CROP PRODUCTIVITY AND WEED DYNAMICS IN RICE BASED FARMING SYSTEMS

by

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Crop productivity and weed dynamics in rice based farming systems"** 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 to me of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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ANOVA	Analysis of Variance
B: C ratio	Benefit cost ratio
BLW	Broad leaved weeds
CD	Critical difference
Cm	Centimeter
DAS	Days after sowing
Day^{-1}	per day
DAT	Days after Transplanting
et al.	and co-workers/co-authors
Fig.	Figure
G	gram
g m^{-2}	gram per square meter
Ha	Hectare
ha^{-1}	per hectare
$hill^{-1}$	Per hill
i.e.	that is
Kg	Kilogram
kg ha^{-1}	Kilogram per hectare
K	Potassium
KAU	Kerala Agricultural University
M	metre
m^{-2}	per square metre
MOP	Muriate of potash
MSL	Mean sea level
N	Nitrogen
P	Phosphorus
$Plant^{-1}$	per plant
$Panicle^{-1}$	per panicle
pH	Negative logarithm of hydrogen ion concentration
RH	Relative humidity

SEm	Standard Error
spp.	species
viz.	Namely
WCE	Weed control efficiency

LIST OF SYMBOLS

%	per cent
^{0}C	Degree Celsius
₹	Rupees
@	at the rate of
&	and

Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food for the largest number of people on earth. Worldwide, the cultivation of nearly 90 per cent of rice crop is in irrigated, rainfed and deep-water systems which is equivalent to about 134 m ha (Halwart and Bartley, 2007).

In Kerala, paddy fields are typical wetland ecosystems with several noteworthy ecological and economic functions. Despite its significance in every realm of the agrarian economy, the performance of the crop in recent years is dismal. During the past two decades, numerous farmers have been opting for crops of their choice and converting paddy fields for other crops, which resulted in a reduction in the cultivated area from 6.78 lakh ha in 1985-'86 to 1.99 lakh ha in 2015-'16 (FIB, 2017). The greatest challenge in rice farming is to make it a remunerative venture by the inclusion of different crops and related enterprises in the rice based cropping system.

Rice-rice-fallow is identified as the major rice based cropping system in the southern districts of Kerala *viz.*, Thiruvananthapuram, Kollam and Pathanamthitta (John *et al.*, 2014). Utilization of summer fallows for raising different crops increases system productivity and reduces the risk in production. In summer fallows, crops such as tuber crops, vegetables and fodder crops have been reported to be potential candidates for inclusion in rice based sequences (John *et al.*, 2014).

Farming systems approach has been recognized far and wide as a viable strategy to meet the manifold objectives of poverty reduction, food security, environmental soundness and sustainability, especially for small and marginal farmers. The advantages arising out of the efficient management of synergisms among enterprises, and diversity of produce make integrated farming systems often less risky (Gangwar *et al.*, 2010).

Diversification of crops along with a livestock component in the cropping system reduces the risk, increases and stabilizes the farm income. Low land rice ecosystems offer opportunities for the enhancement and culture of aquatic organisms (Halwart and Bartley, 2007). Integrating rice and fish, is one such technology which could help to produce rice and fish simultaneously by optimizing resource use through complementary use of land and water. Such integration reduced the cost of production of rice by 17.6 per cent with an enhancement in production to the tune of 15 per cent. Integrating fish with rice cultivation has been successful and profitable in the coastal rice regions *viz*. *Kuttanadu, Kole* and *Pokkali* lands of Kerala (Padmakumar *et al*., 2002).

The principal objective during the process of diversification in rice fields is to evolve new enterprise combinations that improve productivity and farmer's income. In addition to the objective of improvement in rice productivity, the focus will be to provide farmers the flexibility to choose a harmonious combination of enterprises that cause least disturbance to the ecosystem.

Weeds continue to be the major impediments of rice production. The yield losses owing to weeds range from 12 to 80 per cent depending on the associated environment and management practices adopted (Rao and Nagamani, 2013). Efficient weed management in rice is concerned with sustainable use of resources in rice production so as to shift the crop weed balance in favour of rice. A weed shift is the change in the composition of weeds in a weed population in response to natural or manmade changes in an agricultural system. Weeds are more resilient and can swiftly take advantage of the varied conditions created by any crop production system. A major approach to reduce the predominance of any given weed species is to increase the diversity of crops within the cropping system. Weed shift is also influenced by crop, cropping system, variety, type of soil, tillage, method of sowing, water, nutrient and weed management methods (Murphy and Lemerle, 2006; Koocheki *et al*., 2009). The crucial component of eco-efficient weed management is regular monitoring to identify shifts in weed populations and identify problematic weeds periodically. A classical example of the weed shift reported in the rice based cropping systems in India was , when in rice-wheat system, *Phalaris minor* and *Avena sativa* were found to be major weeds, while in rice-rice it was *Echinochloa sp.* and *Cyperus sp*. and in rice-mung+sesame *Cyanotis axillaris*, *Euphorbia hirta* and *Ipomea aquatic* (Ramanjaneyulu *et al*., 2006). Hence, the inclusion of crops with different growth habits and land preparation during summer in rice based sequences can, influence weed dynamics in the subsequent rice.

