weed management practices showed that the net income was significantly higher (Rs. 31966.62 ha^{-1}) for W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) followed by W_2 (mechanical weeding with cycle hoe). The net income realized from W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS) was on par with W_1 (hand weeding) and W_3 (mechanical weeding with power weeder). The net income from the unweeded control was significantly inferior to all the other treatments.

The treatments when compared with the control, net income was significantly higher for control (MAS 946-1) compared to Aiswarya.

4.4.2 Benefit Cost Ratio

The benefit cost ratio was significantly influenced by the weed management practices. Among the different weed management practices of variety Aiswarya the benefit cost ratio from W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) was higher. The next highest BC ratio was recorded by W_2 (mechanical weeding with cycle hoe) and it remained on par with W_3 (mechanical weeding with power weeder) and W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS). Lowest B: C ratio was recorded by the weedy check

The treatments when compared with the control, benefit cost ratio was significantly higher (1.62) for W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and it was on par (1.60) with control (MAS 946-1: hand weeding at 15, 30, 45 DAS).

4.4.3 Net Retuns per Rupee Invested on Weed management

The results pertaining to net returns per rupee invested on weed management are presented in Table 46. Net returns per rupee invested on weed management was higher for chemical weed management practices, with Rs 14.00 Re^{-1} for W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) and Rs 12.66 Re^{-1} for W_6 (pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS). Mechanical weeding resulted in lower net returns per rupee invested (cycle hoe – Rs.5.02 Re^{-1} and power weeder – Rs. 4.51 Re^{-1}), followed by hand weeding (for variety Aiswarya: Rs. 2.18 Re^{-1} and Rs. 3.41 Re^{-1} for variety MAS 946-1). The returns for W_4 (straw mulching @ 4 t ha^{-1}) was Rs. 2.46 $Re^{-1.}$

Table 40. Effect of weed management practices on NPK uptake of crop, kg ha^{-1}

Treatments	N	P	K
W_1: Hand weeding (HW)	232.99	46.54	124.07
W_2: MW with cycle hoe	175.81	36.99	104.42
W_3:MW with power weeder	163.92	35.68	105.83
W_4:Straw mulching	160.86	31.59	111.54
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	217.31	45.18	124.50
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	171.52	40.44	105.99
W_7:Weedy check	89.11	25.87	79.87
Control :MAS 946-1 (HW)	269.11	48.65	128.14
SE m (±)	1.738	0.669	0.760
CD (0.05)	5.227	2.063	2.34
Treatment *Vs* Control	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 41. Effect of weed management practices on nitrogen removal by weed, kg ha^{-1}

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	1.01	3.09	4.64	6.28
W_2: MW – Cycle hoe	1.80	4.11	7.11	8.09
W_3:MW – power weeder	1.37	4.04	6.77	7.49
W_4:Straw mulching	0.62	4.35	8.09	10.09
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	1.09	3.83	6.61	7.17
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	1.83	4.92	7.24	8.49
W_7:Weedy check	13.83	22.97	39.04	44.65
Control :MAS 946-1 (HW)	1.053	3.21	4.48	5.53
SE m (±)	0.062	0.06	0.187	0.178
CD (0.05)	0.192	1.92	0.578	0.550
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 42. Effect of weed management practices on phosphorus removal by weed, kg ha^{-1}

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	0.40	0.89	1.92	2.57
W_2: MW with cycle hoe	0.52	1.12	2.05	3.45
W_3:MW with power weeder	0.50	1.21	2.04	3.54
W_4:Straw mulching	0.26	1.08	2.66	3.30
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	0.38	0.94	1.86	2.48
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	0.49	1.07	2.01	3.09
W_7:Weedy check	3.24	5.74	8.18	10.14
Control :MAS 946-1 (HW)	0.43	0.88	1.76	2.53
SE m (±)	0.024	0.048	0.070	0.147
CD (0.05)	NS	NS	0.216	NS
Treatment *Vs* Control	NS	NS	S	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 43. Effect of weed management practices on potassium removal by weed, kg ha^{-1}

Treatments	20 DAS	40 DAS	60 DAS	Harvest
W_1: Hand weeding (HW)	3.06	3.77	4.21	6.38
W_2: MW with cycle hoe	4.71	5.56	5.95	9.23
W_3:MW with power weeder	4.48	5.54	6.06	9.16
W_4:Straw mulching	3.28	5.29	5.46	8.69
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	2.85	3.54	4.19	6.29
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	3.21	4.49	5.53	7.77
W_7:Weedy check	7.25	7.99	14.70	22.34
Control :MAS 946-1 (HW)	2.87	3.64	4.57	6.44
SE m (±)	0.139	0.186	0.178	0.327
CD (0.05)	0.431	0.575	0.548	1.008
Treatment *Vs* Control	S	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 44. Effect of weed management practices on nutrient status of soil after the experiment, kg ha^{-1}

Treatments	Nitrogen	Phosphorus	Potassium
W_1: Hand weeding (HW)	480.85	21.13	188.86
W_2: MW with cycle hoe	434.93	22.11	184.55
W_3:MW with power weeder	460.59	22.14	186.80
W_4:Straw mulching	491.29	20.79	191.77
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	474.58	22.23	195.19
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	468.95	21.24	197.02
W_7:Weedy check	426.58	19.50	164.63
Control :MAS 946-1 (HW)	475.23	21.68	189.52
SE m (±)	8.866	0.763	2.094
CD (0.05)	NS	NS	NS
Treatment *Vs* Control	NS	NS	NS

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Table 45. Effect of weed management practices on economics

Treatments	Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
W_1: Hand weeding (HW)	69000	91113.00	22113.00	1.32
W_2: MW – Cycle hoe	54636	78665.98	24029.98	1.44
W_3:MW – power weeder	52000	72679.71	20679.71	1.39
W_4:Straw mulching	58000	70959.33	12959.33	1.22
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	51000	82966.62	31966.62	1.62
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	51500	72672.36	21172.36	1.41
W_7:Weedy check	48336	52427.00	4091.00	1.08
Control :MAS 946-1 (HW)	69000	110387.07	41387.03	1.60
SE m (±)	-	2645.761	2641.046	0.045
CD (0.05)	-	8025.89	8011.59	0.138
Treatment *Vs* Control	-	S	S	S

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

Seed-Rs.27/kg Grain-Rs.17/kg Straw- Rs. 2/kg
FYM-Rs.400/ton Urea- Rs.8/kg Rajphos- Rs.10/kg
MOP-Rs.18/kg Man-Rs.350/day Woman-Rs.160/day
Oxyfluorfen-Rs.190/100 ml Pretilachlor-Rs.135/250 ml

Table 46. Net returns per rupee invested on weed management, Rs. $Re.^{-1}$

Treatments	Net returns per rupee invested
W_1: Hand weeding (HW)	2.18
W_2: MW – Cycle hoe	5.02
W_3:MW – power weeder	4.51
W_4:Straw mulching	2.46
W_5:OF @ 0.15 kg a.i ha^{-1} + HW	14.00
W_6:PC @ 0.75 kg a.i ha^{-1} + HW	12.66
Control :MAS 946-1 (HW)	3.41

MW – mechanical weeding; OF – oxyfluorfen; PC – pretilachlor

DISCUSSION

5. DISCUSSION

The experiment entitled "Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)" was conducted to evaluate the efficacy and economics of weed management strategies in aerobic rice. The results of the study are discussed briefly in this chapter.

5.1 OBSERVATION ON WEEDS

5.1.1 Weed Composition

Observations on weed species revealed that broadleaved weeds, grasses and sedges competed with aerobic rice. The most important broad leaved weeds were *Cleome rutidospermum, Melochia nodiflora, Ageratum conyzoides, Trianthema portulacastrum, Centella asiatica, Commelina jacobi* and *Oldenlandia umbellata.* The most important sedges identified were *Cyperus rotundus* and *Fimbristylis miliacea.* Among grasses *Cynodon dactylon* and *Panicum repens* were the prominent ones.

The degree and nature of weed crop competition is dependent on the weed species infesting the area, density of infestation and duration of infestation (Rao *et al*., 2007). The results of the present study revealed that there was considerable diversity of weed flora in the experimental field. Broadleaved weeds were the most dominant group followed by sedges and grasses. Weed community in the aerobic rice is reported to be dominated by broadleaved weeds followed by sedges and grasses (Jayadeva *et al*., 2011 and Sunil *et al*., 2010). Anwar *et al.* (2012) also reported that the relative composition of the broadleaved weeds, sedges, and grasses were about 60 per cent 20 per cent, and 20 per cent, respectively, in aerobic rice field, and the most dominant weed species were *Scoparia dulcis, Cleome rutidospermum, and Cyperus rotundus*. In contrast, Jayasuria *et al*. (2011) accounted from their trial with aerobic rice that grassy weeds constituted about 80 per cent of total weed community. The differences in the weed composition might be due to variation in agro ecological conditions and weed seed bank composition among the study areas. The field was previously under a bulk crop of cassava. The major weed flora noted in the cassava field were grasses like *Cynodon dactylon*, sedges like *Cyperus rotundus* and broad leaved weeds like *Ageratum conyzoides, Trianthema portulacastrum* and *Melochia nodiflora.* These weeds were also observed under the aerobic condition. This suggests that effect of soil type and soil moisture conditions are more decisive in determining the weed flora rather than the crop under aerobic irrigated conditions.

5.1.2. Effect of Weed Management Practices on Weed Growth

5.1.2.1. Weed Density

The most commonly used methods for quantitative assessment of weed response are weed count and weed dry weight (Rana *et al.*, 2002). In the present study the vegetation analysis parameters *viz.*, absolute density, relative density, absolute frequency, relative frequency, summed dominance ratio and importance value were used for determining the effect of the treatments on weed growth.

The results of the vegetation analysis parameters indicated that broad leaved weeds were the most dominant both in terms of species diversity and infestation density. Grass weed density was comparatively low. The weed management practices adopted influenced the weed growth of all type of weeds and resulted in significant reduction in weed population. The pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS, was effective in controlling grasses, sedges and broad leaved weeds. Oxyfluorfen was applied three days after sowing and weed density was observed on 20, 40 and 60 DAS. The weed density under pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS was either lesser or remained on par with that under hand weeding at all the three stages of growth. The reduced total weed population was mainly due to effective control of weeds at all stages of crop growth.

Pre-emergence application of pretilachlor @ 0.75 kg a.i ha^{-1} followed by hand weeding at 20 DAS could effectively reduced the weed density only up to 20 DAS. Thereafter, the treatment efficiency was found to decrease. Between the different classes of weeds, *ie*. broad leaved weeds, sedges and grasses, pretilachlor was more effective in controlling broadleaved weeds and sedges than grasses.

