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CHARACTERIZATION AND MANAGEMENT OF WEEDY RICE

(*Oryza sativa* f. *spontanea*)

by

ANJALI K

(2014-11-111)

THESIS

Submitted in partial fulfilment of the

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DEPARTMENT OF AGRONOMY

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DECLARATION

I, hereby declare that this thesis, entitled **"CHARACTERIZATION AND MANAGEMENT OF WEEDY RICE (*Oryza sativa* f. *spontanea*)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellayani,

Date: 09/09/2016

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CERTIFICATE

Certified that this thesis, entitled **"CHARACTERIZATION AND MANAGEMENT OF WEEDY RICE (*Oryza sativa* f. *spontanea*)"** is a record of bonafide research work done independently by **Ms. Anjali K. (2014-11-111)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
B: C ratio	-	Benefit Cost Ratio
BPH	-	Brown plant hopper
CD (0.05)	-	Critical difference at 5 % level
Chla	-	Chlorophyll
cm	-	Centimetre
CMS	-	Cytoplasmic male sterility
CO_2	-	Carbon dioxide
COA	-	College of Agriculture
DAS	-	Days after sowing
DSMO	-	Dimethyl sulphoxide
dSm^{-1}	-	Deci Seimens per metre
DSR	-	Direct seeded rice
Eg.	-	Example
EC	-	Electric conductivity
et al.	-	Co-workers/ Co-authors
Fig.	-	Figure
FL	-	Flag leaf
FW	-	Fresh weight
g	-	Gram
$g\ m^{-2}$	-	Gram per square metre
GM	-	Gall midge
ha	-	Hectare
HI	-	Harvest index
$hill^{-1}$	-	per hill
i.e.	-	that is
IDM	-	Integrated disease management

IPM	-	Integrated pest management
IPCC	-	Indian panel of climate change
IRRI	-	International rice research institute
IWM	-	Integrated weed management
K	-	Potassium
KAU	-	Kerala Agricultural University
KCl	-	Pottasium chloride
K_2O	-	Muriate of potash
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
LAI	-	Leaf area index
LAD	-	Leafarea duration
m	-	Metre
Mg	-	Milli gram
Mg 100 g^{-1}	-	Milligram per hundred gram
Mha	-	Million hectare
M moles $m^{-2}s^{-1}$	-	Milli moles per meter per second
MO	-	Moncompu
Mt	-	Million tonnes
m^{-2}	-	per square metre
MSL	-	mean sea level
N	-	Nitrogen
NS	-	Not significant
OTC	-	Open top chamber
P		Phosphorus
P_2O_5	-	Phosphorus pentoxide
plant $^{-1}$	-	per plant
panicle^{-1}	-	per panicle

pH	-	Negative logarithm of hydrogen ion concentration
PKD	-	Palakkad
ppm	-	Parts per million
RH	-	Relative humidity
Rs. Ha^{-1}	-	Rupees per hectare
RUBiSCO	-	Ribulose 1,5-bis phosphate carboxylase oxygenase
S	-	Significant
SEm	-	Standard error of mean
sp.	-	Species
t ha^{-1}	-	Tonnes per hectare
TSP	-	Total soluble protein
TVM	-	Thiruvananthapuram
viz.	-	Namely
Vs.	-	Versus
WCE	-	Weed Control Efficiency
WRM	-	Weedy rice morphotype

LIST OF SYMBOLS

%	-	per cent
°C	-	Degree Celsius
@	-	at the rate of
µg	-	Microgram
% v/v	-	Percentage volume by volume
% w/v	-	Percentage weight by volume

Introduction

1. INTRODUCTION

More than half of the world population consider rice as their principal energy source and Asia accounts for 90 per cent of world rice production. To meet the global rice demand it is estimated that about 114 Mt of additional milled rice needs to be produced by 2035 (Singh *et al*., 2015). In India, the most common method of rice crop establishment is manual transplanting of seedlings in puddled soil. However, to cope up with the problems of labour and water shortage, farmers are shifting from puddled transplanted rice to Direct Seeded Rice (DSR). DSR has advantages like early and easy establishment, lower water requirement, less labour intensive, early maturity by 7 to 10 days and low methane emission (Chauhan, 2012a). Though DSR has all these benefits, one of the major threats that has evolved by continuous adoption of this system was the emergence of one of the most serious weeds in rice field *ie*. weedy rice (*Oryza sativa* f. *spontanea* Roschevicz). It is biosimilar to cultivated rice in most of the attributes and very difficult to identify during the initial stages. Weedy rice is regarded as the most problematic weed of 21^{st} century and has already invaded the major rice growing states of the country with an infestation level of 5 to 60 per cent (Varshney and Tiwari, 2008).

Weedy rice, a menace in rice field has largely evolved by natural hybridization between wild and cultivated rice (Rathore *et al*., 2016). It is presently considered as a major problem in rice fields of Kerala. During recent years, heavy infestation of weedy rice in rice fields of Kerala caused a yield reduction of 30 to 60 per cent with a severity of infestation ranging from 3 to 10 mature plants m^{-2} (Abraham *et al*., 2012). It has already infested large rice growing areas across major rice tracts of Kerala *viz*., Palakkad, Kuttanad and Kole lands with its diverse morphotypes. Weedy rice has competitive advantage over cultivated rice as it grows taller and faster, tillers profusely and competes with cultivated rice for nutrients, light and space. It flowers much earlier than cultivated rice and produces grain that shatter easily thus enhancing the weed seed bank. Important traits for the success of weedy rice are early shattering of the grain and variable seed dormancy (Chauhan, 2013). It cannot be differentiated from cultivated rice during the vegetative stage and by the time panicle emerges the damage has already been done. Morphological characterization is hence aimed at identifying the morphological characters of different weedy rice morphotypes in comparison with cultivated rice. With its good physiological traits weedy rice has high level of adapting ability to environmental stress (Rathore *et al.,* 2016). Study of physiological and agronomic characters of weedy rice will help to assess its competing ability.

The yield loss under weedy rice infestation ranged between 60 to 80 per cent under moderate (15-20 weedy rice panicles m^{-2}) to high (21-30 panicles m^{-2}) infestation (Azmi and Karim, 2008). Yield of tall and short rice cultivars are reduced by 60 and 90 per cent respectively by weedy rice densities of 35 to 40 plants m^{-2}, indicating greater loss associated with weedy rice than other grassy weeds (Kwon *et al*., 1991). Different variants of weedy rice exhibited different growth habits and this affects the growth and yield of cultivated rice differently (Estorninos *et al*., 2002).

In the absence of selective herbicides, increasing crop competitiveness by higher seed rate and seed priming will help to reduce the weedy rice population (Juraimi *et al.,* 2013). The yield of rice increased with increase in crop seeding rates and seed priming reduces the emergence time, boosts germination percentage and favours competitive advantage over weedy rice. Seeding rates greater than 150 kg ha^{-1} were practiced in some weedy rice infested areas to reduce the problem of weedy rice. High seeding rates improve the ability of crop to suppress weeds more effectively by facilitating quick canopy closure (Chauhan and Johnson, 2011a). Seed priming improved competitive ability of crop against weeds with faster emergence and increased vigour which are the key factors for weed suppression (Clark *et al.,* 2011). Seed priming should be considered as a management strategy for weedy rice by increased weed competitiveness in direct seeded rice. Increasing rice crop interference could reduce weedy rice growth significantly. Hence information on the combined effect of higher seed rate and seed priming will help to develop a strategy for management of weedy rice.

One of the many factors affecting rice production is changing climate as evident from the changes in atmospheric carbon dioxide, rainfall and temperature which will affect the competitiveness of major weeds of rice. As per the projections of Intergovernmental Panel on Climate Change (IPCC), the atmospheric carbon dioxide concentration is expected to reach 730 to 1020 ppm by 2100 (Meehl *et al.*, 2007). Ziska *et al.* (2010) reported that weedy rice responds more strongly to rising carbon dioxide levels than cultivated rice with its greater competing ability suggesting the magnitude of weedy rice as a problem weed in future rice production system. Studying crop weed response in elevated CO_2 condition will help to assess its nature of weediness in rice production systems in the era of climate change.

Keeping the above in view, the present study has been proposed with the following objectives

- Morpho-physiological and agronomic characterization of weedy rice morphotypes of Kerala
- Formulation of a management strategy
- Assessment of the crop-weed interference under elevated CO_2 concentration

Review of Literature

2. REVIEW OF LITERATURE

Rice (*Oryza sativa L.)* is a major food crop that feed more than half of the world population. More than 90 per cent of the world's rice area and production is from Asia. India accounts for an annual production of 104 million tons from 45 million hectares. However, to meet the estimated demand of 122 million tons in 2020, the production should increase 22 per cent in the next 10 years. Factors unfavourable to rice production include dwindling land and water resources, labour shortage, hike in fuel prices and changing climatic conditions. Transplanted rice production system largely practiced by Indian farmers faced a shift to direct seeded rice (DSR) production system. According to Chauhan and Johnson (2010), DSR had various advantages like easy to plant and establish, less labour intensive, consumes less water, matures 7 to 10 days earlier, and has fewer methane emissions. Kumar and Ladha (2011) reported that in spite of these advantages, one of the major problems of DSR was the emergence of weeds, and weedy rice (*Oryza sativa* f. *spontanea* Roschevicz) is one of the serious groups among them.

Weedy rice is reported to have infested more than 50 countries of the various continents of which Asia is the most infested. Infestation of weedy rice was first reported from Malaysia, Philippines and Vietnam during 1990s (Mortimer *et al.,* 2000). This unwanted plant of the genus *Oryza* with red or rough pericarp was first documented in USA in 1846 (Londo and Schall, 2007). Weedy rice is known by different names in different parts of the world like Padi Angina in Malaysia, Valvi in Sri Lanka, Khoanok in Thailand and Junglidhan in India (Varshney and Tiwari, 2008). Weedy rice infestation was first reported in India in 1994. The problem was reported from various upland rice production systems of India *i.e.,* from rice ecosystems of eastern states like Uttar Pradesh, Bihar, Odisha, Manipur, West Bengal, and the hilly tracts of the northeast where DSR has been practiced for a long time (Singh *et al.*, 2013).

Weedy rice infestation was first reported from Kerala during 2005, when farmers shifted largely to chemical weeding and mechanical harvesting in the context of acute labour shortage and high wage rate. In Kerala many farmers abandoned rice cultivation due to the severe incidence of weedy rice in rice fields during 2008-09 (Abraham and Jose, 2014). Survey conducted during 2009 to 2012 in major rice growing tracts of Kerala recorded a weedy rice population of 1 to 15 plants m^{-2} from infested areas (Jose, 2015).

Watanabe *et al.* (1996) reported a yield loss of 60 percentages under 35 percentage infestation of weedy rice and 75 percentage yield loss was recorded under serious infestation in direct seeded rice. Chin *et al.* (2000) studied the yield loss in rice proportionate to weedy rice infestation and found that the yields were 4.05, 2.75 and 0.43 t ha^{-1} respectively when the number of weedy rice seeds m^{-2} was 10,100 and 1000. Azmi and Karim (2008) reported that in Malaysia weedy rice infestation reduced the yield by 60 percentages under moderate infestation of 15 to 20 panicles of weedy rice m^{-2} and by 80 percentages under high infestation of 21 to 30 panicles m^{-2} and 100 percentage yield loss under heavy infestation. Abraham and Jose (2014) reported a crop yield loss of 30 to 60 per cent for weedy rice infestation of 3 to 10 mature weedy rice plants m^{-2}.

Weedy rice is a natural mutant of cultivated rice with morphological characters similar to rice which make their differentiation difficult in the early growth stages. The research works done on the biology of weedy rice in comparison with cultivated rice and various management practices are reviewed in this chapter. As the competitiveness of this weed in the future era of climate change is studied, relevant literature on crop weed competitiveness on elevated CO_2 levels is also reviewed.

2.1 WEEDY RICE

2.1.1 Origin and Evolution of Weedy Rice

Weedy rice is complex of *Oryza* morphotypes of the grass family poaceae with more than 20 wild species and 10 different genome types. According to Chauhan (2012), weedy rice belongs to the same genus *Oryza* as that of cultivated rice. But it exhibits some weedy characters which helps for its better survival and establishment in the rice production systems. Characters which adds to the competitiveness of weedy rice includes greater seed dormancy and longevity, high susceptibility to seed shattering, and red pigmentation of pericarp. The above mentioned traits makes the management of weedy rice more difficult and hence it reduces the farmers income by reducing grain yield, quality and profit (Chauhan, 2013).

According to Chen *et al.* (2004), wild rice species, particularly those of the *O. sativa* (AA) complex (i.e., *O. rufipogon*, *O. barthii* and *O. longistaminata*) and three species of the *O. officinalis* complex (i.e., *O. punctata*, *O. latifolia* and *O. officinalis*), have become invasive and troublesome weeds in rice production system. They are expected to be the progenitor of weedy rice. Weedy rice exhibit both phenotypic and genotypic variations (Kumar and Ladha, 2011) and such variations lead to the evolution of weedy rice morphotypes and ecotypes. Chauhan (2013) reported that weedy rice grows unintentionally and vigorously in and around cultivated rice.

Three major hypotheses of weedy rice evolution/origin include natural hybridization between wild rice and cultivated rice, through a process of "de-domestication" of cultivated rice to weedy rice and through direct adaptation of wild rice to continuous habitat disturbance along with domestication of crop species (Londo and Schall, 2007).

2.1.2 Dispersal of Weedy Rice

Weedy rice found to spread rapidly from infested to non infested areas by several means. The most common mechanism of weedy rice seed dispersal includes use of weedy rice contaminated seed lots. According to Delouche *et al.* (2007), contaminated seed lots act as the major source for the dispersion of weedy rice. Use of machineries contaminated with weedy rice seeds also act as another source. Kanwar *et al.* (2013) reported that use of certified seeds and proper cleaning of machineries could be adopted as appropriate measures to control weedy rice spread and establishment. Weedy rice also gets dispersed by irrigation water, irrigation channels, heavy winds, storms, floods etc. Reports are available highlighting the importance of awns for seed dispersal. Awn helps for the spread of weedy rice by sticking in to the fur of animals and cloths of humans. Apart from this awns also help in the easy movement of weedy rice though water. Presence of parallel rows of trichomes on grain surface of weedy rice helps in better grip of seeds and facilitate seed dispersal (Jose, 2015).

2.1.3 Spread and Distribution of Wild and Weedy Species in India and Kerala

Since India is considered as the center of origin of cultivated rice, germplasm of various weedy and wild relatives are associated with this rice growing area. Similar to two groups of rice cultivars *viz.*, indica and japonica, weedy rice is also classified into two and further classification was possible based on the cultivated and wild types. According to Suh *et al.* (1997), Indian weedy rice belongs to indica type, emphasizing that these weedy rice biotypes might have originated by natural hybridization between cultivated rice (indica type) and wild rice.

Being the center of origin of rice, a rich source of wild rice genome are present here and the various species includes *O. nivara* (AA), *O. rufipogon* (AA), *O. malampuzhaensis* (BBCC), *O. eichingeri* (BBCC), *O. granulata* (GG), *O.*

meyeriana (GG), *O. indandamanica* (GG), and *O. ridleyi* (HHJJ). Among the wild rice species *O. nivara* and *O. rufipogon* are likely to cross pollinate easily since it shares the same genome as cultivated rice (Brar and Khush, 1997).

According to Vaughan and Sitch (1991) in India, wild and weedy species of rice are mostly concentrated at the eastern (Uttar Pradesh, Bihar, Odisha, Manipur, and West Bengal) and southern parts (Karnataka, Kerala etc), while a few or no infestation was reported from some northern states like Punjab and Haryana. The most common weedy rice species found in Indian rice fields are *O. sativa f. spontanea* (Vaughan, 1994). Western Ghats acts as the biodiversity hot spot of wild and weedy rice species in southern India and its extension in Kerala (especially places like Bhoothathankettu, Parambikulam, and Kuralai forest reserves) acts as the *insitu* reserve of the same (Thomas *et al*., 2001).

2.1.4 Weedy Rice Emergence

Weedy rice exhibits greater competing potential than cultivated rice by its various characters like profuse tillering, taller growth habit, variable seed dormancy, prolific seed shattering, early establishment of vigorous root system *etc* (Kanwar *et al*., 2013). This imparts greater competing potential to weedy rice for various growth resources like water, nutrients, light *etc*.

According to Gealy *et al*. (2000), weedy rice emergence depends upon various characters like soil texture, soil moisture, seed burial depth, tillage methods and soil temperature. Its emergence decreases with an increase in seed burial depth both under moist and flooded soil conditions. Vidotto and Ferrero (2000) stated that no emergence was recorded from seeds placed below 4 cm depth under flooded conditions (water depth 4 to 5 cm). From the study conducted at Italy it was noted that maximum emergence of weedy rice was recorded from top 0 to 5 cm depth of soil, while zero emergence was noted at a depth of below 10 cm soil layer (Chauhan, 2012b).

Suh and Ha (1993) reported that cultivated rice is found more vulnerable to flooding than weedy rice, in such a way that weedy rice recorded 60 to 100 per cent germination at a water depth of 9 cm, while it was zero for cultivated rice. It was also reported that weedy rice emergence was high under no till system than rotary tillage or ploughing and rotary tillage. This was due to the fact that deep burial of seeds during ploughing prevents the germination of weedy rice seeds and reduces the infestation than no till plots. Ferrero and Vidotto (1999) also reported a decrease in weedy rice seed germination from 2.5 to 7.2 per cent as the burial depth increase from 0 to 10 cm.

2.2 MORPHOLOGY OF WEEDY RICE

According to Hussain *et al.* (2010) weedy rice exhibits morphological characteristics that are similar to cultivated rice in the early stages of growth, making them more difficult to control than other weeds.

According to Adair and Jodon (1973), culm angle in weedy rice morphotypes ranged from erect to open and suggested that the erect growth habit was recessive to that of a spreading or procumbent growth. Estorninos *et al.* (2002) reported that weedy rice might vary among different variants. The presence of erect plant types could be due to back-crossing between accessions or with the commercial rice cultivar (Gealy *et al.*, 2006). Leaf attitude of weedy rice is classified into erect, semi erect and descending catagories (IRRI, 2007). Variations were observed even in weedy rice morphotypes collected from the same location (Chauhan, 2013).

Larinde in1979 reported about weedy rice morphotypes with different awn length and awn colour from USA. He also reported about some morphotypes with short awns or without awns which might be due to the result of segregation after natural crossing. Gealy and Estorninos (2004) reported that the specific rate of outcrossing appeared to be influenced by many factors like the rice variety, the weedy rice ecotype, vertical and horizontal distances between panicles, synchronization of flowering, and aspects of the environment that are not well understood. Burgos (2005) reported that purple coloured pigmentation in the leaf sheath, leaf margin and culm region of weedy rice morphotypes helps in their differentiation from cultivated rice. Microscopic analysis of weedy rice grain surface reported the presence of trichomes and long awns (FAO, 2007). Awns sticks on the fur of animals and help in weedy seed dispersal.

Nelson (1908) reported that weedy rice was always found growing in "clumps" because of numerous tillers up to 60 plant^{-1}. Quereau (1920) stated that weedy rice had an open growth habit with culms growing at an angle of about 65^{o} from the vertical rather than essentially erect like the cultivated rice. Shivrain (2010) and Song *et al*. (2014), reported that there exist high phenotypic diversity in weedy accessions across different countries, both within and among geographical regions.

2.3 PHYSIOLOGY OF WEEDY RICE

Kannangara (1991) reported that chlorophyll content can be used as an effective index of high photosynthetic efficiency in rice breeding programmes. Hussain *et al*. (2010) stated that chlorophyll contents at 60 to 70 days after sowing (DAS) were higher for rice than those of the weedy rice accessions. Leaf colour was either green, light green or dark green in all the weedy rice accessions, but commercial varieties only have dark green leaves at the later growth stages (Hussain *et al*., 2010). A significant reduction of leaf chlorophyll content, flag leaf area and total biomass of cultivated rice was recorded due to weedy rice competition, irrespective of fertilizer application (Kodituwakku *et al*., 2011).

According to Ishihara and Saito (1987); and Hirasawa *et al.* (1988), stomatal aperture as well as conductance was strongly correlated with leaf photosynthesis in rice. Maruyama and Tajima (1990) and Ohsumi *et al.* (2007) reported that varietal differences in stomatal conductance were positively correlated with leaf conductance as well as with the rate of photosynthesis. Swamy *et al.* (2010) reported that stomatal number correlates positively with stomatal conductance and frequency and was higher at adaxial surface than abaxial surface.

As per Minotti and Sweet (1981) there were several traits that contributed to weed competitiveness in rice and greater root volume is one among them. According to Lal *et al.* (2013), higher root-shoot ratio helped plants for better water absorption and uptake. Mahajan *et al.* (2014) reported that high root biomass and volume correlated positively with competitiveness.

Dodson in 1898 reported that weedy rice was found hardier than cultivated rice due to several characters, easy and heavy grain shattering is one among them. Sastry and Sitharaman (1973) reported that early seed shattering of weedy rice was a specific character controlled by the gene Sh exhibited shattering character either in dominant homozygous or heterozygous. According to Ferrero (2010) the germinability of shattered and non shattered seeds is about 20 per cent at 9 days after flowering and reaches 85 per cent at 12 days after flowering. Molecular level works on the shattering ability showed that abscission layer was formed by the inactivation of the CTD phosphates like gene OsCPL 1 hastening seed shattering in rice (Abraham *et al.*, 2012). Yearly addition of weedy rice seeds to soil seed bank intensifies the problem over years and management of weedy rice becomes more difficult (Chauhan, 2013).

Environmental conditions, especially moisture and temperature had significant influence on seed dormancy and viability. A rapid loss of seed dormancy of weedy rice was reported at a moisture content of 6 to 14 per cent and it was very low at moisture content below 5 per cent and above 18 per cent (Leopold *et al.*, 1988). Gu *et al.* (2006) reported that seed dormancy was associated with environmental factors during seed development. Seed dormancy will be longer for seeds of the dry region since waiting for the wet period favourable for germination (Veasey *et al.*, 2004). High variations in seed longevity helps to retain the viability of weedy rice seeds in soil seed bank and germinate as and when the condition become favourable. This makes weedy rice more persistent in our cultivated rice systems (Azmi and Karim, 2008). According to Suh (2008), dormancy of weedy rice range from a few months to years, and fluctuate with ecotype and storage conditions.

According to Noldin (2000), seed longevity of weedy rice in soil varies with ecotypes and factors like burial depth, soil moisture, and seed dormancy. From study conducted by Noldin *et al.* (2006) at two locations in Texas and USA, it was found that weedy rice seed longevity increased with increases in burial depth. They found that seeds from the 5 cm soil layer exhibit zero viability after one year, while that buried 12 to 25 cm deep remained viable longer than two years. Some ecotypes form Arkansas, U.S, retained viability (more than 20 per cent) even after 10 years when buried at a depth of 17 cm.

Deep ploughing or tillage is not recommended in areas severely infested with weedy rice because it helps in deep placement of seeds and keeps them viable in soil seed bank for longer periods. Chin *et al.* (2000) reported that reduction in viability of weedy rice seeds was faster in moist condition than under submerged conditions. One of the most important characters that add to the dispersion, distribution and competitiveness of weedy rice was its heavy and early seed shattering. Azmi and Karim in 2008 reported that seed shattering behaviour is biotype specific and varies from a few days to a few weeks.

2.4 AGRONOMY OF WEEDY RICE

According to Stansel *et al.* (1965) and Smith (1968), height is a competitive trait in plant communities and weeds taller than the crop are usually most competitive during the latter half of the season. Taller plants have greater effect on the yield components than growth of the crop as a result of the shading effect and lodging. Patterson (1982) reported that increasing shade would increase plant height until photosynthate production limits growth. Weedy rice morphotypes are taller compared to cultivated rice varieties (Kwon *et al.*, 1991 and Suh *et al.*, 1997). Chauhan and Johnson (2010) reported that shading caused by rice interference could not influence height of different weedy rice biotypes. Chauhan (2013) stated that weedy rice morphotypes were more tolerant to shade than cultivated rice. Jose *et al.* (2013) reported about some weedy rice morphotypes with dwarf stature from Kerala.

Earliness in flowering was observed in weedy rice compared to cultivated rice. Weedy rice flowering depends on various characters like day length, plant age, and biotype (Longevin *et al.,* 1990). Early flowering resulted in early grain maturing and seed shattering. Shattered seeds were further added to soil seed bank and intensify the problem in future (Perreto *et al*., 1993). Weedy rice recorded a flowering period ranging from 8 to 93 days, which was far higher than cultivated rice (7 to 22 days). The floret opening period in weedy rice was also found one hour longer compared to cultivated rice, providing more chance for cross pollination in some weedy rice biotypes (Mongkolbunjong *et al*., 1999). Olguin et al. (2007) reported that compared to cultivated rice, panicles emerge earlier and mature asynchronously in weedy rice.

Devendra *et al.* (1983) reported that a low Leaf Area Duration (LAD) could lead to incomplete development of the sinks and will result in a lower yield. According to Ferrero and Vidotto (1999) it is very difficult to distinguish between weedy rice and rice crop in the seedling stage but once tillering starts, weedy rice could be easily identified by their more numerous, longer and more slender tillers. Zhang *et al*. (2002) commented about the significant effect of tillering on LAI of rice. Rathore *et al.* (2016) reported a marked difference in the panicle length and number of panicles in rice and weedy rice.

Morphotypes with pigmented nodes exhibited colourless or white awns (Larinde, 1979). Weedy morphotypes having anthocyanin in the apiculus also showed pigmentation in other plant parts like ligules, margins of leaves, internodes and auricles. This dominant character of anthocyanin pigmentation is controlled by multiple genes (Espinoza *et al.,* 2005). Jose *et al.* (2013) reported that thousand grain weight of weedy rice ranged between 18 to 19.5 g. Zhang *et al*. (2015) reported about the existence of pollen sterility in weedy rice morphotypes *viz.*, Cytoplasmic Male Sterility (CMS) which was used in hybrid breeding programmes. Sterile and half filled grains in weedy rice always exhibited a higher germination percentage and even half filled grains were found to germinate under favourable conditions (Jose, 2015).

2.5 MANAGEMENT OF WEEDY RICE

Since weedy rice mimics cultivated rice, all the measures adopted to control weedy rice will naturally affect the cultivated rice. Management of weedy rice is remaining as a challenge for the Indian farmers. Various studies conducted so far revealed that, management of this weed is not possible using a single methodology and hence an integrated approach is needed. According to Mahajan and Chauhan (2013), adoption of Integrated Weed Management (IWM) strategies, which includes preventive, cultural, mechanical, chemical and biotechnological approaches should be adopted for the effective management of weedy rice under Indian conditions. Management of weedy rice by enhancing rice competitiveness is a relatively new approach.

2.5.1 By Enhancing Rice Competitiveness

Apart from other management practices, weedy rice infestation could be reduced by increasing the rice competitiveness either by the adoption of high crop seeding rate or by priming methods.

2.5.1.1 *Adoption of High Crop Seeding Rates*

One approach that helps to increase crop competitiveness against weeds is the use of higher seed rate (Mortensen *et al.* 1998; Gibson *et al.* 2002; Chauhan and Johnson., 2011b). According to Ahmed et al (2014) use of high seed rate results in quick closure of canopy and which helps to suppress weeds more effectively.

Competitiveness of rice could be increased by using higher seed rate and narrow spacing. This helps in the faster closure of crop canopy and adds to its competing potential. As per the studies of Azmi *et al.* (2000), when the seed rate increased from 20 to 80 kg ha^{-1} rice grain yield was increased in DSR system of Malaysia which was severely infested with weedy rice.

Increasing plant density is one of the ways to increase the yield. An increased yield was observed with an increase in plant density up to a limit and thereafter a decline in yield was recorded. This reduction in yield might be due to the reduction in resources per plant. So the reduction in yield will not be compensated by increasing plant number (Yoyock, 1979). Optimum plant density had positive effect on yield of rice (Sivaesarajah *et al.*, 1995). As per the works of Kenneth and Helms (1996), number of panicles per unit area decides yield variations up to 90 per cent in rough rice. It was also reported that number of plants per unit area has an impact on plant architecture, growth and development and production of photosynthates. Very high plant density limits the access of growth resources such as light, water and nutrients due to greater competition among the plants (Abuzar *et al.*, 2011).

Sharma (1994) reported that there was a positive correlation between high seed rate and yield up to a certain level and beyond that optimum level of seed rate, plant yield would start to decline. Height of cultivated rice was reported to decrease with increases in weedy rice density (Kwon *et al.*, 1991). Akbar and Ehsanullah (2004) reported that seeding density had no significant effect on plant height. According to Harris and Vijayaragavan (2015) plants tend to grow taller in search of light at a high seeding rate or closer spacing.

Plant population had a significant effect on photosynthetic characters of rice crop and LAI per plant increase along with an increase in density. According to Akita (1982), increase in number of plants per unit area makes more leaf area available for the production of photosynthates. So high LAI per unit area is due to increase in number of plants per unit area (Hu *et al.*, 2000).

Increase in rice yield with increase in seed rate (density) has been reported by Baloch *et al.* (2002). According to them the plants have sufficient space at low seed rate and this enables to utilize more nutrients, water and solar radiation for better photosynthesis. It was noticed that as the seed rate increased, yield per plant decreased. Although per plant yield was higher at the lowest seed rate (density), this did not compensate for the contribution in terms of yield by more plants at the higher density (Harris and Vijayaragavan, 2015).

Evans and Datta (1979) reported that highest seed rate might result in greater contribution from each plant towards flower and grain formation than lower seed rates and greater radiation during the reproductive and ripening stages. Kennath and Helms (1996) reported that grain yield in rough rice was highest at optimum plant population. Harris and Vijayaragavan (2015) suggested that higher yield may be due to other factors like the panicle and spikelet number m^{-2}, percentage of filled grains, thousand grain weight and harvest index.

According to Miller *et al.* (1991), panicle density was the key factor that determines and contributes 89 per cent of differences in yield. Baloch *et al.* (2002) supported the findings that greater number of plants per unit area multiplies the panicle number per unit area. Increasing seed rate beyond optimum result in more plant population per unit area resulting in severe competition between plants. This further adds to production of unhealthy plants with small panicle making crop susceptible to pests and diseases (Harris and Vijayaragavan, 2015).

Murata *et al.* (1957) reported that if seed rate is increased beyond an optimum point, there would be an increase in leaf area and vegetative parts per unit area, which will result in increased respiratory rates and which in turn will lead to a reduction in the number of grains. Yoshida (1972) also reported a reduction in number of spikelets beyond an optimum plant density. The physiological explanation of this might be of the fact that increase in photosynthetic apparatus and vegetative parts per unit area will result in a proportionate increment in the respiratory rates which in turn could lead to a reduction in filled grains (Harris and Vijayaragavan., 2015).

According to Akbar and Ehsanullah (2004) high sterility percentage was recorded at a higher seed rate. Harris and Vijayaragavan (2015) reported that compared to panicle density number of filled grains panicle^{-1} is the most important factor that contributes to yield.

Akita (1982), reported that increasing the value of HI is one of the ways to increase the crop yield. Sink formation and ripening are the two physiological processes that explain the improvement in HI.

Finding of Phuhong *et al.* (2005) explains that in lowland rice, higher seeding rates favoured rice against weeds and, at the same time, increased yields under weedy conditions. Zhao *et al.* in 2007 reported that in Philippines, seeding rates of 100 to 300 viable seeds m^{-2} increased yield and decreased weed biomass in aerobic rice systems. According to Guillermo *et al.* (2009), at low seeding rates, crop plants take more time to close their canopy, which enhances the weed growth. High seeding rates improve the ability of crops to suppress weeds and can reduce yield loss even under partially weedy conditions.

As per the finding of Ahmed *et al.* (2014), weed infestation level and seeding rate had significant influence on rice biomass which was found to increase when seed rate was increased from 20 to 100 kg ha^{-1}. Lower seed rate results in lesser crop densities and crop cover during the initial growing period, leaving more resources for the growth of weeds and thus enables them to establish and grow quickly.

Weiner *et al.* (2001) reported that in wheat highest crop biomass was recorded from plots treated with high seeding rate even in the presence of weeds. Ni *et al.* (2004) reported about strong and consistent negative effects due to increased crop density. Ahmed et al. (2014) reported that under weed free conditions, the number of grains $panicle^{-1}$ decreased with increase in seeding rate and under partially weeded condition, grain yield was increased by 30 to 33 per cent.

Chauhan (2013) reported that leaf number of rice plant was affected by cultivar and weedy rice density. It was found that leaf production of cultivated rice was significantly affected by weedy rice densities and a decline was observed in the leaf production with increase in weedy rice densities. Variations were reported in the growth and morphological characteristics of different weedy rice morphotypes, further affecting the competitive interactions between weedy rice and cultivated rice.

Diarra *et al.* (1985) reported that blackhull weedy rice biotypes had 27 per cent more tillers and 18 per cent more straw than strawhull biotypes. Number of tillers in five weedy rice variants of Phillippines ranged from 34 to 48 tillers $plant^{-1}$ (Chauhan and Johnson 2010).

Aboveground shoot biomass of cultivated rice was affected by the interactions of factors like rice cultivar, weedy rice variant and weedy rice density. Cultivars differed in their competitive ability at low weed infestation but poor response was shown at high weed infestation. The grain yield of cultivated rice was significantly affected by the interaction between weedy rice variants and density (Chauhan, 2013).

Taller weed plants are known to reduce crop yield more than shorter weed plants (Liebman *et al*., 2001), mainly because of more shading. Low light is known to significantly decrease growth and grain yield in rice (Gibson and Fischer 2004; Praba *et al*. 2004). High weedy rice infestation can decrease the yield of cultivated rice drastically (Chauhan, 2013).

Kwon *et al*. (1991) reported that rice yield declined by an average of 270 kg ha^{-1} for each weedy rice plant up to 20 weedy rice plants m^{-2}. In a study in the U.S., rice yield reductions were between 100 and 755 kg ha^{-1} for every weedy rice plant m^{-2} (Ottis *et al*., 2005).

2.5.1.2 *Adoption of Priming Methods*

Rice competitiveness was increased by various priming methods like hydropriming and hardening. According to Anwar *et al*. (2012) seed priming had significant effect in reducing mean germination time and increasing germination percentage, germination index and seedling vigour index.

According to Rowse (1995) and Farooq *et al*. (2007) seed priming results in partial hydration of seeds without radicle emergence and activation of most of the physiological processes enhancing the germination and vigour of primed seeds. Such seeds imbibe and revive metabolic activities soon after sowing even after redrying back to initial moisture content exhibiting reduced physiological heterogeneity in germination.