In this context, the present investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with following objectives

i. Study the weed dynamics of different rice based integrated farming systems during summer and subsequent *Virippu* rice crop.

ii. Assess the system productivity of the different rice based integrated farming systems

Review of Literature

2. REVIEW OF LITERATURE

Rice is a major food crop of India, growing in an area of 43 m ha (GOI, 2016). In Kerala, paddy fields are typical wetland ecosystems with several striking ecological and economic functions. Continuous growing of rice for a long period reduces crop yield and system productivity (Yadav *et al.*, 1998), soil fertility and increases multiple nutrient deficiency (Fujisaka *et al.*, 1994; Singh and Singh, 1995; Dwivedi *et al.*, 2001).

A reduction in rice yield owing to weed infestation has been reported in many studies by investigators worldwide (Johnson *et al.*, 2004; Prasad, 2011; Matloop *et al.*, 2014). Yield losses in rice fields by weeds are more than the combined loss of insect pest and diseases (Abbas *et al.*, 1995). Diversified and intensive rice based system helps to ensure higher productivity, profitability, food security and environmental safety. Diversified rotational cropping systems could reduce the weed density (Mandal *et al.*, 2011). Intensive cropping system with the inclusion of cereals, pulses and vegetables fulfill basic family needs and helps in risk reduction due to weather abnormalities.

Rice fields offer a suitable environment for other aquatic organisms (fish). Simultaneous cultivation of rice with fish is one of the best ways to increase food production from limited land and is practised in many countries in the world. Besides, control of weeds in the rice field when integrated with fish has been reported (Dan *et al.*, 1997; Rothuis *et al.*, 1999).

Hence, diversifying and intensifying of the rice based cropping system by integrating with different compatible enterprises offers an opportunity to increase productivity of the system and reduce the weed problems. Hence, this study entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with the aim of assessing the system productivity and weed dynamics of different rice based integrated farming systems during summer and subsequent *Virippu* rice crop.

The relevant literature on productivity and weed dynamics in rice based systems are reviewed in this chapter.

2.1 WEED COMPOSITION IN DIFFERENT RICE ECOSYSTEMS

Rice is grown under semi aquatic, semi-arid and aerobic conditions. In all the three conditions, weeds posed major problems in rice fields by competing for space, light, water and nutrients. However, the composition of the weeds varies with the situation.

According to Lakshmi (1983) and Rajan (2000), *Brachiaria ramosa, Echinochloa colona, Echinochloa crussgalli, Cyperus rotundus, Cleome viscosa, Sacciolepis indica* and *Monochoria vaginalis* were the predominant weeds in first crop of rice in Onnattukara region of Kerala.

Tomar (1991) observed the presence of grasses, sedges and broad leaved weeds in rice fields in the proportion of 75, 25 and 5 per cent respectively.

Piepho (1993) reported that increase in the water level in rice fields reduced the population of grasses, sedges and broad leaved weeds.

According to Sivakumar and Balasubramanian (2000), *Leptochloa chinensis, Echinochloa colona, Cyperus rotundus, Cyperus difformis, Fimbristylis littoralis, Rotala densiflora, Sphenoclea zeylanica, Eclipta alba* and *Marsilea quadrifolia* were the common weeds in rice when integrated with fish.

According to Saha *et al.* (2005), weeds *viz. Cyanodon dactylon, Setaria glauca, Dactyloctenium aegypticum, Cyperus iria, Cyperus difformis, Fimbristylis miliaceae, Echinochloa colona, Echinochloa crussgalli, Ludwigia parviflora, Scoparia dulcis, Desmidium trifolium, Borreria hispida, Sida rhombifolia, Phyllanthus niruri, Cleome viscosa and Alysicarpus vaginalis* dominated in rainfed upland rice.

Echinochloa colona, Cyperus difformis, Fimbristylis miliaceae and *Commelina sp.* dominated among weeds in transplanted rice grown in lowlands (Singh *et al.*, 2005).

Mandal *et al.* (2011) reported that *Echinochloa colona, Digitaria sanguinalis, Ludwigia parviflora* were the major weeds in rice fields grown under irrigated conditions in lowlands.

Reshma (2014) recorded that *Cleome rutidosperma, Melochia nodiflora, Ageratum conyzoides, Trianthema portulacastrum, Centella asiatica, Commelina jacobi and Oldenlandia umbellata, Cyperus rotundus, Fimbristylis miliacea, Cynodon dactylon and Panicum repens* were the major weed species in aerobic rice fields.