Straw mulching @ 4 t ha^{-1} reduced the weed density up to 20 DAS. Thereafter, the weed density increased as the straw degraded with time. Devasinghe *et al*. (2011) also reported that application of rice straw mulch at the time of crop establishment in direct seeded rice results in suppressing growth and development of a wide range of weeds. They attributed this to the action of rice straw as a physical barrier or due to the allelopathic effect of rice straw against developmental processes and progression of the associated weeds. The allelopathy has been attributed to the release of certain phytotoxic compounds by rice straw which in aid of other ecosystem factors, have the ability to accumulate in the soil in sufficient amounts and probably with sufficient persistence to cause a remarkable reduction in weed growth. Further, straw mulching was observed to induce a general chlorosis in the young rice plants, possibly due to the temporary immobilization of nitrogen that might have set in during the slow decomposition of straw, which had a C/N ratio of 72:1. Generally, when organic substances with C/N ratio wider than 30:1 are added to soil there is immobilization of soil nitrogen during the initial decomposition process Tisdale *et al.* (2003).

Mechanical weeding using cycle hoe and power weeder was beneficial. However the weeding efficiency varied depending on the row space. While the weeds growing in the inter row area got effectively controlled, the intra row weeds remained unaffected because of the inaccessibility of the weeders in the narrow intra row area. Melander *et al.* (2005) also observed the difficulty of mechanical weeding in controlling weeds in the inter hill spaces of rice.

5.1.2.2 Weed Dry Weight

The influence of the weed management practices on weed dry weight was in conformity with the results on weed density discussed earlier. The weed dry weight recorded by the weedy check remained high all throughout the crop growth and showed a steady increase with increase in crop age. At 60 DAS, the total weed dry weight was as high as 52.71 g m^{-2} under weedy check while that under pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS it was only 5.54 g m^{-2}. Weed dry weight was the least with pre- emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS during all growth stages of rice. These results are in line with those of Singh *et al.* (2005) who observed lower weed count (14.7 m^2) and weed dry weight (4.4 g m^2) with pre-emergence application of oxyfluorfen @ 0.25 kg a.i ha^{-1}.

The control MAS 946-1 (hand weeded at 15, 30 and 45 DAS) recorded significantly lower weed dry weight at 40 and 60 DAS when compared with the test variety Aiswarya maintained weed free in a similar manner. MAS 946-1, the aerobic rice variety exhibited high tillering capacity compared to Aiswarya as evidenced from Table 35. The profused tillering nature of MAS 946-1 might have resulted in quick ground cover there by discouraging weed growth in the inter row spaces (Hittalmani, 2009).

5.1.2.3 Weed Control Efficiency

The weed control efficiency, which measures the relative reduction in weed dry weight due to weed management practices also revealed the superiority of the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS in effectively controlling weed growth during all growth stages of rice. Pre-emergence application of pretilachlor @ 0.75 a.i ha^{-1} + hand weeding at 20 DAS was observed to control weeds effectively only up to 20 DAS. Thus for controlling weeds at the later stages, either hand weeding or a suitable post-emergent herbicide is required along with the pre-emergence application of pretilachlor. Similar results have been reported by Singh *et al.* (2008) and Murali *et al.*, (2010).

Both cycle hoe and power weeder were equally effective in controlling weeds at 40 DAS as evidenced by a WCE of 85 per cent each. However the weed control efficiency of power weeder was observed to decrease at 60 DAS (74 per cent). This could be attributed to the tiller damage caused by power weeding at 45 DAS and the inability of the crop to overcome this at the later stages of growth.

The weed control efficiency of hand weeding was significantly higher in control (MAS 946-1) compared to the variety Aiswarya. This can be attributed to the genetic potential and growth habit of MAS 946-1, the variety released exclusively for aerobic cultivation.

5.1.2.4 Weed Index

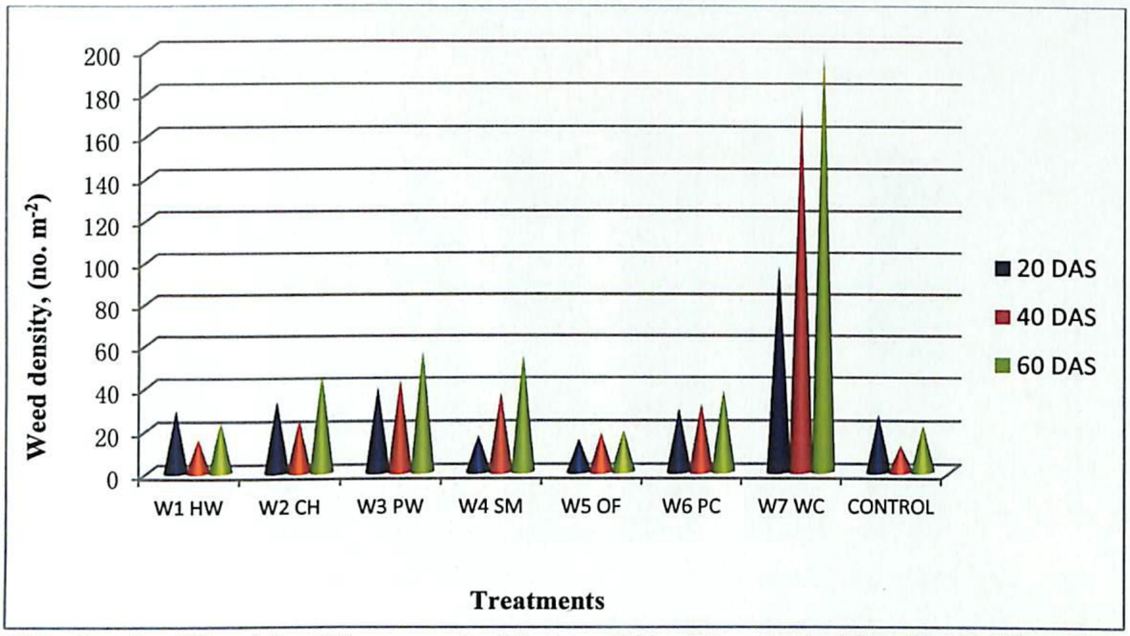
Weed index, an ideal parameter to judge the effectiveness of weed management practices, is an indicator of reduction in crop yield due to the presence of weeds in comparison with weed free check or hand weeding. A lower weed index indicates higher effectiveness. In general, higher the weed control efficiency lower the weed index. Weed control efficiency (WCE) eventually gets translated in to grain yield. Weed management practices with low weed control efficiency resulted in reduced yield. The increase in rice grain yield by increasing weed control efficiency has also been reported by Anwar *et al.* (2012) and Jayasuria *et al.* (2011).

The presence of weeds resulted in a yield reduction of 45.46 per cent in aerobic rice, as indicated by the weed index for weedy check. Singh *et al.* (2006) also reported that aerobic soil conditions are conducive for germination and growth of highly competitive weeds, which cause grain yield loss of 50-91 per cent. Weed index was least with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS (8.85 per cent) followed by mechanical weeding with cycle hoe (11.37 per cent). Although weed index is a measure of yield loss due to weeds, a comparatively higher weed index was recorded by power weeding (24.99 per cent) compared to weeding with cycle hoe (11.37 percent). This is probably a reflection of yield loss due to the tiller damage under power weeding rather than due to the effect of weeds, because the effect of cycle hoe and power weeder on weed dry weight was at par (Table 28).

5.1.2.5 Nutrient Removal by Weeds

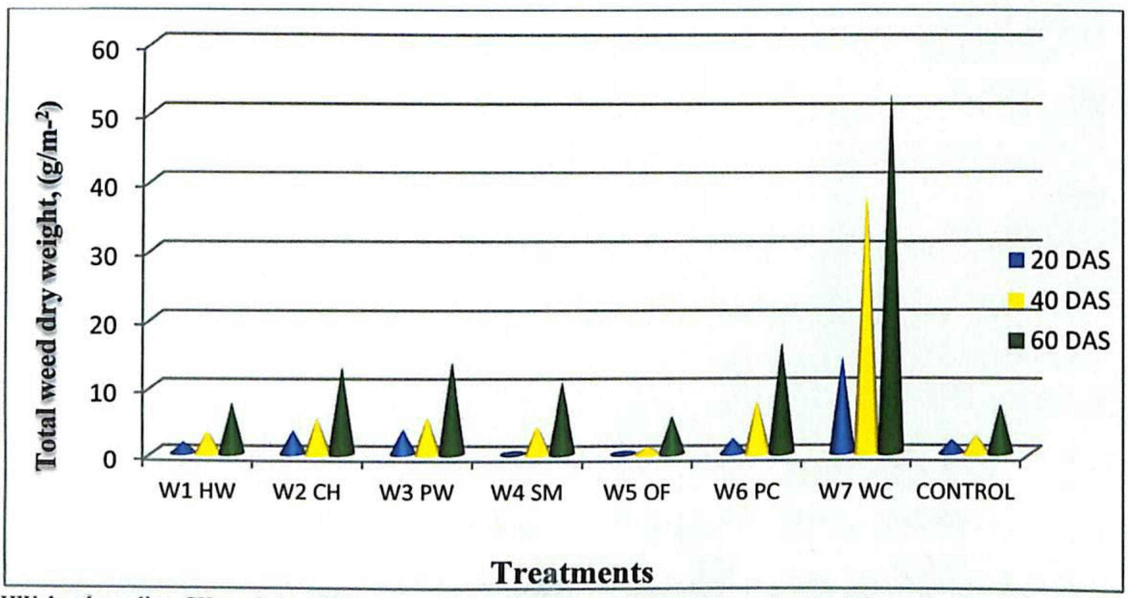
Nutrient removal is a product of weed dry weight and nutrient content in weeds. Weeds remove a large amount of plant nutrients from the soil. The unweeded check registered significantly higher removal of nutrients probably due to higher crop weed competition for growth factors especially nutrients. Increase in nutrient removal by increase in weed competition was also reported by Nair *et al.* (2002) and Bhanurekha *et al.* (2003). Singh *et al.* (2005) also observed that in direct seeded rice, uptake of nutrient by weeds was higher under weedy check (34.8, 15.6 and 42.3 kg N, P and K ha^{-1}).

While nitrogen removal was significantly lower with hand weeding followed by pre-emergence application of oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS, potassium removal by weeds was significantly lower with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS followed by hand weeding. Lesser nutrient removal by weeds in these treatments was due to lower weed population and dry weight recorded by the same as discussed earlier. However the phosphorus removal by weeds did not show any significant difference.