Many researchers studied the effect of seed priming on rice (Lee and Kim, 2000; Ruan *et al.*, 2002; Basra *et al.*, 2004). Primed seeds showed uniform germination, increased germination rate, better allometric attributes and faster emergence of seedlings (Basra *et al.*, 2005; Kaya *et al.*, 2006; Farooq *et al.*, 2007). Farooq *et al.* (2009) tried various priming methods to improve speed and synchrony of seed germination using methods like soaking prior to sowing, hardening, hormonal priming, hydropriming, osmohardening, osmoconditioning, wetting and drying, ascorbate priming and solid matrix priming.

Du and Tuong (2002) reported a positive influence of seed priming on weed suppression in direct seeded rice even at a low seeding rate. Zhao *et al.* (2007) reported that seed priming did not have any significant influence on weed suppression. Anwar *et al.* (2012) reported 22 to 27 per cent reduction in weed dry weight by various priming methods in rice. Seed priming and primed stands of rice were found to be more competitive against weeds than unprimed ones.

According to Harris *et al.* (1999) even simple on farm priming (soaking seeds overnight in water) increases the germination rate and early vigour resulting in higher yields of upland rice. Du and Tuong (2002) and Kaur *et al.* (2005) reported that priming leads to faster crop growth, early flowering and high yield. Findings of Anwar *et al.* (2012) showed that relative yield loss due to rice weed competition was as high as 30 per cent and it was reduced to 20 per cent by various priming methods.

Clark *et al.* (2001) opined that seed priming improved the competitive ability of crop against weeds along with increased vigour and faster emergence which are the key factors for tolerating weeds. Harris *et al.* (2002) reported that seed priming helped rice seedlings to compete more successfully with weeds. Zhao *et al.* (2006) and Anwar *et al.* (2012) showed that priming results in rapid seed germination thereby enhancing the competitiveness of rice by imparting characters like early vigour, faster growth rate and high crop biomass.

Harris *et al.* (2002) reported that due to seed priming rice seedlings could compete more successfully with weeds. According to Anwar *et al.* (2012), priming methods like hydropriming and hardening results in plants with similar height. He also reported that seed priming enhanced plant height from early growth stage (15 DAS) to harvest and resulted in taller plants.

Clark *et al.* (2001) reported that better crop stand from primed seeds resulted in rapid canopy development giving preliminary advantage to rice plants over weeds. Basra *et al.* (2005) reported that priming results in synchronized seed emergence with high vigour. Farooq *et al.* (2009) observed that primed seeds recorded high LAI and which might be due to the increased efficiency in resource capture and photosynthate assimilation. Anwar *et al.* (2012) reported that tillering was not significantly influenced by priming techniques but it helps to maintain a weed free condition for crop growth resulting in increased tillering. He also reported that improved LAI was possible while for primed seeds due to the strong and energetic start by vigorous seedlings.

Farooq *et al.* (2006) reported that number of tillers and panicles were not affected by priming treatments, while thousand grain weight was high for seeds subjected to hardening followed by hydropriming. Anwar *et al.* (2012) stated that primed seeds exhibited an enhanced germination rate (2 times higher) than unprimed seeds. Of the various priming methods tested hardening and hydroprimig had almost similar effect.

According to Anwar *et al.* (2012) competition between rice and weeds results in the reduction of Harvest Index (HI) by 10 per cent and seed priming could be effectively used to overcome this problem. He also reported that seedling emergence rate, indicated by higher germination percentage and speed of germination was enhanced by seed priming reflected as higher germination index, lower mean germination time and days to 50 per cent germination.

2.6 RESPONSE OF RICE AND WEEDY RICE TO ELEVATED ATMOSPHERIC CO_2

Rising carbon dioxide concentration by various anthropogenic activities had a major role in climate change. Global carbon dioxide concentration has risen from 280 to 300 $\mu mol\ mol^{-1}$ in the past 250 years and is expected to reach 600 $\mu mol\ mol^{-1}$ sometime around 2050 (Bolin, 1998; IPCC, 2007). Climate change also influences the weed communities in rice production system by affecting the weed species distribution and prevalence within weed and crop communities (Mahajan *et al.*, 2014).

Various weed management operations could be affected by climate change and ultimately influence the competitiveness of major weeds associated with rice production system. According to Ziska (2003), weeds showed a greater response to elevated CO_2 rather than crops. He also reported that weedy rice responded well to elevated CO_2 concentration compared to cultivated rice varieties. Singh and Jasrai (2011) reported that effects of elevated CO_2 to plant growth was more pronounced during early growth stages and reduced greatly at later stages of growth.

Kimball *et al.* (2002) reported that plants with C_3 photosynthetic pathways showed greater response to elevated CO_2 compared to plants with C_4 pathways. Since weedy rice behave like a C_4 weed with C_3 mechanism, which adds to its competitiveness (Fuhrer, 2003). He also reported that increased atmospheric CO_2 levels are likely to be accompanied by higher temperature favouring C_4 weeds over C_3 crops.

Ziska *et al.* (2010) suggest weedy rice as one of the most problematic weed in future rice production system as it responds more strongly to rising CO_2 level than cultivated rice with greater competing ability. Mahajan *et al.* (2014) reported that climate change not only affect the crop-weed competition, but also trigger early flowering leading to weed seed germination in several flushes causing serious weed management issues. This earliness in flowering of weedy rice might help to complete its life cycle faster and initiation of more life cycles even within a single crop period.

Weedy rice had high tillering nature which resulted in a high LAI for this plant group (Seeneweera *et al.*, 1994). Matsui *et al.* (1997) demonstrated that high temperature during flowering induced pollen sterility in rice. This indicated that high temperature associated with elevated carbon dioxide levels induce sterility in rice. Kim *et al.* (2003) reported a liner relationship between the percentage increase in yield at elevated CO_2 and the percentage increase in spikelet number. However, Sherchand and Sharma (2004) reported that elevated CO_2 had only little effect on number of grains panicle^{-1}.

It can be concluded that to maintain the sustainability of rice production system research should focus on environmental factors affecting crop weed interactions. As climate change has became a reality and it is time to alter the weed management strategies with approaches that will combat the adversities of climate change. Innovative approaches should be developed to assist farmers cope with the challenges of climate change.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation on 'Characterization and management of weedy rice (*Oryza sativa* f. *spontanea*)' was aimed at morpho-physiological and agronomic characterization of weedy rice morphotypes of Kerala, formulation of a management strategy and assessment of crop-weed interference under elevated CO_2 concentration. The whole programme was carried out during 2014-16 as three separate experiments as given below

Experiment I: Morpho- physiological and agronomic characterisation of weedy rice (Pot culture)

Experiment II: (a) Management of weedy rice by enhancing rice competitiveness (Microplot study)

(b) Management of weedy rice by enhancing rice competitiveness (confirmatory trial in farmer's field)

Experiment III: Effect of elevated CO_2 concentration on growth of rice and weedy rice (Pot culture inside OTC)

3.1 EXPERIMENT DETAILS

3.1.1 Location

Pot culture experiment on 'Morpho-physiological and agronomic characterization of weedy rice morphotype' was carried out at College of Agriculture, Vellayani. Micro plot experiment on 'Management of weedy rice by enhancing rice competitiveness' was undertaken in the wetlands of the Instructional Farm College of Agriculture (COA), Vellayani, Kerala. The experimental field is located at 8^0 25'49'' N latitude and 76^0 39' 04'' E longitudes at an altitude of 29 m above the mean sea level. Confirmatory trial was conducted in farmer's field of Kanjirathadi padasekharam, in Nemom block, Thiruvananthapuram district, Kerala. Third experiment on 'Effect of elevated CO_2 concentration on growth of rice and weedy rice' was undertaken as a pot culture experiment in the Open Top Chamber (OTC) facility available in the Department of Plant Physiology, College of Agriculture, Vellayani.

3.1.2 Climate and Season

Pot culture experiments were taken up during October 2014 - January 2015 and the field experiments were conducted during December 2015 and 2016. A warm humid tropical climate is experienced by the area. The data on various weather parameters, *viz.,* weekly rainfall, maximum and minimum temperature, relative humidity and sun shine hours during the period are presented in Appedix I and graphically represented in Fig 1.

3.1.3 Soil

The soil of the experimental site belonged to the textural class of sandy clay and the taxonomical order Oxisol. The physico-chemical properties of the soil were estimated from the composite sample collected at 15 cm depth from field prior to experiment. Data are given in Table 1.

3.1.4 Cropping History of the Experimental Site

The experimental site at COA, Vellayani are single cropped wet lands from May-June to September- October. The site at farmer's field are double cropped wet lands where first crop was raised under semi dry system and second crop as transplanted or wet sown crop.

Fig 1: Weather data during crop period (December 2014-March 2015)

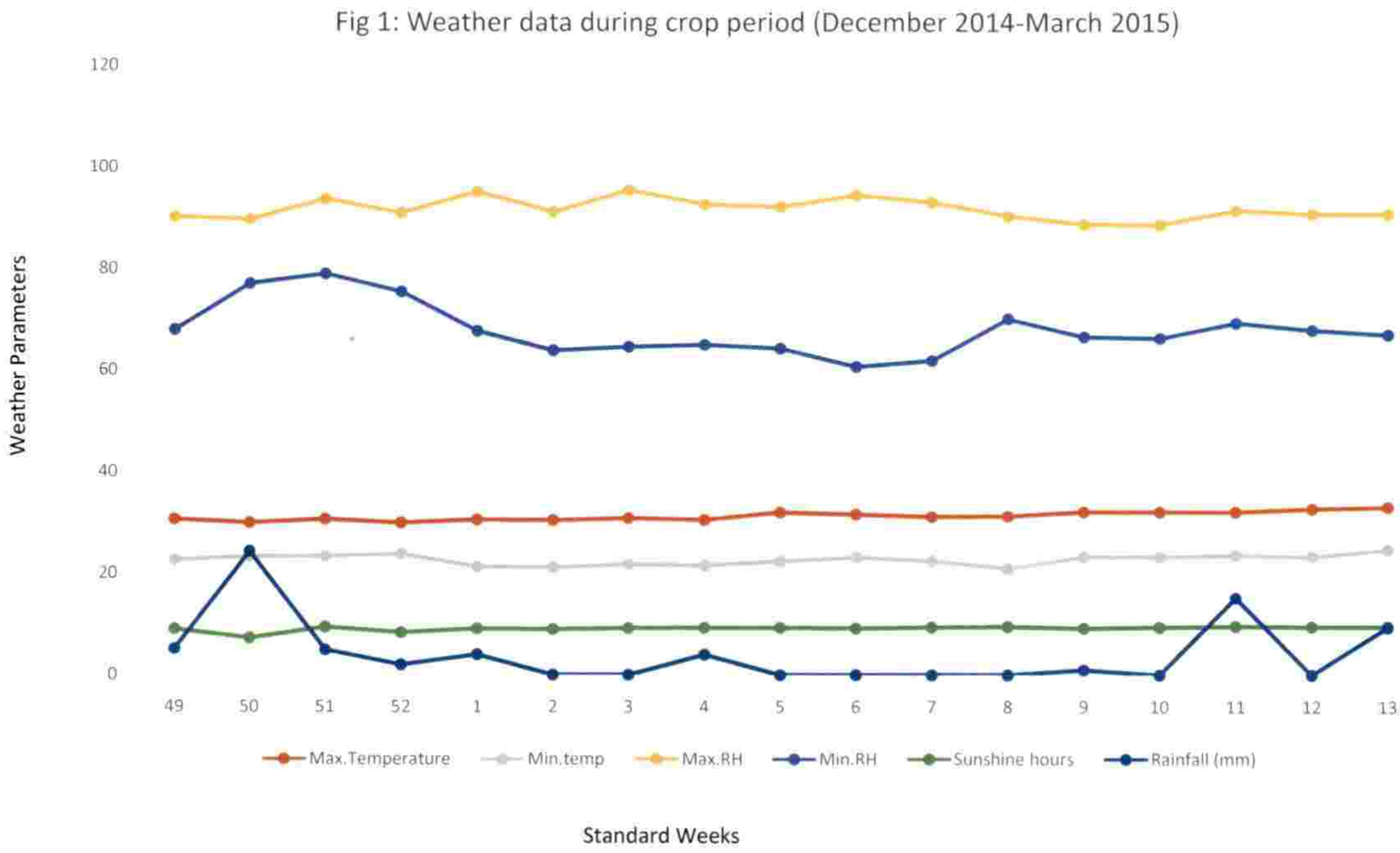

Table 1. Physico-chemical properties of soil at experiment site

A. Mechanical composition			
Parameters	Content	Status	Methodology
Coarse sand (%)	47.05		Bouyoucos Hydrometer Method (Bouyoucos, 1962)
Fine sand (%)	11.40		
Silt (%)	10.05		
Clay (%)	31.50		
Texture		Sand clay loam	
A. Chemical Properties			
Soil reaction (pH)	5.41	Strongly acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
EC (dS m^{-1})	0.4	Normal	1:2.5 soil solution ratio using conductivity meter (Jackson, 1973)
Organic carbon (%)	1.8	High	Walkley and Black's rapid titration (Jackson, 1973)
Available N (kg ha^{-1})	575.7	High	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg ha^{-1})	27.44	High	Bray colorimetric method

			(Jackson, 1973)
Available K (kg ha^{-1})	188.54	Medium	Ammonium acetate method (Jackson, 1973)

3.2 MATERIALS

3.2.1 Crop and variety

The most popular rice variety of the state Uma, was used for the field experiment. It was developed by Rice Research Station, Moncompu, Kerala which is a cross between MO-6 and Pokkali (Pedigree selection, 1988). It is a medium duration red, medium bold variety having a dormancy period of three weeks and suited to all three seasons in Kerala. Other promising characteristics of the variety are dwarfness, medium tillering, non lodging, resistance to brown plant hopper (BPH), gall midge (GM) biotype-5 and other major pests.

3.2.2 Manures and Fertilizers

The organic manure source used for the experiment was well decomposed dry cow dung containing 0.55 per cent N, 0.23 percent P_2O_5 and 0.46 per cent K_2O. Nitrogen, phosphorus and potassium 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. Half N, full P and half K were applied as basal and the remaining half N and K were applied at the time of panicle initiation.

3.2.3 Open Top Chamber (OTC)

Open Top Chamber (OTC) is a structure constructed using UV stabilized polyethylene sheets supported on iron frames and 1 m^2 area at the top end is kept open for free movement of air.

3.3 METHODS

3.3.1 Experiment 1: Morpho-physiological and Agronomic Characterisation of Weedy Rice Morphotypes (Pot culture)

3.3.1.1 *Design and Layout*

Design : Completely Randomised Design

Treatments : 8 morphotypes + 2 cultivated varieties (control)

Replication : 3

The experiment consisted of growing 8 weedy rice morphotypes collected from major rice tracts of Kerala along with one short duration rice variety (Jyothi) and one medium duration rice variety (Uma) in pots. The major locations from where these morphotypes collected included Thiruvananthapuram, Kuttanad, Kole lands of Thrissur district, Palakkad, Kozhikode and Kaipad lands of Kannur (Ezhome).

3.3.1.2 *Treatments*

T_1 : WRM -1 (Weedy Rice Morphotype from Trivandrum having red awn colour)

T_2 : WRM-2 (Weedy Rice Morphotype from Trivandrum having white awn colour)

T_3 : WRM -3 (Weedy Rice Morphotype from Kuttanad having white awn colour)

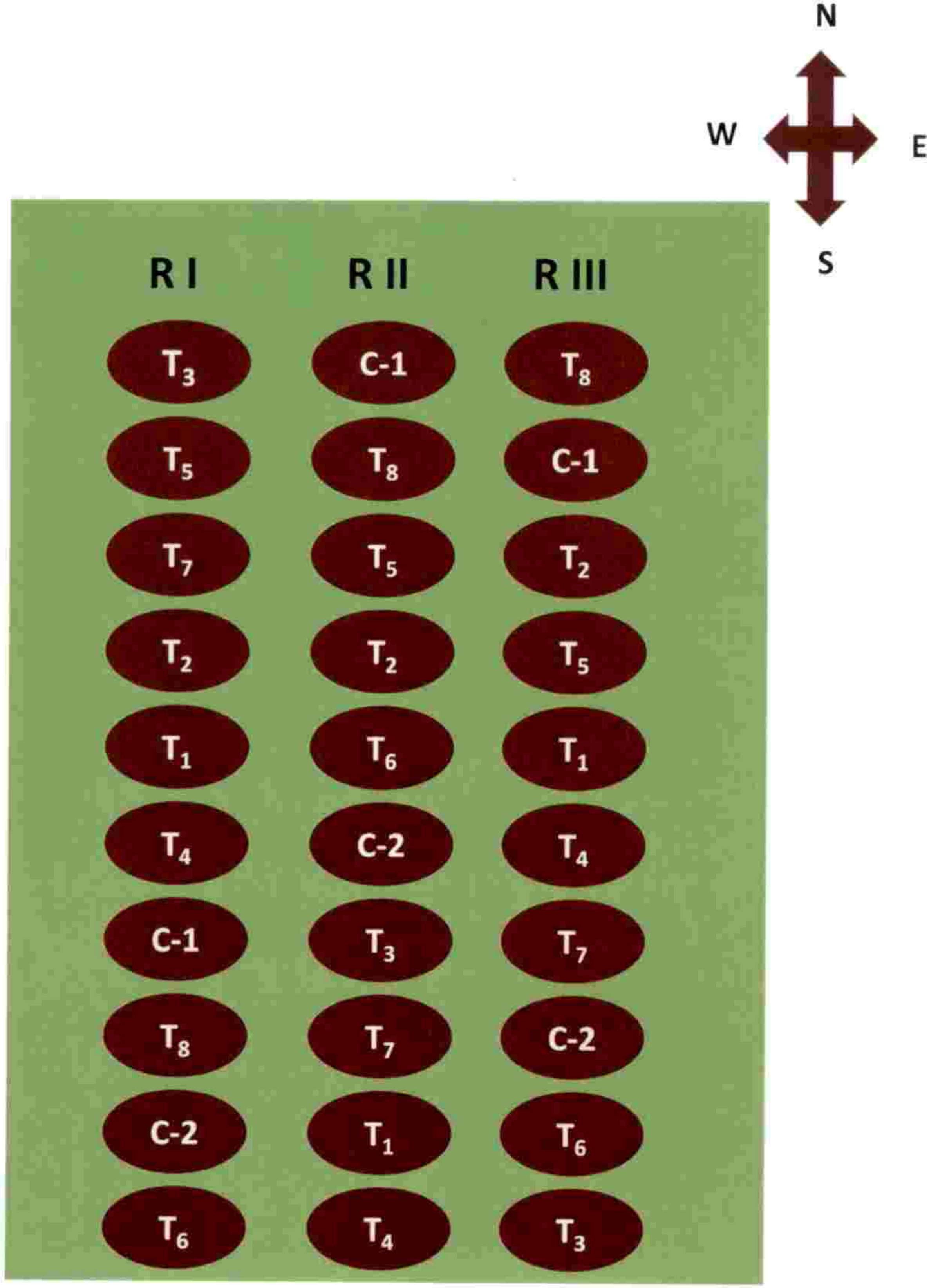

Plate 1: Layout of pot culture experiment

T_4 : WRM -4 (Weedy Rice Morphotype from Kole having white awn colour)

T_5 : WRM -5 (Weedy Rice Morphotype from Palakkad having red awn colour)

T_6 : WRM -6 (Weedy Rice Morphotype from Palakkad having white awn colour)

T_7 : WRM -7 (Weedy Rice Morphotype from Kozhikode having white awn colour)

T_8 : WRM -8 (Weedy Rice Morphotype from Ezhome having pink awn colour)

Control (cultivated varieties)

T_9 : Jyothi (Short duration)

T_{10} : Uma (Medium duration)

3.3.1.3 ***Sowing and Establishment***

Weedy rice seeds were allowed to germinate after breaking dormancy and pre germinated seeds (two seeds per pot) were sown in earthen pots of size 50 cm depth and 30 cm diameter filled with clayey soil collected from rice field. Flooded situation was maintained throughout the crop growth period and all packages of practices were followed. Morpho- physiological and agronomic characters were observed at periodical intervals and recorded for both weedy rice and cultivated rice.

3.3.1.4 ***Crop Management***

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

Plate 2: Field view of pot culture experiment

3.3.1.5 *Pest and Disease Management*

Pests viz., rice stem borer, leaf roller, rice bug and bacterial blight disease were controlled effectively by adopting Integrated Pest Management (IPM) and Integrated Disease Management (IDM) strategies. The pest and pathogen population were maintained below economic threshold level.

3.3.1.6 *Harvest*

After panicle emergence each weedy rice morphotype was separately bagged in order to prevent the shattering of grains. Panicles from each weedy rice morphotype and cultivated rice varieties were harvested separately, grains seperated and yield was recorded.

3.3.1.7 *Observations*

3.3.1.7.1 *Morphological Characters at 15 DAS (for Rice and Weedy Rice)*

All these observations were recorded based on the 'Morphometric Descriptors for wild and cultivated rice' of IRRI, 2007.

3.3.1.7.1.1 *Attitude of Leaf Blade*

Measured as the angle of attachment between the leaf blade and the main panicle axis. Various classes included are

- Erect (1)
- Semi-erect (intermediate) (3)
- Horizontal (5)
- Descending (7)

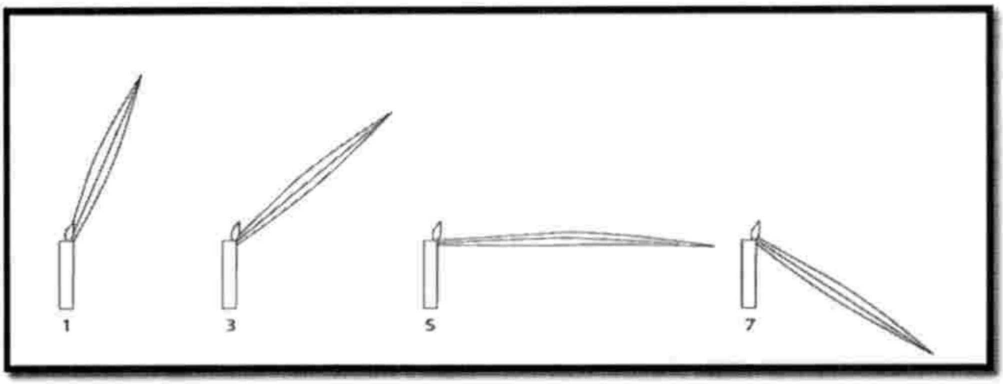

Plate 3: Attitude of leaf blade

3.3.1.7.1.2 *Anthocyanin Colouration of Nodes*

The presence and distribution of purple colour (anthocyanin) was observed on the outer surface of the nodes on the culm. Various classes included are

- Absent
- Light purple
- Purple
- Purple lines

3.3.1.7.1.3 *Colour and Length of Ligule*

A ligule is a thin outgrowth at the junction of leaf and leaf stalk of many grasses.

➢ **Ligule colour**

Various classes include

- Absent (liguleless)
- Purple
- Whitish
- Light purple
- Yellowish green
- Purple lines

- **Ligule length(mm)**

Measured from base of collar to the tip of the ligule of the penultimate leaf, *i.e.* the leaf below the flag leaf.

3.3.1.7.1.4 *Presence of Awns*

Recorded as

- Absent
- Present

3.3.1.7.1.5 *Colour of Awns*

Awn colour was observed visually after anthesis and grouped into the following categories

- Absent (awnless)
- Whitish
- Straw
- Gold
- Brown (tawny)
- Light green
- Red
- Purple
- Black

3.3.1.7.1.6 *Awn Length*

The length of the awn in 'mm' was taken from the tip of the grain to the tip of the awn.

3.3.1.7.1.7 *Number of Tillers Plant^{-1}*

Recorded as the total number of panicle bearing and non bearing tillers.

3.3.1.7.1.8 *Culm Thickness (cm)*

Measured as the outer diameter of basal portion of the main culm.

3.3.1.7.2 *Physiological Characters (at 15 DAS & at 50 % Flowering Stage of Rice and Weedy Rice)*

3.3.1.7.2.1 *Chlorophyll Content*

Chlorophyll content was estimated by DMSO (Dimethyl sulphoxide) method. A weighed quantity of sample (0.5g) was taken and cut into small bits. These bits were put in test tubes and incubated overnight at room temperature, after pouring 10 ml DMSO : 80% acetone mixture(1:1v/v). The coloured solution was decanted into a measuring cylinder and made up to 25 ml with the DMSO- acetone mixture. The absorbance was measured and readings were taken at 663. 645, 480 and 510 nm using spectrophotometer. The chlorophyll content was expressed as mg g^{-1}

Chla a = $(12.7 \times A_{663} - 2.69 \times A_{645}) \times V/1000 \times 1/$ fresh weight

Chla b = $(22.9 \times A_{645} - 4.68 \times A_{663}) \times V/1000 \times 1/$ fresh weight

Total Chla (a +b) = $(8.02 \times A_{663} + 20.2 \times A_{645}) \times V/1000 \times 1/$ fresh weight

3.3.1.7.2.2 *Total Soluble Protein*

The total soluble protein of leaf samples were estimated using simple protein dye binding assay of Bradford (1976) using bovine serum albumin as the standard. One hundred milligram of CBB 250 was dissolved in 50 ml of 95 % ethanol. To this 100 ml of 85 % (w/v) orthophophoric acid was added. The resulting solution was diluted to a final volume of 200 ml with distilled water. 0.1 g of leaf samples were taken from third fully opened leaves and was ground to a thin paste and soluble protein was extracted with 10 ml of phosphate buffer (pH 7.8). The extract was centrifuged at 5000 rpm for 10 minutes. To the 20 μl of the supernatant a known volume (5 ml) of diluted dye binding solution was added. The solution was mixed well and allowed to develop a blue colour for at least 5 minutes but no longer than 30 minutes and the absorbance was measured at 596 nm. The protein content was calculated using the BSA standard in the range of (10-100 µg). The protein content was expressed as mg^{-1} FW.

3.3.1.7.2.3 *Stomatal Frequency*

Stomatal count refers to the number of stomata per unit area of leaf. A thick mixture of thermocol and xylene was prepared and this was smeared on both the surfaces of leaves and allowed to dry. It was peeled gently after drying and the peel was observed under microscope and counted using a 40 x objective and 10 x eye pieces. The field of the microscope was measured using a stage micrometer and stomatal frequency per unit area was calculated for both abaxial and adaxial surfaces.

Stomatal frequency = No of stomata/ area of the microscopic field.

3.3.1.7.2.4 *Stomatal Conductance (gs)*

Stomatal conductance was measured using the SAI-1 Porometer of company Delta T Devices and was expressed in milli moles $m^{-2}s^{-1}$.

3.3.1.7.2.5 *Root Volume*

The individual root system volume was measured by means of displacement method.

3.3.1.7.2.6 *Root dry weight*

After harvest root samples were carefully separated and dried in an oven at 70 $\pm 5\,^0$C till constant weight was attained and the dry weight was expressed in 'g'.

3.3.1.7.2.7 *Root Shoot Ratio*

After harvest root and shoot were separated dried to constant weight and ratio of weight of roots to shoots were worked out.

3.3.1.7.2.8 *Grain Threshability*

Determined by hand grip technique (Azmi *et al.*, 2000). Five matured panicles of each morphotype were shattered by hand grip and the grains that were detached from the panicle were counted as shattered. The percentage of shattering was calculated by dividing the number of shattered seed over the total number of seeds panicle^{-1} multiplied by 100.

3.3.1.7.2.9 *Seed Longevity*

Seed longevity is the seed viability after dry storage. Longevity was checked by germination test of the dry stored seeds at monthly interval for a period of 18 months.

3.3.1.7.3 *Agronomic Attributes (for Rice and Weedy Rice)*

3.3.1.7.3.1 *Plant Height*

Height of the plant was recorded at 50% flowering stage. The height was measured from the base of the plant to the tip of the longest leaf at vegetative stage and to the tip of the longest ear head at harvest stage. The mean was expressed in 'cm'.

3.3.1.7.3.2 *Days to 50 % Flowering*

Number of days taken by 50 % of the hills to flower was recorded.

3.3.1.7.3.3 *Leaf Area Index (LAI)*

Leaf Area Index was calculated at 50 % flowering stage. LAI was computed by the following formula developed by Watson (1947).

$$LAI = \frac{\text{Leaf area plant}^{-1}\ (cm^2)}{\text{Land area occupied by the plant}\ (cm^2)}$$

In field study as there was no definite spacing for weedy rice plants, leaf area m^{-2} was used to indicate the crux of this index.

3.3.1.7.3.4 *Leaf Area Duration of Flag Leaf*

Leaf area duration (LAD) was calculated using the formula suggested by Watson (1947) and expressed in days.

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

L_i = LAI at first stage

$L_i + 1$= LAI at second stage

$(t_2 - t_1)$ = time interval between stages in days

3.3.1.7.3.5 *Panicle Type*

Panicles were classified according to the branching, angle of primary branches and spikelet into various classes

- Compact
- Intermediate
- Open

3.3.1.7.3.6 Panicle Length

Length of main axis of five randomly selected panicles of observational plants was measured from base to the tip and the average expressed in 'cm'.

3.3.1.7.3.7 *Number of Grains Panicle^{-1}*

The entire spikelets including filled and unfilled grains were counted from five panicles and the mean number of spikelets panicle^{-1} was worked out.

3.3.1.7.3.8 *Sterility Percentage*

The number of filled and unfilled grains panicle^{-1} was obtained from ten randomly selected panicle separately and sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Number of total grains per panicle}} \times 100$$

3.3.1.7.3.9 *Grain Yield Plant^{-1}*

Five sample plants were harvested individually, threshed, cleaned, dried to 14 per cent moisture, weighed and average out to express the grain yield plant^{-1} in g plant^{-1}.

3.3.1.7.3.10 *Straw Yield Plant^{-1}*

The straw obtained from five sample plants was dried to constant weight under sun, weighed and averaged out and the straw yield expressed in g plant^{-1}.

3.3.1.7.3.11 *Thousand Grain Weight*

One thousand grains were counted from the cleaned and dried produce from the observational plants and the weight of the grains was recorded in 'g'.

3.3.2 Experiment II (a): Management of Weedy Rice by Enhancing Rice Competitiveness (Microplot Study)

3.3.2.1 *Methods*

3.3.2.1.1 *Design and Layout*

Design : Randomised Block Design (RBD)

Treatments : 9

Replication : 3

Variety : Uma

Season : Third crop, December 2014 - March 2015

Plot size : 1×1 m^2

3.3.2.1.2 *Treatments*

T_1- Seed rate of 100 kg ha^{-1} + without priming

T_2- Seed rate of 100 kg ha^{-1} + hydropriming

T_3- Seed rate of 100 kg ha^{-1} +hardening with 2.5 % KCl

T_4- Seed rate of 120 kg ha^{-1} + without priming

T_5- Seed rate of 120 kg ha^{-1} + hydropriming

T_6- Seed rate of 120 kg ha^{-1} + hardening with 2.5 % KCl

T_7- Seed rate of 140 kg ha^{-1} + without priming

T_8- Seed rate of 140 kg ha^{-1} +hydropriming

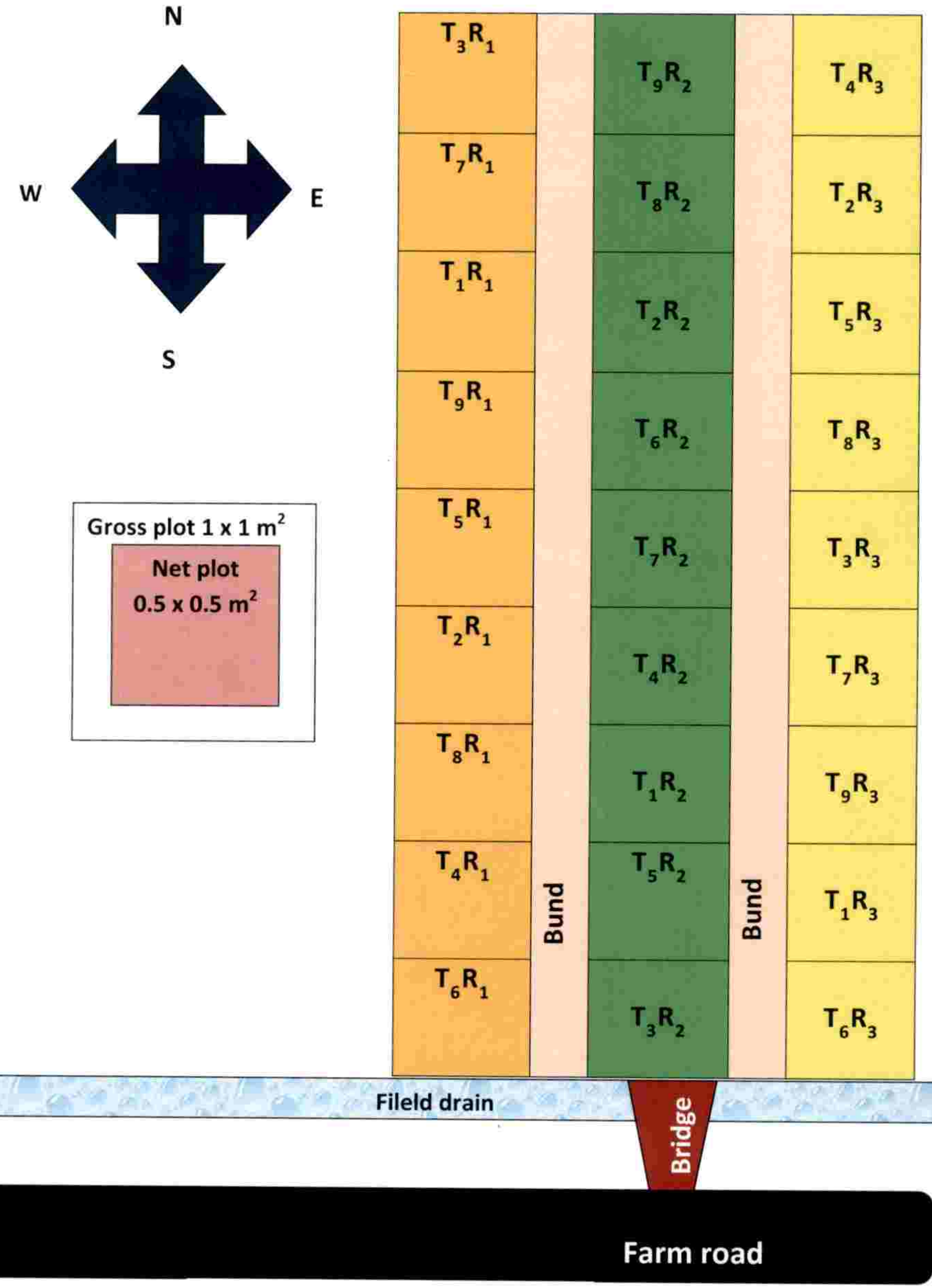

Plate 4: Layout of micorplot study

T_9- Seed rate of 140 kg ha^{-1} +hardening with 2.5 % KCl

3.3.2.1.3 *Field Preparation*

Weedy rice management by enhancing rice competitiveness in terms of high seeding density and seed priming was evaluated by raising cultivated rice and most common weedy rice morphotype in micro plots. The experimental area was ploughed twice, levelled and weeds and stubbles were removed. The micro plots of size 1 ×1 m^2 were separated by bunds of 10 cm width and drainage channels were provided on the sides.