Arya (2015) observed that in rice, before flooding, broad leaved weeds *viz. Cleome rutidosperma, Commelina jacobi* and *Heliotropium indicum* dominated, whereas after flooding sedges such as *Cyperus iria, Cyperus difformis, Cyperus compressus* and grasses *viz. Echinochloa colona, Echinochloa stagnina* and *Oryza sativa f. spontanea* were more.

2.2 WEED DYNAMICS

2.2.1 Rice Based Cropping Systems

Vijayabaskaran and Kathiresan, (1993) reported that land management practices in the summer significantly reduced weed biomass during succeeding rice and cotton crops in Cauvery delta region. Summer ploughing and growing of green manure crops significantly decreased the weed seed reserve in the soil whereas inclusion of an upland crop like mung bean in the existing rotation with rice in lowland disturbed the weed flora.

Malik *et al.* (1998) noted that the high percentage of weeds viz. *Phalaris minor* (86 %), *Avena sp.* (83 %), *Melilotus indica* (56 %) and *Anagallis arvensis* (42 %) in rice-wheat system was reduced to 30 to 50 per cent when either or both the crops were replaced.

Growing and incorporation of green manure crop of *Sesbania aculeata* at the age of 45 days during summer season reduced weed competition in the first and second season of rice (Gnanavel and Kathiresan, 2002).

Ngouajio *et al.* (2003) suggested that including cowpea in the cropping system suppressed the weed population in the system.

Varughese (2006) inferred that in wet land rice ecosystem, raising of two crops of banana in succession to rice crop resulted in weed shifts and checked the weed spread.

Shift of obnoxious weeds *viz.*, *Echinochloa crussgalli* was noted when diancha, bhindi or short duration cassava was included as summer crops in the rice based cropping system (Varughese, 2007a).

Pradhan *et al.* (2014) reported that in rice- garden pea system, the high density of *Echinochloa colona* (1364-1435 m^{-2}) was reduced (20-20.9 m^{-2}) by increasing the cropping intensity.

Pot culture and field studies revealed that inclusion of an oilseed crop like sunflower before the rice crop satisfactorily controlled weeds and reduced herbicide use in rice-wheat cropping system. Growing of sunflower as an intercrop and in rotation reduced weed density in the standing and succeeding crops. Rhizosphere of sunflower severely reduced germination, density and biomass of weeds. The residual effect of sunflower persisted up to 75 days in the succeeding crop (Rawat, 2017).

2.2.2. Rice-Fish Integrated Systems

Piepho and Alkamper (1991) observed that integration of fishes *viz.*, common carp (*Cyprinus carpio*), Nile tilapia (*Tilapia nilotica*) and Tahi silver barb (*Puntius gonionotus*) in paddy fields reduced the number of sedges and broadleaved weeds at low water levels (5-7 cm).

Dan *et al.* (1997) reported that integration of fish in the lowland rice reduced weeds effectively.

Fish reared in rice field suppressed weed growth either by feeding on the weed or grassy seeds or by uprooting plants (Haroon and Pittman, 1997).

Rothuis *et al.* (1999) suggested that rearing of fish in fields simultaneously along with rice reduced the biomass of aquatic weeds.

Studies revealed that long term integration of fish and poultry with lowland transplanted rice reduced weeds. Integrated fish + poultry reduced weeds by 30 per cent whereas fish and poultry independently reduced weeds by 26 and 24 per cent respectively (Kathiresan, 2007).

Frei *et al.* (2007) observed that weed biomass was considerably reduced in the rice-fish integration compared to rice alone. The reduction was to the tune of 82-86 per cent thereby suggesting that fish can play an important role in weed control.

Fishes grown in rice fields reduced the intensity of weeds compared to the rice-rice system (Channabasavanna *et al.*, 2009).

Kathiresan (2009) reported that in rice-fish integrated farming system, the herbivorous fish species *viz.* grass carp (*Ctenopharyngodon idella*), Tilapia sp. (*Sarothero donniloticus*) and common carp (*Cyprinus carpio*) reduced weed biomass of *Echinochloa sp*. (33.17 %), *Cyperus rotundus* (31.82 %) and *Eclipta alba* (28.75 %).

Sousa *et al.* (2012) observed that integration of fish in rice fields reduced monocotyledonous weeds.

2.3 NUTRIENT REMOVAL BY WEEDS

Moorthy and Mitra (1991) reported that in transplanted rice, 13.7 to 19.4 kg of nitrogen, 1.5 to 1.8 kg of phosphorus and 17.4 to 33.7 kg of potassium was removed by weeds from one hectare.

Chandrakar and Chandrakar (1992) reported that nutrient removal by weeds was higher and to the tune of 86.5, 12.4 and 134.5 kg ha^{-1} NPK in weedy check plots of upland rice.

Singh *et al.* (2005) reported that higher removal of nitrogen (34.8 kg ha^{-1}), phosphorus (15.6 kg ha^{-1}) and potassium (42.3 kg ha^{-1}) by weeds was recorded in weedy check.