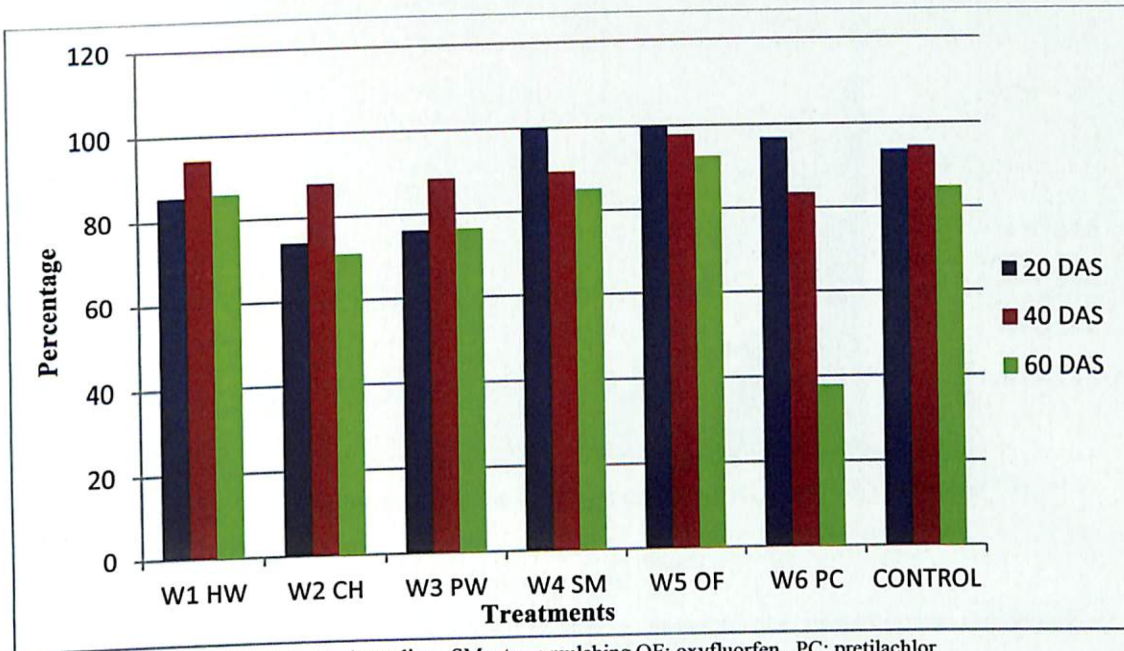
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 3. Effect of weed management practices on total weed density, number m^{-2}



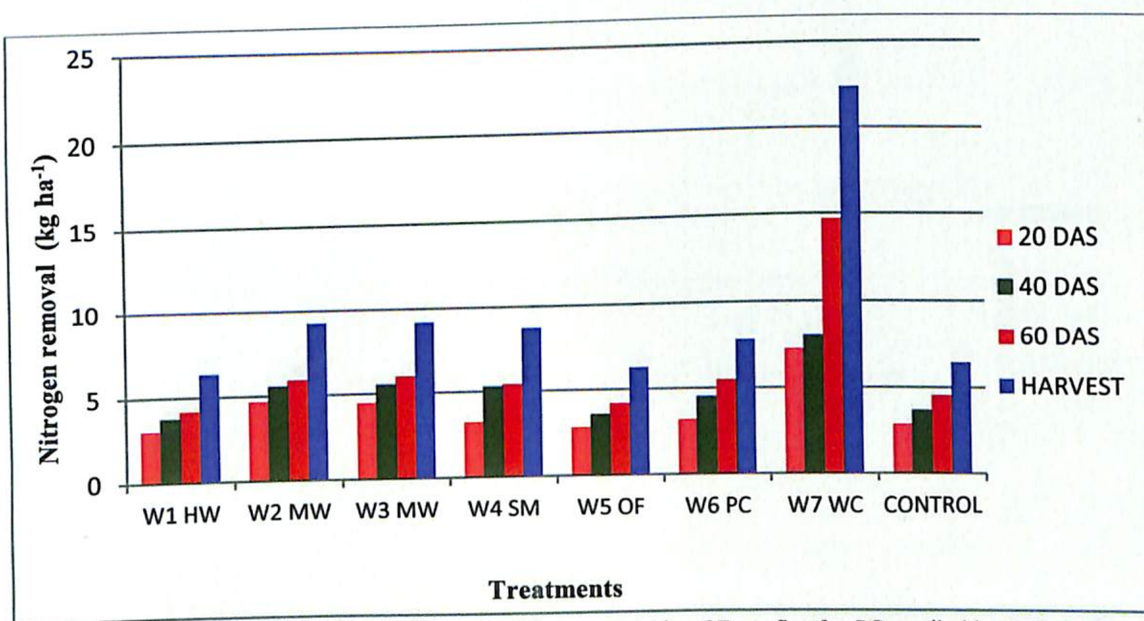
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 4. Effect of weed management practices on total weed dry matter production, gm^{-2}



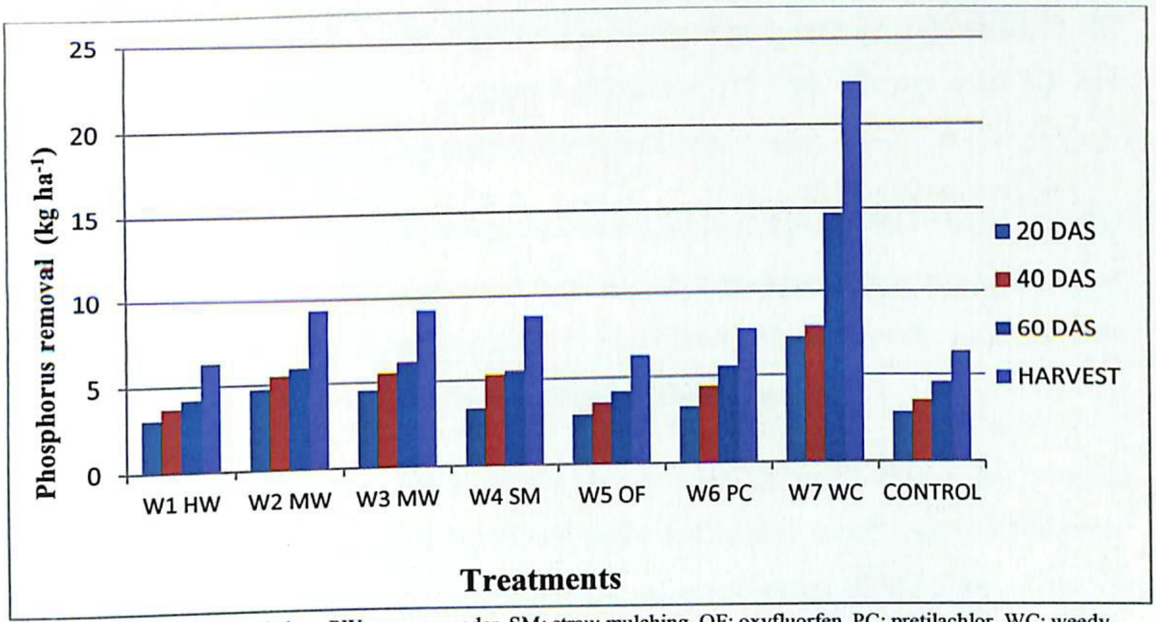
HW: hand weeding., MW: mechanical weeding., SM: straw mulching OF: oxyfluorfen., PC: pretilachlor

Figure 5. Effect of weed management practices on total weed control efficiency, per cent



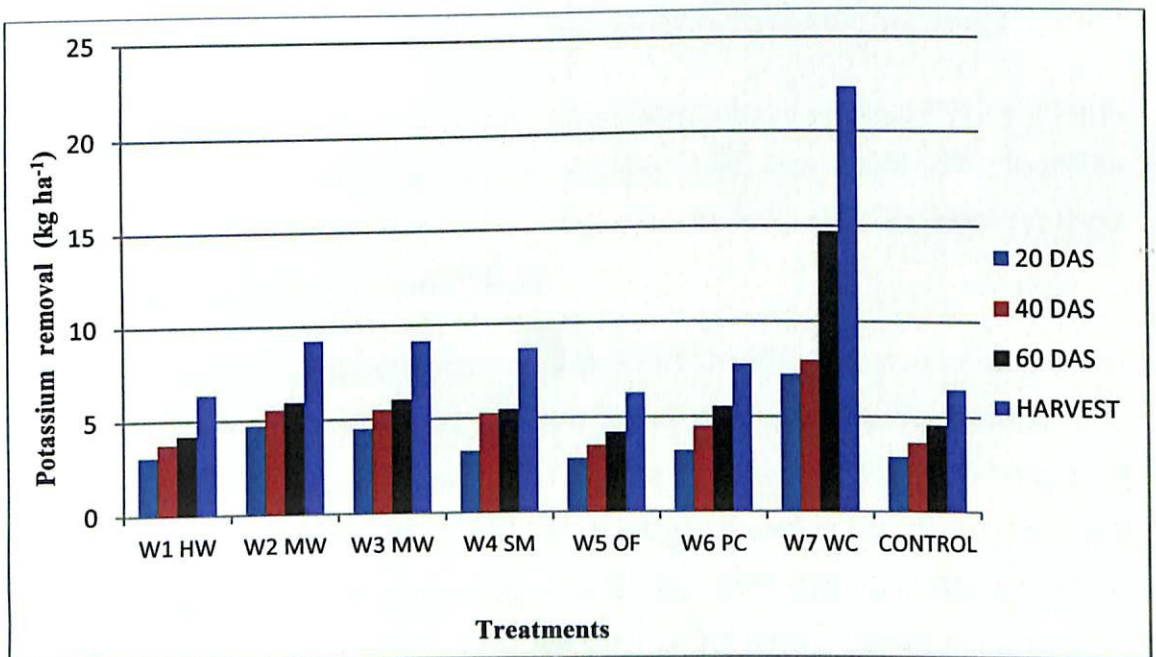
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 6. Effect of weed management practices on nitrogen removal by weeds, kg ha^{-1}



HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 7. Effect of weed management practices on phosphorus removal by weeds, kg ha^{-1}



HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 8. Effect of weed management practices on potassium removal by weeds, kg ha^{-1}

The variation noted in the NPK removal by weeds can be attributed to the high N and K contents (on an average 1.5 per cent N and 1.2 per cent K) and extremely low P content of weeds (on an average 0.12 per cent). Nutrient removal by weeds was lower for control MAS 946-1 (hand weeded at 15, 30 and 45 DAS) when compared with the variety Aiswarya maintained weed free by hand weeding. Weed dry weight was significantly lower for the control. This might have directly contributed to the lower nutrient removal.