3.3.2.1.4 *Application of Manures and Fertilizers*

Dry cowdung powder was incorporated at the time of last ploughing. Full dose of phosphorous along with half dose of nitrogen and potassium were applied as basal dose at 15 DAS and remaining dose of chemical fertilizers were topdressed at 55 days after sowing (DAS) as per the Package of Practices Recommendations 'Crops' (KAU, 2011).

3.3.2.1.5 *Application of Lime*

Lime @ 600 kg ha^{-1} was applied in two split doses, the first dose of 350 kg ha^{-1} as basal dressing at the time of first ploughing and the second dose of 250 kg ha^{-1} as top dressing one month after sowing. For top dressing, lime was applied one week prior to the application of fertilizers.

3.3.2.1.6 *Seed Treatment and Sowing*

Weighed quantities of seeds in accordance with the seed rate were subjected to hydropriming and hardening after germination test. In hydropriming, seeds were soaked in water for 48 h and redried back to original moisture content. In hardening, seeds were dipped in 2.5% KCl solution for 18 hours and redried back to original

Plate 5: General field view of microplot experiment

Plate 6: Bagged weedy rice panicle

Plate 7: A panicle of weedy rice in field situation

moisture content (Sheela, 1993). Seeds were broadcasted in each plot as per treatments.

3.3.2.1.7 ***Crop Management***

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

3.3.2.1.8 ***Weed Management***

Rice was raised along with the most common weedy rice of the locality maintaining a standard weedy rice population of 7 plants m^{-2} and the other weeds were removed as and when it appeared in the field.

3.3.2.1.9 ***Pest and Disease Management***

Rice bug incidence was managed by suitable IPM practices.

3.3.2.1.10 ***Harvest***

The crop was harvested when the grains attained maturity, leaving one row on four sides as border. The net plot area was harvested separately, threshed, winnowed and weight of grains and straw from individual plots were recorded. After panicle emergence weedy rice plants were separately bagged in order to prevent the shattering of grains. Grains from weedy rice and cultivated rice were harvested separately and yield was recorded.

3.3.2.1.11 ***Observations***

All the agronomic attributes of rice crop as well as weedy rice was recorded from the observational plants at the time of harvest. The methodology of all these observations are explained under 3.3.1.5.3

3.3.2.1.12 *Grain Yield ha^{-1}*

The net plot area leaving one border row from all sides was harvested individually, threshed, cleaned, dried to 14% moisture and weighed to express the grain yield in t ha^{-1}.

3.3.2.1.13 *Straw Yield ha^{-1}*

The straw obtained from net plot area was dried to constant weight under sun and weighed to express the straw yield in t ha^{-1}.

3.3.2.1.14 *Harvest Index (HI)*

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

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

3.3.3 Experiment II (b): Management of Weedy Rice by Enhancing Rice Competitiveness (Confirmatory Trial in Farmer's Field)

The field experiment was repeated under farmer's field situation during December 2015 to March 2016 for confirmation of results.

3.3.3.1 *Methods*

3.3.3.1.1 *Design and Layout*

Design : Randomised Block Design (RBD)

Treatments : 9

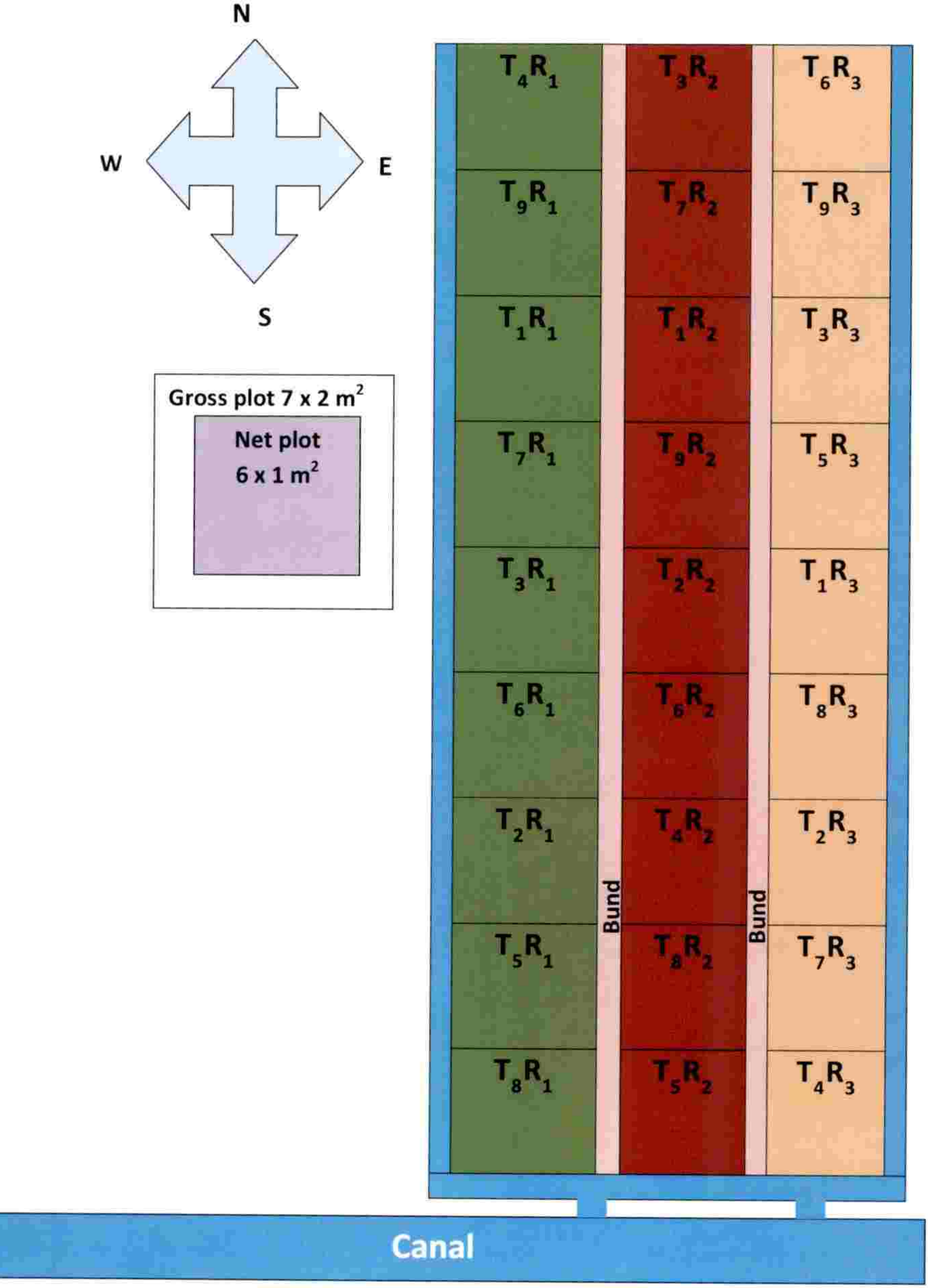

Plate 8: Layout of field expriment

Replication : 3

Variety : Uma

Season : Third crop, December 2015 - March 2016

Gross plot size : 7×2 m^2

Net plot size : 6×1 m^2

3.3.3.1.2 *Main Field Preparation*

The experimental area was ploughed twice, levelled and weeds and stubbles were removed. Three blocks with twenty seven plots were laid out in randomized design with a plot size of 7 x 2 m^2. The blocks were separated with bunds of 30 cm width and two drainage channels were provided in between the blocks. All other field level operations were repeated exactly as in Experiment II (a).

3.3.3.1.3 *Observations*

All set of observations listed under Experiment II (a) were repeated for this experiment also.

3.3.3.1.3.1 *Observations on Weeds*

3.3.3.1.3.1.1 *Weedy Rice Count m^{-2}*

Weedy rice population was estimated from the net plot area using a quadrat of size 50 x 50 cm from each plot at harvest stage. The weedy rice population was expressed as the number of plants m^{-2}.

Plate 9: General filed view of management study in farmers field

Plate 10: Various stages of rice establishment
a) Field layout b) Sowing
c) Harvesting d) Threshing

3.3.3.1.3.1.2 *Weedy Rice Dry Weight (g m^{-2})*

The weedy rice plants from the net plot area in each plot were uprooted, cleaned, dried under shade and oven dried at 70 ± 5 ^{0}C, till it recorded constant weight and expressed as g m^{-2}.

3.3.3.1.3.1.3 *Weed Control Efficiency*

Weed control efficiency was calculated using the following formula (Upadhyay and Sivanand, 1985).

$$WCE = \frac{(X-Y) \times 100}{X}$$

WCE = weed control efficiency

X = weed dry weight from treatment which recorded maximum number of weeds

Y = weed dry weight from the treatment for which weed control efficiency has to be worked out.

3.3.3.1.4 *Economic Analysis*

For analysing the economics of cultivation, net income and benefit cost ratio were determined based on cost of cultivation and prevailing price of the crop produce.

3.3.3.1.5 *Net Income*

Net income was computed using the formula, Net income (Rs. ha^{-1}) = Gross income – Cost of cultivation

3.3.3.1.6 ***Benefit Cost Ratio (BCR)***

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

3.3.4 Experiment III: Effect of Elevated CO_2 Concentration on Growth of Rice and Weedy Rice (Pot Culture in OTC)

3.3.4.1 ***Methods***

The most common morphotype of weedy rice and two cultivated rice varieties (Jyothi and Uma) were raised in pots under elevated CO_2 concentration of 500 ppm in OTC (Chamber A), OTC without external CO_2 supply (Chamber B) and Open condition.

3.3.4.1.1 ***Design and Layout***

Design : Completely Randomised Design

Treatments : 9

Replications : 3

Location : OTC at COA, Vellayani.

3.3.4.1.2 ***Treatments***

T_1- Jyothi in Chamber A

T_2- Weedy rice in Chamber A

T_3- Uma in Chamber A

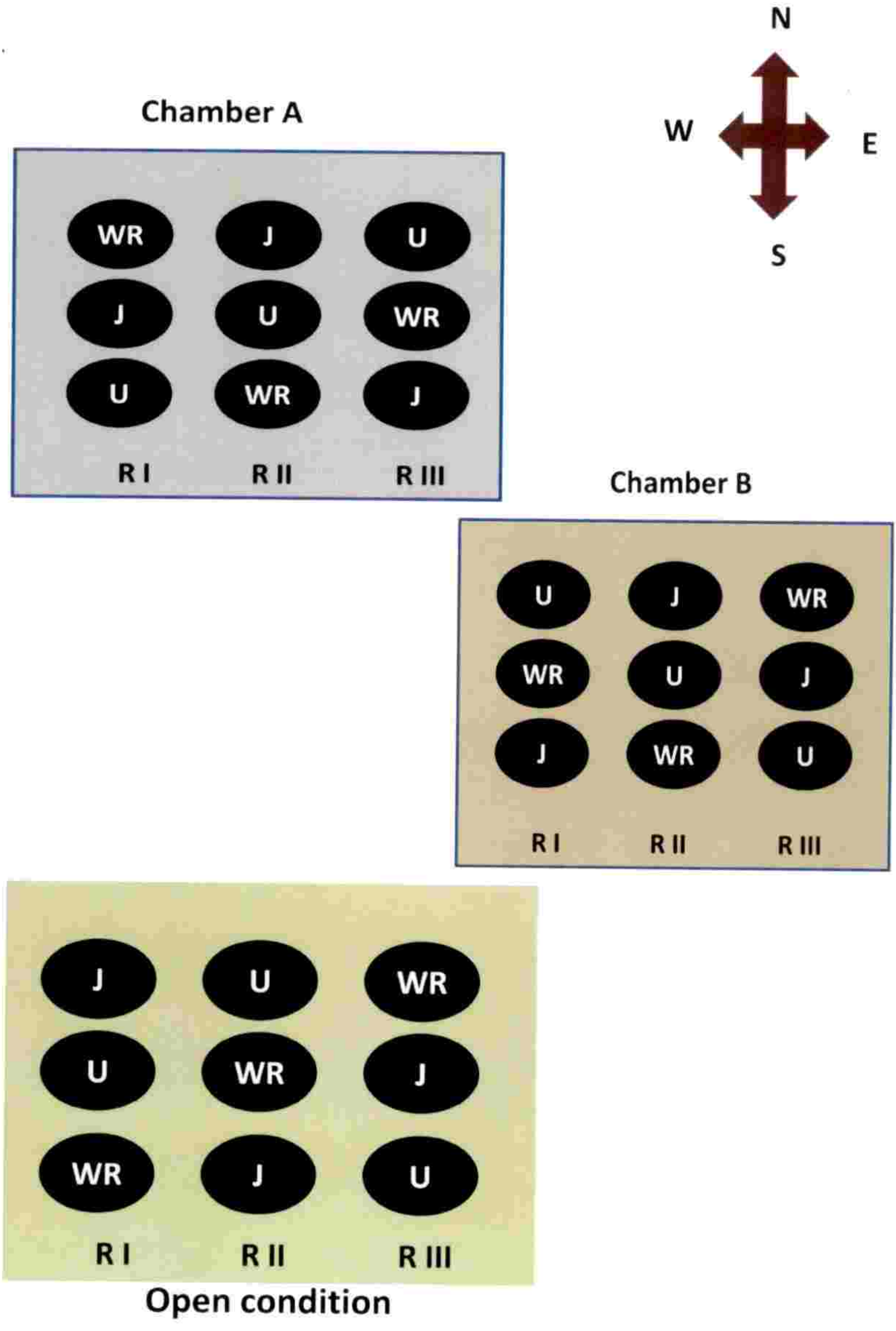

Plate 11: Layout of experiment at OTC

T_4- Jyothi in Chamber B

T_5- Weedy rice in Chamber B

T_6- Uma in Chamber B

T_7- Jyothi under open condition

T_8- Weedy rice under open condition

T_9- Uma under open condition

3.3.4.1.3 *Sowing and Establishment*

Seeds of most common morphotype of weedy rice present in the locality were allowed to germinate after breaking dormancy. Pre germinated seeds of Jyothi, Uma and weedy rice were sown (two seeds per pot) in plastic pots of size 30 cm depth and 20 cm diameter filled with clayey soil collected from rice field. Flooded situation was maintained throughout the crop growth period and all package of practices were followed.

3.3.4.1.4 *Pest and Disease Management*

No pest and disease were observed inside the chambers as well as open condition.

3.3.4.1.5 *Harvest*

After panicle emergence weedy rice panicles were separately bagged inorder to prevent shattering of grains. Panicles from weedy rice, Jyothi and Uma were harvested separately, grains removed and yield was recorded.

3.3.4.4 ***Observations***

All the yield attributing characters as explained under Experiment II were observed separately for Uma, Jyothi and Weedy rice at 30 DAS and 50% flowering.

3.3.4.6 ***Statistical Analysis***

The data recorded were subjected to Analysis of Variance techniques (ANOVA) as applied to Completely Randomized Design and Randomized Block Design described by Cochran and Cox (1965). The treatment *vs.* control comparison is denoted as 'S' when significant and 'NS' when not significant.

Results

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4. RESULTS

The experiment entitled "Characterization and management of weedy rice (*Oryza sativa* f. *spontanea*)" was taken up during 2014-16 as three separate experiments *viz.*, morpho- physiological and agronomic characterization of weedy rice (Pot culture); management of weedy rice by enhancing rice competitiveness (micro plot and farmers field); and effect of elevated CO_2 concentration on growth of rice and weedy rice. The main objectives of the study were morpho-physiological and agronomic characterization of weedy rice morphotypes of Kerala; formulation of management strategy and assessment of crop-weed interference under elevated CO_2 concentration. The data recorded from the study was analyzed statistically and the results are presented in this chapter.

4.1 EXPERIMENT I: MORPHO-PHYSIOLOGICAL AND AGRONOMIC CHARACTERIZATION OF WEEDY RICE MORPHOTYPES

4.1.1 Morphological Characterization

Observations were recorded based on the 'Morphological Descriptors for wild and cultivated rice' (IRRI, 2007).

4.1.1.1 *Attitude of Leaf Blade*

The result on attitude of leaf blade is presented in Table 2.

Leaf blade attitude of weedy rice morphotypes belonged to the categories of Erect, Semi erect and Descending. The most common leaf blade attitude was semi erect (intermediate) type similar to cultivated varieties *viz.,* Jyothi and Uma. This included morphotypes from Thiruvananthapuram, Kuttanad, Kole and Palakkad. Morphotypes collected from Palakkad with white coloured awns (WRM- 6) and Ezhome had descending attitude, while that from Kozhikode had an erect attitude.

Table 2. Attitude of leaf blade in weedy rice morphotypes and rice varieties

Treatment	Category			
	Erect	Semi erect (intermediate)	Horizontal	Descending
T_1(WRM- 1)	-	Thiruvananthapuram red	-	-
T_2 (WRM- 2)	-	Thiruvananthapuram white	-	-
T_3 (WRM- 3)	-	Kuttanad	-	-
T_4 (WRM- 4)	-	Kole	-	-
T_5 (WRM- 5)	-	Palakkad red	-	-
T_6 (WRM- 6)	-	-	-	Palakkad white
T_7 (WRM- 7)	Kozhikode	-	-	-
T_8 (WRM- 8)	-	-	-	Ezhome
Control				
Cultivar - 1	-	Jyothi	-	-
Cultivar - 2	-	Uma	-	-

WRM: Weedy Rice Morphotype

4.1.1.2 *Anthocyanin Colouration of Nodes*

The intensity of anthocyanin colouration at nodes of various morphotypes is presented in Table 3.

The intensity of colour varied from purple to purple lines. Similar to cultivated rice varieties (Jyothi and Uma), weedy rice morphotypes WRM- 2 (Thiruvananthapuram white), WRM- 3 (Kuttanad) and WRM- 7 (Kozhikode) lacked any anthocyanin pigmentation at the nodal region. However, morphotypes from Ezhome had an intense purple nodal pigmentation. Morphotypes from Kole (WRM- 4) and Palakkad (WRM- 5) had purple line, whereas those from Thiruvananthapuram (WRM- 1) and Palakkad (WRM- 6) had light purple pigmentation.

4.1.1.3 *Colour of Ligule*

The result on colour of ligule is presented in Table 4.

A wide variation in ligule colouration was observed ranging from whitish to purple line. Two of the morphotypes had ligule colour similar to cultivated rice varieties. Morphotypes from Thiruvananthapuram (WRM- 2), Kuttanad (WRM- 3) and Palakkad (WRM- 6) had whitish ligule, while another morphotype from Thiruvananthapuram (WRM- 1) and Palakkad (WRM- 5) had yellowish green ligule similar to Jyothi and Uma. Morphotype from Ezhome (WRM- 8) showed the same colour for ligule as well as nodal region *viz*., light purple. Morphotype from Kole (WRM- 4) belonged to purple line category and that from Kozhikode was in light purple category.

Table 3. Anthocyanin pigmentation of nodes in weedy rice morphoypes and rice varieties

Treatment	Category			
	Absent	Purple	Light purple	Purple lines
T_1 (WRM- 1)	-	Thiruvananthapuram red		-
T_2 (WRM- 2)	Thiruvananthapuram white	-	-	-
T_3 (WRM- 3)	Kuttanad	-	-	-
T_4 (WRM- 4)	-	-	Kole	-
T_5 (WRM- 5)	-	-	Palakkad red	-
T_6 (WRM- 6)	-	-	-	Palakkad white
T_7 (WRM- 7)	Kozhikode	-	-	-
T_8 (WRM- 8)	-	Ezhome	-	-
Control				
Cultivar - 1	Jyothi	-	-	-
Cultivar - 2	Uma	-	-	-

WRM: Weedy Rice Morphotype

Table 4. Colour of ligule in weedy rice morphotypes and rice varieties

Treatment	Category					
	Absent	Whitish	Yellowish green	Purple	Light purple	Purple lines
T_1(WRM- 1)	-	-	Thiruvananthapuram red	-	-	-
T_2(WRM- 2)	-	Thiruvananthapuram white	-	-	-	-
T_3(WRM- 3)	-	Kuttanad	-	-	-	-
T_4(WRM- 4)	-	-	-	-	-	Kole
T_5(WRM- 5)	-	-	Palakkad red	-	-	-
T_6(WRM- 6)	-	Palakkad white	-	-	-	-
T_7(WRM- 7)	-	-	-	-	Kozhikode	-
T_8(WRM- 8)	-	-	-	Ezhome	-	-
Control						
Cultivar – 1	-	-	Jyothi	-	-	-
Cultivar – 2	-	-	Uma	-	-	-

WRM: Weedy Rice Morphotype

4.1.1.4 *Colour of Awn*

The result on awn colour is presented in Table 5.

There was wide variation in the colour of awns ranging from whitish to black. Morphotype from Kozhikode (WRM- 7) had whitish awn colour while that from Thiruvananthapuram (WRM- 2) and Kuttand (WRM- 3) had straw coloured awns. Morphotype from Kole alone (WRM- 4) had brown coloured awns. Morphotypes from Palakkad (WRM- 6) exhibited light green and red coloured (WRM- 5) awns. Another morphotype from Thiruvananthapuram (WRM- 1) had red coloured awns, while purple coloured awn was observed in Ezhome (WRM- 8).

4.1.1.5 *Length of ligule (mm)*

The results are presented in Table 6.

A significant variation was noticed in the ligule length of morphotyes during initial stages and at 50 per cent flowering stage. During initial stages, the ligule length ranged from 3.70 mm (WRM- 4) to 13.7 mm (WRM- 8). Ligule length of WRM- 2 was found to be on par with WRM- 5 and WRM- 7 (4mm). Among cultivated rice varieties, Jyothi recorded higher ligule length (9.7 mm) compared to Uma (6.7 mm) at 15 DAS. At 50 per cent flowering, ligule length became insignificant with Uma recording a ligule length of 7.7 mm. Among weedy rice morphotypes, Palakkad (WRM- 6) recorded significantly higher ligule length (22.3 mm) followed by Ezhome and Thiruvananthapuram with a ligule length of 14.7 and 14 mm. At 50 per cent flowering morphotype from Kozhikode (WRM- 7) recorded significantly lower ligule length (4.3 mm) and was comparable with morphotypes from Kole (WRM-4) and Palakkad (WRM- 5) with a ligule length of 5 and 5.3 mm respectively.

Table 5. Pigmentation of awns in weedy rice morphotypes

Treatment	Category								
	Absent	Whitish	Straw	Gold	Brown	Light green	Red	Purple	Black
T_1 (WRM- 1)	-	-	-	-	-	-	TVM red	-	-
T_2 (WRM- 2)	-	-	TVM white	-	-	-	-	-	-
T_3 (WRM- 3)	-	-	Kuttanad	-	-	-	-	-	-
T_4 (WRM- 4)	-	-	-	-	Kole	-	-	-	-
T_5 (WRM- 5)	-	-	-	-	-	-	PKD red	-	-
T_6 (WRM- 6)	-	-	-	-	-	PKD white	-	-	-
T_7 (WRM- 7)	-	Kozhikode	-	-	-	-	-	-	-
T_8 (WRM- 8)	-	-	-	-	-	-	-	Ezhome	-
Control									
Cultivar - 1	Jyothi	-	-	-	-	-	-	-	-
Cultivar - 2	Uma	-	-	-	-	-	-	-	-

WRM: Weedy Rice Morphotype TVM: Thiruvananthapuram PKD: Palakkad

4.1.1.6 *Culm thickness (cm)*

The results are presented in Table 6.

Culm thickness during initial stages varied from 1.57 to 2.43 cm. Morphotype from Thiruvananthapuram (WRM- 1) recorded a higher culm thickness (2.43 cm) followed by morphotypes from Kole (2.4 cm), Palakkad (2.3 cm) and Kozhikode (2.07 cm). A significantly lower culm thickness was recorded by morphotype from Thiruvananthapuram (WRM- 2) and Ezhome (WRM-8) at 1.57 cm each at 15 DAS. No significant difference in culm thickness was observed between cultivated rice varieties (Jyothi and Uma) and weedy rice morphotypes during initial stages. There was a significant difference in the culm thickness of weedy rice and cultivated rice at reproductive stage. At 50 per cent flowering morphotype from Kuttandu recorded a significantly higher culm thickness (3.37 cm), followed by Thiruvananthapuram (3.23 cm) while rice varieties Jyothi and Uma had a culm thickness of 1.93 and 2.27 cm only. All the weedy rice morphotypes had higher culm thickness compared to cultivated rice varieties at 50 per cent flowering stage.

4.1.1.7 *Number of tillers plant^{-1}*

The results are presented in Table 6.

There was a marked difference in the tillering habit of weedy rice morphotypes and cultivated rice varieties. Number of tillers in weedy rice morphotypes was found to range from 8 to 20. Morphotype from Palakkad with red awn colour showed a significantly higher tillering habit (20), which was on par with the number of tillers plant^{-1} in morphotypes from Thiruvananthapuram (16 and 17) and Kole (16). Morphotype from Ezhome only exhibited a low tillering habit compared to cultivated rice varieties.

Table 6. Length of ligule, culm thickness and number of tillers plant^{-1} of WRM and rice varieties

Treatment	Length of ligule (mm)		Culm thickness (cm)		No of tillers plant^{-1}
	15 DAS	50 % Flowering	15 DAS	50 % Flowering	50 % Flowering
T_1 (WRM- 1)	5.70	11.00	2.43	2.57	15.67
T_2 (WRM- 2)	10.30	14.00	1.57	3.23	16.67
T_3 (WRM- 3)	6.70	7.30	2.00	3.37	13.67
T_4 (WRM-4)	3.70	5.00	2.40	2.43	16.00
T_5 (WRM-5)	4.00	5.30	1.73	2.47	19.67
T_6 (WRM-6)	6.00	22.30	2.30	2.57	13.00
T_7 (WRM-7)	4.00	4.30	2.07	2.27	11.67
T_8 (WRM-8)	13.70	14.30	1.57	2.43	8.33
SE m (±)	0.60	0.40	0.37	0.08	0.94
CD (0.05)	1.90	1.60	0.41	0.22	2.68
Control					
Cultivar –1(Jyothi)	9.70	10.30	1.87	1.93	10.33
Cultivar – 2 (Uma)	6.70	7.70	2.20	2.27	9.00
C-1 vs Treatments	S	NS	NS	S	S
C-2 vs Treatments	NS	S	NS	S	S

`WRM: Weedy Rice Morphotype DAS: Days After Sowing

4.1.2 Physiological Characterisation

4.1.2.1 *Chlorophyll Content (mg 100 g^{-1})*

The results are presented in Table 7.

There was no significant difference between the chlorophyll a content of weedy rice morphotypes and cultivated rice varieties during initial stages, but at 50 per cent flowering stage a marked difference was observed. Morphotype from Ezhome recorded significantly higher chlorophyll a content both at 15 DAS (1.74 mg 100g^{-1}) and at 50 per cent flowering stage (1.84 mg 100g^{-1}). There was no significant increase in chlorophyll a content during the course of growth. Morphotype from Thiruvananthapuram and Kozhikode recorded significantly lower chlorophyll a content at 15 DAS (1.26 mg 100g^{-1}) and at 50 per cent flowering stage (0.93 mg 100g^{-1}).

No significant difference was observed between rice and weedy rice in chlorophyll b content at 15 DAS and at 50 per cent flowering. Highest chlorophyll b content at 15 DAS was recorded by morphotype collected from Ezhome (0.69 mg 100g^{-1}) followed by morphotype from Kozhikode (0.36 mg 100g^{-1}). At 50 per cent flowering stage morphotype from Thiruvananthapuram (0.53 mg 100g^{-1}) recorded higher chlorophyll b content followed by the morphotype from Kole (0.52 mg 100 g^{-1}).

No significant difference was observed in total chlorophyll content during the initial stages (15 DAS), while a marked difference was there during the later stages (at 50 per cent flowering stage). Morphotype from Ezhome (WRM-8) recorded higher total chlorophyll content of 2.43 mg 100g^{-1} during the initial stages followed by that from Kozhikode. Morphotype from Thiruvananthapuram (WRM-2) recorded lower total chlorophyll content of 1.54 mg 100g^{-1}.

Table 7. Chlorophyll and Total soluble protein content in WRM and rice varieties

Treatment	Total chlorophyll (mg 100^{-1} g)		Chlorophyll a (mg 100^{-1} g)		Chlorophyll b (mg 100^{-1} g)		TSP (mg g^{-1})	
	15 DAS	50% FLW	15 DAS	50% FLW	15 DAS	50% FLW	15 DAS	50% FLW
T_1 (WRM- 1)	1.68	2.20	1.35	1.68	0.33	0.53	0.13	1.07
T_2 (WRM- 2)	1.54	1.71	1.26	1.34	0.28	0.38	0.30	0.84
T_3 (WRM- 3)	1.63	1.76	1.33	1.37	0.30	0.39	0.30	0.56
T_4 (WRM-4)	1.72	1.63	1.46	1.11	0.26	0.52	0.41	0.59
T_5 (WRM-5)	1.62	2.19	1.31	1.70	0.32	0.49	0.45	0.61
T_6 (WRM-6)	1.61	2.00	1.30	1.53	0.31	0.48	0.36	0.50
T_7 (WRM-7)	1.79	1.18	1.44	0.93	0.36	0.25	0.18	0.55
T_8 (WRM-8)	2.43	1.72	1.74	1.84	0.69	-0.12	0.43	0.83
SE m (±)	0.68	0.03	1.16	0.04	0.80	1.19	1.57	1.75
CD (0.05)	0.00	0.02	0.00	0.03	0.01	0.01	0.01	0.01
Control								
Cultivar– 1 (Jyothi)	1.17	2.52	0.86	1.73	0.31	0.79	0.51	0.73
Cultivar – 2 (Uma)	1.15	3.41	0.92	1.61	0.24	1.80	0.44	1.38
C-1 vs Treatments	NS	S	NS	S	NS	NS	NS	NS
C-2 vs Treatments	NS	S	NS	S	NS	NS	NS	NS

WRM: Weedy Rice Morphotype DAS: Days After Sowing

FLW: Flowering TSP: Total Soluble Protein

A significant difference in total chlorophyll content was observed between weedy rice morphotypes and cultivated rice varieties at 50 per cent flowering stage. Among the weedy rice morphotypes, Thiruvananthapuram (WRM-1) recorded significantly higher total chlorophyll content (2.20 mg $100g^{-1}$), followed by Palakkad (2.19 mg $100g^{-1}$). Morphotype from Kozhikode (1.18 mg $100g^{-1}$) recorded significantly lower total chlorophyll content. Rice variety Uma recorded significantly higher chlorophyll content (3.41) followed by Jyothi (2.52 mg $100g^{-1}$).

4.1.2.2 *Total Soluble Protein (mg g^{-1})*

The results are presented in Table 7.

No significant variation was observed between the Total Soluble Protein (TSP) of rice and weedy rice morphotypes at both the stages. TSP of weedy rice morphotypes ranged from 0.13 to 0.45 mg g^{-1} at 15 DAS and 0.50 to 1.07 mg g^{-1} at 50 per cent flowering stage. Morphotype from Palakkad recorded a higher TSP value at 15 DAS while that from Thiruvananthapuram recorded lower TSP at 50 per cent flowering (1.07 mg g^{-1}).

4.1.2.3 *Stomatal Characteristics*

4.1.2.3.1 *Stomatal Frequency (no of stomata cm^{-2})*

The results are presented in Table 8.

Stomatal frequency expressed as the number of stomata cm^{-2} was used to assess the photosynthetic efficiency of the particular plant group. Stomatal number was counted both at adaxial and abaxial surfaces. It was found that most of the weedy rice morphotypes had a higher stomatal count and frequency than cultivated rice varieties Jyothi and Uma. However, it was statistically non significant. Morphotypes collected from Palakkad, Kole, Kuttanad, Thiruvananthapuram and

Table 8. Stomatal characteristics of WRM and rice varieties

Treatment	Stomatalfrequency (no of stomata cm^{-2})		Stomatal conductance (milli moles m^{-2} s^{-1})
	Adaxial	Abaxial	15 DAS
T_1 (WRM- 1)	659.22	536.32	58.80
T_2 (WRM- 2)	477.10	346.74	179.10
T_3 (WRM- 3)	636.88	413.41	124.45
T_4 (WRM-4)	715.09	647.67	107.30
T_5 (WRM-5)	703.92	491.25	106.10
T_6 (WRM-6)	726.26	391.06	159.75
T_7 (WRM-7)	569.83	480.45	66.25
T_8 (WRM-8)	659.59	603.36	48.20
SE m (±)	48.01	38.33	24.02
CD (0.05)	143.96	114.92	72.01
Control			
Cultivar– 1 (Jyothi)	581.01	435.75	125.45
Cultivar – 2 (Uma)	693.11	602.98	123.60
C-1 vs Treatments	NS	NS	NS
C-2 vs Treatments	NS	NS	NS

WRM: Weedy Rice Morphotype

Ezhome showed a higher stomatal count (704, 715, 637, 659 and 660 cm^{-2} respectively) compared to cultivated variety Jyothi (581 cm^{-2}) on the adaxial surface. Morphotype from Thiruvananthapuram recorded a lower stomatal count (477 cm^{-2}) in comparison with cultivated rice varieties on the adaxial side. The same trend was observed in abaxial surface also.

4.1.2.3.2 *Stomatal Conductance (milli moles m^{-2} s^{-1})*

The results are presented in Table 8.

Stomatal conductance was found to be non significant between weedy rice and cultivated rice. Stomatal conductance of cultivated rice varieties Jyothi and Uma were 125.45 and 123.60 milli moles m^{-2} s^{-1} respectively while weedy rice morphotypes exhibited a wide variation ranging from 48.20 milli moles m^{-2} s^{-1} (Ezhome) to 179.10 milli moles m^{-2} s^{-1} (Thiruvananthapuram).

4.1.2.4 *Root Characters*

A marked difference was observed in the root characteristics of rice and weedy rice especially in root volume and root dry weight.

4.1.2.4.1 *Root Volume* (cm^3)

The results are represented in Table 9.