Higher (5.55 kg ha^{-1}) quantity of nitrogen was removed in the unweeded fields, which was 13.4 times more than the weed controlled fields (Dharumarajan *et al.*, 2009).

The highest removal of nutrients by weeds was noted in the unweeded control throughout the crop growth in directed seeded rice (Singh *et al.*, 2013).

Nutrients removal by weeds was higher in unweeded plots at all the growth stages of semi dry rice (Arya, 2015).

2.4 SYSTEM PRODUCTIVITY AND PROFITABILITY

2.4.1 Rice based Cropping Systems

Rice based cropping system is a major cropping system followed in India, which includes crops *viz.*, wheat, pulses, oilseeds, vegetables, green manure crops in rotation with rice. Rice-wheat system is the most widely adopted rice based cropping system followed in India (Yadav, 2002). Rice-rice-fallow was identified as the major rice based cropping system in the southern districts of Kerala *viz.*, Thiruvananthapuram, Kollam and Pathanamthitta (John *et al.*, 2014).

A five year study conclusively confirmed that a third crop of vegetable *viz.* bhindi, groundnut, green gram was profitable than keeping the field fallow. The maximum profit was obtained from rice-rice-bhindi cropping sequence (CSRC, 1989).

Diversification of cropping system through inclusion of pulse and oilseed was more beneficial and resulted in higher productivity and net profit compared to the cereal-cereal sequence (Umarani *et al.*, 1992).

Hegde (1992) stated that inclusion of legumes in the rice based cropping systems increased rice yields.

According to Prabhakaran and Janardhan (1997), the grain yield of rainy season rice increased (4.7-5.4 t ha^{-1}) in the rice-groundnut-cowpea cropping sequence compared to the rice-rice system (4.1- 4.5 t ha^{-1}).

Investigations carried out at Rice Research Station, Kayamkulam to identify the most suitable rice-based cropping system for Onattukara tract proved that rice-rice-groundnut was the most efficient cropping system followed by rice-rice-bhindi in terms of production efficiency and benefit: cost ratio (Pillai, 1998).

Diversification of rice based cropping system with potato increased the net return due to the higher sale price of potato (Roy *et al.*, 1999).

Black gram grown in fallows of rice based cropping systems resulted in higher rice equivalent yield, followed by cotton and soybean (Anbumani *et al.*, 2000).

Inclusion of pulses, oilseeds and vegetables in the cropping system was more beneficial than growing cereal continuously (Kumpamat, 2001; Raskar and Bhoi, 2001).

Bationo *et al.* (2002) inferred that the yield of rice grown in succession after cowpea doubled.

Sharma *et al.* (2004) suggested that production and land use efficiency could be increased through the inclusion of vegetables and legumes in rice based cropping system.

Varughese (2006) based on a study of rice-based diversified cropping systems, reported that the highest production potential and net income were obtained from one crop of rice followed by two crops of Nendran banana, followed by two crops of rice and bhindi.

A study with different types of cowpea revealed that rice-rice-cowpea (grain or vegetable purpose) system was found to be better with highest gross returns. Inclusion of summer legumes had beneficial effect on the system yield as a whole. The potential benefit of crop diversification was very much evident as fallowing during third crop season resulted in least returns and energy output (PDCSR, 2006).

Singh *et al.* (2007) recorded that among the different rice based cropping systems in Uttar Pradesh, rice-pea-okra and rice-pea-onion were the most productive.

Mishra *et al.* (2007) recorded that inclusion of vegetables and pulses in rice based systems increased profit.

Bastia *et al.* (2008) concluded that the maximum number of effective tillers (362 m^{-2}), longest panicles (23 cm) and maximum number of grains $panicle^{-1}$ (112) were observed in rice when grown in rice-groundnut-green gram cropping system.

Singh *et al.* (2008) observed that inclusion of potato, vegetables, peas and ground nut in rice-wheat cropping system led to increased production (95%) and land use efficiency (11 %).`

Inclusion of high value crops *viz.* vegetables and pulses in rice based cropping system increased the gross and net income (Kumar *et al.*, 2008).

Shrikant *et al.* (2011) concluded that among the different rice based cropping systems investigated, rice-potato-cowpea system resulted in highest (22.29 t ha^{-1}) total system productivity.

Jat *et al.* (2012) reported that system productivity in terms of rice equivalent yield (REY) was higher in rice-fenugreek-okra. Rice-fenugreek-okra (₹ 96286 ha^{-1}) and rice-onion-cowpea (₹ 84511 ha^{-1}) generated the highest net income. However, the highest rice yield (5.12 t ha^{-1}) was recorded from rice-onion-cowpea cropping system.

According to Prasad *et al.* (2013), significantly higher rice equivalent yield was recorded in intensified rice-wheat system by inclusion of green gram in the summer fallows.