In general, the weed observations mainly weed density, weed dry weight, weed index and nutrient removal by weeds were lower and weed control efficiency was higher with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS for the rice variety Aiswarya raised under aerobic condition.

5.2 OBSERVATIONS ON CROP

5.2.1 Effect of Weed Management Practices on Crop Growth Characters

The data revealed that weeds pose a serious constraint on the growth attributes of rice in terms of plant height, tiller number, leaf area index and drymatter production. This is quite evident from the significantly low values recorded for these growth parameters under the weedy check.

Plant height was significantly influenced by the different weed management practices. Plants were observed to grow taller with increase in weed control efficiency. It was higher in all weed control treatments at all the stages of observation compared to weedy check. Plant height recorded was highest for hand weeding treatment and it was on par with the pre-emergence application of oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS. The increase in plant height was possibly due to better weed suppression at the proper time resulting in maximum utilization of moisture and nutrients by the crop. Similar results have been reported by Riyaz *et al.* (2006). At 40 DAS, 60 DAS and harvest mechanical weeding with cycle hoe was also found to be as effective as these two treatments. The crop weed competition was less in these treatments that can be observed from the low values of absolute density and weed dry matter production in these plots, which could be the probable reason for the higher plant height. In addition to suppressing weed growth mechanical weeding has also been reported to increase plant height through soil aeration and improving the organic carbon content of soil by incorporating weeds as green manure (Vijayakumar *et al.*, 2006). The treatments (rice variety Aiswarya) when compared with control (MAS 946-1) revealed shorter plants for control. The variety MAS 946-1 inherently has good response to added nutrients and it avoids lodging with its shorter plant stature (Hittalmani, 2009).

Tillering plays a vital role in determining rice grain yield since it is closely related to the number of productive tillers per unit area. At all stages of growth pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding recorded highest value and it remained on par with manual weeding. Hand weeding and pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} had 69.25 per cent more tillers per plant compared to weedy check. This might be due to the lower crop-weed competition on account of better weed control efficiency offered by these treatments.

The third best treatment was mechanical weeding with cycle hoe. Shad (1986) observed that mechanical weeding caused root pruning and ultimately resulted in increased number of tillers per plant. The weed control efficiency of mechanical weeding with cycle hoe and power weeder was 85 per cent and 75 per cent each respectively at 40 DAS and 60 DAS. However, the percentage increase in tiller count over the weedy check presented a different picture. While the tiller count per hill increased by 60.75 per cent (40 DAS) and 82.21 per cent (60 DAS) over weedy check with cycle hoe, the same was only 53 percent and 75 per cent with power weeder. This can be attributed to the tiller damage caused by the power weeder due to the lack of sufficient inter row space availability for operating the power weeder.

Control (MAS 946-1) maintained weed free by hand weeding was significantly superior with respect to its tillering capacity compared to the variety Aiswarya. This is possibly a varietal character of the aerobic rice variety.

The leaf area index (LAI) is a determinant of dry matter production and its variations determine the final crop yield. In general the leaf area index increased from 20 DAS to 60 DAS and thereafter it declined. It is an important measure of potential photosynthetic area and thus of the growth capability (Potter and Jones, 1997). Weedy check recorded the lowest leaf area index, which may be attributed to the severe competition between the crop and the weeds. Nair (2001) reported a decrease in leaf area index due to weed competition. Leaf area index was highest in hand weeding and was on par with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The increase in tillering capacity might have facilitated higher photosynthetic rate and an increased leaf area index as suggested by Thiyagarajan *et al.* (2002).

The total drymatter production per unit area is the pre requisite for higher production. Dry matter production depends on the effectiveness of photosynthesis which in turn depends on large and efficient assimilating area and favourable environmental conditions. The total dry matter production was significantly higher with hand weeding and it remained on par with mechanical weeding with cycle hoe and pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS, accounting for 57 per cent, 54.5 per cent and 53 per cent increase respectively over that of the weedy check. The low weed density and weed dry weight recorded by these treatments might have reduced the crop weed competition and enabled the crop to utilize the growth factors in a better manner. Further the higher leaf area index might have also resulted in better photosynthesis leading to higher dry matter production. These results are in line with the findings of Saha *et al.*, 2005) and Sunil *et al.* (2010).

In general the growth attributes - plant height, number of tillers per hill, leaf area index and dry matter production were higher with the pre-emergence application of oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS and it was as effective as hand weeding.

5.2.2 Effect of Weed Management Practices on Yield Attributing Characters and Yield

Effective weed control especially during the critical period of crop weed competition has a positive role in determining the yield attributing characters and yield of rice. Grain yield is highly dependent on the number of productive tiller count. The productive tiller count was found to be significantly higher with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The effectiveness of oxyfluorfen has been previously reported by Kathiresan and Manoharan (2002). It was 92 per cent higher than weedy check which is perhaps due to the less tiller production. Biswas *et al.* (1992) have reported a similar decrease in panicle production to the tune of 37 per cent due to rice-weed competition. The productive tiller count of the control MAS 946-1(hand weeded) and that of Aiswarya with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS were on par indicating the superiority of MAS 946-1 as an aerobic rice variety.

The effect of hand weeding and pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS were significantly higher and on par with respect to the number of filled grains per panicle and thousand grain weight. The higher leaf area index observed in these treatments might have contributed to better photosynthates accumulation. Further the higher weed control efficiency and consequently reduced crop weed competition might have also helped the crop to acquire balanced and adequate nutrition for proper grain filling. Proper weed management with an adequate source provide healthy environment for the crop and ultimately better yields. It is quite possible that a weed free healthy crop stand can produce robust grains with more thousand grain weight (Tomar *et al.*, 2003; Kumari and Prasad, 2003). The sterility percentage was least for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS for the variety Aiswarya. The fact that pre-emergence application of oxyfluorfen could reduce the sterility by 41 per cent as compared to the weedy check clearly indicates the importance of efficient weed management on effective grain filling.

Grain yield was significantly higher for hand weeding (3889 kg ha^{-1}) and it was on par with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS (3500 kg ha^{-1}). All the weed management practices tested significantly out-yielded the weedy check. Weed control efficiency was eventually translated in to grain yield. The weed control efficiency was also reflected in the relative yield loss expressed as weed index which has been discussed earlier. The increase in rice grain yield with increase in weed control efficiency has also been reported by Jayasuriya *et al.* (2011) and Anwar *et al.* (2012). Naturally, weedy check resulted in maximum yield loss. Weed removal reduces inter specific competition for resources and enables crop to utilize the available resources more efficiently than weeds which eventually results in higher yield.

Mechanical weeding with cycle hoe and power weeder also resulted in reasonably good yields (3333.33 kg ha^{-1} and 3055.67 kg ha^{-1} respectively), although less than the best treatments. However pre-emergence application of pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS and straw mulching @ 4 t ha^{-1} were not observed to be promising. Both these treatments could effectively control weeds only during the early stage of crop growth, up to 20 DAS. This finding justifies the implication of critical period of crop weed competition. Anwar *et al.* (2013) have reported that the critical period of crop weed competition for aerobic rice is between 20 DAS and 43 DAS.

Grain yield is a function of the yield attributes like productive tiller count, filled grains per panicle, sterility percentage and thousand grain weight. In the present study all the yield attributes were observed to respond significantly to weed management practices. These findings are in agreement with those of Sunil *et al.* (2010) who observed that all the yield attributes of aerobic rice is significantly influenced by weed control practices. Studies have showed that the panicle number per square metre is the most important factor in increasing grain yield of rice and 89 per cent of yield changes is due to the effect of this factor (Miller *et al.* 1991). Thus the significantly high grain yield recorded by hand weeding and pre-emergence application of oxyfluorfen might be due to the effect of weed management on yield attributes, specifically on the productive tiller count. Singh and Sharma (1994) also opined that hand weeding or one pre-emergence herbicide followed by a hand weeding had a significant positive influence on yield attributing characters of rice.

The grain yield (4944.33 kg ha^{-1}) of control (MAS 946-1) was significantly higher than that of the variety Aiswarya maintained weed free by hand weeding (3889 kg ha^{-1}). The superiority of the variety MAS 946-1 under aerobic condition has been reported by Jinsy *et al.* (2014)

The straw yield was significantly higher with hand weeding followed by pre-emergence application of oxyfluorfen @0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The least straw yield was recorded under the weedy check. The poor straw yield of weedy check is a reflection of the severe crop weed competition which resulted in poor growth of the crop. However the straw to grain ratio which indicates the photosynthates partitioning efficiency revealed a different picture. While the straw: grain was 1.62 for hand weeding and 1.66 for pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS it was 1.98 under the weedy check, for the rice variety Aiswarya. A high straw to grain ratio shows that more photosynthates are being utilized for producing straw rather than grain. The low straw to grain ratio in the best treatments is due to the high grain yield and straw yield. These results are in conformity with those of Rashid and Bahar (2013). The control MAS 946-1 revealed its adaptation to aerobic condition with the highest straw yield (6777.79 kg ha^{-1}) and lowest straw to grain ratio as compared to variety Aiswarya.

The harvest index also exhibited a similar trend as grain yield and straw yield. Harvest index was observed to increase with weed control efficiency.