A significant variation was observed in the root volume of rice and weedy rice both at 15 DAS and 50 per cent flowering. At 15 DAS, Jyothi and Uma recorded a root volume of 14.13 and 7.07 cm^3 respectively while morphotype from Kuttanad recorded a very high root volume of 35.33 cm^3 followed by Palakkad (28.26 cm^3). It was noticed that there exist an increment of 2.5 to 5 times in root volume between weedy rice morphotypes and cultivated rice. At harvest stage also a wide variation was observed, with morphotype from Palakkad recording a higher root volume (84.78

Table 9. Root volume, root dry weight and root shoot ratio of WRM and rice

Treatment	Root volume (cm^3)		Root dry weight (g)		Root shoot ratio	
	15 DAS	Harvest	15 DAS	Harvest	15 DAS	Harvest
T_1 (WRM- 1)	21.20	70.65	0.15	7.15	0.25	0.31
T_2 (WRM- 2)	7.07	84.31	0.12	9.60	0.36	0.39
T_3 (WRM- 3)	35.33	77.61	0.49	14.80	0.37	0.55
T_4 (WRM-4)	14.13	70.31	0.73	9.15	0.30	0.36
T_5 (WRM-5)	28.26	84.78	0.26	13.25	0.47	0.45
T_6 (WRM-6)	7.07	77.72	0.35	7.45	0.36	0.30
T_7 (WRM-7)	14.13	70.33	0.17	9.00	0.34	0.34
T_8 (WRM-8)	14.13	84.39	0.15	12.50	0.43	0.43
SE m (±)	0.78	0.16	0.02	0.34	0.87	0.04
CD (0.05)	5.83	0.49	0.03	1.01	0.00	0.04
Control						
Cultivar– 1 (Jyothi)	14.13	56.48	0.21	10.10	0.38	0.38
Cultivar – 2 (Uma)	7.07	63.51	0.06	6.70	0.28	0.28
C-1 vs Treatments	S	S	S	NS	NS	NS
C-2vs Treatments	S	S	S	S	NS	NS

WRM: Weedy Rice Morphotype DAS: Days After Sowing

cm^3) followed by Thiruvananthapuram (84.31 cm^3), while root volume of cultivated rice varieties Jyothi and Uma were 56.48 and 63.51 cm^3 respectively. At harvest stage also an increment of 1.3 to 1.5 times was observed between the root volumes of weedy rice and cultivated rice.

4.1.2.4.2 *Root Dry Weight (g)*

The results on root dry weight are presented in Table 9.

A significant variation was observed in the root dry weight of various weedy rice morphotypes and cultivated rice varieties. At 15 DAS, morphotype from Kole recorded significantly higher root dry weight of 0.73 g followed by Kuttanad (0.49 g), while cultivated rice varieties Jyothi and Uma recorded lower values of 0.21 g and 0.06 g respectively. At the harvest stage also a significant variation was observed, with morphotype from Kuttanad recording higher root dry weight (14.80 g) followed by Palakkad (13.25 g).

4.1.2.4.3 *Root Shoot Ratio*

The results are presented in Table 9.

No significant variation was observed between the root shoot ratios of weedy rice and cultivated rice. Weedy rice morphotypes had a root shoot ratio of 0.30 to 0.55, while it was 0.28 to 0.38 for the cultivated rice varieties at harvest.

4.1.2.5 *Grain Threshability (per cent)*

The result on grain threshability is presented in Table 10.

Shattering percentage expressed as grain threshability was studied using hand grip method. A significant difference in grain threshability was observed between weedy rice and cultivated rice (Uma). Grain threshability of weedy rice morphotypes

Table 10. Grain threshability and seed longevity of WRM and rice after harvest

Treatment	Grain threshability (%)	Seed longevity (months)
T_1 (WRM- 1)	35.28	12.00
T_2 (WRM- 2)	37.80	10.67
T_3 (WRM- 3)	46.32	15.00
T_4 (WRM-4)	34.04	9.00
T_5 (WRM-5)	30.02	14.00
T_6 (WRM-6)	29.73	10.00
T_7 (WRM-7)	30.13	8.00
T_8 (WRM-8)	41.17	4.97
SE m (±)	2.02	0.80
CD (0.05)	6.07	2.41
Control		
Cultivar– 1 (Jyothi)	34.35	6.00
Cultivar – 2 (Uma)	17.83	9.03
C-1 vs Treatments	NS	S
C-2 vs Treatments	S	NS

WRM: Weedy Rice Morphotype

ranged from 29.73 per cent to 46.32 per cent, while it was 17 and 34 per cent for cultivated rice varieties Uma and Jyothi respectively. High grain threshability in weedy rice indicates its grain shattering nature. Among the weedy rice morphotypes, WRM-3 from Kuttanad recorded a significantly higher grain threshability.

4.1.2.6 *Seed Longevity (months)*

The results are presented in Table 10.

Seed longevity studied for a period of 18 months at monthly interval indicated longer period of viability for weedy rice morphotypes compared to cultivated varieties. Seed longevity of weedy rice was found to range from 5 to 18 months, while for cultivated varieties (Jyothi and Uma) it ranged between 6 to 9 months. Weedy rice morphotype collected from Kuttanad recorded significantly higher seed longevity compared to other morphotypes.

4.1.3 Agronomic Characterization

4.1.3.1 *Growth Attributes at Harvest*

4.1.3.1.1 *Plant Height (cm)*

The result on plant height is presented in Table 11.

A significant variation existed in plant height between weedy rice morphotypes and cultivated rice varieties. All the weedy rice morphotypes were taller than cultivated rice and its height ranged from 105 to 115.67 cm. Morphotype collected from Thiruvananthapuram was found to be taller followed by that from Palakkad, while height of cultivated rice varieties Jyothi and Uma were 96 and 91 cm respectively.

4.1.3.1.2 *Days to 50 per cent Flowering*

The results are presented in Table 11.

Earliness in flowering was observed for weedy rice morphotypes compared to cultivated rice varieties. Days to 50 per cent flowering of weedy rice morphotypes was found to range between 49 to 51 days, while that of cultivated rice varieties ranged between 62 to 82 days. Morphotype from Kole flowered earlier followed by morphotype from Palakkad.

4.1.3.1.3 *Leaf Area Index (LAI)*

The results are presented in Table 11.

Most of the weedy rice morphotypes had a very high LAI value compared to cultivated rice (above 5) at 50 per cent flowering stage. Morphotype from Palakkad recorded significantly higher LAI of 5.74, while that from Ezhome recorded lower value of 2.20. Cultivated rice varieties Jyothi and Uma recorded LAI values of 3.30 and 3.44 respectively.

4.1.3.1.4 *Leaf Area Duration (LAD)*

The results are presented in Table 11.

No significant variation was observed between the LAD of weedy rice and cultivated rice varieties. It was found to be 31 to 32 days for weedy rice and 33 to 34 days for cultivated rice.

4.1.3.2 *Yield Attributes at Harvest*

4.1.3.2.1 *Panicle Length (cm)*

The results are presented in Table 12.

Table 11. Vegetative attributes of WRM and rice varieties at 50% flowering

Treatment	Plant height (cm)	Days to 50% flowering (Days)	LAI	LAD of FL
T_1 (WRM- 1)	108.97	51.43	5.24	32.00
T_2 (WRM- 2)	115.67	51.03	4.22	33.67
T_3 (WRM- 3)	110.20	50.36	3.90	32.67
T_4 (WRM-4)	110.80	49.63	4.96	32.67
T_5 (WRM-5)	113.27	50.13	5.74	31.67
T_6 (WRM-6)	112.77	50.19	5.63	32.33
T_7 (WRM-7)	108.83	51.13	3.77	33.33
T_8 (WRM-8)	105.07	50.43	2.20	31.33
SE m (±)	0.73	2.65	0.32	1.03
CD (0.05)	2.19	NS	0.94	NS
Control				
Cultivar–1 (Jyothi)	96.17	61.58	3.30	33.00
Cultivar – 2 (Uma)	91.17	81.88	3.44	34.00
C-1 vs Treatments	S	S	S	NS
C-2 vs Treatments	S	S	S	NS

WRM: Weedy Rice Morphotype

LAD: Leaf area duration

LAI: Leaf area index

FL: flag leaf

A significant variation in panicle length was observed between weedy rice and cultivated rice. All the weedy rice morphotypes recorded panicle length in the range of 16 to 18 cm, except the morphotype from Palakkad (22.13 cm). Panicle length of cultivated rice varieties Jyothi and Uma were 23.00 and 23.73 cm respectively. Morphotype from Kozhikode recorded lower panicle length of 16.80 cm.

4.1.3.2.2 *Number of Grains Panicle^{-1}*

The result is presented in Table 12.

Number of grains panicle^{-1} in weedy rice morphotypes was found to be lower compared to cultivated rice varieties. Number of grains panicle^{-1} in weedy rice morphotypes ranged between 45 to 60 while, cultivated rice varieties recorded higher number of grains panicle^{-1} (66 and 94).

4.1.3.2.3 *Sterility Percentage*

The results are presented in Table 12.

A significant variation was observed in the sterility percentage of rice and weedy rice. Weedy rice morphotypes exhibited a higher sterility percentage of 17.78 to 32.79, while the cultivated rice varieties exhibited a lower sterility percentage of 9.24 to 12.85. Morphotype from Kuttanad recorded a higher sterility percentage of 32.79 followed by that from Ezhome (26.72).

4.1.3.2.4 *Thousand Grain Weight (g)*

The results are presented in Table 13.

Weedy rice morphotypes exhibited a lower thousand grain weight compared to cultivated rice varieties. Test weight (1000 grain weight) of weedy rice

Table 12. Yield attributes of WRM and rice varieties at harvest

Treatment	Panicle length(cm)	No of grains / panicle	Sterility percentage
T_1 (WRM- 1)	17.43	59.00	26.55
T_2 (WRM- 2)	17.67	57.00	22.78
T_3 (WRM- 3)	16.83	50.00	32.79
T_4 (WRM-4)	16.83	45.67	24.19
T_5 (WRM-5)	17.57	53.33	17.78
T_6 (WRM-6)	22.13	59.00	19.09
T_7 (WRM-7)	16.80	60.33	21.63
T_8 (WRM-8)	18.17	48.67	26.72
SE m (±)	0.50	3.20	3.49
CD (0.05)	1.51	9.60	NS
Control			
Cultivar–1 (Jyothi)	23.00	66.33	12.85
Cultivar – 2 (Uma)	23.73	93.67	9.24
C-1vs Treatments	S	S	S
C-2vs Treatments	S	S	S

WRM: Weedy Rice Morphotype

morphotypes ranged between 20.03 to 21g, while cultivated rice varieties recorded a higher value (Jyothi: 22.77 g; Uma: 23.80g).

4.1.3.2.5 *Grain Yield (g plant^{-1})*

The results are presented in Table 13.

Grain yield of cultivated rice varieties was found to be superior in comparison with the grain yield of weedy rice morphotypes. Grain yield of weedy rice morphotypes ranged between 4.35 to 5.36 g plant^{-1}. Morphotype from Kuttanad registered significantly higher grain yield (5.36 g) followed by Palakkad (5.3 g plant^{-1}) and Ezhome (5.29 g plant^{-1}). Cultivated rice varieties Jyothi and Uma recorded grain yields of 8.98 and 10.53 g plant^{-1} respectively.

4.1.3.2.6 *Straw Yield (g plant^{-1})*

The result is presented in Table 13.

A significant variation was observed in the straw yield of rice and weedy rice morphotypes, while it was found non significant among the various morphotypes. Weedy rice morphotype from Palakkad recorded a higher yield of 17.96 g plant^{-1} followed by Kuttanad (17.76 g plant^{-1}). Cultivated rice varieties Jyothi and Uma recorded straw yields of 23.34 and 20.55 g plant^{-1} respectively.

4.1.3.2.7 *Panicle Type*

The result on panicle type is presented in Table 14.

As per morphometric descriptors of IRRI, panicle is classified in to three different types *viz.,* compact, intermediate and open. Morphotypes from Thiruvananthapuram, Kole and Palakkad had compact panicle similar to Jyothi and Uma.

Table 13. Yield attributes of WRM and rice varieties at harvest

Treatment	1000 grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant^{-1} (g)
T_1 (WRM- 1)	20.61	4.78	15.51
T_2 (WRM- 2)	21.00	4.35	14.09
T_3 (WRM- 3)	20.17	5.36	17.76
T_4 (WRM-4)	20.30	4.99	15.19
T_5 (WRM-5)	20.03	4.64	15.61
T_6 (WRM-6)	20.17	5.30	17.96
T_7 (WRM-7)	20.27	4.42	15.80
T_8 (WRM-8)	20.87	5.29	17.21
SE m (±)	0.43	0.21	0.92
CD (0.05)	NS	0.63	NS
Control			
Cultivar–1 (Jyothi)	22.77	8.98	23.34
Cultivar – 2 (Uma)	22.80	10.53	20.55
C-1 vs Treatments	S	S	S
C-2 vs Treatments	S	S	S

WRM: Weedy Rice Morphotype

4.1.3.2.8 *Awn Length (cm)*

The result on awn length is presented in Table 14.

Awn length ranged from 2.38 to 9.23 cm, with morphotype from Ezhome having the longest awn (9.23 cm) followed by that from Thiruvananthapuram (7.41 cm) and Kozhikode (7.36 cm). Both the cultivated rice varieties Jyothi and Uma lacked awns.

4.2 EXPERIMENT: II (a) MANAGEMENT OF WEEDY RICE BY ENHANCING RICE COMPETITIVENESS (MICRO PLOT EXPERIMENT)

4.2.1 Effect of Treatments on Agronomic Attributes of Rice at Harvest

4.2.1.1 *Plant Height (cm)*

The result is presented in Table 15.

Plant height remained unaffected due to various treatments. Plant height of rice was found to range from 108.0 to 139.0 cm.

4.2.1.2 *Days to 50 per cent Flowering*

The results on days to 50 per cent flowering are presented in Table 15.

Data showed that days to 50 per cent flowering were not influenced by the weed management practices.

4.2.1.3 *Leaf Area Index (LAI)*

The result on Leaf Area Index is presented in Table 15.

LAI was significantly influenced by the various management practices. It ranged between 2.5 to 5.44. T_7 (seed rate of 140 kg ha^{-1}) recorded significantly

Table 14. Panicle type and awn length of WRM and rice varieties

Treatment	Panicle type	Awn length (cm)
T_1 (WRM- 1)	Compact	4.31
T_2 (WRM- 2)	Intermediate	7.41
T_3 (WRM- 3)	Intermediate	3.48
T_4 (WRM-4)	Compact	4.11
T_5 (WRM-5)	Compact	6.69
T_6 (WRM-6)	Intermediate	2.38
T_7 (WRM-7)	Open	7.36
T_8 (WRM-8)	Open	9.23
SE m (±)	-	0.03
CD (0.05)	-	0.12
Control		
Cultivar–1 (Jyothi)	Compact	Absent
Cultivar – 2 (Uma)	Compact	Absent

WRM: Weedy Rice Morphotype

Table 15. Effect of treatments on vegetative characters of rice at harvest (microplot study)

Treatment	Plant height (cm)	Days to 50% flowering (Days)	LAI	LAD of flag leaf (Days)
T_1 - seed rate of 100 kg ha^{-1} + without priming	108.33	80.82	2.81	39.90
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	125.58	81.61	2.98	39.24
T_3 - seed rate of 100 kg ha^{-1} + hardening with 2.5 % KCl	125.88	80.87	2.50	40.24
T_4 - seed rate of 120 kg ha^{-1} + without priming	110.28	81.08	4.86	40.24
T_5 - seed rate of 120 kg ha^{-1} + hydropriming	120.45	80.90	2.90	40.57
T_6 - seed rate of 120 kg ha^{-1} + hardening with 2.5 % KCl	117.33	81.25	4.22	40.24
T_7 - seed rate of 140 kg ha^{-1} + without priming	121.67	81.45	5.44	40.90
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	125.64	80.99	4.85	39.24
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	139.43	81.31	2.85	40.57
SE m (±)	7.51	0.45	0.35	1.14
CD (0.05)	NS	NS	1.05	NS

LAI: Leaf Area Index LAD: Leaf Area Duration

higher LAI value of 5.44 and was on par with T_8 (4.85). Seed rate of 100 kg ha^{-1} along with hardening recorded distinctly lower LAI of 2.5 and was found to be on par with other treatments of same seed rate (T_1 and T_2 with 2.81 and 2.98).

4.2.1.4 *Leaf Area Duration (LAD) of Flag Leaf (Days)*

The results on LAD are presented in Table 15.

Weed management practices did not have any influence on LAD of flag leaf. All treatment combinations of varying seed rates and priming techniques recorded LAD values between 39 to 40 days.

4.2.1.5 *Panicle Length (cm)*

The result on panicle length is presented in Table 16.

The length of panicle was not significantly influenced by any of the treatments.

4.2.1.6 *Number of Grains Panicle^{-1}*

The results are presented in Table 16.

The number of grains per panicle was significantly influenced by the various management practices. Treatment with a seed rate of 100 kg ha^{-1} along with hydropriming (T_2) recorded significantly higher number of grains per panicle (120) and was on par with T_5 (seed rate of 120 kg ha^{-1} along with hydropriming). A seed rate of 140 kg ha^{-1} without priming (T_7) recorded significantly lower number of grains panicle^{-1} (99), which was on par with same seed rate (T_8 andT_9). Priming methods also exhibited significant effect on number of grains panicle^{-1}. Seeds subjected to

Table 16. Effect of treatments on yield attributes of rice at harvest (microplot study)

Treatment	Panicle length (cm)	No of grains $panicle^{-1}$	Sterility percentage
T_1 - seed rate of 100 kg ha^{-1} + without priming	21.57	105.90	14.87
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	20.86	120.02	10.40
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	21.41	112.89	12.83
T_4 - seed rate of 120 kg ha^{-1} + without priming	20.63	112.74	12.73
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	21.28	119.81	11.58
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	20.93	116.73	12.12
T_7 - seed rate of 140 kg ha^{-1} + without priming	21.35	99.77	16.92
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	20.72	106.33	16.05
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	21.50	105.29	15.79
SE m(±)	0.53	1.36	0.12
CD (0.05)	NS	4.08	0.37

hydropriming recorded panicles with more number of grains compared to seeds subjected to hardening.

4.2.1.7 *Sterility Percentage*

The result on sterility percentage is presented in Table 16.

The data indicated that sterility percentage was significantly influenced by various management practices. Seed rate of 100 kg ha^{-1} with hydropriming recorded significantly lower sterility percentage of 10.4 and was on par with T_5 (11.58). Distinctly higher sterility percentage of 16.92 was recorded by T_7, which was on par with T_8.

4.2.1.8 *Thousand Grain Weight (g)*

The results are presented in Table 17.

Effect of management practices on thousand grain weight of rice was found to be non significant.

4.2.1.9 *Grain Yield (t ha^{-1})*

The result on the effect of management practices on grain yield of rice is presented in Table 17.

The results indicated that grain yield was significantly influenced by the treatments. Among all the treatments, a seed rate of 100 kg ha^{-1} with hydropriming registered significantly higher grain yield of 4.44 t ha^{-1} followed by 120 kg ha^{-1} seed rate and hydropriming (4.07 t ha^{-1}). Management practices receiving a very high seed rate of 140 kg ha^{-1} recorded significantly lower and comparable grain yield among different seed treatments.

Table 17. Effect of treatments on yield attributes of rice at harvest

(microplot study)

Treatment	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index
T_1 - seed rate of 100 kg ha^{-1} + without priming	22.92	3.55	6.04	0.37
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	22.89	4.44	6.72	0.40
T_3 - seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	23.29	4.00	5.77	0.41
T_4 - seed rate of 120 kg ha^{-1} + without priming	23.56	3.64	6.19	0.37
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	23.46	4.07	6.37	0.39
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	23.26	3.80	5.70	0.40
T_7 - seed rate of 140 kg ha^{-1} + without priming	23.22	2.60	4.16	0.38
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	23.29	2.72	4.03	0.40
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	23.32	2.70	4.34	0.38
SE m(±)	0.39	0.09	0.29	0.04
CD (0.05)	NS	0.25	0.85	NS

4.2.1.10 *Straw Yield (t ha^{-1})*

The results on the effect of treatments on straw yield are presented on Table 17.

Straw yield was found to be significantly influenced by the various treatments. A significantly higher straw yield of 6.72 t ha^{-1} was recorded with 100 kg seeding rate with hydropriming, which was on par with 120 kg seeding rate with hydropriming.

4.2.1.11 *Harvest Index (HI)*

The result on harvest index is presented in Table 17.

Effect of management practices on HI of rice was found to be non significant.

4.2.2 Effect of Treatments on Agronomic Attributes of Weedy Rice at Harvest

4.2.2.1 *Plant Height (cm)*

The result on plant height is presented in Table 18.

Data showed that the management practices had significant influence on height of weedy rice plants. A seed rate of 140 kg ha^{-1} with hardening recorded significantly higher plant height of 124.05 cm. But no regular trend was observed on plant height with respect to the treatments.

4.2.2.2 *Days to 50 per cent Flowering*

The result on days to 50 per cent flowering is presented in Table 18.

No significant variation in the number of days taken for flowering of weedy rice plants was observed.

Table 18. Effect of treatments on vegetative characters of weedy rice at harvest (microplot study)

Treatment	Plant height (cm)	Days to 50% flowering (Days)	Leaf area m^{-2} (cm^2)	LAI	LAD of flag leaf (Days)
T_1 - seed rate of 100 kg ha^{-1} + without priming	110.11	52.68	6709.13	0.78	33.33
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	113.50	51.38	4549.65	0.58	34.67
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	120.81	50.88	6605.07	1.07	33.67
T_4 - seed rate of 120 kg ha^{-1} + without priming	106.85	51.61	6909.07	1.02	33.67
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	107.61	52.28	5378.75	0.37	33.00
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	102.96	51.44	6228.06	0.58	33.33
T_7 - seed rate of 140 kg ha^{-1} + without priming	114.74	52.38	11651.17	1.70	34.33
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	116.88	51.68	11253.74	1.57	33.67
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	124.05	52.28	12011.87	0.85	33.33
SE m(±)	2.69	1.54	786.98	0.11	0.93
CD (0.05)	8.06	NS	262.49	0.30	NS

LAI: Leaf Area Index LAD: Leaf Area Duration

4.2.2.3 *Leaf Area Index (LAI)*

Results are presented in Table 18.

Leaf area m^{-2} of weedy rice ranged between 4549.65 to 11651.17 cm^2. T_2 (seed rate of 100 kg ha^{-1} + hydropriming) recorded significantly lower values of leaf area m^{-2} (4549.65 cm^2). T_7 (seed rate 140 kg ha^{-1} without priming) recorded significantly higher leaf area (11651.17 cm^2) which was on par with T_9 (seed rate 140 kg ha^{-1} + hardening) and T_8 (seed rate 140 kg ha^{-1} + hydropriming) with 12011.87 and 11253.74 cm^2 respectively.

4.2.2.4 *Leaf Area Duration (LAD) of flag leaf (Days)*

The result on LAD of flag leaf is presented in Table 18.

No significant variation in the LAD of flag leaf of weedy rice was observed. It was found to range between 33 to 35 days.

4.2.2.5 *Panicle Length (cm)*

The result on panicle length of weedy rice is presented in Table 19.

No significant variation in the panicle length of weedy rice was observed. It was found to range between 15.75 to 17.27 cm.

4.2.2.6 *Number of Grains Panicle^{-1}*

The result on number of grains panicle^{-1} of weedy rice is presented in Table19.

Number of grains panicle^{-1} was found to be unaffected by various treatment combinations and number of grains panicle^{-1} ranged between 67 to 70.

Table 19. Effect of treatments on yield attributes of weedy rice at harvest (microplot study)

Treatment	Panicle length (cm)	No of grains panicle $^{-1}$	Sterility percentage
T_1 - seed rate of 100 kg ha^{-1} + without priming	15.84	69.47	30.39
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	17.15	67.07	30.94
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	17.27	68.80	30.45
T_4 - seed rate of 120 kg ha^{-1} + without priming	15.75	68.93	31.39
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	16.26	69.47	30.55
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	16.26	68.70	31.05
T_7 - seed rate of 140 kg ha^{-1} + without priming	16.48	70.23	31.75
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	17.06	67.90	31.15
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	16.44	69.23	31.19
SE m(±)	0.56	0.84	1.00
CD (0.05)	NS	NS	NS

4.2.2.7 *Sterility Percentage*

The result on sterility percentage is presented in Table 19.

Data revealed that weedy rice had more sterile and unfilled grains compared to cultivated rice. Management practices had no significant influence on sterility percentage of weedy rice.

4.2.2.8 *Thousand Grain Weight of weedy rice (g)*

The results are presented in Table 20.

No significant variation on thousand grain weight of weedy rice plants was observed. It was found to range between 20.1 to 21.07 g.

4.2.2.9 *Grain Yield of weedy rice (g m^{-2})*

The result on grain yield of weedy rice is presented in Table 20.

Higher seed rate along with priming techniques had significant influence on grain yield of weedy rice. Seed rate of 100 kg ha^{-1} with hydropriming (T_2) recorded significantly lower grain yield (48.83 g m^{-2}) from weedy rice population, while treatments with high seed rate of 140 kg ha^{-1} (T_7, T_8, T_9) recorded a high grain yield (91.42 to 104.00 g m^{-2}) for weedy rice.

4.2.2.10 *Straw Yield of weedy rice (g m^{-2})*

The result on straw yield of weedy rice plants is presented in Table 20.

Data on straw yield also showed similar trend as that of grain yield. Treatments with higher seed rates of 140 kg ha^{-1} (T_7, T_8 and T_9) recorded a higher straw yield of 271.07, 228.06 and 225.53 g m^{-2} respectively.

Table 20. Effect of treatments on yield attributes of weedy rice at harvest (microplot study)

Treatment	1000 grain weight (g)	Grain yield (g m^{-2})	Straw yield (g m^{-2})	Harvest index
T_1 - seed rate of 100 kg ha^{-1} + without priming	20.67	79.02	190.38	0.29
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	21.07	48.83	119.00	0.29
T_3 - seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	20.23	70.00	174.55	0.29
T_4 - seed rate of 120 kg ha^{-1} + without priming	20.37	75.24	171.32	0.31
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	20.10	52.37	128.97	0.29
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	20.23	50.84	126.33	0.29
T_7 - seed rate of 140 kg ha^{-1} + without priming	20.33	104.00	271.07	0.28
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	20.93	91.42	228.06	0.29
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	20.13	95.35	225.53	0.30
SE m(±)	0.42	0.03	0.10	0.04
CD (0.05)	NS	0.13	0.25	NS

4.2.2.11 ***Harvest Index (HI)***

The result on HI of weedy rice is presented in Table 20.

HI was found to range between 0.28 to 0.31. No significant variation on HI of weedy rice plants was observed, when compared with cultivated rice.

4.3 EXPERIMENT: II (b) MANAGEMENT OF WEEDY RICE BY ENHANCING RICE COMPETITIVENESS (FARMERS' FIELD)

4.3.1 Effect of Treatments on Agronomic Attributes of Weedy Rice at Harvest

4.3.1.1 ***Plant Height (cm)***

The result on plant height is presented in Table 21.

The results revealed that the treatments did not have significant influence on the plant height of rice. Plant height was found to range between 90 to 93 cm at 50 per cent harvesting stage with an increase in plant height under higher seed rate of 140 kg ha^{-1}.

4.3.1.2 ***Days to 50 per cent Flowering***

The results are presented in Table 21.

No significant variation on days to 50 per cent flowering was observed by various treatments. The number of days for 50 per cent flowering ranged between 80 to 81 days.

4.3.1.3 ***Leaf Area Index (LAI)***

The results are presented in Table 21.

Table 21. Effect of treatments on vegetative characters of rice at harvest (confirmatory trial)

Treatment	Plant height (cm)	Days to 50% flowering(Days)	LAI	LAD of flag leaf (Days)
T_1 . seed rate of 100 kg ha^{-1} + without priming	91.17	80.34	3.98	39.00
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	90.83	81.14	3.92	38.33
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	91.80	80.41	3.55	39.33
T_4 - seed rate of 120 kg ha^{-1} + without priming	91.17	80.61	5.03	39.33
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	90.97	80.43	4.02	39.67
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	90.30	80.78	5.30	39.33
T_7 - seed rate of 140 kg ha^{-1} + without priming	93.34	80.99	6.11	40.00
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	93.67	80.53	5.07	38.33
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	91.87	80.82	5.26	39.67
SE m(±)	1.42	0.63	0.56	1.62
CD (0.05)	NS	NS	1.18	NS

LAI: Leaf Area Index LAD: Leaf Area Duration

LAI of rice was significantly influenced by the various levels of seed rates followed for managing weedy rice. It ranged between 3.55 to 6.11 with a higher seed rate (140 kg/ha) recording higher LAI values (T_7, T_8 and T_9 with 6.11, 5.07 and 5.26 respectively).

4.3.1.4 *Leaf Area Duration (LAD) of flag leaf (Days)*

The result is presented in Table 21.

The data revealed that LAD was not significantly influenced by any of the treatments.

4.3.1.5 *Panicle Length (cm)*

The result is presented in Table 22.

It was observed that the treatment followed has no significant influence on the panicle length of rice plants.

4.3.1.6 *Number of Grains Panicle^{-1}*

The result is presented in Table 22.

A significant variation in the number of grains panicle^{-1} was observed by the various management practices. It was found to range between 101 to 122 numbers. Seed rate of 100 kg ha^{-1} with hydropriming (T_2) was observed with a significantly higher number of grains panicle^{-1} (122) and was on par with T_5 (121) (seed rate of 120 kg ha^{-1} + hydropriming). All treatments with higher seed rate of 140 kg ha^{-1} (T_7, T_8, T_9) recorded lower number of grains panicle^{-1} with T_7 recording the lowest number of grains (101).

Table 22. Effect of treatments on yield attributes of rice at harvest (confirmatory trial)

Treatment	Panicle length (cm)	No of grains $panicle^{-1}$	Sterility percentage
T_1 - seed rate of 100 kg ha^{-1} + without priming	21.40	107.64	14.50
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	20.72	121.76	10.03
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	20.85	114.63	12.45
T_4 - seed rate of 120 kg ha^{-1} + without priming	20.17	114.48	12.35
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	21.04	121.55	11.20
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	20.24	118.47	11.74
T_7 - seed rate of 140 kg ha^{-1} + without priming	20.25	101.51	16.54
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	20.57	108.07	15.67
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	21.17	107.03	15.42
SE m(±)	0.50	1.93	0.27
CD (0.05)	NS	2.09	0.57

4.3.1.7 *Sterility Percentage*

The result is presented in Table 22.

Sterility of rice was found to increase with increase in seed rate, it ranged between 10.03 to 16.54. Various levels of seed rates had significant effect on sterility percentage. T_7 (seed rate of 140 kg ha^{-1}+ without priming) showed highest sterility percentage of 16.54 and was found on par with T_8 and T_9 (15.67 and 15.42 per cent).

4.3.1.8 *Thousand Grain Weight (g)*

The result is presented in Table 23.

Various management practices have no significant influence on 1000 grain weight of rice.

4.3.1.9 *Grain Yield (t ha^{-1})*

The result is presented in Table 23.

Grain yield was significantly influenced by the various seed rates and seed treatments followed. Among the different seed rates tried, 100 and 120 kg found better when hydroprimed, recording grain yields of 4.3 and 4.24 t ha^{-1} and were on par.

4.3.1.10 *Straw Yield (t ha^{-1})*

The result is presented in Table 23.

Straw yield of rice followed a similar trend as grain yield. Seed rate of 100 or 120 kg ha^{-1} along with hydropriming recorded significantly higher straw yield of 7.31 and 7.21 t ha^{-1}.

Table 23. Effect of treatments on yield attributes of rice at harvest (confirmatory trial)

Treatment	1000 grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index
T_1 - seed rate of 100 kg ha^{-1} + without priming	22.40	3.88	6.61	0.37
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	22.37	4.30	7.31	0.37
T_3-seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	22.77	3.94	6.71	0.37
T_4 - seed rate of 120 kg ha^{-1} + without priming	23.03	3.72	6.07	0.38
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	22.93	4.24	7.21	0.37
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	22.73	3.78	6.44	0.37
T_7 - seed rate of 140 kg ha^{-1} + without priming	22.70	2.57	4.28	0.38
T_8 - seed rate of 140 kg ha^{-1} +hydropriming	22.77	2.68	4.64	0.37
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	22.80	2.74	4.76	0.37
SE m(±)	0.56	0.14	0.26	0.05
CD (0.05)	NS	0.33	0.78	NS

4.3.1.11 *Harvest Index (HI)*

The results are presented in Table 23.

Effect of management practices on HI of rice was found to be non significant.

4.3.2 Effect of Treatments on Agronomic Attributes of Weedy Rice at Harvest

4.3.2.1 *Plant Height (cm)*

The result is presented in Table 24.

Higher seed rates and priming techniques tested for weedy rice management found to have no significant influence on plant height of weedy rice at harvest.

4.3.2.2 *Days to 50 per cent Flowering (Days)*

The result is presented in Table 24.

No significant variation was observed in the number of days taken for 50 per cent flowering of weedy rice plants by the management practices tested.

4.3.2.3 *Leaf Area Index (LAI)*

The results are presented in Table 24.

Leaf area m^{-2} of weedy rice ranged between 4895.50 to 12223.96 cm^2. T_2 (seed rate of 100 kg ha^{-1} + hydropriming) recorded the lowest values of leaf area m^{-2} (4895.50 cm^2). T_7 (seed rate 140 kg ha^{-1} without priming) recorded significantly higher leaf area (12223.96 cm^2) which was on par with T_9 (seed rate 140 kg ha^{-1} + hardening) and T_8 (seed rate 140 kg ha^{-1} + hydropriming) with 10806.00 and 10423.09 cm^2 respectively.

Table 24. Effect of treatments on vegetative attributes of weedy rice at harvest (confirmatory trial)

Treatment	Plant height (cm)	Days to 50% flowering (Days)	Leaf area m^{-2} (cm^2)	LAI	LAD of flag leaf (Days)
T_1 . seed rate of 100 kg ha^{-1} + without priming	103.17	51.80	8906.12	1.32	33.67
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	109.67	50.50	4895.50	0.65	35.00
T_3 – seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	110.00	50.00	7685.51	1.12	34.00
T_4 - seed rate of 120 kg ha^{-1} + without priming	110.35	50.73	7648.46	1.33	34.00
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	104.34	51.40	4049.45	0.54	33.33
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	111.20	50.57	4880.68	0.90	33.67
T_7 - seed rate of 140 kg ha^{-1} + without priming	107.50	51.50	12223.96	1.68	34.67
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	106.50	50.80	10423.09	1.54	34.00
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	104.34	51.40	10806.00	1.63	33.67
SE m(±)	3.13	2.18	796.34	0.09	1.31
CD (0.05)	NS	NS	284.65	0.21	NS

LAI: Leaf Area Index LAD: Leaf Area Duration

4.3.2.4 *Leaf Area Duration (LAD) of flag leaf (Days)*

The result is presented in Table 24.