John *et al.* (2013), based on a five year study on different rice based cropping systems, concluded that the highest average annual rice equivalent was obtained in the sequence rice-rice-amaranthus followed by rice-rice-sweet potato. Rice-rice-pumpkin and rice-rice-vegetable cowpea ranked third and fourth respectively.

Prasad *et al.* (2013) reported that legumes when grown in summer season could increase grain and straw yield of succeeding rice crop.

Alam *et al.* (2017) reported that system productivity of wheat-mung bean-rice system was higher (10 %) than rice- rice system. The system resulted in 26 per cent more gross returns, double net returns and 10 per cent higher benefit: cost ratio than rice-rice system.

2.4.2 Rice based Integrated Farming Systems

Rice based farming system is a sustainable option for subsistence farmers and has been practised in south Asia over 6000 years ago. Besides reducing risk, integration of animal component along with crops makes farming more attractive and profitable.

Rice is semi aquatic in nature and rice based ecosystems provide opportunities for cultivation of aquatic organisms. Rice-fish farming is an age-old practice in India. Integration of fish in rice fields increases resource use efficiency, productivity and profitability and thereby makes rice farming more attractive. In India, though rice is cultivated in an area of 43 m ha, only 20 m ha is suitable for integration of rice and fish (Rao and Singh, 1998). Rice-fish integrated farming has proved to be viable technology in the coastal rice regions lying below the mean sea level *viz. Kuttanadu, Kole* and *Pokkali* lands of Kerala (Padmakumar *et al.*, 2002) and.in the low-lying rice fields in Assam, West Bengal and certain other states of north-eastern region (Mahapatra and Behara, 2011).

Mukhopadhyaya *et al.* (1992) recorded that rice fish integration in the deep water rice fields of West Bengal resulted in fish yield ranging from 263-1215 kg ha^{-1}.

Rangaswamy *et al.* (1992) reported that fish as a component in rice increased profit by 60 per cent compared to conventional rice system.

Lightfoot *et al.* (1992) concluded that reduced competition due to control of weeds by fish and lower insect pest attack was the main reasons for increasing yield the yield of rice.

There are several reports of rice+fish integration in lowland rice fields. The yield of fish ranged from 500 to 700 kg ha^{-1} while that of rice varied from 5 to 6 t ha^{-1} (Mandal *et al.*, 1990; Mukhopadhyay, 1992; and Sinhababu and Venkateswarlu, 1995).

Rangasamy *et al.* (1996) reported that rice-fish-poultry-mushroom system recorded higher (₹. 11755) net profit compared to conventional rice system besides generating an additional employment of 174 man days.

Gupta *et al.* (1998) concluded that rice-fish system recorded 50 per cent higher net returns than the rice monoculture. The higher net returns were attributed to the lower cost of rice cultivation, higher rice yields and additional fish yield.

The rice-fish rotation in Kuttanad resulted in a fish production as high as 2500 kg ha^{-1} in six months (Padmakumar *et al.*, 2002).

Ayyappan *et al.* (2004) observed that good synergism between fish and rice improved the productivity of each other.

According to Mishra and Mohanty (2004), integrated cultivation of fish in rice fields at the rate of 25000 ha^{-1} resulted in a rice equivalent yield of 4.4 t ha^{-1} and net profit of 10781 ₹ ha^{-1}. Rice yields increased by 8.3 per cent in the rice-fish system compared to rice alone.

Corales *et al.* (2004) described the synergistically compatible farm enterprises *viz.* rice, onion, poultry, livestock, and aquaculture in the Palayamanan integrated farming model developed by the Philippine Rice Research Institute.

A study conducted by Jayanthi *et al.* (2004) revealed that highest productivity was obtained by integrating fish and goat rearing with cropping and the increase was 190 per cent more than cropping alone.

Rautaray *et al.* (2005) recorded that rice fish system generated 2.8 fold more income compared to rice alone.

Channabasavanna and Biradar (2007) reported that integrating rice with fish and poultry resulted in higher system productivity (15,555 kg $ha^{-1}year^{-1}$) and net returns

(₹. 48,603ha^{-1} year^{-1}), compared to conventional rice-rice system. The productivity per day was 2.3 times more (42.6 kg $^{-1}$ ha^{-1} day^{-1}) over the conventional system (18.2 kg $^{-1}$ ha^{-1}day^{-1}).

Highest grain and straw yield was observed in the treatments having rice-fish with urea fertilization compared to rice alone (Frei *et al.*, 2007).

Channabasavanna *et al.* (2009) reported that integrated farming system involving rice, goat, fish, and poultry recorded increased productivity (26.3%) and profitability (32.3%) compare to conventional rice-rice system.

Sasidharan *et al.* (2012) reported that integration of fish in rice fields (rice followed by fish) reduced the cost of cultivation by 17.6 per cent and increased production by 15 per cent. Cost incurred for plant protection was reduced to 54 per cent with perceptible decrease in the cost of weeding by 32.7 per cent and savings of 100 per cent on weedicides.