5.2.3 Effect of Weed Management Practices on Nutrient Uptake by Crop

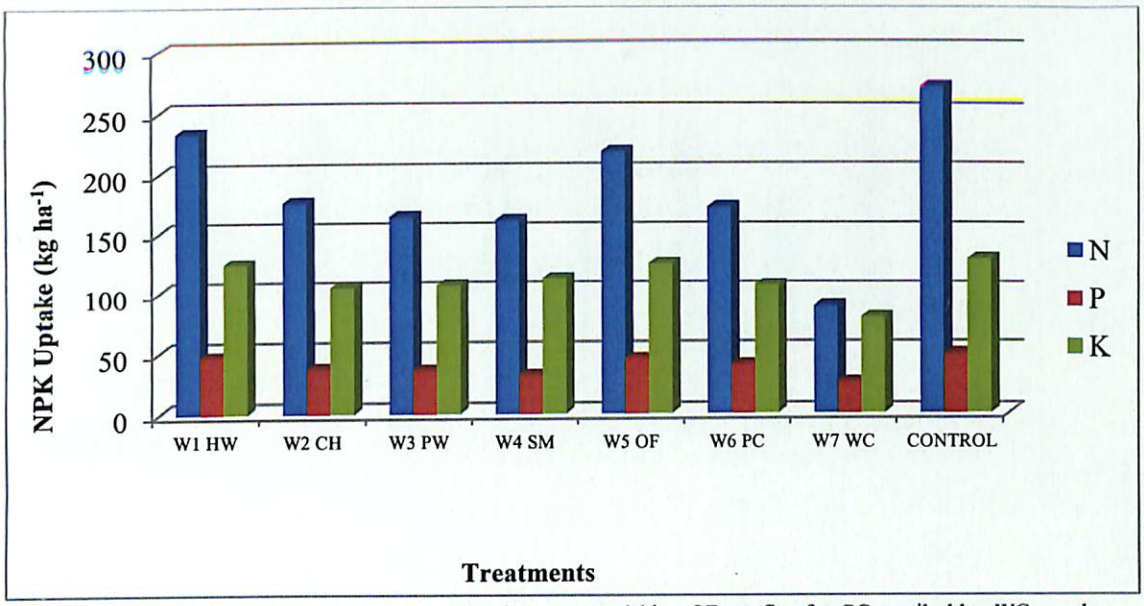
Nutrient uptake by the crop was also found to be significantly influenced by the weed management practices. The nutrient uptake by crop is inversely proportional to the nutrient uptake by weeds. Among the different weed control treatments significantly higher uptake of nutrients was noticed with hand weeding followed by pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Higher nutrient uptake by crop in these treatments was due to lower weed population and their dry weight, which helped the crop to grow in weed free environment and absorb more nutrients from the soil. Whereas, weedy check registered significantly lower uptake of nutrients due to higher crop weed competition for growth factors. These results are in line with Bhanurekha *et al.* (2003) and Singh *et al.* (2005)

When the control (MAS 946-1) was compared against the test variety Aiswarya the nutrient uptake of MAS 946-1 was observed to be significantly higher. The higher grain yield and straw yield of MAS 946-1 might have contributed to higher nutrient uptake since nutrient uptake of dry matter production and nutrient content.

5.2.4 Effect of Herbicide Phytotoxicity on Crop

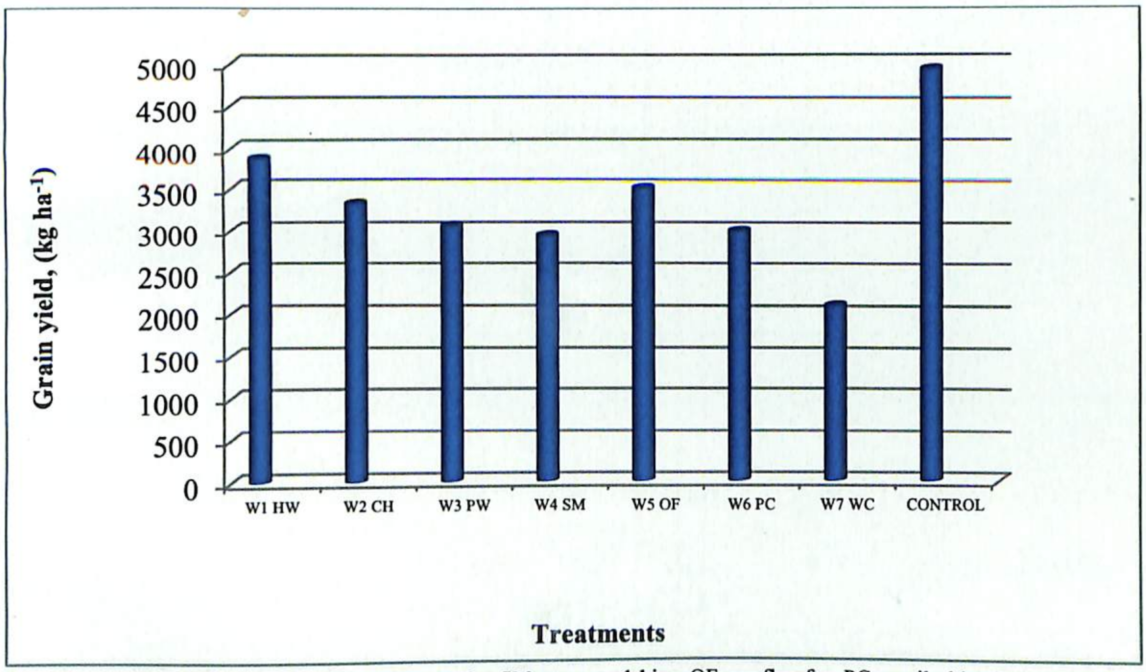
The pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS was observed to the best treatment which remained on par with

Plate 5. Oxyfluorfen phytotoxicity observed in rice seedlings



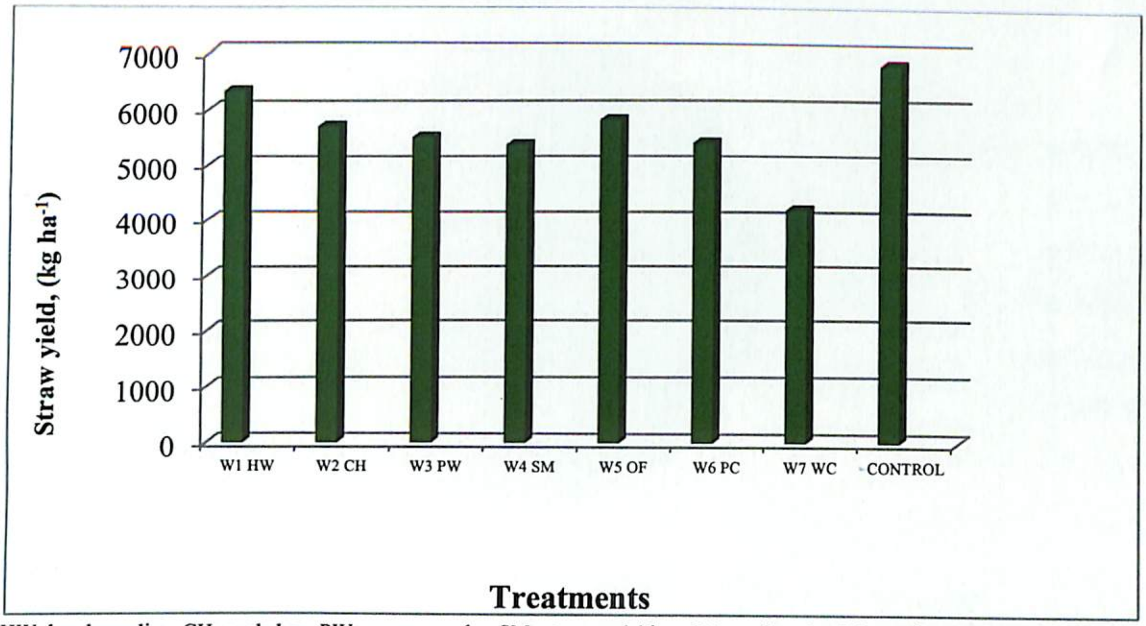
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 9. Effect of weed management practices NPK uptake by crops, kg ha^{-1}



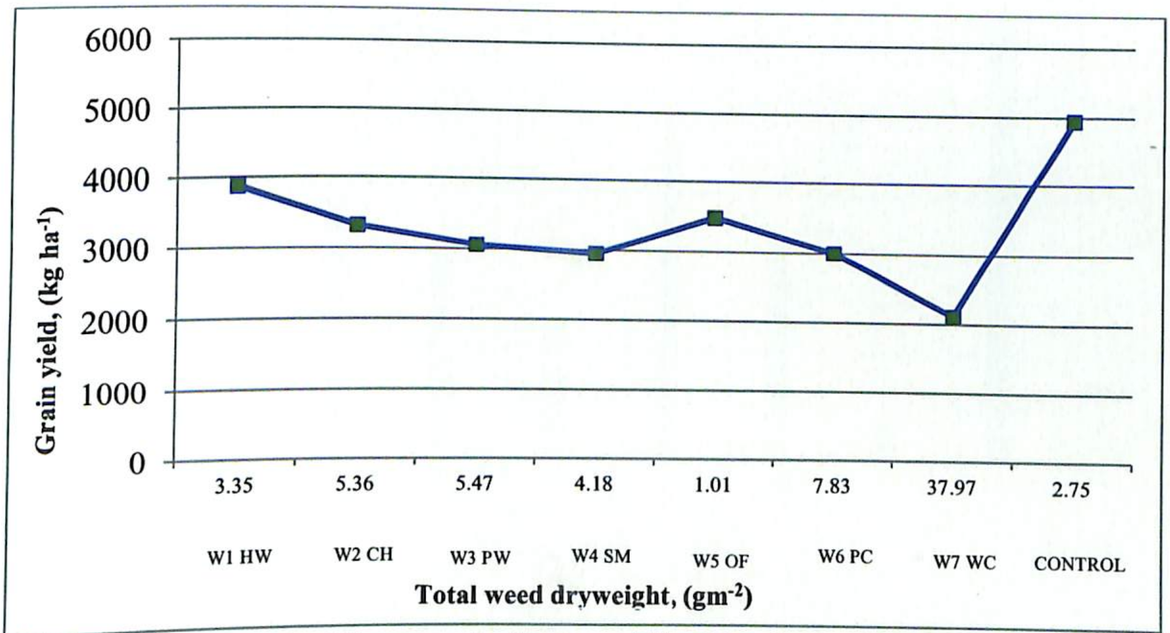
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 10. Effect of weed management practices on grain yield, kg ha^{-1}