LAD of flag leaf of weedy rice was found not significantly influenced by any of the treatments tested.

4.3.2.5 *Panicle Length (cm)*

The result is presented in Table 25.

Treatment effect was found to be non significant on panicle length of weedy rice.

4.3.2.6 *Number of Grains Panicle^{-1}*

The results are presented in Table 25.

Number of grains panicle^{-1} in weedy rice was found to increase with increase in seed rate. It was found to range between 65 to 70. T_7 (seed rate 140 kg ha^{-1} + without priming) recorded significantly higher number of grains panicle^{-1}, which was on par with treatments T_8 (seed rate 140 kg ha^{-1} + hydropriming) and T_9 (seed rate 140 kg ha^{-1} + hardening).

4.3.2.7 *Sterility Percentage*

The result is presented in Table 25.

Weedy rice exhibited a higher sterility percentage compared to cultivated rice, which ranged between 19.92 to 23.76. Treatments with a higher seed rate of 140 kg ha^{-1} exhibited lower sterility percentages of 23.76, 22.84 and 23.07 respectively.

Table25. Effect of treatments on yield attributes of weedy rice at harvest (confirmatory trial)

Treatment	Panicle length (cm)	No of grains/panicle	Sterility percentage
T_1 - seed rate of 100 kg ha^{-1} + without priming	17.78	68.50	20.03
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	18.00	66.07	19.92
T_3 – seed rate of 100 kg ha^{-1} + hardening with 2.5 % KCl	17.68	67.03	21.81
T_4 - seed rate of 120 kg ha^{-1} + without priming	15.92	67.70	20.34
T_5 - seed rate of 120 kg ha^{-1} + hydropriming	17.45	65.93	22.62
T_6 - seed rate of 120 kg ha^{-1} + hardening with 2.5 % KCl	18.68	66.93	21.75
T_7 - seed rate of 140 kg ha^{-1} + without priming	15.10	70.37	23.76
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	18.18	69.43	22.84
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	19.33	69.07	23.07
SE m(±)	1.30	1.05	0.54
CD (0.05)	NS	2.24	1.07

4.3.2.8 *Thousand Grain Weight of weedy rice (g)*

The result is presented in Table 26.

It was observed that the 1000 grain weight of weedy rice is not significantly influenced by any of the management practices.

4.3.2.9 *Grain Yield of weedy rice (g m^{-2})*

The result is presented in Table 26.

Grain yield was recorded for weedy rice plants by bagging the plants with cloth net and expressed in g m^{-2}. Grain yield was found to range between 41.83 to 109.86 g m^{-2}. T_5 (seed rate 120 kg ha^{-1} + hydropriming) recorded significantly lower weedy rice grain yield of 41.83 g m^{-2} and was superior to all other treatments. Treatments with a higher seed rate of 140 kg ha^{-1} (T_7, T_8 and T_9) recorded higher grain yield.

4.3.2.10 *Straw Yield of weedy rice (g m^{-2})*

The results are presented in Table 26.

Data on straw yield of weedy rice also showed a similar trend. T_5 (seed rate 120 kg ha^{-1} + hydropriming) recorded the lowest straw yield of 103.75 g m^{-2}, which was statistically superior to all other treatments. T_7, T_8 and T_9 recorded a higher straw yields.

4.3.2.11 *Harvest Index of weedy rice (HI)*

The results are presented in Table 26.

Various seed rates and priming methods adopted have no significant influence on the HI of weedy rice.

Table 26. Effect of treatments on yield attributes of weedy rice at harvest (confirmatory trial)

Treatment	1000 grain weight (g)	Grain yield (g m^{-2})	Straw yield (g m^{-2})	Harvest index
T_1 - seed rate of 100 kg ha^{-1} + without priming	20.61	80.00	192.40	0.29
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	21.00	46.46	113.05	0.29
T_3 - seed rate of 100 kg ha^{-1} + hardening with 2.5 % KCl	20.17	68.62	170.57	0.29
T_4 - seed rate of 120 kg ha^{-1} + without priming	20.30	75.05	171.12	0.30
T_5 - seed rate of 120 kg ha^{-1} + hydropriming	20.03	41.83	103.75	0.29
T_6 - seed rate of 120 kg ha^{-1} + hardening with 2.5 % KCl	20.17	50.72	125.30	0.29
T_7 - seed rate of 140 kg ha^{-1} + without priming	20.27	109.86	286.26	0.28
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	20.87	104.73	262.39	0.29
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	20.07	97.16	230.12	0.30
SE m(±)	0.59	0.05	0.24	0.03
CD (0.05)	NS	0.12	0.43	NS

4.3.2.12 *Weedy Rice Count m^{-2}*

The result is presented in Table 27.

Weedy rice count expressed as plant population per unit land area was found to be significantly influenced by various levels of seed rates and priming methods tested. T_2 (seed rate 100 kg ha^{-1} + hydropriming) recorded a significantly lower weedy rice count per unit area (3.84) and was on par with T_5 recording 3.85 (seed rate 120 kg ha^{-1} + hydropriming). T_7 (seed rate 140 kg ha^{-1}) recorded a significantly higher weedy rice count of 7.75 which was on par with T_8 (seed rate 140 kg ha^{-1} + hydropriming) and T_9 (seed rate 140 kg ha^{-1} + hardening) with a weedy count of 7.30 and 7.37 respectively.

4.3.2.13 *Dry Weight of Weedy Rice (g m^{-2})*

The result is presented in Table 27.

Data on dry weight of weedy rice exhibited a similar trend like that of count per unit area and was significantly different. T_2 (seed rate 100 kg ha^{-1} + hydropriming) recorded significantly lower weedy dry weight (90.05 g m^{-2}) and was on par with T_5 (seed rate 120 kg ha^{-1} + hydropriming) with 91.98 g m^{-2}. Treatments with higher seed rates (T_7, T_8 and T_9) recorded higher dry weights of 187.01, 172.86 and 175.77 g m^{-2} respectively.

4.3.2.14 *Weed Control Efficiency (WCE)*

The results are presented in Table 27.

Weed control efficiency was calculated by taking T_7 as control, which recorded comparatively higher weed dry weight. Accordingly T_2 (seed rate 100 kg

Table 27. Effect of treatments on weedy rice incidence at harvest (confirmatory trial)

Treatment	Weedy rice count m^{-2}	Dry weight of weedy rice ($g\ m^{-2}$)	Weed control efficiency
T_1 - seed rate of 100 kg ha^{-1} + without priming	5.18	121.73	34.91
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	3.84	90.05	51.85
T_3 - seed rate of 100 kg ha^{-1} + hardening with 2.5 % KCl	5.53	132.77	29.00
T_4 - seed rate of 120 kg ha^{-1} + without priming	4.65	111.60	40.32
T_5 - seed rate of 120 kg ha^{-1} + hydropriming	3.85	91.98	50.82
T_6 - seed rate of 120 kg ha^{-1} + hardening with 2.5 % KCl	4.33	102.36	45.26
T_7 - seed rate of 140 kg ha^{-1} + without priming	7.75	187.01	0.00
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	7.30	172.86	7.56
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	7.37	175.77	6.01
SE m(±)	0.12	3.11	1.73
CD (0.05)	0.29	6.60	3.67

+ hydropriming) and T_5 (seed rate 120 kg ha^{-1} + hydropriming) recorded the significantly higher WCE values of 51.85 and 50.82 per cent respectively, which were superior and on par with other treatments. High weedy rice population and dry weight was observed in treatments with high seed rate.

4.3.2.15 *Economics*

Results are presented in Table 28.

Net income was substantially influenced by the management practices. Net income obtained for all practices except seed rate of 140 kg ha^{-1} was higher than that of other treatments. A higher net income was recorded by T_2 followed by T_5. T_7 recorded a lower net income.

The benefit cost ratio was significantly influenced by various weed management practices and it was found to range from 1.00 to 1.68. Among the management practices, a seed rate of 100 kg ha^{-1} along with hydropriming recorded higher B:C ratio of 1.68 followed by T_5 (seed rate 120 kg ha^{-1} + hydropriming) with a B:C ratio of 1.64. Higher seed rate of 140 kg ha^{-1} without any priming treatments recorded lower B:C ratio of 1.00.

4.4 EXPERIMENT: III EFFECT OF ELEVATED CO_2 CONCENTRATION ON GROWTH OF RICE AND WEEDY RICE

4.4.1 Agronomic Attributes of Rice and Weedy Rice

4.4.1.1 *Plant Height (cm)*

Result is presented in Table 29 and 30.

A significant increase in plant height was observed for weedy rice (57.87 cm) under elevated CO_2 condition in Chamber A, followed by chamber B (56.87 cm) and

Table 28. Effect of treatments on economics of rice production (confirmatory trial)

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income (Rs. ha^{-1})	B:C ratio
T_1 - seed rate of 100 kg ha^{-1} + without priming	56,000	86830	30,830	1.55
T_2 - seed rate of 100 kg ha^{-1} + hydropriming	57280	96369	39,089	1.68
T_3- seed rate of 100 kg ha^{-1}+ hardening with 2.5 % KCl	57325	88329	31,004	1.54
T_4 - seed rate of 120 kg ha^{-1} + without priming	56,800	83389	26,589	1.47
T_5 - seed rate of 120 kg ha^{-1}+ hydropriming	58080	95029	36,949	1.64
T_6 - seed rate of 120 kg ha^{-1}+ hardening with 2.5 % KCl	58125	84749	26,624	1.46
T_7 - seed rate of 140 kg ha^{-1} + without priming	57,600	57639	39	1.00
T_8 - seed rate of 140 kg ha^{-1} + hydropriming	58880	61009	2,129	1.04
T_9 - seed rate of 140 kg ha^{-1} + hardening with 2.5 % KCl	58925	60549	1,624	1.03

open condition (55.47 cm) at one month after sowing. Height of weedy rice increased by 4.3 per cent under elevated CO_2 condition compared to open. However, plant height of Jyothi and Uma was higher in Chamber B followed by Chamber A and Open conditions. Plant height of Jyothi and Uma showed an increase of 17.46 per cent and 11.59 per cent in Chamber B compared to open condition. Lower plant height was recorded for Uma (40.53 cm) under open condition.

When observed at 50 per cent flowering, a same trend was observed. Chamber B recorded taller plants of weedy rice (112.77 cm) and rice (98.16 and 91.06 cm for Jyothi and Uma respectively) followed by chamber A and open condition. A significant variation in plant height was observed among the varieties inside A and B chambers. Weedy rice recorded a greater plant height compared to cultivated varieties. A significant difference in plant height was also found between the chambers due to the increase in CO_2 levels both during initial stages and at 50 per cent flowering stage.

4.4.1.2 ***Number of tillers***

Result is presented in Table 29 and 30.

At 30 DAS, significant increase in tillering was observed under elevated CO_2 condition for both weedy rice and cultivated rice variety Uma. Weedy rice showed 36.5 per cent increase in tillering under elevated CO_2 condition compared to open condition. Variety Jyothi showed low response to elevated CO_2 condition compared to Uma. Weedy rice recorded greater number of tillers (3.67) in chamber A followed by Uma and Jyothi. Jyothi, Uma and weedy rice responded equally to the situation of chamber B while in the open condition, weedy rice recorded greater number of tillers compared to cultivated rice.

At 50 per cent flowering stage also, weedy rice and Uma responded well under elevated CO_2 condition with higher number of tillers (17.33 and 11.33

Table 29. Performance of rice varieties and weedy rice under elevated CO_2 condition

Chamber	Treatment	Plant height (cm)		No of tillers	
		30 DAS	50% FW	30 DAS	50% FW
Chamber A	T_1 (Jyothi)	48.43	96.17	3.00	9.00
	T_2 (Weedy rice)	57.87	108.97	3.67	17.33
	T_3 (Uma)	45.23	90.72	3.33	11.33
Chamber B	T_4 (Jyothi)	50.40	98.16	3.33	9.33
	T_5 (Weedy rice)	56.87	112.77	3.33	13.33
	T_6 (Uma)	46.57	91.06	3.33	8.67
Open condition	T_7 (Jyothi)	41.23	92.43	2.00	4.33
	T_8 (Weedy rice)	55.47	105.07	2.33	6.00
	T_9 (Uma)	40.53	88.37	1.00	3.33
	SE (±)	1.71	1.43	0.27	1.09
	CD (0.05)	5.08	4.26	0.81	3.26

DAS: Days After Sowing FW: Flowering

Table 30. Response of selected systems to the treatments

Treatment mean	Plant height (cm)		No. of tillers	
	30 DAS	50% FW	30 DAS	50% FW
Chamber A	50.51	98.62	3.33	12.56
Chamber B	51.28	100.66	3.33	10.44
Open condition	45.74	95.29	1.78	4.22
Inside chamber A	S	S	S	S
Inside chamber B	S	S	NS	S
Between chambers	S	S	NS	S
Open condition	S	S	NS	S

DAS: Days After Sowing FW: Flowering

respectively). Compared to open condition the number of tillers of weedy rice and Uma in chamber A increased 3.46 and 3.40 times respectively. A significant difference in tillering habit was observed among varieties in chamber A while it was on par between varieties in Chamber B during initial stages. At 50 per cent flowering stage, a significant variation was observed in tillering both under chamber A and B. No significant variation was observed in tillering behavior between chambers during initial stages. Uma under open condition had lower number of tillers both during 30 DAS and at 50 per cent flowering stage, while weedy rice exhibited significantly higher tiller number of 2.33 and 6 respectively.

4.4.1.3 *Days to 50 per cent Flowering*

Result is presented in Table 31 and 32.

Earliness in flowering was observed for weedy rice, Jyothi and Uma under elevated CO_2 condition. Weedy rice showed a significant earliness in flowering inside chamber A (35 days), followed by chamber B (43 days) and open condition (50 days). Compared to open condition earliness of 15 and 7 days was recorded in Chamber A and B respectively. Uma and Jyothi also recorded an earliness of 8 and 17 days in Chamber B and A, respectively.

4.4.1.4 *LAD of Flag Leaf (Days)*

The results are represented in Table 31 and 32.

Leaf area duration of flag leaf was found to increase with increasing carbon dioxide levels. However under open condition rice varieties recorded higher LAD values (36 and 37 days for Jyothi and Uma) compared to weedy rice (33 days). Weedy rice retained greenness of leaves for a longer period similar to cultivated varieties in both chambers. A significant difference was observed in the leaf area

Table 31. Performance of rice varieties and weedy rice under elevated CO_2 condition

Chamber	Treatment	Days to 50% flowering (Days)	LAD of FL (Days)	LAI	
				30 DAS	50 % flowering
Chamber A	T_1 (Jyothi)	61.78	39.00	0.85	3.47
	T_2 (Weedy rice)	45.97	40.20	0.93	4.23
	T_3 (Uma)	77.57	42.33	0.92	2.92
Chamber B	T_4 (Jyothi)	62.28	39.00	1.16	3.03
	T_5 (Weedy rice)	48.27	39.33	0.89	3.87
	T_6 (Uma)	79.69	40.33	0.75	2.23
Open condition	T_7 (Jyothi)	67.78	36.00	0.40	2.25
	T_8 (Weedy rice)	51.57	33.67	0.64	2.02
	T_9 (Uma)	81.88	37.00	0.27	1.25
	SE (±)	0.34	1.08	0.07	0.33
	CD (0.05)	1.02	3.22	0.22	0.98

LAD: Leaf Area Duration LAI: Leaf Area Index

DAS: Days After Sowing FL: Flag leaf

Table 32. Response of selected systems to the treatments

Treatment	Days to 50% flowering (Days)	LAD of FL (Days)	LAI	
			15 DAS	50 % flowering
Chamber A	61.77	34.89	0.90	3.54
Chamber B	62.41	34.89	0.94	3.04
Open condition	67.08	37.56	0.44	1.84
Inside chamber A	S	S	NS	NS
Inside chamber B	S	S	S	S
Between chambers	S	S	S	S
Open condition	S	S	S	NS

LAD: Leaf Area Duration　　LAI: Leaf Area Index

DAS: Days After Sowing　　FL: Flag leaf

duration between varieties in chamber A and B; between chambers and open condition.

4.4.1.5 *Leaf Area Index*

The results are presented in Table 31 and 32.

A significant increase in Leaf area index was observed under elevated CO_2 for both weedy rice and cultivated rice variety Uma at 30 DAS and at 50 per cent flowering stage. For Jyothi significantly higher LAI was observed in chamber B followed by chamber A and open conditions. Jyothi under elevated CO_2 recorded a higher LAI at 30 DAS while weedy rice recorded significantly higher LAI at 50 per cent flowering stage. Uma under open condition recorded significantly lower LAI during both the growth stages indicating the significant effect of elevated CO_2 levels on LAI. A marked difference in LAI was observed between chambers and open condition at both the stages.

4.4.1.6 *Panicle Length (cm)*

The result is presented in Table 33 and 34.

Panicle length of Jyothi, weedy rice and Uma was found to increase with carbon dioxide levels. Panicle length varied significantly within the chambers under all the three situations but it was non significant between chambers. Weedy rice recorded a significantly lower panicle length in comparison with Jyothi and Uma under all the three conditions.

Table 33. Performance of rice varieties and weedy rice under elevated CO_2 condition

Chamber	Treatment	Panicle length (cm)	Number of grains panicle^{-1}	Sterility percentage
Chamber A	T_1 (Jyothi)	22.24	100.00	45.46
	T_2 (Weedy rice)	16.43	63.67	40.98
	T_3 (Uma)	20.41	114.00	26.27
Chamber B	T_4 (Jyothi)	21.85	95.67	51.05
	T_5 (Weedy rice)	16.07	60.08	45.97
	T_6 (Uma)	20.56	105.00	23.99
Open condition	T_7 (Jyothi)	21.43	98.33	6.10
	T_8 (Weedy rice)	16.97	48.33	14.92
	T_9 (Uma)	18.40	90.67	6.22
	SE (±)	0.57	3.93	2.91
	CD (0.05)	1.72	11.67	8.64

Table 34. Response of selected systems to the treatments

Treatment mean	Panicle length (cm)	Number of grains panicle^{-1}	Sterility percentage
Chamber A	19.69	66.89	37.57
Chamber B	19.49	67.89	40.34
Open condition	18.93	93.33	9.08
Inside chamber A	S	S	S
Inside chamber B	S	S	S
Between chambers	NS	S	S
Open condition	S	S	NS

4.4.1.7 *Number of Grains Panicle^{-1}*

The result is presented in Table 33 and 34.

Number of grains per panicle was found to be higher under elevated carbon dioxide condition for both cultivated rice and weedy rice. Among the three, Uma recorded a significantly higher number of grains panicle^{-1} (114) compared to weedy rice (64) and Jyothi (100) in chamber A. A similar trend was observed in Chamber B and Open conditions too. Uma recorded a higher response to elevated CO_2 condition compared to weedy rice and Jyothi.

4.4.1.8 *Sterility Percentage*

The results are presented in Table 33 and 34.

Results revealed that sterility percentage varied significantly between the chambers and among the varieties. Sterility percentage was found to be higher in Chamber B compared to Chamber A and it was found significantly lower under open condition. Jyothi in Chamber B recorded a significantly higher sterility percentage of 51.05 while Jyothi in open condition recorded a lower sterility (6.1 per cent). However, among the plant groups, weedy rice recorded significantly higher sterility percentage followed by Uma and Jyothi in open condition. A significant variation was observed between cultivars within Chamber A, Chamber B and between chambers.

4.4.1.9 *Thousand Grain Weight (g)*

The result is presented in Table 35 and 36.

The thousand grain weight was found to be significantly influenced by elevated CO_2 levels. Cultivated rice varieties Jyothi and Uma recorded significantly higher thousand grain weight of 24 g each in chamber A. A significant difference

Table 35. Performance of rice varieties and weedy rice under elevated CO_2 condition

Chamber	Treatment	1000 grain weight (g)	Grain yield plant $^{-1}$ (g)	Straw yield plant $^{-1}$ (g)
Chamber A	T_1 (Jyothi)	23.90	7.22	33.54
	T_2 (Weedy rice)	21.00	9.88	48.67
	T_3 (Uma)	23.90	17.75	59.45
Chamber B	T_4 (Jyothi)	23.03	6.80	32.94
	T_5 (Weedy rice)	20.17	6.79	37.86
	T_6 (Uma)	23.03	14.36	45.07
Open condition	T_7 (Jyothi)	22.67	9.28	30.77
	T_8 (Weedy rice)	20.17	5.70	22.91
	T_9 (Uma)	22.90	8.62	20.55
	SE (±)	0.38	1.06	3.84
	CD (0.05)	1.13	3.15	11.41

Table 36.Response of selected systems to the treatments

Treatment mean	1000 grain weight (g)	Grain yield plant^{-1} (g)	Straw yield plant $^{-1}$ (g)
Chamber A	22.93	11.62	47.22
Chamber B	22.08	9.32	38.63
Outside condition	21.91	7.87	24.74
Inside chamber A	S	NS	NS
Inside chamber B	S	NS	S
Between chambers	S	S	S
Open condition	S	NS	NS

was observed in thousand grain weight inside Chamber A, Chamber B, between Chambers and Open condition. An increase in CO_2 level was found to have a higher thousand grain weight. There was no significant difference between the thousand grain weight of weedy rice in open condition and elevated CO_2 condition.

4.4.1.10 *Grain Yield Plant^{-1}* (g)

The result is presented in Table 35 and 36.

Among the different situations, Uma in chamber A recorded significantly higher grain yield of 17.75 g plant^{-1} followed by Uma in chamber B with a grain yield of 14.36 g plant^{-1}. Variety Uma was found to respond well under elevated CO_2 condition compared to cultivated rice variety Jyothi and weedy rice plants. Uma showed a percentage increment of 51.4 per cent in chamber A and 40 per cent in chamber B, while weedy recorded an increment of 42.3 and 16 per cent respectively. Variey Jyothi exhibited a negative response to elevated CO_2 levels. When comparing between yields under various CO_2 concentrations, for all the varieties a higher grain yield per plant was recorded in Chamber A with an elevated CO_2 level (2.3 times than open condition), followed by Chamber B (recorded 1.6 times than open condition).

No significant variation was observed among varieties within Chamber A and Chamber B and open condition. A significant variation was observed between chambers, indicating the effect of elevated CO_2 on grain yield.

4.4.1.11 *Straw Yield Plant^{-1} (g)*

The result is presented in Table 35 and 36.

Straw yield per plant also followed a similar trend like that of grain yield per plant. Uma in chamber A recorded a significantly higher straw yield of 59.45 g plant^{-1} followed by weedy rice in chamber A. Among the chambers, higher straw yield was recorded in Chamber A followed by Chamber B and open condition. Weedy rice and Uma recorded significantly lower straw yield of 23 and 20 g plant^{-1} respectively. No significant variation was observed inside Chamber A and in open condition, but a marked difference was observed inside Chamber B and between chambers.

Discussion

5. DISCUSSION

Weedy rice (*Oryza sativa* f. *spontanea*) has emerged as a major threat to rice cultivation in Kerala and has already established in the major rice growing tracts of Kerala like Palakkad, Kuttanad and Kole lands. The present study entitled "Characterization and management of weedy rice (*Oryza sativa* f. *spontanea*)" was aimed at agro-morphological and physiological characterization of various weedy rice morphotypes collected across the state and formulation of a management strategy by employing high crop seeding rates and priming methods. Crop weed interference under elevated CO_2 concentration was also studied to understand the competitiveness and potential of this weed in the future era of climate change. The results of this study are briefly discussed in this chapter.

5.1 MORPHO-PHYSIOLOGICAL AND AGRONOMIC CHARACTERIZATION OF WEEDY RICE MORPHOTYPES

5.1.1 Morphological Characterization

The main objective of the study was to compare the morphological characteristics among the morphotypes as well as between the morphotypes and cultivated rice so as to find out a morphometric relationship between weedy and cultivated rice during early growth stages. For this purpose, various morphotypes of weedy rice were collected across the state, representing the major rice tracts of Kerala and morphological characterization was done both for qualitative and quantitative traits. There were many similar characters among weedy rice morphotypes and cultivated varieties. However, some characters varied significantly between weedy rice and cultivated rice during initial growth stages *viz.,* culm thickness, colour and length of ligule and number of tillers plant^{-1}.

Attitude of leaf blade was found to vary widely among various weedy rice morphotypes. Most of the weedy rice morphotypes exhibited a semi erect or intermediate attitude similar to cultivated rice. But a marked difference was recorded by the morphotypes collected from Palakkad and Ezhome. Morphotype from Kozhikode had an erect attitude. According to Adair and Jodon (1973) the distribution of the culm angle in weedy rice morphotypes ranging from erect to open suggested that the erect plants' growth habit is recessive to that of a spreading or procumbent growth. The presence of erect plant types could be due to back-crossing between accessions or with the commercial rice cultivar (Gealy *et al.*, 2006). In the present study, variations in morphology among morphotypes might be due to the variations in the agro-ecological situations in which the morphotype was developed and the variety cultivated. Since weedy rice emerged by natural hybridization between wild rice and cultivated rice, naturally the weedy rice morphotype present in a location may have characters of most common cultivated rice varieties of that location. Variations were observed among morphotypes of the same location which were in line with the findings of Estorninos *et al.* (2002) and Chauhan (2013) that weedy rice might vary among different variants. It could also be attributed to the variation in the availability of natural resources, nutrients and emergence pattern under field situation.

Anthocyanin pigmentation at the nodes could be used as a character to differentiate between weedy rice and cultivated rice varieties in Ezhome, which exhibited an intense purple pigmentation at the nodal region. However, some morphotypes lacked anthocyanin pigmentation at the nodes (Trivandrum white, Kuttanad and Kozhikode). Since morphotypes with and without pigmentation at the nodal region were observed, presence or absence of anthocyanin pigmentation at the nodal region alone could not be considered as a morphometric character for weedy rice identification. Varieties like Purple puttu, Violet sundhari *etc.*, also possess anthocyanin pigmentation in plant parts. In heavily infested areas cultivating

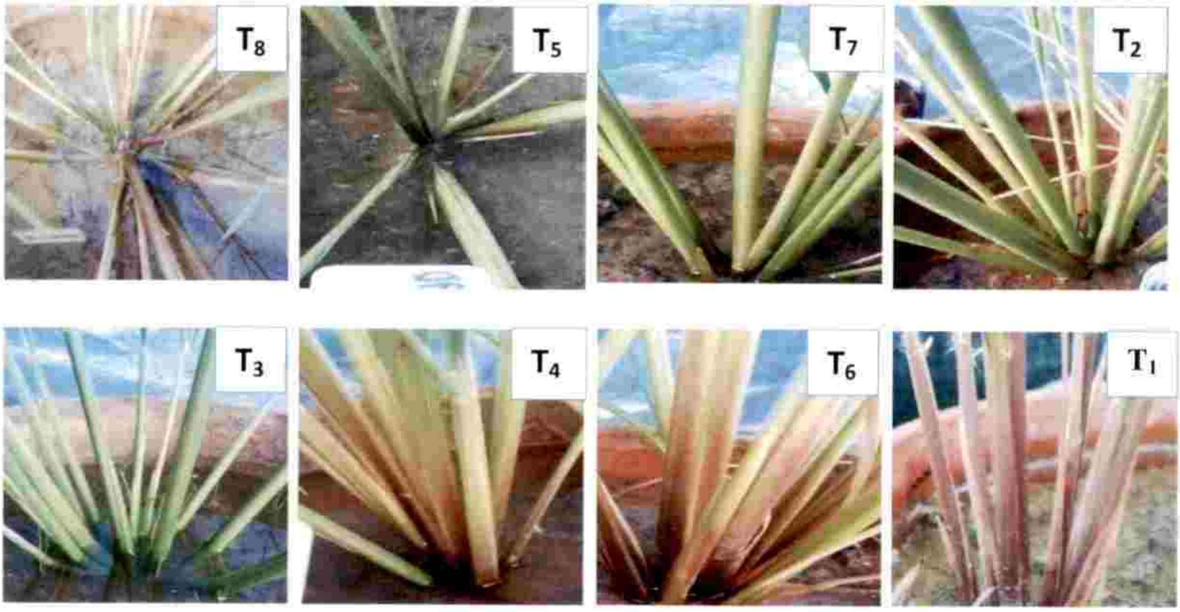

Plate 12: Anthocyanin pigmentation at the nodes in weedy rice morphotypes

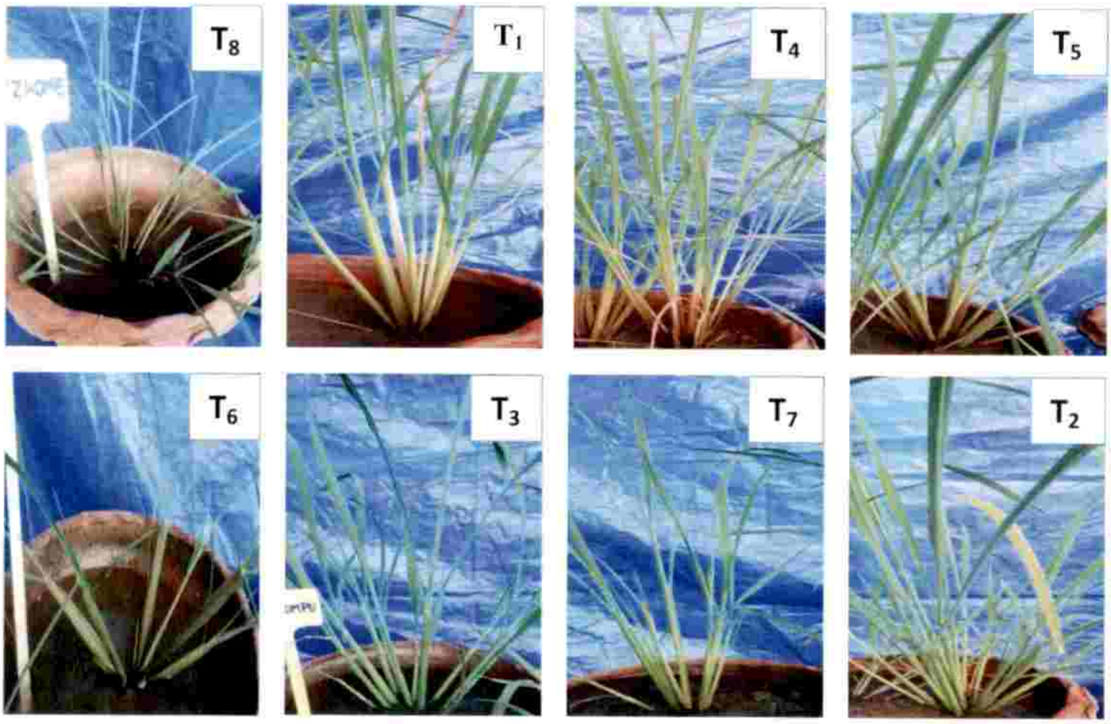

Plate 13: Attitude of leaf blade of weedy rice morphotypes

pigmented rice can ease the roguing of non pigmented weedy rice from infested fields.

Colour of ligule is another character which could be used for differentiation between weedy rice and cultivated rice. Ligule colour ranged between whitish to purple. Morphotypes from Ezhome, Kozhikode and Kole lands could be differentiated from cultivated rice using the ligule pigmentation, as they had purple shaded ligule. Burgos (2005) reported purple coloured pigmentation in the leaf sheath, leaf margin and culm region of weedy rice morphotypes which aid in differentiation from cultivated rice.

Results of morphological study revealed that weedy rice morphotypes were highly diverse but not structured to a geographical region, with different types of morphotypes in the same field. Awn colour can be used as the best indication for this diversity. Morphotypes collected from Trivandrum and Palakkad exhibited both white and red awn colour. Apart from this, a wide variation in awn colour was observed ranging from whitish to black. Morphotype from Trivandrum and Kuttand had straw coloured awns; Kozhikode had whitish awns; Kole had brown awns; Palakkad had light green and Ezhome had purple coloured awns. Larinde (1979) reported about the variation in awns with short awns or without awns, which might be the result of segregation after natural crossing. In the present study, some morphotypes were observed with very short awns or without awns. Repeated back crossing between weedy rice and cultivated rice varieties might have imparted the awnless nature of cultivated rice to weedy rice making it very similar to cultivated rice.