Multilevel farming system evolved at the Regional Agricultural Research Station, Kumarakom consisting of rice, fish, broiler duck and male buffalo increased income by 4-5 folds, productivity 3 fold and cropping intensity by 200-300 per cent than single crop of rice (Sasidharan *et al.*, 2012).

Studies on a rice based integrated farming system (0.20 ha) involving rice, vegetables, fish, milch cow and duck unit revealed that a gross income of ₹ 2, 97,999 and net income of ₹ 60,555 was generated annually (CSRC, 2015).

2.5 EFFECT ON SOIL NUTRIENT STATUS

2.5.1 Rice based Cropping Systems

Inclusion of pulses in the rice based cropping system resulted in better soil fertility status compared to oilseeds in cropping system (Mohanty and Batista, 2002).

According to Varughese (2006), appreciable nutrients were recycled from crop residues of banana in rice based cropping system cropping system which consequently improved the available soil nutrient status.

Pillai *et al.* (2007) concluded that including legumes *viz.* cowpea and groundnut in the rice based cropping system resulted in positive balance of nitrogen in the soil.

Diversification of rice- wheat cropping system with leguminous crop (green gram and berseem) increased NPK and organic carbon status of soil (Alok *et al.*, 2008).

2.5.2 Rice-Fish Integrated Farming System

Balusamy (1996) observed that unutilized fish feed, decayed *Azolla* and fish excreta settled at the fish trench bottom had a higher nutrient value, which when recycled enriched the soil.

A study conducted in rice-fish system revealed that most of the soil parameters *viz.* soil pH 6.6-7, available N 7.9- 10.7 mg/100g, available P 0.29-0.67 mg/100g, organic carbon 0.16 - 0.53 per cent were in optimum range (Mohanty *et al.*, 2004).

Integrating rice with fish improved the soil fertility by increasing the availability of nitrogen and phosphorus (Giap *et al.*, 2005; Dungan *et al.*, 2006).

Integration of fish with rice crop helped to improve nitrogen availability to the rice crop. The mineralized form of nutrients present in the feed provided to fish and the excreta could be easily taken up by the rice crop (Oehme *et al.*, 2007).

Tsuruta *et al.* (2011) reported an increase in nitrate nitrogen concentration in the rice-fish plots compared to rice-only because of unutilized fish food and excreta from fish. The fertilizing effect of the fish increased rice yield.

From the above review, it is clearly evident that studies on rice based integrated farming systems in which crops and fish are simultaneously grown are meagre. Literature on the composition of weeds under diverse ecological situations and the weed shifts subsequent to inclusion of crops with varying growth habits is, to a certain extent available. However, information on weed dynamics under rice-based integrated farming systems, especially under rice+fish integration are scanty.

In this context, the findings of the present study will provide an insight into the weed dynamics under rice based integrated farming systems involving simultaneous growing of various crops and fish. The influence of land modifications and varying water regimes will be brought out in the present study. Information on the overall performance of these systems will also be evaluated in terms of system productivity and economics.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was conducted with the objective of studying the performance and weed dynamics of different cropping sequences in rice based integrated farming system. The materials used and methods adopted are presented in this chapter.

3.1 EXPERIMENTAL SITE

The study was conducted as part of the ongoing All India Co-ordinated Research Project on Integrated Farming System being implemented in the Integrated Farming System Research Station (IFSRS) of Kerala Agricultural University located at Karamana, Thiruvananthapuram, Kerala. The experimental site is geographically located at 8^{o} 28^{1} 25^{11} N latitude and 76^{o} 57^{1} 32^{11} E longitudes and at an altitude of 5 m above mean sea level.

3.1.1 Climate

A warm humid tropical climate prevails over the experimental site. The data on various weather parameters *viz.*, mean maximum and minimum temperature, relative humidity (RH), rainfall and duration of bright sunshine hours during the cropping period were collected from the agromet observatory, IFSRS, Karamana.

The rainfall received during the period of summer crop extending from February to May 2016 was 438.13 mm while that during the first crop season (*Virippu* rice) extending from June to October 2016 was 606.50 mm. During summer, the maximum temperature varied between 30.31 °C and 33.60 °C while the minimum temperature varied between 20.89 °C and 27.39 °C. During first crop season, the maximum temperature varied between 29.79 °C and 31.71 °C while the minimum temperature varied between 23.49 °C and 25.29 °C. The weather data during the cropping period are abridged in Appendix - Ia and Ib and presented graphically in Fig.1a and 1b.