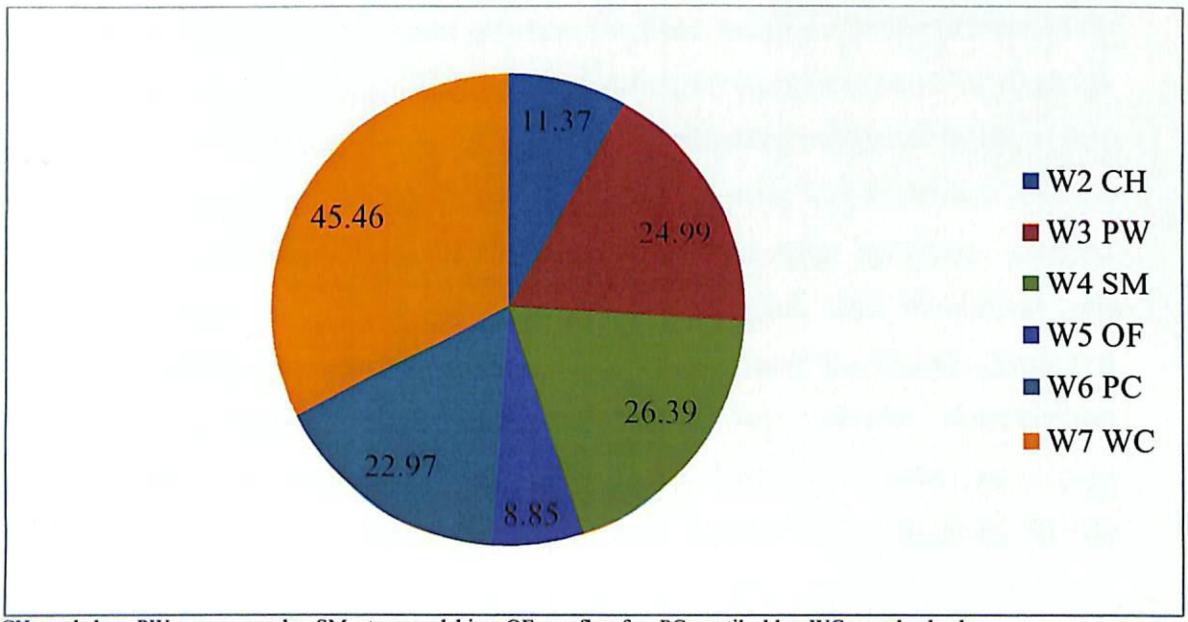
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 11. Effect of weed management practices on straw yield, kg ha^{-1}



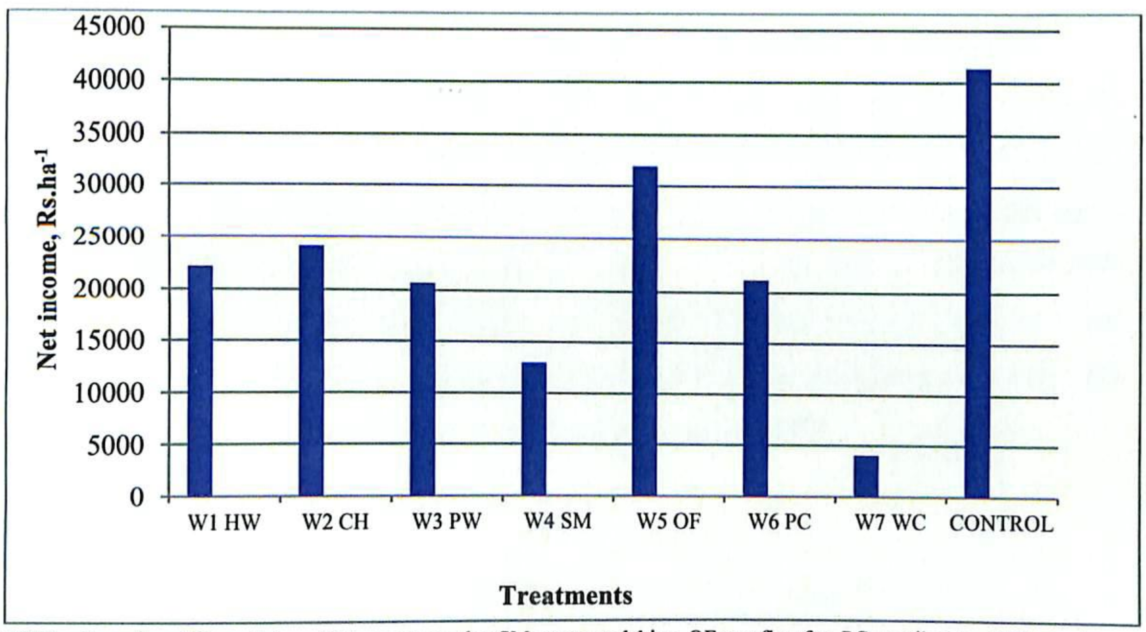
HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 12. Effect of total weed dry weight on grain yield



CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 13. Effect of weed management practices on weed index, per cent



HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 14. Effect of weed management practices on net income, Rs. ha^{-1}

the conventional weed management practice, the hand weeding. In the present study slight phytotoxicity was observed for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1}. Vein clearing and leaf tip burning were observed in the young rice seedlings. However the new leaves that emerged were free of damage and the rice seedlings recovered from damage within 15 days after spraying. Similar observations have been made by Abraham *et al.* (2010) and Kathiresan and Manoharan (2002). Ramachandiran *et al.* (2012) also reported the toxicity symptoms of oxyfluorfen at the early stages of rice crop which recovered later. Aerobic soil conditions helped to reduce herbicide injury to the crop. Rice plant shows high tolerance to herbicide and may suffer slight initial injuries which disappear shortly but seldom phytotoxicity persists up to crop harvest Chauhan and Johnson (2011b).

5.3 ECONOMICS OF WEED MANAGEMENT

5.3.1 Cost of Cultivation

Cost of cultivation was highest in the cases were weeds were managed solely by hand weeding. Of the total cost of cultivation 33 per cent was observed to be incurred for labour required for hand weeding. This could be reduced to nearly half or even lesser with mechanical weeding as evidenced by 20 per cent labour for cycle hoe and 12 per cent for power weeder (Fig. 17). In herbicidal treatments supplemented with hand weeding 16 per cent of the total cost was incurred for weed management. Even though the labour requirement for straw mulching was very less (7 per cent) the same advantage was not reflected in grain yield.

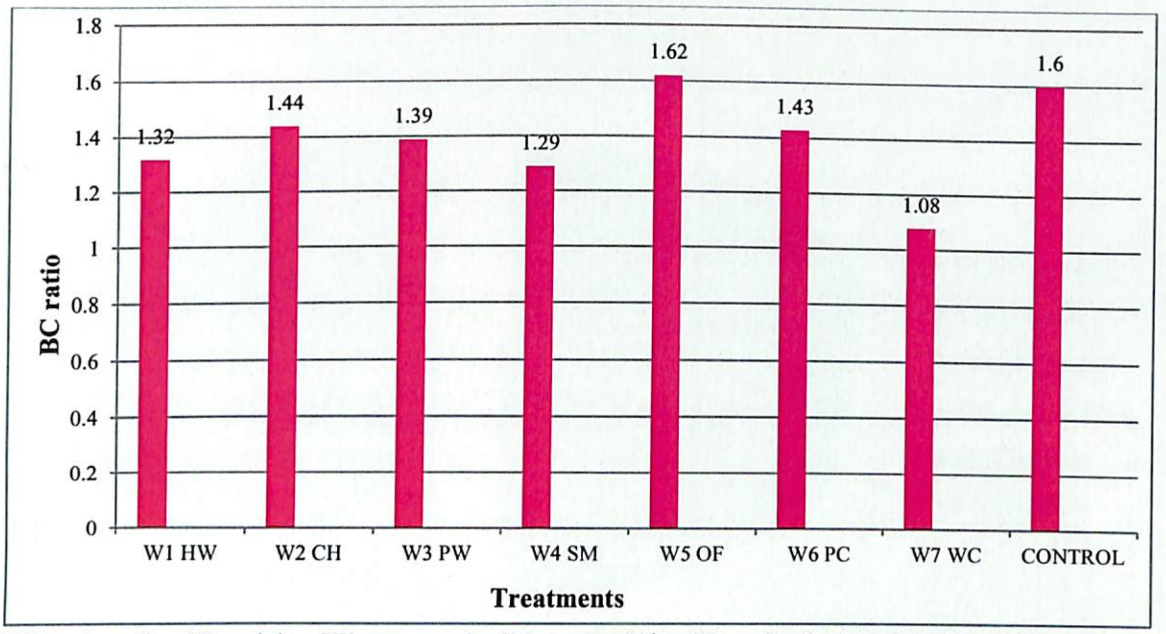
5.3.2 Net Income and BC ratio

The data on economics of weed management revealed that net income and benefit cost ratio were appreciably influenced by the weed management practices. The increase in net income in pre- emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS was due to higher grain yield and straw yield, lower cost on weed control and better control of weeds throughout the crop growth period. The net income from the unweeded control was significantly inferior to all the other treatments. Though hand weeding recorded higher yield, net income and B: C ratio was less due to the increased cost of manual weeding as compared to the herbicide treatments. The lower net income and benefit cost ratio obtained in hand weeding were because of more man days that was required for hand wedding at 15, 30 and 45 DAS resulting in considerable increase in the cost of cultivation. Similar results were obtained by Maity and Mukherjee, (2009). Benefit cost ratio was highest for pre- emergence application of oxyfluorfen @ 0.15 kg ai ha^{-1} + hand weeding at 20 DAS. The same was reported by Laskar *et al.* (2005). The B: C ratio also confirmed the superiority of the use of herbicide for weed management in aerobic rice.

5.3.3 Net Returns per Rupee Invested on Weed Management

Net returns per rupee invested on weed management was highest (Rs.14.00 ha^{-1}) for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Mechanical weeding with cycle hoe (5.02) as well as power weeder (Rs. 4.51 $ha^{-1)}$ also proved beneficial in terms of returns per rupee invested. Even though the growth attributes, yield attributes and yield were higher for hand weeding the returns per rupee invested for hand weeding was only Rs.2.18. Thus the present study endorsed the fact that hand weeding is a laborious, expensive and time consuming weed management option.

The present study revealed that the adoption of an appropriate weed management strategy is critical in aerobic rice cultivation. The alternate wet and dry conditions in the aerobic soil promoted weed growth which resulted in 45.5 per cent yield reduction in rice. The pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} followed by hand weeding at 20 days after sowing was observed to be the best weed management practice for aerobic rice in terms of growth attributes, yield attributes, yield and economics.