In addition, certain demarcating characters were observed in some weedy rice morphotypes like distinct black ring at the nodal region (morphotype from Palakkad and Kole), characteristic bend at the nodal region (morphotype from Kozhikode), presence of adventitious roots (morphotype from Kuttanad), apiculus colouration (for

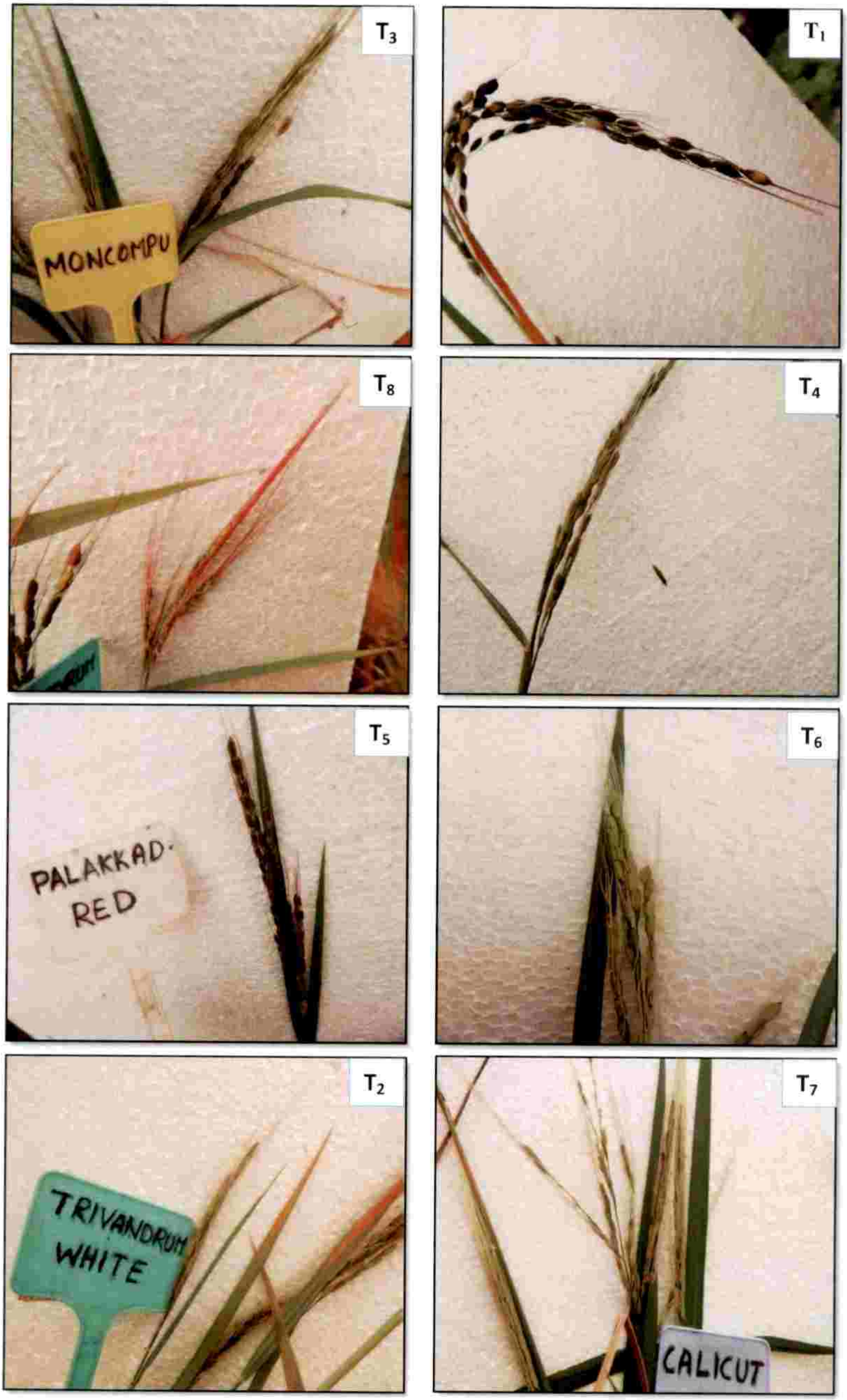

Plate 14: Awn colour of weedy rice morphotypes

all morphotypes) and presence of very short awns (morphotype from Trivandrum). These characters might have emerged as an adaptation to the ecological situation in the prevailing tract. Presence of adventitious roots for morphotypes from Kuttanad helped them to thrive under water logged condition. This observation was in confirmation with the findings of Gealy and Estorninos (2004), who reported that the specific rate of back crossing appeared to be influenced by aspects of the environment that are not well understood. Hence, a thorough knowledge of the ecosystem and cultivation practices of a particular area is needed to differentiate and manage weedy rice in cultivated fields. Microscopic analysis of rice and weedy rice grain surface revealed that weedy rice grain surface is hairy with trichomes and help them for easy dispersal. Presence of trichomes and long awns helped in weedy rice seed dispersal *via*, fur of animals and through water (Jose, 2015).

Morphological traits were analyzed quantitatively by recording characters like ligule length, number of tillers plant^{-1}and culm thickness. Significant variation was observed in the ligule length of morphotypes during initial stages. Jose *et al.* (2013) reported a ligule length ranging from 2 to 20 mm for weedy rice collected from Kuttanad and in the present study a ligule length of 3.70 mm to 13.7 mm was recorded for weedy rice and 9.7 and 6.7 mm respectively for Jyothi and Uma. Results showed that 75 per cent of weedy rice morphotypes had smaller ligules compared to cultivated rice varieties during initial stages. Upto 15 DAS shorter ligule could be used as a demarcating character between weedy rice and cultivated rice. However, at later stages this difference becomes less significant. It could be inferred that length of ligule could be considered as a character to differentiate with Jyothi during early stages and with Uma at later stages.

Culm thickness of weedy rice was also found to exhibit distinctiveness. Culm of weedy morphotypes was found to be more cylindrical compared to cultivated rice. Results revealed that most of the weedy rice morphotypes had higher culm thickness

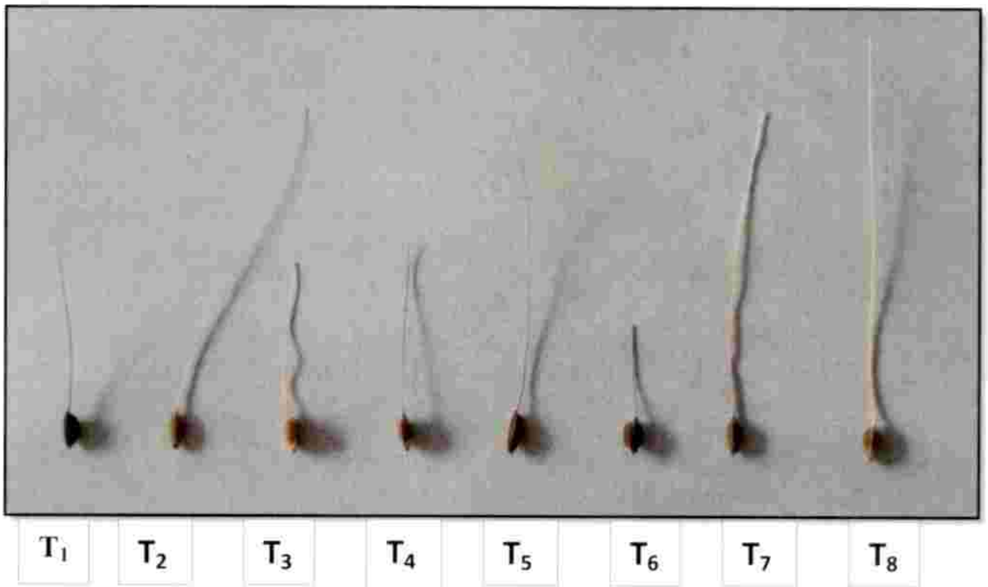

Plate 15: Awn length of weedy rice morphotypes

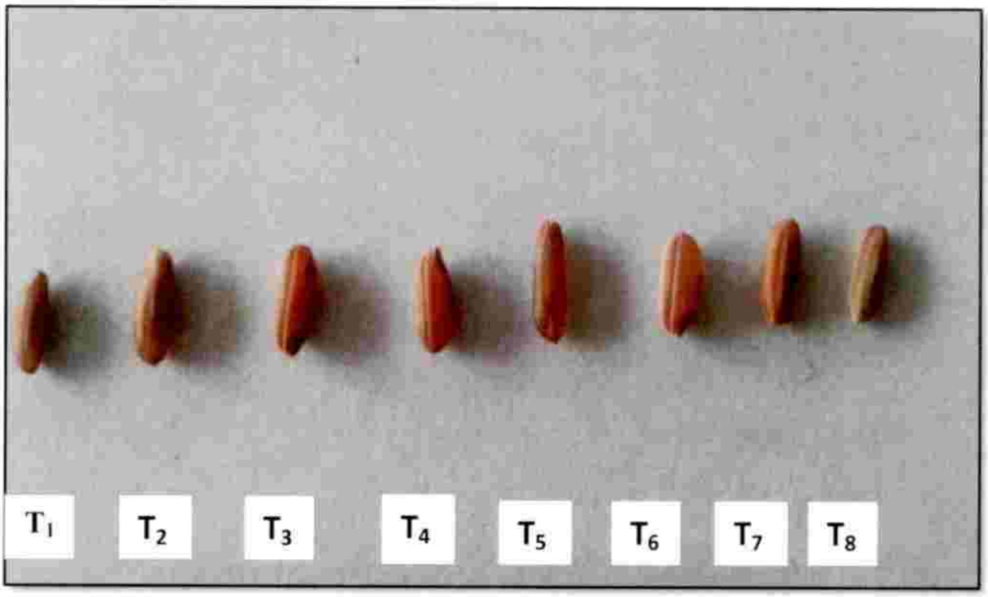

Plate 16: Colour of pericarp of weedy rice morphotypes

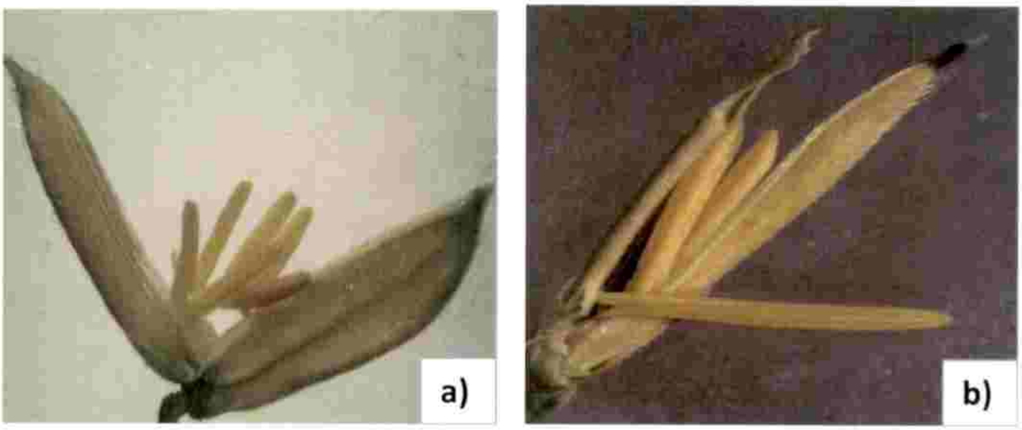

Plate 17: Microscopic view of spikelet a) Rice variety Uma b) Weedy rice

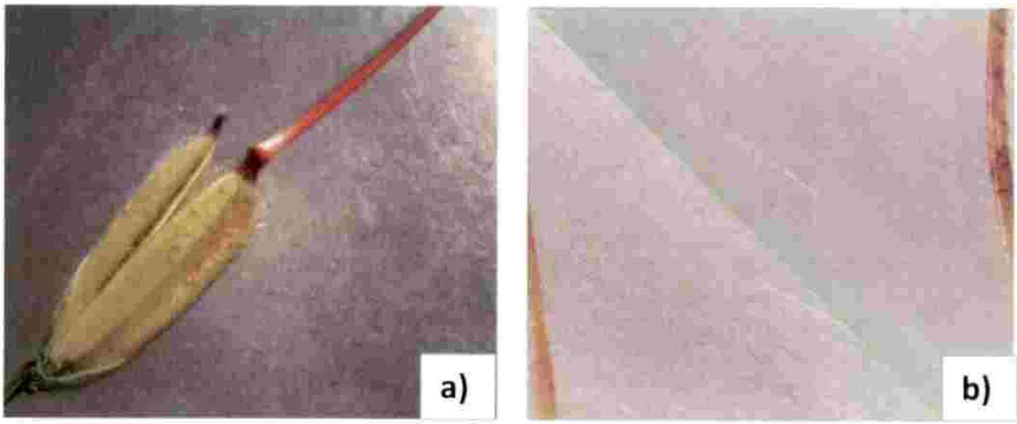

Plate 18: Trichomes present on weedy rice a) Grain surface b) Awns

R) Rice (Uma)	1) WRM-1 (Trivandrum red)
2) WRM- 2 (Trivandrum white)	3) WRM- 3 (Mancompu)
4) WRM- 4 (Kole land)	5) WRM- 5 (Palakkad red)
6) WRM- 6 (Palakkad white)	7) WRM- 7 (Kozhikode)
8) WRM- 8 (Ezhome)	

Plate 19: Root characteristics of weedy rice morphotypes in comparison with Uma

compared to cultivated rice varieties both at initial as well as later growth stages, which could be used for identification of this weed species from cultivated rice.

Number of tillers plant^{-1} varied widely between weedy rice and cultivated rice. Higher tiller number was observed in weedy rice compared to cultivated rice during initial as well as later stages of growth. About 87 per cent of weedy rice morphotypes had higher tiller number (ranged from 11 to 20) compared to cultivated rice (10 and 9 for Jyothi and Uma respectively) and the only morphotype from Ezhome recorded a lower tiller number of eight. Hence it could be concluded that high tiller number and its lean nature could be used as a trait to differentiate between weedy rice and cultivated rice.

The study documented the existing variations amongst the weedy rice morphotypes of Kerala. As many of the characters was very similar to cultivated rice it was not possible to differentiate between them using a single character. As different morphotypes exhibited different characters the results drawn from this study should be limited to those areas from where morphotypes were collected. There existed high phenotypic diversity in weedy rice accessions across different countries, both within and among geographical regions (Shivrain, 2010 and Song *et al.*, 2014). Similarities between weedy rice and cultivated rice increasing year after year might be due to the repeated back crossing and gene flow between two plant types.

However a combination of quantitative and qualitative morphological traits could be used for the identification of weedy rice from cultivated rice. Of the various quantitative traits studied, length of ligule, culm thickness and number of tillers were significantly different for weedy rice during the early growth stages. It could be inferred that weedy rice plants were lanky, thin, with more round culm, with or without anthocyanin pigmentation at the nodal region, short ligule and with more number of tillers and awned grains.

Plate 20: Differnce in plant height between Uma & weedy rice

Plate 21: Grain shattering in weedy rice

Plate 22: Root system of weedy rice in pot culture study

Plate 23: Weedy rice morphotype having very short awns

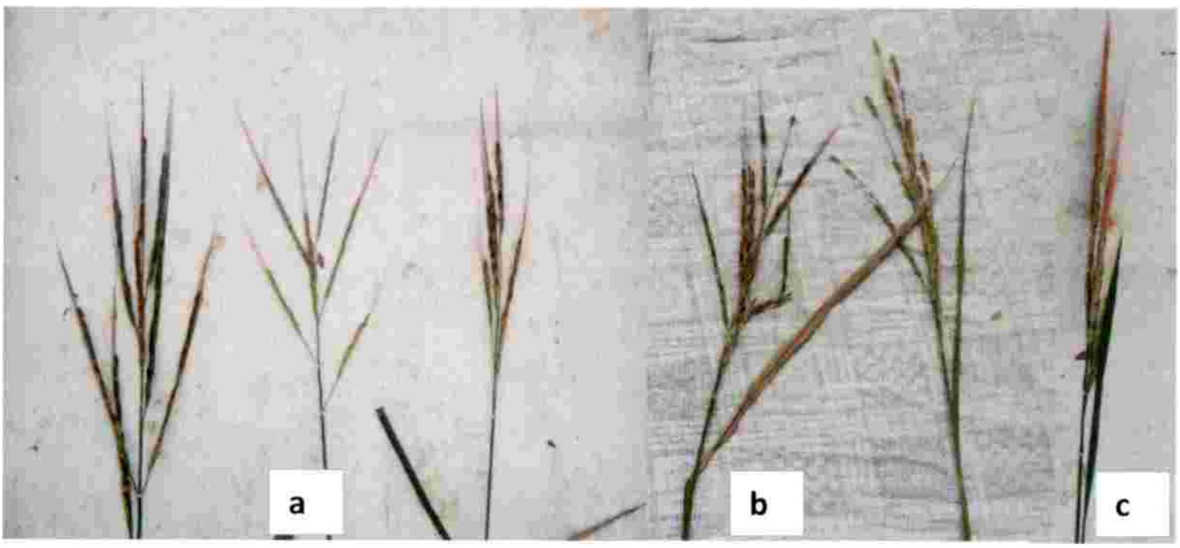

Plate 24: Panicle type of weedy rice morphotyes
a) Open b) Intermediate c) Compact

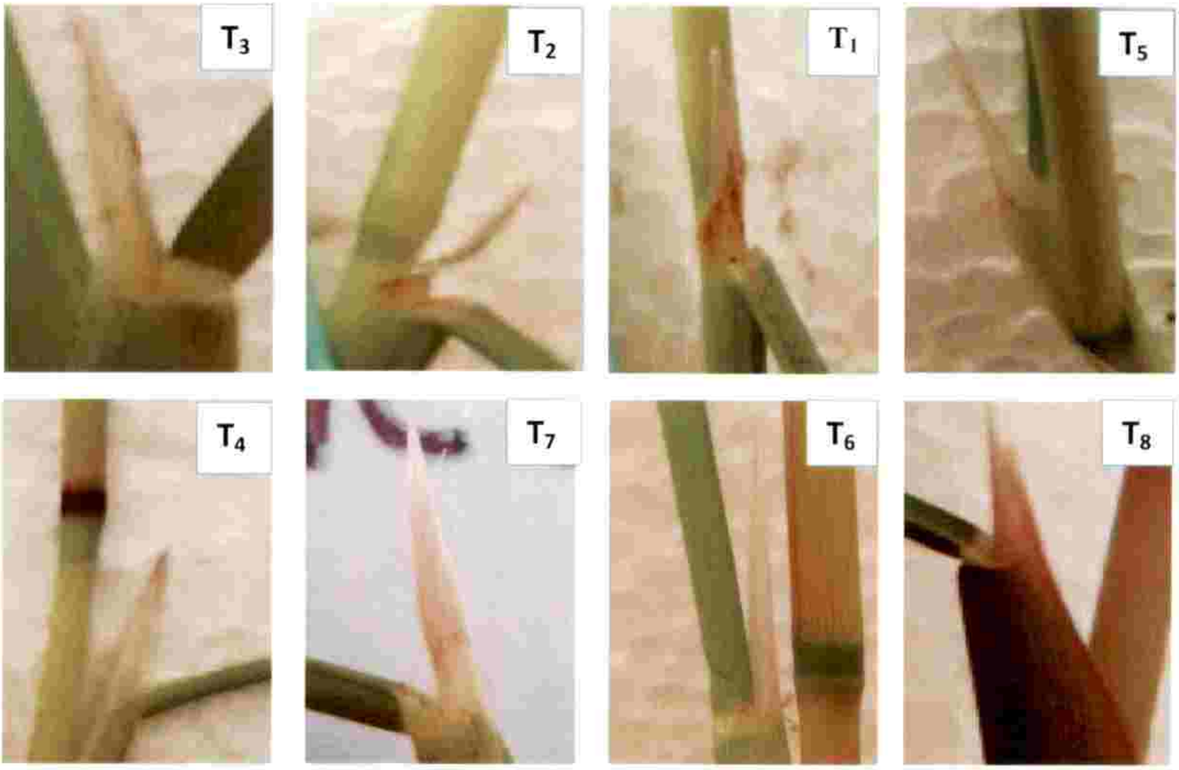

Plate 25: Ligule colour of weedy rice morphotypes

Plate 26: Distinct black ring at the nodal region of weedy rice

Plate 27: Adventitious root emergence in weedy rice morphotype from kuttanad

Plate 28: Apiculus colouration at the grain tip of weedy rice

Plate 29: Characteristic bend at the nodal region of weedy rice

5.1.2 Physiological Characterisation

Data on physiological characterisation revealed that weedy rice exhibited superiority over cultivated rice varieties in various physiological parameters which imparted more competitiveness to weedy morphotypes in comparison with rice. In future this might result in the greater survival and invasiveness of the weedy rice in rice fields of Kerala.

Results of physiological characterization showed that at 15 DAS weedy rice morphotypes exhibited a higher value of chlorophyll a, b and total chlorophyll content compared to cultivated rice varieties, though it was statistically non significant. Rathore *et al*. (2016) also observed a statistically non significant variation in chlorophyll content between rice and weedy rice. Higher chlorophyll content during initial stages of growth might have increased photosynthetic activity resulting in high competing ability of weedy rice compared to cultivated rice varieties. This was in agreement with the findings of Kannangara (1991), who reported that chlorophyll content could be used as an effective index for high photosynthetic efficiency in rice.

However, during reproductive stage chlorophyll content in rice was found to be higher compared to weedy rice. Hussain *et al*. (2010) also observed higher chlorophyll content for rice at 60 to 70 DAS, than weedy rice accessions. Rice plants exhibited more greenness than weedy rice morphotypes at 50 per cent flowering stage while weedy rice had paler leaves. Leaf colour was either green, light green or dark green in all the weedy rice accessions, but commercial varieties have only dark green leaves at the later growth stages (Hussain *et al*., 2010). These results suggest that higher chlorophyll content during initial stages enhanced photosynthetic efficiency and thereby contributed more competing ability for weedy rice compared to cultivated rice. Dissimilarities in the leaf colour at early stages makes hand weeding impossible and incomplete.

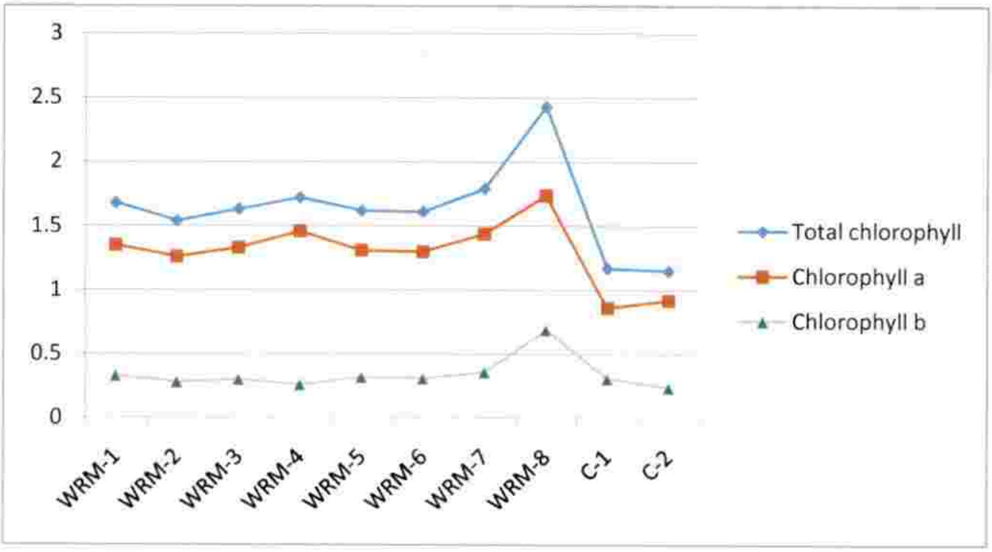

Fig 2: Variations in chlorophyll content of weedy rice morphotypes and cultivated rice varieties at 30 DAS (mg 100^{-1}g)

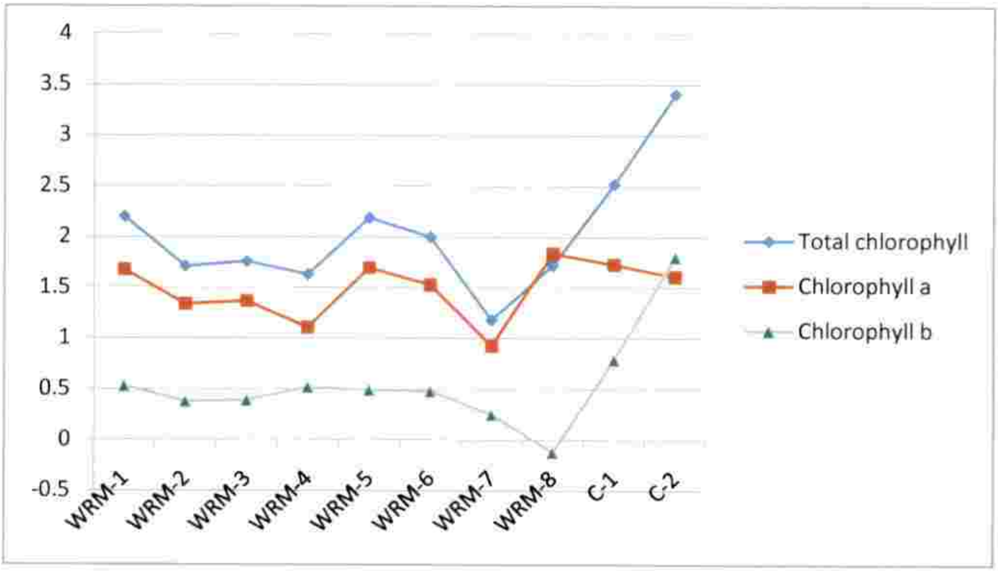

Fig 3: Variations in chlorophyll content of weedy rice morphotypes and cultivated rice varieties at 50% flowering

Total Soluble Protein (TSP) is an indication of total enzymatic activity of a plant. About 50 per cent of TSP are associated with Rubisco (ribulose-1,5-bisphosphate carboxylase-oxygenase) protein in rice leaves (Makino *et al.,* 1987). Results on total soluble protein indicated that there was no significant variation between the TSP values of weedy rice morphotypes and cultivated rice. All the weedy morphotypes recorded a lower TSP content both at 15 DAS (0.13 to 0.45 mg g^{-1}) and at 50 per cent flowering stage (0.5 to 1.07 mg g^{-1}) compared to cultivated rice varieties Jyothi and Uma (0.51 and 0.44 mg g^{-1} at 15 DAS and 0.73 and 1.38 mg g^{-1} at 50 per cent flowering stage respectively). The study confirms the finding that among the species of *Oryza* the differences in enzymatic properties of Rubisco are less (Makino *et al.,* 1987).

Data on stomatal characteristics *viz.*, conductance and frequency suggest that most of the weedy rice morphotypes had a higher stomatal frequency and conductance, giving some additional advantages to them in comparison with cultivated rice varieties though it was statistically non significant.

Stomatal frequency, is used to assess the photosynthetic efficiency of a particular plant group. It was counted both at adaxial and abaxial surfaces and expressed as the number of stomata cm^{-2}. Stomatal frequency was found to be higher in the adaxial surface for both weedy rice (morphotypes) and cultivated rice than abaxial surface. Out of eight weedy rice morphotypes, six recorded higher stomatal frequency than Jyothi, while only three weedy rice morphotypes recorded higher value of stomatal frequency than Uma. This indicated that stomatal characteristics varied with weedy rice morphotypes, rice cultivar and growing conditions. Similar results were reported by Swamy *et al*. (2010), stating that stomatal number correlated positively with stomatal conductance and frequency and stomatal number was found to be higher in the adaxial surface compared to abaxial surface.

Stomatal conductance is closely related to leaf photosynthesis by regulating gas flow. Weedy rice morphotypes recorded wide variation in stomatal conductance ranging from 48.20 to 179.10 milli moles m^{-2} s^{-1} and majority of morphotypes exhibited similar range of stomatal conductance as that of cultivated rice. Rathore *et al.* (2016) also observed the same. According to Ishihara and Saito (1987) and Hirasawa *et al.* (1988), stomatal apertures as well as conductance were strongly correlated with leaf photosynthesis in rice. The aggressivity of weedy rice expressed in its height and root characters can be attributed to the stomatal characters of weedy rice.

Results on root characters revealed a significant difference between rice and weedy rice, enhancing the competitive efficiency of weedy rice plants compared to cultivated rice. At 15 DAS, weedy rice morphotypes had root volume which was 2-5 times that of cultivated rice varieties. During initial stages 62 per cent of weedy morphotypes recorded higher root volume compared to Jyothi, while it was 87 per cent when compared with Uma. There were several traits that contributed to weed competitiveness of which root volume is one among them (Minotti and Sweet, 1981). Greater root volume of weedy rice during initial growth stages might add to its weedy potential and could cause greater threat to cultivated rice. At reproductive stage also the same trend was followed with root volume 1.3 to 1.5 times higher than cultivated rice. Higher root volume would lead to greater root spread and in turn more absorption of water and nutrients during critical growth stages of rice. Similarly root dry weight also indicated the competitive advantages of weedy rice over cultivated rice. Mahajan *et al.* (2014) reported that high root biomass and volume correlated positively with competitiveness.

Higher root shoot ratio helped plants for better water absorption and uptake (Lal *et al.*, 2013). In the present study, root-shoot ratio did not show any significant variation between weedy rice and cultivated rice. Weedy rice morphotypes exhibited a ratio between 0.25 to 0.47, while it was 0.38 and 0.28 for Jyothi and Uma at 15 DAS. Proportionate increase in root dry weight made the root shoot ratio of weedy rice in a similar range as that of cultivated rice.

Shattering percentage of weedy rice morphotypes was expressed as grain threshability. Result on grain thereshability indicated that all the weedy rice morphotypes had a higher threshability percentage. Grain threshability of weedy rice morphotypes ranged from 29.73 per cent to 46.32 per cent, while it ranged from 17 to 34 per cent for cultivated rice varieties, Uma and Jyothi respectively. The significance in grain threshability of weedy rice indicated its high grain shattering nature and further addition of its seeds to soil seed bank. From this study, it was clear that yearly addition of weedy seeds to soil seed bank intensifies the problem over years giving the advantage of early colonization of rice fields as observed by Olajumoke *et al.* (2016).

Seed longevity is another character which adds to the competitiveness of weedy rice. From the seed longevity studies conducted for a period of 18 months at monthly interval, it could be inferred that weedy rice morphotypes exhibited variable seed dormancy which is a strong indication of its greater competitiveness. Seed longevity of cultivated rice varieties Jyothi and Uma was 6 and 9 months respectively, while it varied from 5 to 18 months for weedy rice. The high variation in seed longevity kept the seeds of weedy rice viable in the soil seed bank and made the weed more persistent in rice cultivation system. Similar observations were made by Azmi and Karim (2008). Shattering expressed as grain threshability and variable seed dormancy were the two important weedy traits that attributed to the persistence and spread of weedy rice in rice production system.

5.1.3 Agronomic Characterization

5.1.3.1 *Vegetative Attributes at 50per cent Flowering*

Vegetative attributes that were studied included plant height, number of tillers, days to 50 per cent flowering, Leaf Area Index (LAI) and Leaf Area Duration (LAD) of flag leaf. Results revealed that there was significant difference in plant height, days to 50 per cent flowering and LAI between weedy rice and cultivated rice. All the morphotypes were found to be taller than cultivated rice varieties and similar results were reported by Kwon *et al.* (1991) and Suh *et al.* (1997). Plant height of weedy rice morphotypes ranged between 105 to 115.67 cm, while the height of cultivated rice varieties Jyothi and Uma were 96 and 91 cm respectively. Jose *et al.* (2013) reported that weedy rice variants from Kuttand were usually taller (130 to 145 cm) than cultivated rice. According to Stansel *et al.* (1965) and Smith (1968), height is a competitive trait in plant communities and weeds taller than the crop are usually most competitive and have a greater effect on the yield components as a result of the shading effect and lodging. This taller growth habit of weedy rice result in competition between weedy rice and cultivated rice for above ground growth factor *ie.,* light. Taller weedy rice shade the rice plants reducing photosynthetic ability and thereby yield. Patterson (1982) reported that increasing shade would increase plant height until photosynthate production limits growth. Weedy rice morphotypes were reported to be more tolerant to shade than cultivated rice (Chauhan, 2013). However, some dwarf weedy rice morphotypes were observed by Jose *et al.* (2013), which might be due to the repeated back crossing between weedy rice and cultivated rice.

Earliness in flowering was observed in weedy rice morphotypes compared to cultivated rice varieties. Fifty percent of weedy rice population flowered in between 49 to 51 DAS, while Jyothi and Uma flowered at 61 and 82 DAS. Early flowering resulted in early grain maturing and seed shattering. Shattered seeds added to soil seed bank would intensify the problem in future (Perreto *et al.*, 1993). Earliness in

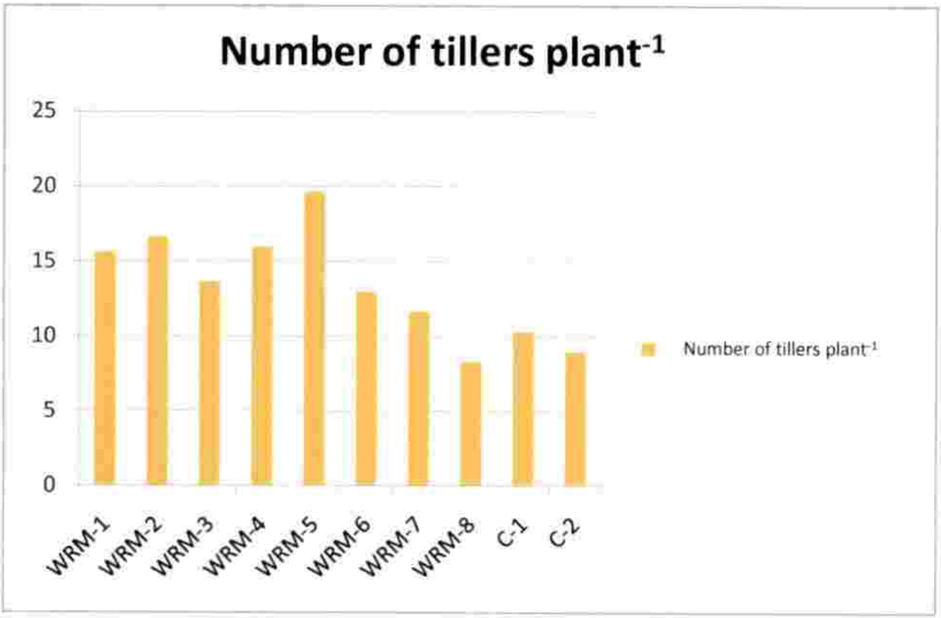

Fig 4: Variations in number of tillers plant^{-1}of weedy rice morphotypes and cultivated rice varieties at 30 DAS

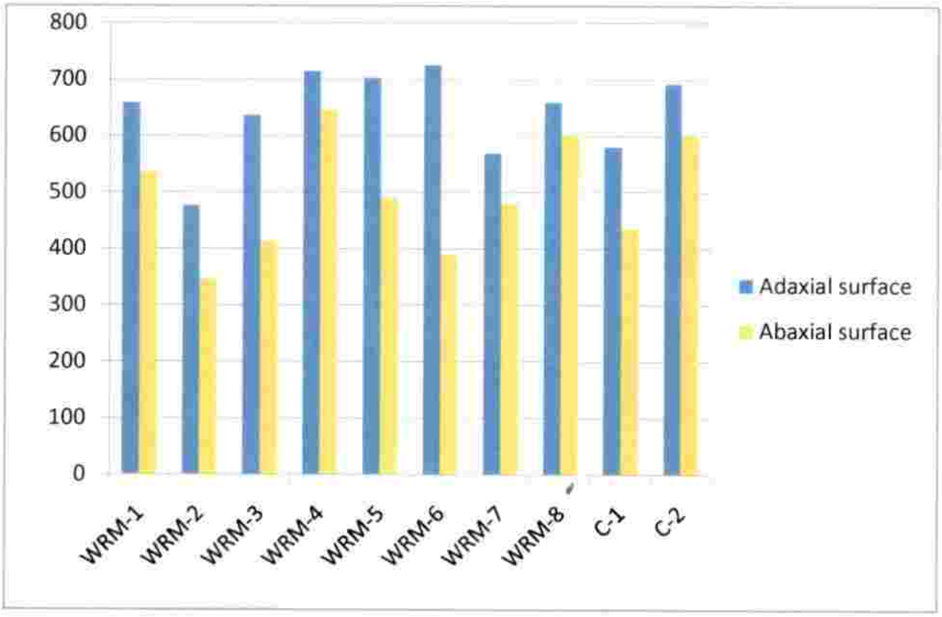

Fig 5: Variations in stomatal frequencies of weedy rice morphotypes and cultivated rice varieties

flowering was found to be an additional advantage for weedy rice to survive in rice fields. The results are in confirmation with the findings of Olguin *et al.* (2007) who observed earliness in panicle emergence and asynchronisation of grain maturity in weedy rice compared to cultivated rice.