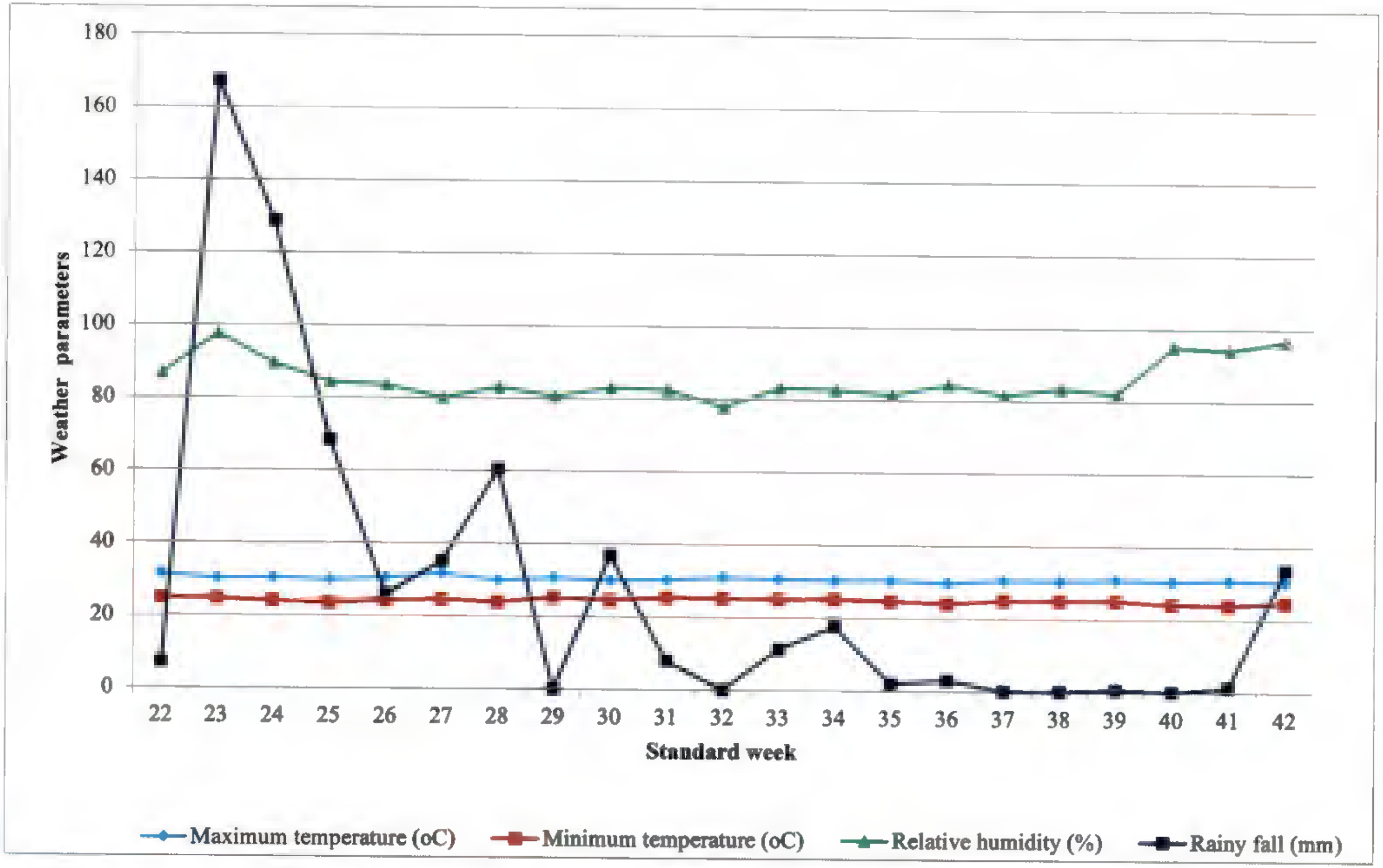

Fig. 1a. Weather data during summer crop period (February to May 2016)