HW: hand weeding, CH: cycle hoe, PW: power weeder, SM: straw mulching, OF: oxyfluorfen, PC: pretilachlor, WC: weedy check

Figure 15. Effect of weed management practices on B:C ratio

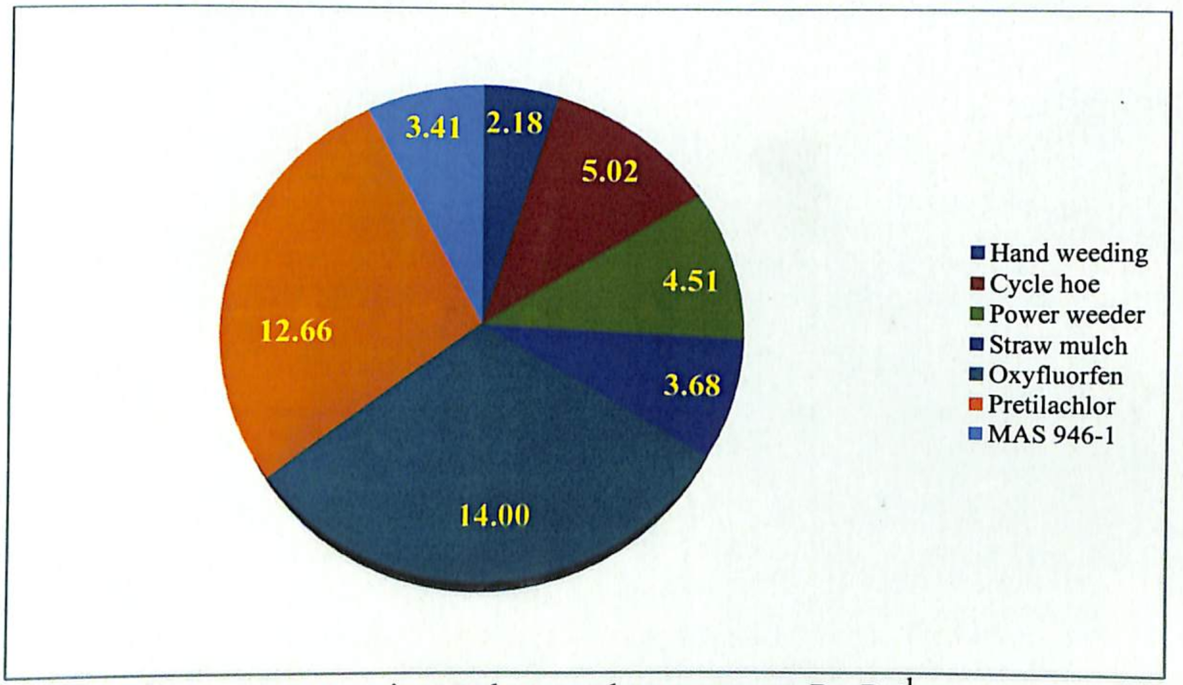


Figure 16. Returns per rupee invested on weed management, Rs. Re^{-1}

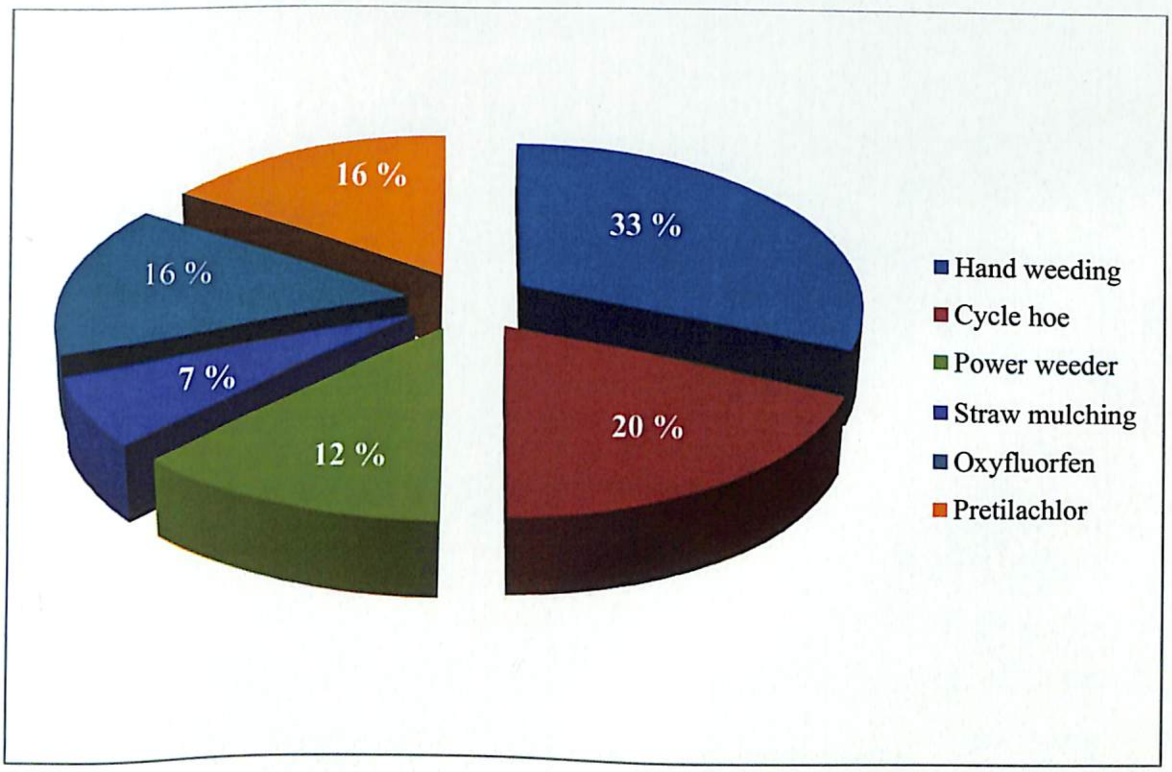


Figure 17. Relative labour required for weed management, per cent

SUMMARY

6. SUMMARY

The experiment entitled "Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)" was undertaken at the Instructional Farm, College of Agriculture, Vellayani, Thiruvanthapuram, during January, 2013 to May, 2014. The main objectives of the study were to assess the extent of yield loss due to weeds in aerobic rice, to assess the most suitable weed management strategy for aerobic rice and to study the economic feasibility.

The field experiment, laid out in randomised block design, comprised seven weed management practices (rice variety – Aiswarya) as compared against a control (rice variety – MAS 946-1), replicated thrice. The treatments were $W_{1:}$ hand weeding at 15, 30 and 45 DAS (days after sowing) ,W_2 : mechanical weeding, W_3 : mechanical weeding with power weeder, W_4 : mulching with straw @ 4 t ha^{-1},W_5 : oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS, W_6 : pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS, W_7 : weedy check and control (C) MAS 946 – 1, maintained weed-free up to 45 DAS by hand weeding at 15, 30 and 45 DAS. The results of the study are summarized below.

There was substantial diversity in weed flora in the experimental site. Two grass species, two species of sedges and seven species of broad leaved weeds were observed to compete with rice. Broad leaved weeds were the most dominant both in terms of species diversity and infestation density. Pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS, was effective in controlling all types of weeds. The weed density under pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS was either lesser or remained on par with that under hand weeding at all the three stages of growth. In the treatment, pretilachlor @ 0.75 kg a.i ha^{-1} + hand weeding at 20 DAS, the weed density was less up to 20 DAS but the efficacy of herbicide decreased thereafter.

Straw mulching @ 4 t ha^{-1} reduced the weed density up to 20 DAS. Thereafter weed density increased as the straw degraded with time. Mechanical weeding with cycle hoe and power weeder was beneficial. But the effectiveness of weeding was low because inter row area got effectively controlled; the intra row weeds remained unaffected because of the inaccessibility of the weeders in the narrow intra row area.

Weed dry weight was less with the pre- emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS during all growth stages of rice. Weedy check recorded the highest weed dry weight and it showed a steady increase with the crop age. The control, MAS 946-1 (hand weeded at 15, 30 and 45 DAS) recorded significantly lower weed dry weight at 40 and 60 DAS when compared with the test variety Aiswarya, maintained weed free in a similar manner.

Weed control efficiency also revealed the superiority of the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS in effectively controlling weed growth during all growth stages of rice. Pre-emergence application of pretilachlor @ 0.75 a.i ha^{-1} + hand weeding at 20 DAS was observed to control weeds effectively only up to 20 DAS. Both cycle hoe and power weeder were equally effective in controlling weeds up to 40 DAS as evidenced by a WCE of 85 per cent each. The weed control efficiency of hand weeding was significantly higher in control (MAS 946-1) compared to the variety Aiswarya.

Weed index was least with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS (8.85 per cent) followed by mechanical weeding with cycle hoe (11.37 per cent). The presence of weeds resulted in a yield reduction of 45.46 per cent in aerobic rice, as indicated by the weed index for weedy check.

Nitrogen removal was significantly lower with hand weeding followed by pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS potassium removal by weeds was significantly lower with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS followed by hand weeding. Nutrient removal by weeds was lower for control MAS 946-1 (hand weeded at 15, 30 and 45 DAS) when compared with the variety Aiswarya maintained weed free by hand weeding. The unweeded check registered significantly higher removal of nutrients.

Plant height recorded was highest for hand weeding treatment and it was on par with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Tiller production was significantly higher with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding and was on par with manual weeding. Hand weeding and pre-emergence application of oxyfluorfen @ 0.15 kg ai ha^{-1} recorded 69.25 per cent more tillers per plant as compared to weedy check. Control (MAS 946-1) maintained weed free by hand weeding was significantly superior with respect to its tillering capacity compared to the variety Aiswarya. Leaf area index was highest with hand weeding and was on par with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The total dry matter production was significantly higher with hand weeding and it remained on par with mechanical weeding with cycle hoe and pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. In general the growth attributes - plant height, number of tillers per hill, leaf area index and dry matter production were higher with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS and it was as effective as hand weeding.

The productive tiller count was found to be significantly higher with the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The productive tiller count of the control MAS 946-1(hand weeded) and that of

Aiswarya with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS were on par indicating the superiority of MAS 946-1 as a true aerobic rice variety. The effect of hand weeding and pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS were significantly higher and on par with respect to the number of filled grains per panicle and thousand grain weight. Further sterility percentage was least for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS for the variety Aiswarya.

Grain yield was significantly higher for hand weeding (3889 kg ha^{-1}) and it was on par with pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS (3500 kg ha^{-1}) efficiently than weeds which eventually results in higher yield. Mechanical weeding with cycle hoe and power weeder also resulted in reasonably good yields (3333.33 kg ha^{-1} and 3055.67 kg ha^{-1} respectively), although less than the best treatments. The grain yield (4944.33 kg ha^{-1}) of control (MAS 946-1) was significantly higher than that of the variety Aiswarya maintained weed free by hand weeding (3889 kg ha^{-1}). The straw yield was significantly higher with hand weeding followed by pre-emergence application of oxyfluorfen @0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. The control MAS 946-1 revealed its adaptation to aerobic condition with the highest straw yield (6777.79 kg ha^{-1}) and lowest straw to grain ratio as compared to variety Aiswarya.

Among the different weed control treatments significantly higher uptake of nutrients was observed with hand weeding followed by pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. When the control (MAS 946-1) was compared against the test variety Aiswarya the nutrient uptake of MAS 946-1 was observed to be significantly higher.

In the present study slight phytotoxicity was observed for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1}. Vein clearing and leaf tip burning were observed in the young rice seedlings. However the new leaves that emerged were free of damage and the rice seedlings recovered from damage within 15 days after spraying.