A marked difference was observed between the LAI of weedy rice and cultivated rice. Majority of the weedy rice morphotypes recorded higher LAI values than cultivated rice. Higher values of LAI for weedy morphotype might be due to their high tillering nature. Zhang *et al.* (2002) stated that tillering had significant effect on LAI of rice and all weedy morphotypes except Ezhome recorded high tiller number per unit land area. Studies of Ferrero and Vidotto (1999) in Italy showed that it was very difficult to distinguish between weedy rice and rice crop in the seedling stage but once tillering starts, weedy rice could be easily identified by their more numerous, longer and more slender tillers.

No significant variation was observed between the LAD of weedy rice and cultivated rice. Cultivated rice was found to remain greener for longer period compared to weedy morphotyes, though it was statistically non significant. This might be due to the earliness in flowering and maturity observed in weedy rice, leading to senescence. Devendra *et al.* (1983) reported that a low LAD could lead to incomplete developement of the sinks and thus lower yield.

5.1.3.2 *Yield Attributes at harvest*

Various yield attributes analyzed were number of grains panicle^{-1}, panicle length, sterility percentage, test weight, grain yield and straw yield. A significant variation was observed in all these characters between rice and weedy rice. Number of grains panicle^{-1} in weedy rice morphotypes was found to be lower (45 to 60) compared to cultivated rice varieties. Jyothi and Uma recorded higher number of grains panicle^{-1} (66 and 94). This was in confirmation with the findings of Jose *et al.*

(2013), who reported that the number of grains per panicle in weedy rice ranged between 30 to 80.

A significant variation was observed in the sterility percentage of rice and weedy rice morphotypes. Weedy rice morphotypes exhibited sterility percentage ranging from 17 to 33, while it was 9 to 13 for cultivated rice. Jose *et al*. (2013) reported a sterility of 30 to 60 per cent for the weedy rice from Kuttanad. Zhang *et al*. (2015) opined that, there existed pollen sterility in weedy rice, and this cytoplasmic male sterility (CMS) could be used in hybrid breeding programmes. Sterile and half filled grains in weedy rice exhibited a higher germinability, which added to its competitiveness even if there exist high sterility percentage.

Weedy rice and cultivated rice are usually differentiated with the presence of awns. Most of the cultivated rice varieties lack awns except a few traditional varieties which bear very short awns, while most of the weedy rice morphotypes had awns. Awn length of weedy rice morphotypes exhibited wider variation and it ranged from 2.38 to 9.23 cm. These findings are in concurrence with the studies of Jose *et al.* (2013), who reported an awn length of 2.5 to 8 cm for the weedy rice variants in Kerala. It was observed that there was no direct correlation between awn colour and anthocyanin pigmentation at the nodal region. In some cases morphotypes with nodal pigmentation exhibited colourless or white awns and this was in confirmation with the findings of Larinde (1979). Some weedy morphotypes from Trivandrum and Kuttanad were noticed with reduced or no awns, which might be due to the repeated back crossing between weedy rice and cultivated rice resulting in the disappearance of that particular character.

Results on thousand grain weight indicated that weedy rice morphotypes recorded a lower thousand grain weight (20.03 to 21g) compared to cultivated rice (Jyothi: 22.77 and Uma: 23.80 g). Lower thousand grain weight in weedy rice might be due to its lower grain filling. This was in confirmation with the findings of Jose et al. (2013), who observed that thousand grain weight of weedy rice was in the range of 18 to 19.5 g.

Data on grain and straw yield plant^{-1} of rice and weedy rice exhibited a significant variation. Cultivated rice varieties Jyothi and Uma recorded a higher grain yield of 8.98 and 10.53 g plant^{-1} respectively, when compared to weedy rice morphotypes (4.35 to 5.36 g plant^{-1}). Lower grain yield of weedy rice might be due to their lesser number of grains panicle^{-1}, low thousand grain weight and higher sterility percentage. Grain yield of cultivated rice was 2.42 times higher than that of weedy rice morphotypes. Straw yield also followed the same trend as that of grain yield.

Weedy rice had shorter panicles compared to panicles of cultivated rice and only morphotype from Palakkad only recorded a higher panicle length of 22.13 cm. This might be due to the repeated back crossing between the weedy lines and cultivated lines which impart longer panicle to weedy population. Rathore *et al.* (2016) reported that there was a marked difference in the panicle length and number of panicles in rice and weedy rice. Variation was also observed in the panicle type also. As per morphometric descriptors of IRRI, panicle type of weedy rice can be compact, intermediate or open and Kuttanad morphotypes recorded an intermediate panicle type. However, Jose *et al.* (2013) recorded open or compact weedy rice panicles among the weedy rice variants from Kuttanad. Morphotypes from Trivandrum, Kole and Palakkad recorded compact type of panicle as that of cultivated rice. This clearly indicated that weedy rice morphotypes of these locations are acquiring characters more similar to cultivated rice by repeated back crossing.

From the study on agro-morphological and physiological characterisation of weedy rice morphotypes of Kerala in comparison with two most common cultivated rice varieties *viz*., Jyothi (short duration) and Uma (medium duration), it could be concluded that early identification between weedy rice and cultivated rice is difficult though it is possible using selected morphological traits. Agro- physiological characterization revealed the reasons for its high competitive ability as it grow rapidly in height, exhibit high photosynthetic rate, produce abundant roots, high tillering capacity along with grain shattering. The study clearly illustrated the rising negative impact of weedy rice on growth and yield of rice in Kerala in the years to come.

5.2 MANAGEMENT OF WEEDY RICE BY ENHANCING RICE COMPETITIVENESS

5.2.1 Effect of Treatments on Vegetative and Yield Attributes of Rice

The objective of this experiment was to study the possibility of increasing crop competitiveness against weedy rice by adopting a high seeding rate and various priming techniques. The experiment under taken in micro plots by raising cultivated rice along with weedy rice morphotype of the locality maintaining a standard weedy rice population of seven plants m^{-2}. This was followed by confirmatory trial taken up in farmer's field in a locality having heavy weedy rice infestation. The results obtained under above two situations are discussed below.

Among the growth attributes of rice studied LAI was significantly influenced by the treatments. Though rice plant height was not significantly influenced by the treatments, plants were found taller in plots receiving higher seed rate of 120 and 140 kg ha^{-1}. Increase in plant height might be the result of higher competition set up due to high plant density. Harris and Vijayaragavan (2015) confirmed that plant tends to grow taller in search of light when the spacing becomes closer or when go for a high seeding rate. On the contrary, Akbar and Ehsanullah (2004) reported that seeding density had no significant effect on height. Among the priming methods tested, hydropriming showed superiority over hardening with 2.5% KCl by producing vigourous and fast growing seedlings during the initial stages. Anwar *et al*. (2012) reported that seed priming enhanced plant height from the beginning to harvest and produced taller plants compared to unprimed seeds. However, the effect of high seed rate and priming did not result in any significant variation in plant height.

Influence of various treatments on days to 50 per cent flowering was found non significant. A marked difference was observed in LAI and was found to range between 2.5 to 5.44 in microplots and 3.55 to 6.11 in farmers field. Treatment receiving higher seed rates of 140 kg ha^{-1} recorded the highest LAI, which might be due to the higher plant population in unit land area. Hu *et al.* (2000) reported that plant population had a significant effect on photosynthetic characters of rice. High LAI was due to the increase in number of plants per unit area. Akita (1982) confirmed that increase in number of plants per unit area resulted in high leaf area and enhanced production of photosynthates. LAI values exceeding the optimum indicated an excessive number of leaves $plant^{-1}$ which caused shading of lower organs of assimilation thereby adversely affecting photosynthesis. Of the various priming methods tested non of them showed any influence on enhancing LAI as effect of priming was limited to the initial growth phase of upto two weeks. On the contrary, Farooq *et al.* (2009) reported that primed seeds recorded high LAI due to the increased efficiency in resource capture and photosynthate assimilation. LAD of flag leaf which give an indirect index of leaf senescence was found non significant by the enhanced seed rates and priming methods.

Of the various yield attributes analyzed, number of grains $panicle^{-1}$, sterility percentage, grain and straw yield were found significantly influenced by adopting high seed (100 or 120 kg ha^{-1}) rate along with hydropriming.

Results showed that treatments had significant effect on number of grains $panicle^{-1}$. A seed rate of 100 kg ha^{-1} along with hydropriming recorded significantly higher number of grains (120 and 122 respectively in microplot and farmers field) followed by seed rate of 120 kg ha^{-1} with hydropriming. All the treatments with a higher seed rate of 140 kg ha^{-1} (T_7, T_8 and T_9) recorded lower number of grains, which might be due to the greater competition for various growth factors resulted from increased plant population. Yoshida (1972) also observed a reduction in number of spikelet beyond an optimum plant density. When seed rate was increased beyond an optimum point, there would be an increase in leaf area which resulted in increased respiratory rates and in turn lead to a reduction in number of grains (Murata *et al.*, 1957). From this study it could be inferred that a seed rate of 140 kg ha^{-1} had a negative effect on number of grains $panicle^{-1}$. Among various priming methods, hydropriming exhibited significant influence with increased number of grains $panicle^{-1}$. According to Anwar *et al.* (2012) seed priming had significant effect in reducing mean germination time thereby increasing germination percentage, germination index and seedling vigour index and a vigourous seedling naturally contributes to more number of spikelet $plant^{-1}$ and an increased yield.

Rice seeding rates of 100 or 120 kg ha^{-1} with hydropriming recorded high grain yield and lower sterility percentage, while high seeding rates of 140 kg ha^{-1} (T_7, T_8 and T_9) recorded higher sterility percentage and lower grain yield. Seeding rate increased beyond an optimum lead to marked reduction in filled grains $panicle^{-1}$ consequent to mutual shading and reduction in transfer of photosynthates to sink. This was in confirmation with the findings of Akbar and Ehsanullah (2004).

According to Farooq *et al.* (2007) seed priming resulted in partial hydration of seeds without radicle emergence and thus enhanced the germination and vigour of seeds. Partial hydration of seed without radicle emergence result in activation of most of the physiological processes and such seeds imbibe and revive metabolic activities soon after sowing though redried back to initial moisture (Rowse, 1995). Primed seeds showed uniform germination, increased germination rate, better allometric attributes and faster emergence of seedlings (Basra *et al.*, 2005, Kaya *et al.*, 2006, Farooq *et al.*, 2007) which improved the competitive ability of seedlings.

In microplot study it was found that an increase in seed rate increased the grain yield up to 13 per cent and further increase (140 kg ha^{-1} + hydropriming) resulted in reduction in yield up to 27 per cent. A similar trend was observed in confirmatory trial with yield increase upto 10 per cent in seed rate of 120 kg ha^{-1} with hydropriming and 39 per cent yield reduction at 140 kg ha^{-1} with hydropriming. The higher grain yield registered in these treatments correspond to the lower weedy rice population recorded in these treatments. High crop seeding rates suppressed weedy rice population and hydropriming resulted in enhanced vigour of rice seedlings. The synergistic effect of these two might have resulted in high competing ability of rice over weedy rice reducing its count. Better crop stand from hydroprimed seeds sown at 100 or 120 kg ha^{-1} resulted in rapid canopy development and gave preliminary advantage to rice plants over weedy rice. Although per plant yield was higher at lower seed rate this did not compensate for the contribution in terms of yield by more plants at higher density. Above optimum LAI values recorded in treatments receiving higher seed rates (140 kg ha^{-1}) support these findings. Results of Zhang *et al.* (2015) revealed positive correlation between high seed rate and yield up to a certain level and beyond that optimum level yield would start to decline because of severe competition for various growth factors. Clark *et al.* (2001) opined that seed priming improved the competitive ability of crop against weeds, increased vigour of primed stand was the key factor for tolerating weeds.

An inverse relationship was found between the grain yield of rice and weedy rice population present in respective treatments. Reduction in grain yield was observed in treatments with an exceptionally high seed rate, which was directly correlated to the higher weedy rice count m^{-2} recorded in these treatments. Higher weedy rice count was recorded in plots receiving the highest seed rate without priming. This might be due to the sever completion set up among rice plants in which weedy rice took advantage of this situation. Chauhan (2013) supported this finding, by stating that with each increase in weedy rice density, the grain yield of

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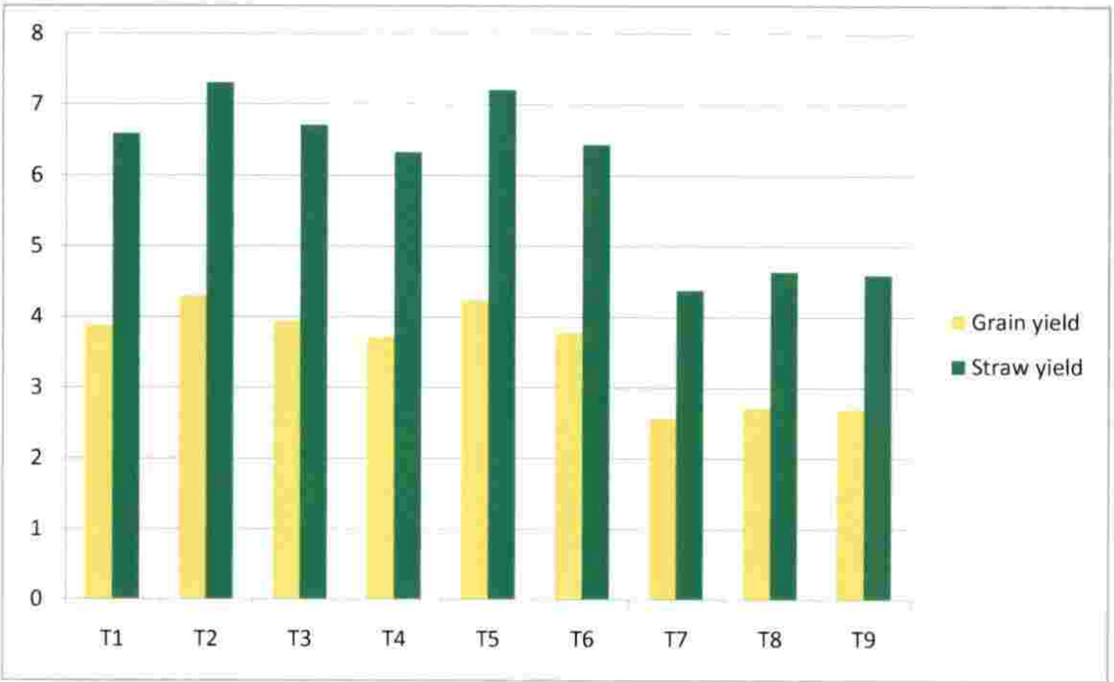

Fig 6: Effect of treatments on grain and straw yield of rice (t ha^{-1})

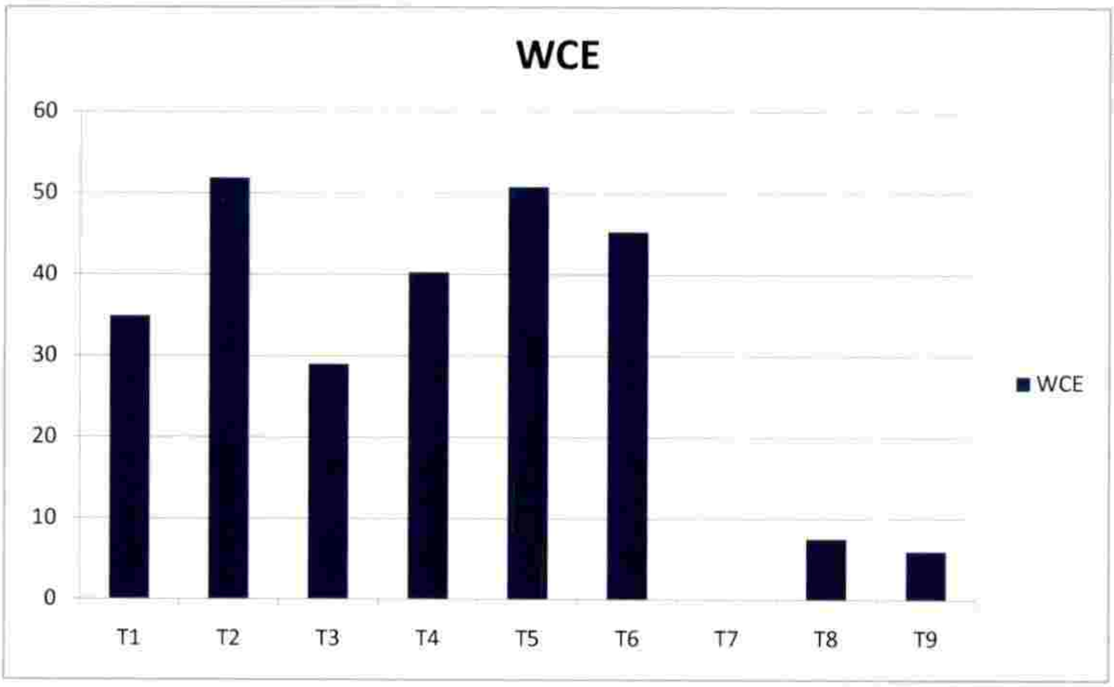

Fig 7: Effect of treatments on Weed Control Efficiency of rice

cultivated rice declined significantly. In a previous study in U.S., rice yield reductions were between 100 and 755 kg ha^{-1} for every weedy rice plant m^{-2} (Ottis *et al.*, 2005). Rice yield declined by an average of 270 kg ha^{-1} for each weedy rice plant up to 20 weedy rice plants m^{-2} (Kwon *et al.* 1991). Ahmed *et al.* (2014) reported that grain yield in rice was increased by 30 to 33 per cent under unweeded situation by adopting a higher seed rate.

A similar trend was observed in straw yield. Seed rate of 100 kg ha^{-1} along with hydropriming (T_2) recorded higher straw yield of 6.72 and 7.31 t ha^{-1} in microplot and farmers field respectively and was followed by seed rate of 120 kg ha^{-1} with hydropriming (6.37 and 7.21 t ha^{-1} respectively in microplot and farmers field). Thousand grain weight and HI values were not influenced by the treatment combination of increased seed rate and various priming methods. Economic analysis of the study indicated that T_2 (100 kg ha^{-1} + hydropriming) along with T_5 (120 kg ha^{-1} + hydropriming) turned out to be the most economic treatment registering a B: C ratio of 1.68 and 1.64 respectively. Highest seed rate of 140 kg ha^{-1} with or without priming recorded the lowest B:C. The most economic management practice was use of hydroprimed seeds at a rate of 100 kg ha^{-1} for suppression of weedy rice and improving competitive ability of rice.

Weedy rice count and dry weight were recorded lower in T_2 (seed rate 100 kg ha^{-1} + hydropriming) and T_5 (seed rate 120 kg ha^{-1} + hydropriming), with high weed control efficiencies of 51.85 and 50.82 per cent respectively. At above optimum crop density, canopy closes quickly and shade out the weedy rice plants. Such an advantage obtained during the initial stages will be reflected later as high yield. Phuhong *et al.* (2005) reported that in lowland rice, higher seeding rates (within the optimal range) favoured rice against weeds and increased the yield even under weedy conditions.

Based on the results from microplot and the confirmatory trial at farmers field it could be concluded that seed rate of 100 kg ha^{-1} along with hydropriming (T_2) could be recommended as the most economic practice for management of weedy rice in rice fields.

5.2.2 Effect of Treatments on Vegetative and Yield Attributes of Weedy Rice

Enhancing rice competitiveness by adopting high cropping density and priming techniques was conducted to suppress growth and emergence of weedy rice plants. Of the various growth factors of weedy rice analyzed, plant height and LAI, grain and straw yield were influenced by the treatments during both the years. Weedy rice plants were found to be taller at a high seed rate of 140 kg ha^{-1} in microplot while no such trend was observed in farmers' field. This was in confirmation with the findings of Kwon *et al.* (1991) who reported that height of cultivated rice plants was found to decrease with increase in weedy rice density. Weedy rice plants taller than cultivated rice would further add to its competitive ability by better harvest of light. According to Chauhan (2012), taller weed plants are known to reduce crop yield more than shorter weed plants mainly because of more shading of crop plants. Low light is known to significantly decrease growth and grain yield in rice (Praba *et al.*, 2004). Earliness in flowering was observed in weedy rice compared to other cultivated rice varieties. It flowered at 51 to 53 DAS while, rice took 80 to 82 days for flowering. Weedy rice flowered one month earlier than cultivated rice leading to early seed maturity and shattering.

The highest seed rate of 140 kg ha^{-1} (T_7, T_8 and T_9) recorded higher leaf area m^{-2} for weedy rice in both the situations. This might be due to the high weedy rice count recorded from unit land area. Exceptionally high crop seeding rate generated severe competition among rice plants and weedy rice took advantage of the situation recording high weed densities. High tiller number and plant height of weedy rice might shade rice plants which is evident from the higher leaf area m^{-2} (11651.17 and

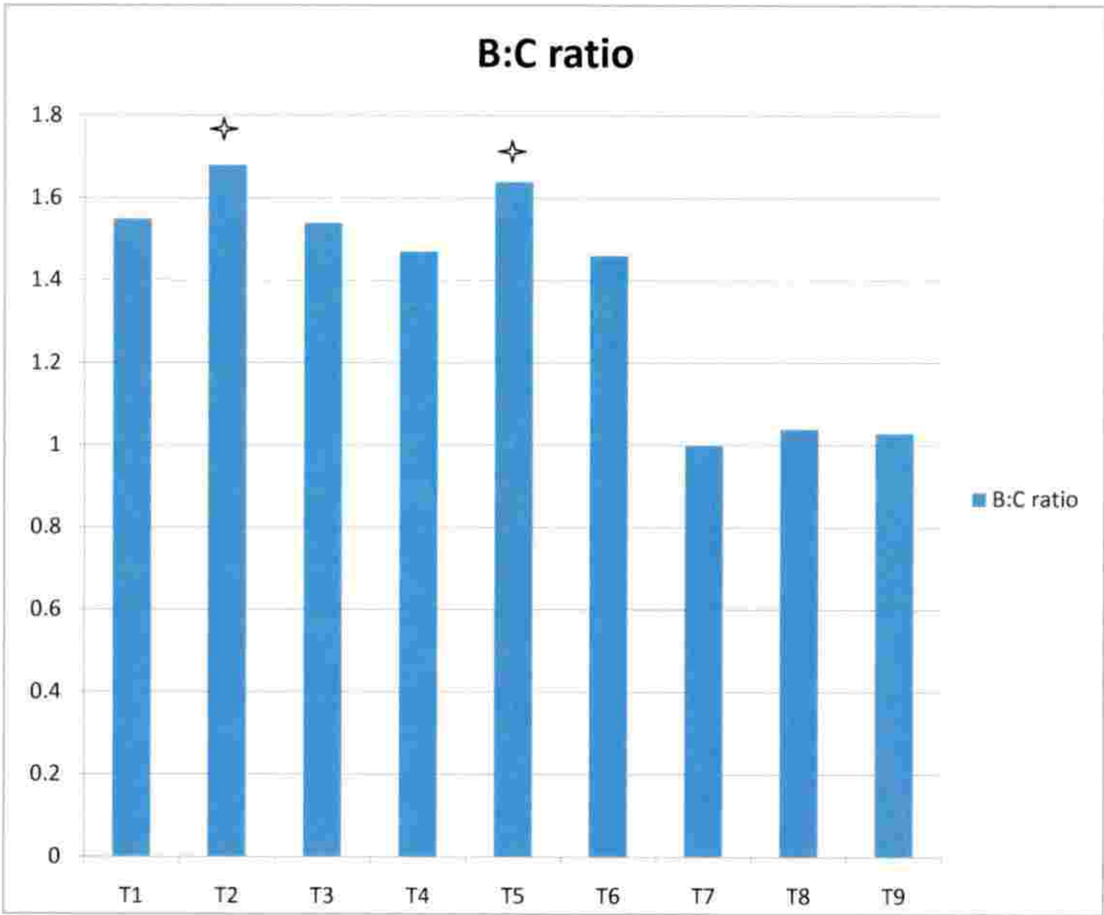

Fig 8: Effect of treatments on B:C ratio of rice

12223.96 cm^2 respectively in microplot and farmers field) recorded by weedy rice plants at 140 kg ha^{-1} without priming. Chauhan (2013) reported that leaf production of cultivated rice was significantly affected by weedy rice densities and a decline was observed with increment in weedy rice densities which further lead to a reduction in LAI. LAD of flag leaf in weedy rice remained unaffected by the treatments and was ranged between 33 to 35 days, while it was 39 to 41 days for rice. A significant difference between the LAD of rice and weedy rice was observed under microplot and farmers field with rice remaining greener for a long period enhancing its photosynthetic efficiency.

Panicles of weedy rice were found to be shorter compared to rice under both the studies. Higher seed rate and priming methods had no influence on panicle length of weedy rice as it was genetically determined. Weedy rice panicles recorded lesser number of grains per panicle (67 to 70 both in microplot and farmers field) and remained unaffected by the treatments. Weedy rice panicles contained more sterile and half filled grains with sterility percentage of 30 to 32, than cultivated rice (below 17 per cent) irrespective of the treatments. However sterility percentage of weedy rice was lower in farmers' field (19 to 24). It could be observed that repeated back crossing between persistent weedy rice population and cultivated rice under farmers' field situation lead to more filling of weedy rice panicles. Thousand grain weight of weedy rice plants ranged between 20 to 22 g in both the experiments and was not altered by the treatments. Jose *et al.* (2013) also reported a lower thousand grain weight for weedy rice (below 19 g).

Grain yield of weedy rice was between 42 to 110 g m^{-2} in both microplot and farmers field situation. Higher grain yields for weedy rice was observed in treatments with the highest seed rate of 140 kg ha^{-1} (T_7, T_8 and T_9) which was directly correlated to the higher weedy rice counts m^{-2} recorded in these treatments. Straw yield of weedy rice plants also followed a similar trend like grain yield.

5.3 EFFECT OF ELEVATED CO_2 CONCENTRATION ON GROWTH AND YIELD OF RICE AND WEEDY RICE

Climate change and associated climatic abrasions are one of the many risk factors affecting the rice production systems of Kerala apart from other threats associated with resource (land, labour, capital) depletion. Rising carbon dioxide concentration by various anthropogenic activities had a major role in climate change. Global carbon dioxide concentration has risen from 280 to 300 $\mu mol\ mol^{-1}$ in the past 250 years due to continuous anthropogenic activities and it is expected to reach 600 $\mu mol\ mol^{-1}$ sometime around 2050 (IPCC, 2007). Climate change also influence the weed communities in rice production system by affecting the weed species distribution, and prevalence within weed and crop communities (Mahajan *et al.*, 2012). Various weed management operations could be affected by climate change and ultimately might have influence on the competitiveness of major weeds associated with rice production system. According to Ziska (2003), weeds showed a greater response to elevated CO_2 rather than crops. In this background, impact of elevated CO_2 on competitiveness of rice and weedy rice has been discussed.

5.3.1 Performance of Rice Varieties and Weedy Rice Under Elevated CO_2 Condition

In this study, the effect of elevated CO_2 concentration on growth of rice and weedy rice was analyzed under elevated CO_2 concentration of 500 ppm in Open Top Chamber (Chamber A) and in ambient conditions (Chamber B and open field). The most common morphotype of weedy rice and two cultivated rice varieties (Jyothi and Uma) were selected for the study. Significant variations in vegetative (no of tillers, leaf area index and leaf area duration) as well as yield attributes and yield (no. of grains panicle^{-1}, grain yield plant^{-1}) were observed under elevated CO_2 levels among the plants. However, the extent of response varied among the cultivars under varying atmospheric situations.

Plate 30: Open Top Chamber (OTC)
a) General view b) Sensors c) CO_2 cylinders and display

Plate 31: Number of tillers and anthocyanin pigmentation of Jyothi, Weedy rice and Uma in chamber A

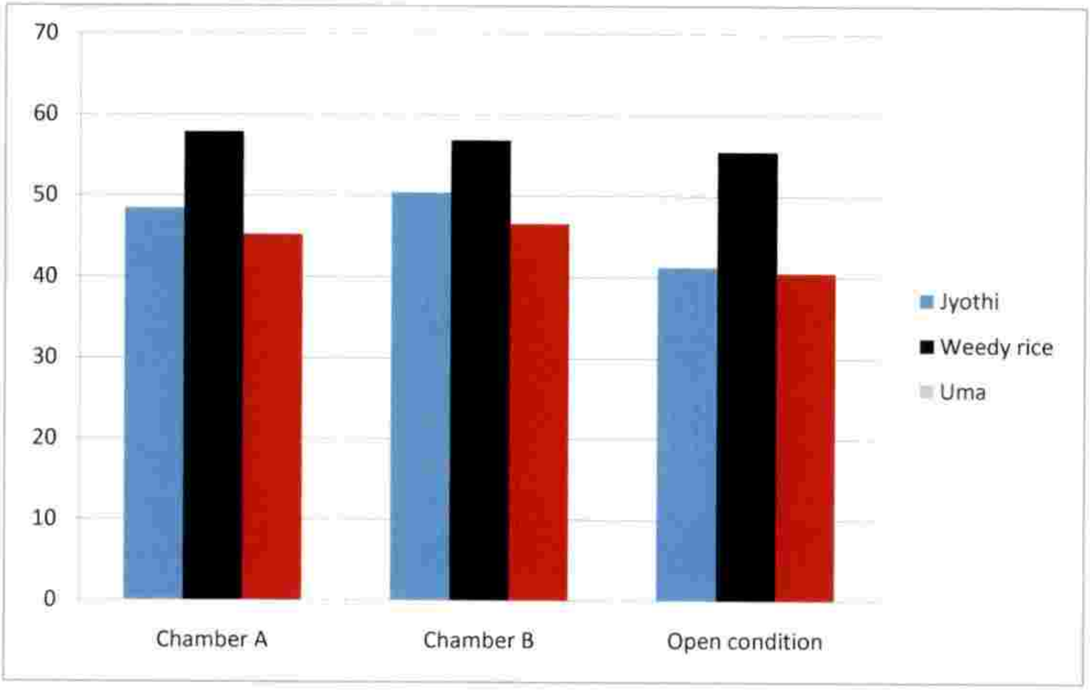

Fig 9: Effect of elevated CO_2 on plant height at 30 DAS (cm)

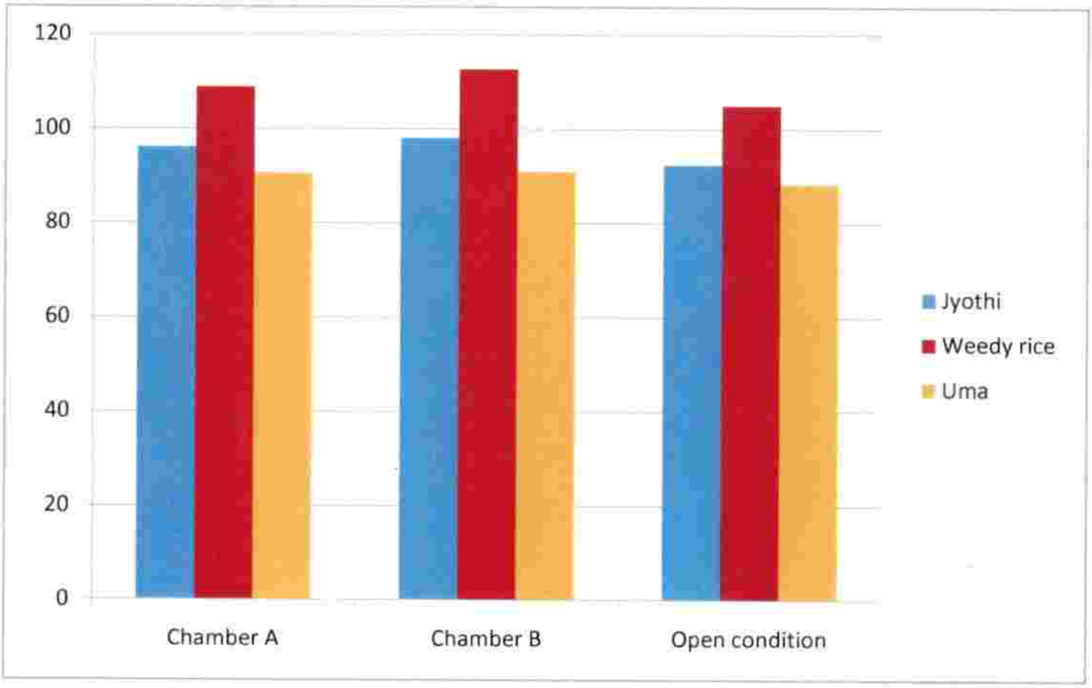

Fig 10: Effect of elevated CO_2 on plant height at 50% flowering (cm)

Of the various growth and yield attributes analyzed, weedy rice responded well compared to cultivated rice variety Jyothi, showing its high competitive potential. There was differential response of rice varieties to elevated CO_2 condition with Uma responding well compared to Jyothi.

Elevated CO_2 had a significant influence on plant height in both rice and weedy rice in all the three situations. There was a linear increase in plant height of weedy rice in chamber A during initial stages and in chamber B during reproductive stages. This clearly indicated that weedy rice responded well to elevated CO_2 condition during the initial stages and at the reproductive stage response was more to the ambient conditions of chamber B. Singh and Jasrai (2011) reported that effects of elevated CO_2 to plant growth was more pronounced during early growth stages and reduced greatly at later stages. On analyzing the response between cultivated rice and weedy rice it was observed that Jyothi responded well to elevated CO_2 than Uma in plant height.

Tilling ability of both weedy rice and cultivated rice was significantly affected by various growing situaions. Compared to ambient conditions (chamber B and Open condition), higher tillering was observed under elevated CO_2 (chamber A) in which weedy rice tillered profusely (17.33) than cultivated rice species (9 and 11.33 for Jyothi and Uma). This was in confirmation with the findings of Ziska *et al.* (2010), who reported that weedy rice responded more strongly to rising CO_2 level than cultivated rice with greater competing ability. Among the cultivars, Uma showed maximum response to elevated CO_2 producing 3.33 times more tillers than in open condition. However, Jyothi was found less responsive to elevated CO_2 levels in terms of tiller production indicating variation in varietal response to carbon dioxide levels

Earliness in flowering was observed under elevated CO_2 condition for both weedy rice and cultivated rice. Compared to the open condition, weedy rice recorded

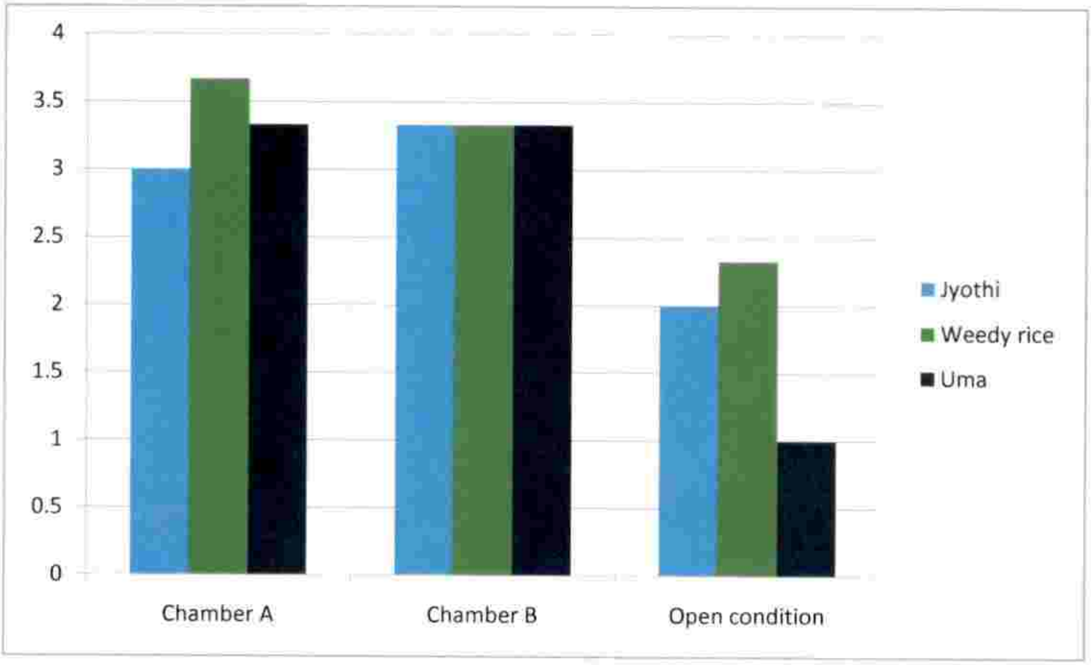

Fig 11: Effect of elevated CO_2 on number of tillers of Jyothi, weedy rice and Uma at 30 DAS

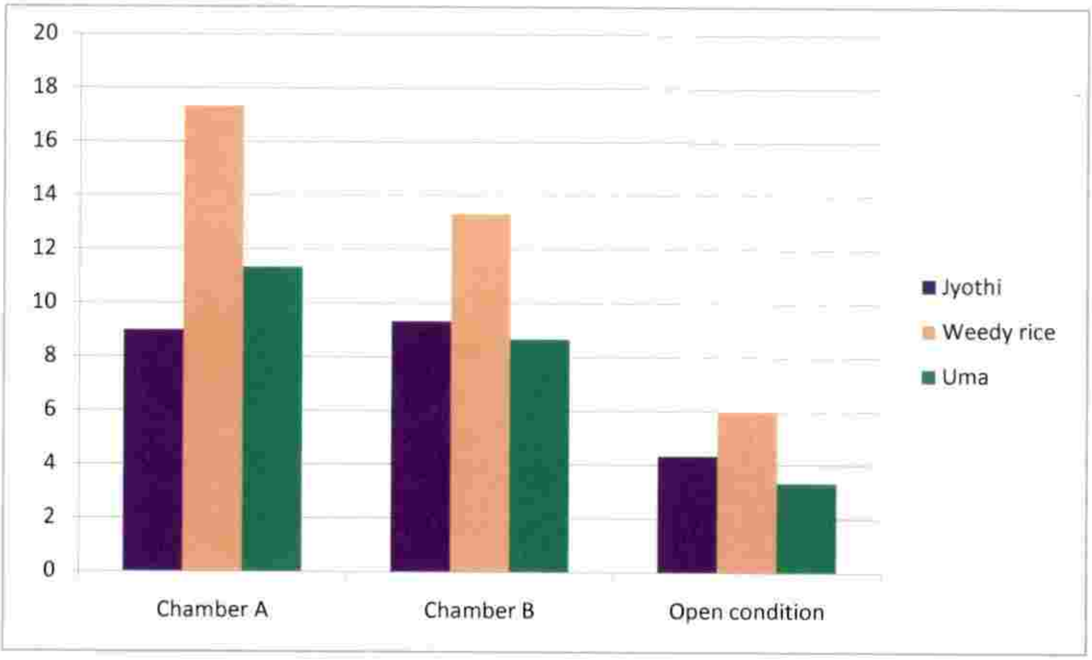

Fig 12: Effect of elevated CO_2 on number of tillers of Jyothi, weedy rice and Uma at 50% flowering

an earliness of 15 and 7 days in Chamber A and B respectively, indicating the favorable effect of elevated CO_2 on flowering. Mahajan *et al.* (2014), observed that climate change not only affect the crop-weed competition, but also trigger early flowering and weed seed germination in several flushes causing serious weed management issues. This earliness in flowering of weedy rice might help to complete its life cycle faster and initiation of more life cycles even within a single crop period. Jyothi and Uma also recorded an earliness of 17 and 8 days in Chamber A and B respectively. Hence, it could be concluded that early flowering induced from elevated carbon dioxide level would contribute to more weed seed bank and might pose serious threats to rice cultivation in future.

Leaf area duration of flag leaf was increased with increase in CO_2 concentration. Uma and weedy rice had a longer duration for flag leaf in both chambers A and B. Under open condition Jyothi and Uma retained the greenness of their leaves for one more week compared to weedy rice.

LAI showed a steady increase with increase in CO_2 concentration for both rice and weedy rice at 50 per cent flowering stage. Uma showed a greater response (2.34 times more than open condition) in chamber A, followed by weedy rice (2.09 times more than open condition). It was noticed that weedy rice under all the three situations recorded a higher LAI which might be due to its high tillering nature (Seeneweera *et al.*, 1994; Sherchand and Sharma., 2004). Higher LAI of weedy rice (3.80) at 50 per cent flowering stage under elevated CO_2 condition (4.23) indicated its high competitive potential as a weed. Panicle length of weedy rice remained unaffected by various levels of CO_2. Though it varied significantly between rice varieties and growing situations.

Number of grains $panicle^{-1}$ was found to increase with an increase in CO_2 levels. Weedy rice recorded a greater response to number of grains $panicle^{-1}$ in chamber A with a percentage increase of 20.69 to 24.09. Kim *et al.* (2003) reported a

Plate 32: Performance of weedy rice, Jyothi and Uma in chamber A

Plate 33: Performance of weedy rice in chamber B, A and open condition

Plate 34: Performance of Jyothi in chamber B, A and open condition

Plate 35: Performance of Uma in chamber B, A and open condition

liner relationship between elevated CO_2 and spikelet number. Varietal variations were observed with Jyothi recording a poor response and Uma exhibiting a greater response to elevated CO_2 concentration. But this was in conflict with the findings of Sherchand and Sharma (2004), who reported that elevated CO_2 had little effect on number of grains panicle^{-1}. Though Uma recorded higher number of grains panicle^{-1} (114) compared to weedy rice (64) and Jyothi (100), percentage increase in number of grains panicle^{-1} was greater for weedy rice under elevated CO_2 condition.

Sterility percentage and thousand grain weight varied significantly between the chambers and among the varieties. Weedy rice recorded a higher sterility percentage compared to cultivated rice under all the situations. But the sterility percentage increased with the increase in the CO_2 levels; which might be due to the rise in temperature associated with increased CO_2 concentration. Matsui *et al.* (1997) demonstrated that high temperature during flowering induced pollen sterility in rice. A significant variation was observed between cultivars within Chamber A, Chamber B and between chambers. Variety Uma recorded a comparatively lower sterility percentage with the increased CO_2 levels, indicating the temperature tolerance of this variety and open up the scope of using this variety in further breeding programmes.

Grain yields varied under various CO_2 concentrations, for weedy rice with a higher grain yield plant^{-1} in Chamber A (1.73 times more than open condition), followed by Chamber B (1.19 times more than open condition). Uma showed a greater percentage increase in grain yield (51.4 per cent in chamber A and 40 per cent in chamber B) followed by weedy rice (42.3 per cent in chamber A and 16 per cent in chamber B). Higher grain yield of Uma was the result of more number of grains panicle^{-1}, low sterility percentage and higher thousand grain weight. Similar results were also reported by Sherchand and Sharma (2004). Jyothi recorded a negative response to elevated CO_2 levels. A significant variation was observed between chambers, indicating the effect of elevated CO_2 on grain yield. This increase in grain

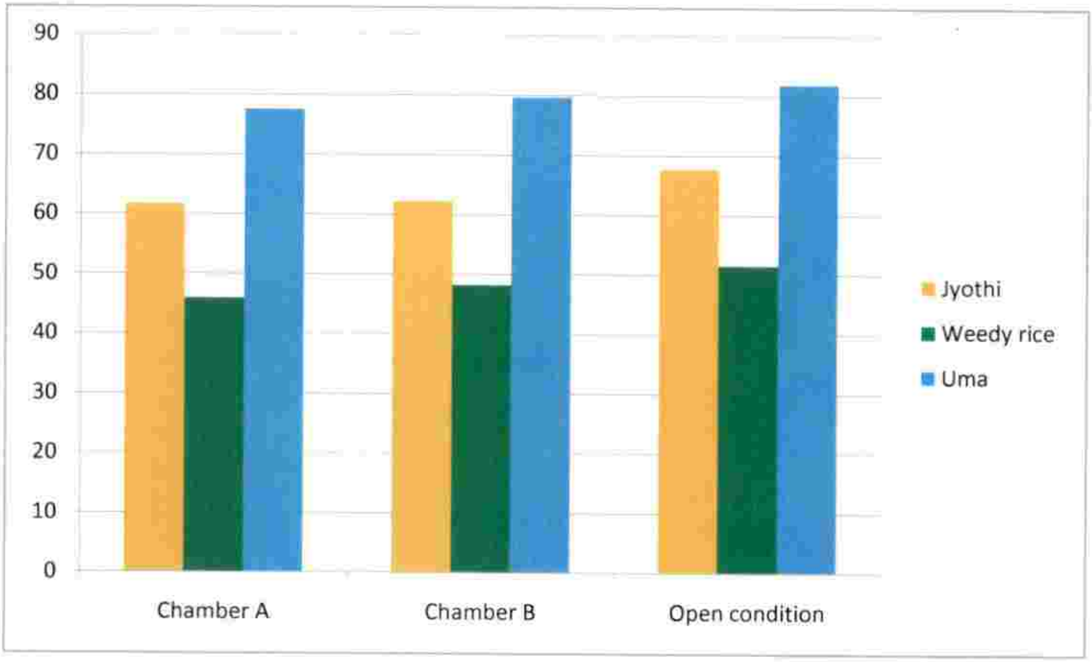

Fig 13: Effect of elevated CO_2 on days to 50% flowering of Jyothi, weedy rice and Uma (days)

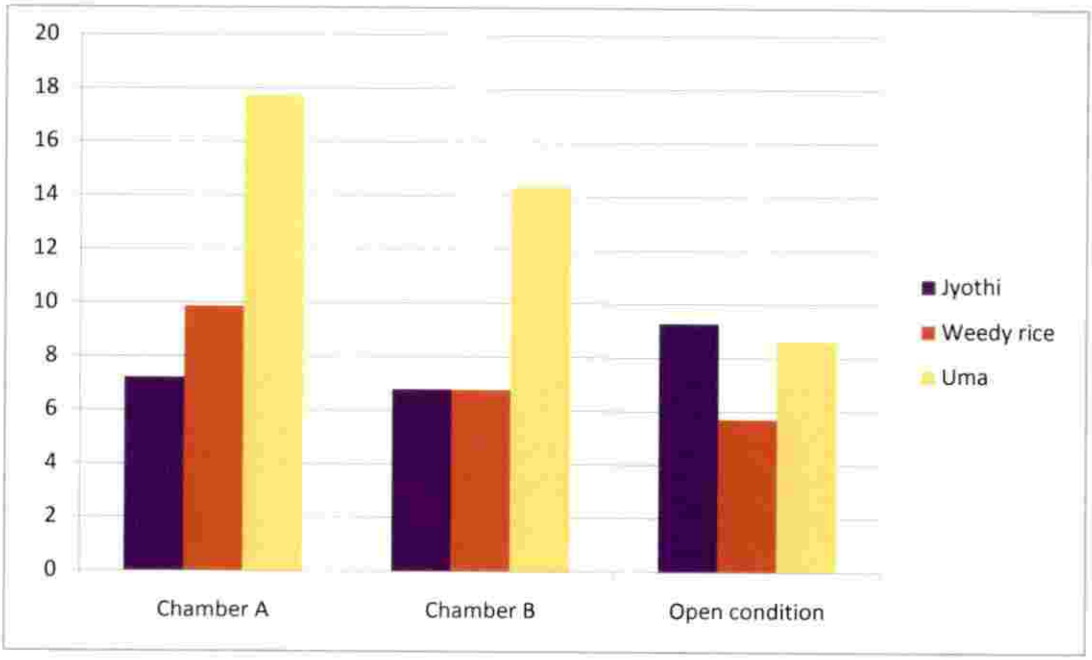

Fig 14: Effect of elevated CO_2 on grain yield of Jyothi, Weedy rice and Uma (g $plant^{-1}$)

yield might be due to increase in number of grains panicle^{-1} under elevated levels of CO_2.

Straw yield plant^{-1} also followed a similar trend like grain yield plant^{-1} and Uma in chamber A recorded higher straw yield followed by weedy rice. Among the chambers, significantly higher straw yield was recorded in Chamber A followed by Chamber B and open condition. According to Sherchand and Sharma (2004), about 30 to 48 per cent increment in straw yield was observed under elevated CO_2 concentration.

It could be concluded that weedy rice responded more strongly to rising CO_2 condition than cultivated rice during the initial stages as evidenced by the higher plant height and profuse tillering. Between the rice varieties, Uma showed a good response to elevated CO_2 and ambient conditions of chamber B. Rice cultivars having the ability to maximize the benefit of elevated CO_2 should be identified for future breeding programmes to counteract the competitiveness of emerging weeds in the scenario of climate change.

Summary

6. SUMMARY

An investigation entitled "Characterization and management of weedy rice (*Oryza sativa* f. *spontanea*)" was carried out as three experiments comprising four separate studies during 2014-16. Experiment I: Morpho- physiological and agronomic characterisation of weedy rice (Pot culture study carried out at College of Agriculture, Vellayani). Experiment II: (a) Management of weedy rice by enhancing rice competitiveness (Micro plot study undertaken in the wetlands of the Instructional Farm College of Agriculture, Vellayani, Kerala) (b) Management of weedy rice by enhancing rice competitiveness (confirmatory trial in farmer's field of Kanjirathadi padasekharam in Nemom block, Thiruvananthapuram district, Kerala). Experiment III: Effect of elevated CO_2 concentration on growth of rice and weedy rice (Pot culture experiment in the OTC (Open Top Chamber) facility available under the Department of Plant Physiology, College of Agriculture, Vellayani). The main objectives of the study were morpho-physiological and agronomic characterization of weedy rice morphotypes of Kerala; formulation of a management strategy and assessment of crop-weed interference under elevated CO_2 concentration.

Morpho-physiological and agronomic characterization of weedy rice morphotypes' was conducted as pot culture laid out in completely randomized design with eight weedy rice morphotypes collected from major rice tracts of Kerala (Trivandrum, Kuttanad, Kole, Palakkad, Kozhikode and Ezhome). Morphological characterization (done using morphometric descriptors) and agro- physiological characterization was done and compared with cultivated rice varieties (Uma and Jyothi). The results of the study are summarized below:

- During initial stages, weedy rice morphotypes exhibited similar morphological characteristics as the cultivated rice varieties.
- Morphological characters that varied significantly (qualitatively and quantitatively) between weedy rice and cultivated rice during initial

growth stages included culm thicknes, colour and length of ligule and number of tillers plant^{-1}.

- Some other demarcating characters like presence of black ring and characteristic bend at the nodal region, presence of adventitious roots were observed in some morphotypes.
- Morphotype from Ezhome exhibited a wide variation from other morphotypes with characters like ligule pigmentation (purple coloured ligules), leaf attitude of flage leaf (deflexed type leaf attitude), colour of awns after anthesis (purple coloured awns) and anthocyanin pigmentation at the nodal region (intense purple anthocyanin pigmentation).
- Physiological characterization of weedy rice morphotypes showed no significant variation in chlorophyll content, Total soluble protein and stomatal characteristics at any stages statistically. However most of the morphotypes recorded a higher chlorophyll contend and stomatal frequency at the initial stages and to the competitiveness of weedy rice.
- Root characteristics in terms of root volume and root dry weight were superior for most of the weedy rice morphotypes compared to cultivated rice.
- All the weedy rice morphotypes collected showed a prominence in awn length ranging from 2.37 to 9.23 cm.
- Shattering percentage expressed as grain threshability was significantly higher for weedy rice ranging from 29.73 to 46.32 %.
- Weedy rice morphotypes recorded wide variation in seed longevity ranging from 5 to 15 months, which is an indication of variable seed dormancy.
- Agronomic attributes of weedy rice morphotypes showed superiority in plant height, Leaf area index and number of tillers per plant.

- Earliness in 50% flowering was observed in weedy rice morphotypes compared to cultivated rice.
- Sterility percentage of weedy rice morphotypes were significantly higher (17.77 to 32.79 %) compared to cultivated rice (9.23 to 12.85%).
- An average grain yield of 4.89 g plant $^{-1}$; straw yield of 16.14 g plant^{-1} and 1000 grain weight of 20.42 g was recorded by weedy rice morphotypes.

The second experiment (both micro plot and confirmation trial in farmer's field) laid out in randomised block design, comprised of nine treatments replicated thrice. The treatments were: T_1: Seed rate of 100 kg ha^{-1} without priming, T_2: Seed rate of 100 kg ha^{-1} along with hydropriming, T_3: Seed rate of 100 kg ha^{-1}with hardening by 2.5 % KCl, T_4: Seed rate of 120 kg ha^{-1} without priming T_5: Seed rate of 120 kg ha^{-1} along with hydropriming, T_6 : Seed rate of 120 kg ha^{-1}with hardening by 2.5 % KCl, T_7: Seed rate of 140 kg ha^{-1} without priming, T_8 : Seed rate of 140 kg ha^{-1} along with hydropriming, T_9 : Seed rate of 140 kg ha^{-1}with hardening by 2.5 % KCl . The results of the study are summarized below:

- In micro plot experiment, a seed rate of 100 kg ha^{-1} along with hydropriming(T_2) recorded higher number of grains per panicle(120.02), grain yield (4.44 t ha^{-1}) and straw yield (6.71 t ha^{-1}) which was on par with T_5 (120 kg ha^{-1} + hydropriming).
- In field experiment, treatments with a higher seed rate of 100 kg ha^{-1} or 120kg ha^{-1} along with hydropriming resulted in superior yield attributes in rice like number of grains per panicle, grain yield and straw yield.
- Seed rate of 100 or 120 kg ha^{-1} with hydropriming recorded lower weedy rice count m^{-2} and dry weight of weedy rice.
- The most economic practice for weedy rice management was T_2 (100 kg ha^{-1} + hydropriming) with a BC ratio of 1.68 which was on par with T_5 (120 kg ha^{-1} + hydropriming) with a BC of 1.64.

The third experiment was laid out in completely randomised block design, comprised of nine treatments replicated thrice. The treatments include combination of three cultivars grown in three different CO_2 levels. Cultivars include two most popular rice cultivars of Kerala, Jyothi (short duration) and Uma (medium duration), grown along with one of the most common weedy rice morphotypes. Various levels of CO_2 provided for plant growth were chamber A (with an elevated CO_2 of 500 ppm, maintained by external supply); chamber B (higher CO_2 contend compared to open by natural build up); and open condition (atmospheric CO_2 level). The results of the study are summarized below:

- Both vegetative and yield attributes varied significantly among chamber A, B and open condition and within chambers.
- Under elevated CO_2 condition in chamber A, the growth characters of both rice and weedy rice showed significant enhancement compared to open.
- Regarding competitiveness of weedy rice, the vegetative as well as yield attributes of weedy rice was significantly high in chamber A which was on par with B and 2.61 times higher than open condition.
- Variety Uma showed a positive response to most of the characters under elevated CO_2 levels, pointing the possibility of exploring that variety in future breeding works.

6.1 Future Lines of Research

In the present study, morphological characters of weedy rice identified for early stage differentiation should be standardized for different agro-ecological units of Kerala. Identification of gens contributing to high competing ability of weedy rice can be incorporated into cultivated rice, to make it more competent. Physiological mechanisms behind seed dormancy and longevity need to be studied so as to combat the problem of weed seed bank build up in soil. An integrated package comprising preventive, cultural, mechanical, biological and chemical methods has to be developed. Rice varieties showing good response to elevated carbon dioxide levels need to be identified to sustain rice production in the coming era of climate change.

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CHARACTERIZATION AND MANAGEMENT OF WEEDY RICE

(*Oryza sativa* f. *spontanea*)

by

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ABSTRACT

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ABSTRACT

The study entitled 'Characterization and management of weedy rice (*Oryza sativa* f. *spontanea*)' was carried out as four separate experiments conducted at COA, Vellayani and farmers' fields of Nemom block during 2014-16. The main objectives of the study were morpho-physiological and agronomic characterization of weedy rice morphotypes of Kerala; formulation of a management strategy and assessment of crop weed interference under elevated carbon dioxide concentration.

Experiment I. 'Morpho-physiological and agronomic characterization of weedy rice morphotypes' was conducted as pot culture laid out in completely randomized design with eight weedy rice morphotypes collected from major rice tracts of Kerala (Trivandrum, Kuttanad, Kole lands, Palakkad, Kozhikode and Ezhome). Morphological characterization of weedy rice morphotypes using morphometric descriptors and its comparison with cultivated varieties revealed that during initial stages most of the weedy rice morphotype possess similar morphological characteristics as the cultivated varieties. Physiological characterization of weedy rice morphotypes revealed no significant variation in chlorophyll content, total soluble protein and stomatal characteristics with cultivated rice varieties. However, root growth in terms of volume and dry weight was significantly higher for most of the morphotypes collected from Trivandrum, Kuttanad, Palakkad, and Ezhome.

Earliness in 50% flowering was observed in all the weedy rice morphotypes compared to cultivated rice. Sterility of weedy rice morphotypes were significantly higher (17.77 to 32.79%) compared to cultivated rice varieties (9.23 to 12.85%). All the weedy rice morphotypes collected showed a prominence in awn length ranging from 2.37 to 9.23 cm. An average grain and straw yield of 4.89 and 16.14 g plant^{-1} and 1000 grain weight of 20.42 g was recorded by weedy rice morphotypes. Shattering percentage expressed as grain threshability was significantly high for weedy rice morphotypes ranging from 29.73 to 46.32%. The

seeds of weedy rice recorded wide variation in longevity ranging from 4.96 to 15 months which is an indication of variable seed dormancy.

Experiment II. 'Management of weedy rice by enhancing rice competitiveness' was undertaken as micro plot study by raising cultivated rice and most common weedy rice morphotype and maintaining a standard weedy rice population of 7 plants m^{-2}. To enhance rice competitiveness, three levels of seed rates *viz.*, 100, 120 and 140 kg ha^{-1} in combination with three types of priming techniques, *i.e.*, without priming, hydropriming and hardening (2.5 % KCl) were included. Among the treatments, seed rate of 100 kg ha^{-1} along with hydropriming (T_2) recorded significantly higher number of grains per panicle (120.02), grain yield (4.44 t ha^{-1}) and straw yield (6.71 t ha^{-1}) which was on par with T_5 (120 kg ha^{-1} + hydropriming).

Confirmatory trial at farmers' field revealed that seed rates of 100 kg ha^{-1} or 120 kg ha^{-1} along with hydropriming (T_2 & T_5) resulted in superior yield attributes in rice *viz.,* number of grains per panicle, grain and straw yield ha^{-1}. Weedy rice count m^{-2} and dry weight were significantly lower under these treatments. T_2 (100 kg+ hydropriming) along with T_5 (120 kg+ hydropriming) turned out to be the most economic treatment with a B:C ratio of 1.68 and 1.64 respectively.

Experiment III. 'Effect of elevated CO_2 concentration on growth of rice and weedy rice', was undertaken as pot study under elevated CO_2 concentration of 500 ppm in Open Top Chamber (Chamber A) and in ambient conditions (Chamber B and open field). The most common morphotype of weedy rice and two cultivated rice varieties (Jyothi and Uma) were selected for the study. Significant variations in vegetative (no of tillers, leaf area index and leaf area duration) as well as yield attributes and yield (no. of grain $panicle^{-1}$, grain yield $plant^{-1}$) were observed under elevated CO_2 levels in all these three systems. Higher grain yield per plant was recorded by weedy rice in Chamber A with an elevated CO_2 level (1.73 times higher than open condition), followed by Chamber

B (recorded 1.19 times more than open condition). However, the extent of response varied among the cultivars under varying atmospheric situations with Uma showing a greater percentage increase in grain yield (51.4% in Chamber A and 40% in Chamber B) followed by weedy rice (42.3% in Chamber A and 16% in Chamber B).

The study revealed significant variation among the weedy rice morphotypes. Cultivated rice and weedy rice exhibited morphological similarity during initial stages of growth. Seed rate of 100 kg ha^{-1} with hydropriming can be recommended as the most effective and economic management strategy for weedy rice. The response of weedy rice to elevated CO_2 was more compared to cultivated rice varieties.

സംഗ്രഹം

കേരളത്തിലുടനീളമുള്ള നെൽവയലുകളിൽ ഒരു വലിയ ഭീഷണിയായി വരിനെല്ല് മാറിക്കൊണ്ടിരിക്കുന്നു. നെല്ലിനോട് ഏറെ സാദൃശ്യം പുലർത്തുന്ന ഈ കളകളെ നെൽച്ചെടിയിൽ നിന്നും വളർച്ചയുടെ ആദ്യനാളുകളിൽ തിരിച്ചറിയുക ഏറെ ശ്രമകരമാണ്. കതിര് വന്നുകഴിഞ്ഞാൽ നെൽമണിയോടൊട്ടി നിൽക്കുന്ന നീണ്ട നാരുകൾ ഉപയോഗിച്ച് ഇവയെ വേർതിരിച്ചറിയാമെങ്കിലും അപ്പോഴേക്കും ഇവ വരുത്തിവെക്കുന്ന നഷ്ടം വലുതായിരിക്കും.

സൂക്ഷ്മമായി നിരീക്ഷിച്ചാൽ വരിനെൽച്ചെടികൾ തമ്മിൽത്തന്നെ ബാഹ്യഘടനയിൽ ഏറെ വ്യത്യാസം പുലർത്തുന്നതായി കാണാം. ഈ വ്യത്യാസങ്ങൾ പഠിച്ചാൽ ഇവയെ വളർച്ചയുടെ ആദ്യഘട്ടത്തിൽ തന്നെ നെൽച്ചെടിയിൽ നിന്നും വേർതിരിച്ചറിയാം. ഈ സാഹചര്യത്തിലാണ് കേരളത്തിലെ പ്രധാന നെല്ലുല്പാദന കേന്ദ്രങ്ങളിൽ നിന്നും ശേഖരിച്ച നിയന്ത്രണത്തിനായി ഒരു പുതിയ മാർഗ്ഗം കണ്ടെത്തൽ, ഭാവിയിലെ കാലാവസ്ഥാവ്യതിയാനം കണക്കിലെടുക്കുമ്പോൾ (ഉയർന്ന അളവിൽ CO_2 ഉള്ള സാഹചര്യം) നെല്ലും, വരിനെല്ലും തമ്മിലുള്ള മത്സരക്ഷമത പഠിക്കൽ എന്നീ ലക്ഷ്യങ്ങളോടെ "വരിനെൽച്ചെടികളുടെ ബാഹ്യ അപഗ്രഥനവും, നിയന്ത്രണവും" എന്ന ഗവേഷണപദ്ധതിക്ക് രൂപം നൽകിയത്. 2014 ഡിസംബർ മാസത്തിൽ തുടങ്ങിയ ഗവേഷണം കാർഷിക കോളേജിലും, നേമം ബ്ലോക്കിലെ കാഞ്ഞിരതടി പാടശേഖരത്തിലുമായി പൂർത്തീകരിച്ചു.

ഗവേഷണത്തിന്റെ ആദ്യഘട്ടത്തിൽ കേരളത്തിലെ പ്രധാനപ്പെട്ട നെല്ലുല്പാദന കേന്ദ്രങ്ങൾ സന്ദർശിച്ച് അവിടെ നിന്നും വരിനെൽച്ചെടിയുടെ വിത്ത് ശേഖരിച്ചു. തിരുവനന്തപുരം, ആലപ്പുഴ (കുട്ടനാട്), തൃശൂർ (കോൾ നിലങ്ങൾ), പാലക്കാട്, കോഴിക്കോട്, കണ്ണൂർ (കൈപ്പാട്) എന്നീ ജില്ലകളിൽ നിന്നും ശേഖരിച്ച വരിനെൽ വിത്തുകൾ ജ്യോതി, ഉമ എന്നീ നെൽവിത്തുകളോടൊപ്പം ചട്ടിയിൽ വളർത്തി, വരിനെൽച്ചെടികൾ തമ്മിലും അവയ്ക്ക് നെൽചെടികളുമായുള്ള വ്യത്യാസങ്ങളും പഠിച്ചു. അന്താരാഷ്ട്ര നെല്ല് ഗവേഷണകേന്ദ്രം പുറത്തിറക്കിയ മാനദണ്ഡങ്ങളുപയോഗിച്ച് നടത്തിയ പഠനത്തിൽ നിന്നും ഉയരം, ചിനപ്പുകളുടെ എണ്ണം, തണ്ടിന്റെ ഉരുണ്ട പ്രകൃതം, വേരിന്റെയും, ഇലയുടെയും ഘടന എന്നീ ബാഹ്യ വ്യത്യാസങ്ങൾക്കുപരിയായി ഉയർന്ന ആനുപാതികത്തി

ലുള്ള ഹരിതകവും, ആസ്യരന്ധ്രങ്ങളും ഇവയുടെ പ്രത്യേകതകളായി കണ്ടെത്തി.

ഗവേഷണത്തിന്റെ രണ്ടാം ഘട്ടത്തിൽ നെൽച്ചെടിയുടെ മത്സരക്ഷമത വർദ്ധിപ്പിച്ച് വരിനെല്ല് നിയന്ത്രണം സാധ്യമാക്കുന്നതിന് ഉയർന്ന വിത്ത്നിരക്കും, വിത്തുപചാരവും സംയോജിപ്പിച്ച് കൊണ്ടുള്ള വിവിധ രീതികൾ പരീക്ഷണ വിധേയമാക്കി. ഉയർന്ന വിത്ത്നിരക്കായ ഹെക്ടർ ഒന്നിന് 100 കിലോ, അല്ലെങ്കിൽ 120 കിലോ എന്ന തോതിൽ വിത്തുകൾ ഹൈഡ്രോപ്രയ്മിങ്ങ് (നെൽവിത്ത് 48 മണിക്കൂർ വെള്ളത്തിൽ കുതിർത്തതിന് ശേഷം ഉണക്കി പഴയ നിലയിലാക്കുന്ന രീതി) തയ്യാറാക്കി വിതയ്ക്കുന്നതിന് യഥാക്രമം 51.85, 50.82 ശതമാനം നിയന്ത്രണം സാധ്യമാക്കി.

ഗവേഷണത്തിന്റെ മൂന്നാം ഘട്ടത്തിൽ ഉയർന്ന അന്തരീക്ഷം CO_2 സാഹചര്യങ്ങളോട് നെൽചെടികളും വരിനെല്ലും എങ്ങനെ പ്രതികരിക്കുന്നു എന്നത് പഠനവിധേയമാക്കി. അന്തരീക്ഷത്തിലെ CO_2 ന്റെ അളവ് 500 പി.പി.എം. എന്ന ഉയർന്ന നിരക്കിൽ ആയിരിക്കുമ്പോൾ (ചേമ്പർ എ) നെല്ചെടിയുടെയും, വരിനെല്ലിന്റെയും ചിനപ്പൂക്കളുടെ എണ്ണം, ഉയരം, നെൽമണികളുടെ എണ്ണം, തൂക്കം എന്നിവയിൽ വർദ്ധനവ് രേഖപ്പെടുത്തി. ഉമയും, ജ്യോതിയും തമ്മിൽ താരതമ്യം ചെയ്യുമ്പോൾ ഉമ ഉയർന്ന CO_2 സാഹചര്യങ്ങളോട് മെച്ചപ്പെട്ട രീതിയിൽ പ്രതികരിക്കുന്നതായി കണ്ടെത്തി.

ഈ പഠനത്തിൽ നിന്നും നെൽച്ചെടികളും വരിനെല്ലും വളർച്ചയുടെ ആദ്യഘട്ടത്തിൽ ഏറെ ബാഹ്യസാദൃശ്യം പുലർത്തുന്നതായും; ഉയർന്ന വിത്തുനിരക്കും (100 കിലോ) ഹൈഡ്രോപ്രയ്മിങ്ങും സംയോജിപ്പിച്ച് കൊണ്ടുള്ള രീതിയിൽ 50 ശതമാനത്തോളം വരിനെൽ നിയന്ത്രണം സാധ്യമായതായും; ഉയർന്ന അളവിൽ ഉള്ള CO_2 സാഹചര്യങ്ങളോട് നെല്ലും വരിനെല്ലും മെച്ചപ്പെട്ട രീതിയിൽ പ്രതികരിക്കുന്നതായും കണ്ടെത്തി.

Appendix

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APPENDIX-I

Weather parameters during the experimental period

(December 2015 - March 2016)

Standard weeks	Temperature (^{0}C)		Relative humidity (%)		Sunshine hours	Rainfall (mm)
	Maximum temperature	Minimum temperature	Maximum R.H.	Minimum R.H.		
49	30.6	22.6	90.1	67.9	9	5.1
50	29.9	23.3	89.6	77.0	7.2	24.3
51	30.6	23.4	93.6	78.9	9.4	4.9
52	29.9	23.8	90.9	75.4	8.3	2.0
1	30.5	21.3	95.1	67.7	9.1	4.0
2	30.4	21.2	91.1	63.9	9.0	0.0
3	30.8	21.8	95.4	64.6	9.2	0.0
4	30.5	21.6	92.6	65.0	9.3	4.0
5	32.0	22.4	92.1	64.3	9.3	0.0
6	31.6	23.2	94.4	60.7	9.2	0.0
7	31.1	22.5	93.0	61.9	9.4	0.0
8	31.2	21.0	90.3	70.1	9.5	0.0
9	32.1	23.3	88.7	66.6	9.2	1.0
10	32.1	23.3	88.6	66.3	9.4	0.0
11	32.1	23.6	91.4	69.3	9.6	15.2
12	32.7	23.3	90.7	67.9	9.5	0.0
13	33.0	24.7	90.7	67.0	9.5	9.4