Of the total cost of cultivation 33 per cent was observed to be incurred for labour required for hand weeding. In herbicidal treatments supplemented with hand weeding, 16 per cent of the total cost was incurred for weed management. Net income and benefit cost ratio were highest with pre- emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Net returns per rupee invested on weed management was highest (Rs.14.00 ha^{-1}) for the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS. Mechanical weeding with cycle hoe (5.02) as well as power weeder (Rs. 4.51 $ha^{-1)}$ also proved beneficial in terms of returns per rupee invested.

The present study revealed that weeds, which are a major constraint to aerobic rice culture, could be efficiently and economically managed by the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} followed by hand weeding at 20 days of sowing.

FUTURE LINE OF WORK

- Exploring the possibility of mechanization in aerobic rice culture starting from sowing to harvest.
- Optimization of spacing for mechanical weeding in aerobic rice.
- Feasibility of using new generation herbicides for weed management in aerobic rice.

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APPENDIX

APPENDIX - I
Weather data for the cropping period
(January 2013 to May 2013)

Standard week	Temperature (°C)		Sunshine hours	Rainfall (mm)	Relative Humidity (%)	
	Maximum	Minimum			Maximum	Minimum
2	30.0	22.6	8.5	24.0	96.4	74.6
3	30.1	20.8	9.4	0.0	96.0	75.1
4	30.5	21.3	9.4	0.0	96.1	73.6
5	30.4	20.8	9.3	0.0	94.3	75.4
6	31.2	22.9	9.2	2.5	93.3	74.3
7	32.0	23.0	9.3	11.0	92.4	75.7
8	31.4	21.8	9.3	0.0	89.9	74.9
9	32.0	21.4	9.5	0.0	91.3	67.4
10	32.1	24.3	9.3	7.0	94.6	80.7
11	32.3	23.9	9.3	34.0	93.4	81.3
12	32.3	23.7	9.8	0.0	91.4	75.4
13	32.6	25.3	9.9	31.0	92.6	76.3
14	32.9	26.0	9.9	0.0	92.7	77.0
15	32.8	25.6	9.7	1.5	89.9	71.4
16	33.2	25.1	10.2	0.0	84.8	76.0
17	33.3	25.0	9.6	20.3	87.0	72.7
18	32.0	26.1	9.2	3.6	90.6	81.7

Efficacy and Economics of Weed Management Strategies in Aerobic Rice (*Oryza sativa* L.)

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Abstract of the
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ABSTRACT

The experiment entitled "Efficacy and economics of weed management strategies in aerobic rice (*Oryza sativa* L.)" was undertaken at the Instructional Farm, College of Agriculture, Vellayani, Thiruvanthapuram, during January, 2013 to May, 2014. The main objectives of the study were to assess the extent of yield loss due to weeds in aerobic rice, to assess the most suitable weed management strategy for aerobic rice and to study the economic feasibility.

The field experiment, laid out in randomised block design, comprised seven weed management practices (variety – Aiswarya) compared against a control (variety – MAS 946-1), replicated thrice. The treatments were $W_{1:}$ hand weeding (HW) at 15, 30 and 45 DAS (days after sowing) ,W_2 : mechanical weeding, W_3 : mechanical weeding with power weeder, W_4 : mulching with straw @ 4 t ha^{-1},W_5 : oxyfluorfen @ 0.15 kg a.i ha^{-1} + HW at 20 DAS, W_6 : pretilachlor @ 0.75 kg a.i ha^{-1} + HW at 20 DAS, W_7 : weedy check and Control (C): MAS 946 – 1, maintained weed-free by HW at 15, 30 and 45 DAS. The results of the study were as follows:

The treatment, W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS) was superior or equally effective as W_1 (hand weeding 15, 30, 45 DAS) with respect to growth attributes and dry matter production of rice.

Yield attributes were significantly superior at W_5 (oxyfluorfen @ 0.15 kg a.i ha^{-1} + hand weeding at 20 DAS). Grain yield was maximum (3889 kg ha^{-1}) with W_1 (hand weeding 15, 30, 45 DAS) and remained at par (3500 kg ha^{-1}) with W_5. Harvest index also was highest for W_1 and remained at par with W_5.

In general, broad leaved weeds were more, compared to grasses and sedges. The total weed density, weed dry matter production and nutrient removal by weeds were lesser at W_5, which recorded the highest weed control efficiency.

The net income and benefit cost ratio of Aiswarya (1.62) was significantly higher at W_5. The treatments when compared against control, revealed the superiority of the aerobic rice variety MAS 946-1 with significantly higher tiller count, grain yield and net income.

Considering the growth, yield attributes, yield and economics, the pre-emergence application of oxyfluorfen @ 0.15 kg a.i ha^{-1} followed by hand weeding at 20 DAS was effective in managing the weed problem in rice (variety Aiswarya) raised under aerobic condition.

സംഗ്രഹം

എയിറോബിക് നെൽകൃഷിയിലെ വിവിധ കള നിയന്ത്രണ മാർഗ്ഗങ്ങളുടെ കാര്യക്ഷമത സംബന്ധിച്ച് ഒരു പഠനം ജനുവരി 2013 മുതൽ മെയ് 2013 വരെയുള്ള കാലയളവിൽ വെള്ളായണി കാർഷികകോളേജിലെ ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ നടത്തുകയുണ്ടായി. എയിറോബിക് നെൽകൃഷിയിൽ കളകൾ കൊണ്ടു ഉണ്ടാകാവുന്ന വിളനഷ്ടം പരിശോധിക്കുകയും, അനുയോജ്യമായ കളനിയന്ത്രണമാർഗ്ഗം ആവിഷ്കരിക്കുകയും ചെയ്യുക എന്നതായിരുന്നു ഈ പരീക്ഷണത്തിന്റെ ഉദ്ദേശം.

പ്രസ്തുത പരീക്ഷണത്തിന് റാംഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പരീക്ഷണ രീതിയാണ് അവലംബിച്ചത്. W_1: കൈകൊണ്ടുള്ള കള നിയന്ത്രണം (നട്ട് 15, 30, 45 ദിവസങ്ങളിൽ), W_2: യന്ത്രമുപയോഗിച്ചുള്ള കള നിയന്ത്രണം (സൈക്കിൾ ഹോ) , W_3: യന്ത്രമുപയോഗിച്ചുള്ള കളനിടയന്ത്രണം (പവർ വീടർ), W_4: വൈക്കോൽ കൊണ്ടുള്ള പുതയിടൽ, W_5: ഓക്സി ഫ്ളൂർ ഫെൻ ഹെക്ടറിന് 0.15 കി.ഗ്രാം വിഷവസ്തു എന്ന തോതിൽ + നട്ട് ഇരുപതു ദിവസങ്ങൾക്കശേഷം കൈകൊണ്ട് കളകൾ നീക്കം ചെയ്യൽ, W_6: പ്രറ്റിലാക്ലോർ ഹെക്ടറിന് 0.75 കി.ഗ്രാം വിഷ വസ്തു എന്ന തോതിൽ + നട്ട് ഇരുപതു ദിവസങ്ങൾക്കു ശേഷം കൈകൊണ്ട് കളകൾ നീക്കം ചെയ്യൽ, W_7: കള നീക്കം ചെയ്യാത്ത വീടി ചെക്ക്, കണ്ട്രോൾ : മാസ് 946-1, നട്ട് 15, 30, 45 ദിവസങ്ങൾക്കുശേഷം കൈകൊണ്ട് കള പറിച്ചു നീക്കൽ എന്നിവയായിരുന്നു കള നിയന്ത്രണ മാർഗ്ഗങ്ങൾ.

നെൽചെടിയുടെ വളർച്ചാ മാനദണ്ഡങ്ങളും ഉണക്കുമ്പോഴുള്ള തൂക്കവും താരതമ്യപ്പെടുത്തിയപ്പോൾ W_5, W_7 നെപ്പോലെ തന്നെ മെച്ചപ്പെട്ടതാണെന്ന് ബോദ്ധ്യപ്പെട്ടു. നെൽചെടിയുടെ വിളവിന്റെ മാനദണ്ഡങ്ങളും വിളവും, താരതമ്മ്യപ്പെടുത്തിയപ്പോഴും W_5 ആണ് മെച്ചപ്പെട്ടത് എന്ന് മനസ്സിലാക്കാൻ കഴിഞ്ഞു.

കളകളുടെ സാന്ദ്രത, ഉണക്കുമ്പോഴുള്ള തൂക്കം, കള നിയന്ത്രണത്തിനുള്ള കഴിവ് എന്നീ ഘടകങ്ങൾ പരിശോധിച്ചപ്പോൾ ഓക്സി ഫ്ളൂർഫെൻ ഹെക്ടറിന് 0.15 കി.ഗ്രാം വിഷവസ്തു എന്ന തോതിൽ നട്ട് 3 ദിവസങ്ങൾക്കുശേഷം നൽകി + നട്ട് ഇരുപതു ദിവസങ്ങൾക്കു ശേഷം കൈകൊണ്ട് കളകൾ നീക്കം ചെയ്യുന്നത് കളനിയന്ത്രണത്തിന് ഫലപ്രദമാണെന്ന് മനസ്സിലായി.

മെച്ചപ്പെട്ട കള നിയന്ത്രണവും വിളവും രേഖപ്പെടുത്തിയ കൈകൊണ്ട് കളകൾ നീക്കം ചെയ്ത പ്ലോട്ടുകളിൽ അറ്റാദായവും, വരവ് ചെലവ് അനുപാതവും താരതമ്യേന കുറവായിരുന്നു. കള നിയന്ത്രണത്തിനുവേണ്ടി വന്ന കൂടിയ കൂലി ചെലവാണ് ഇതിന് കാരണം.

കള നിയന്ത്രണത്തിനുള്ള കഴിവ്, വിളവ്, അറ്റാദായം എന്നീ ഘടകങ്ങൾ കണക്കിലെടുക്കുമ്പോൾ ഓക്സിഫ്ളൂർഫെൻ എന്ന കളനാശിനി ഹെക്ടറിനു 0.15 കി.ഗ്രാം വിഷവസ്തു എന്ന തോതിൽ നട്ട് മൂന്നു ദിവസങ്ങൾക്കുശേഷം ഉപയോഗിക്കുന്നത് + ഇരുപതു ദിവസങ്ങൾക്കുശേഷം കൈകൊണ്ട് കളകൾ നീക്കം ചെയ്യുന്നത് എയിറോബിക് നെൽപ്പാടങ്ങളിലെ കളനിയന്ത്രണത്തിന് വളരെ അനുയോജ്യമാണെന്ന് ഈ പഠനത്തിൽ നിന്നും ബോധ്യപ്പെട്ടു.