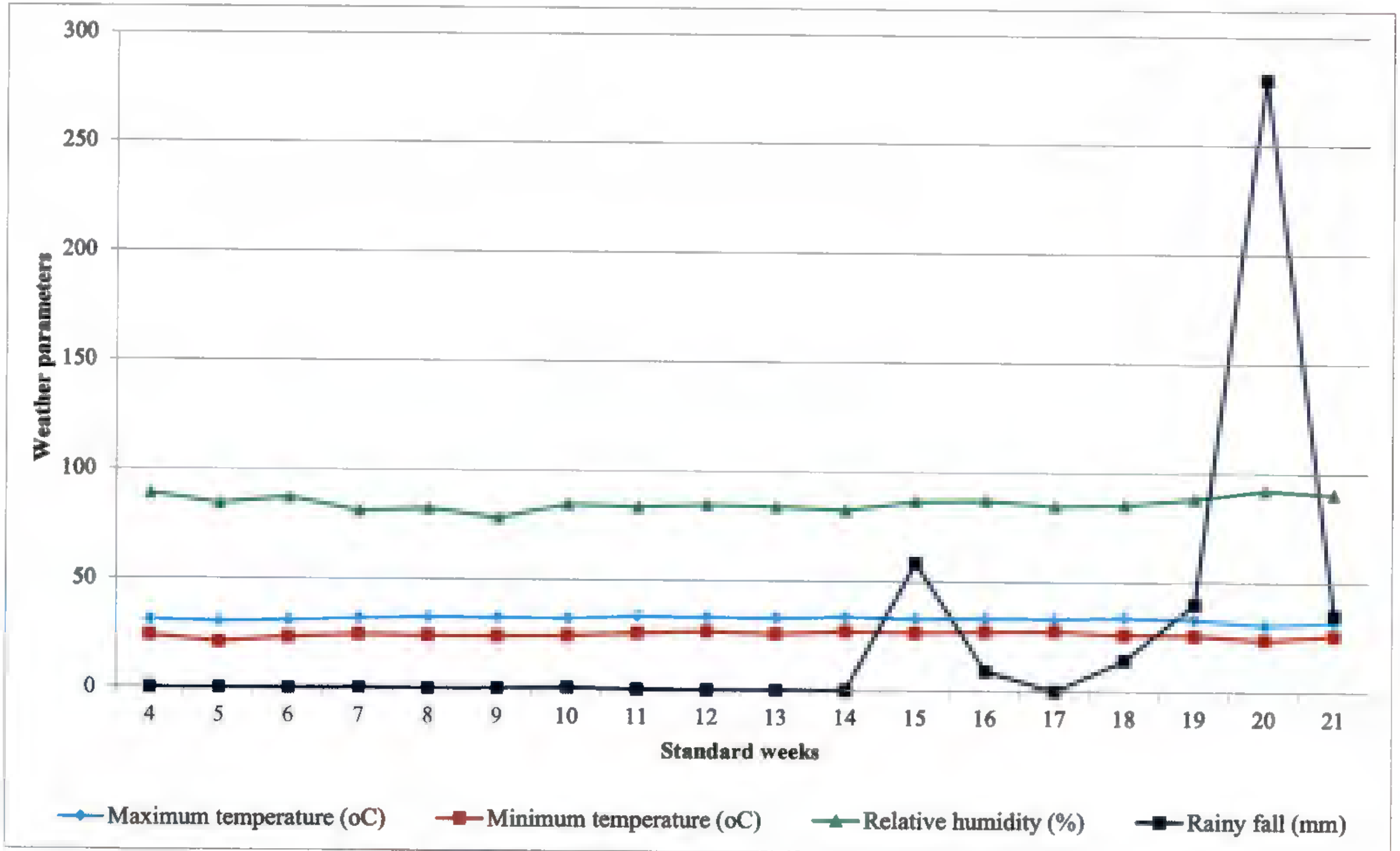

Fig. 1b. Weather data during *Virippu* crop period (June to October 2016)

3.1.2 Cropping Season

The experiment was conducted in two seasons, summer (February - May 2016) crops *viz.*, amaranthus, culinary melon and fodder cowpea followed by the *Virippu* rice (June - October 2016).

3.1.3 Soil

The ongoing study was a part of AICRP experiment started in 2011 and the experiment comprised treatments integrated with and without fish. Hence, composite soil samples were collected from plots, both with and without fish. The physico-chemical properties of soil are presented in Table 1 and 2. The soil properties were rated as per the Package of Practices Recommended by the Kerala Agricultural University (KAU, 2016).

The soil of an experimental site was clayey in texture, acidic in pH, low in available nitrogen, medium in available phosphorus and potassium status.

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

Sl. No.	Fractions	Content in soil (%)		Methods adopted
		Without fish	With fish	
1	Coarse sand	30.8	29.7	International pipette method (Piper, 1950)
2	Fine sand	8.5	7.2	
3	Silt	20	19.5	
4	Clay	39.5	42	
Textural class:		Clay	Clay	

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

Sl No.	Parameters	Content		Rating		Method adopted
		With Fish	Without fish	With fish	Without fish	
1	Soil reaction (pH)	5.33	4.96	Strongly acidic	Very strongly acidic	1:2.5 soil solution ratio using pH meter (Jackson, 1973)
2	Electrical conductivity ($dS\ m^{-1}$)	0.20	0.19	Normal	Normal	Using electrical conductivity meter (Jackson, 1973)
3	Organic carbon (%)	1.58	2.17	High	High	Walkley and Black's rapid titration (Jackson, 1973)
4	Available N ($kg\ ha^{-1}$)	249.20	249.91	Low	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P_2O_5 ($kg\ ha^{-1}$)	24.70	18.76	Medium	Medium	Bray colorimetric method (Jackson, 1973)
6	Available K_2O ($kg\ ha^{-1}$)	154.85	137.36	Medium	Medium	Ammonium acetate method (Jackson, 1973)

3.1.4 Cropping History of the Field

The experiment was a part of the All India Coordinated Research Project on Integrated Farming Systems being implemented at the Integrated Farming System Research Station, Karamana. Vegetable crops, with and without fish, during summer 2015-16 followed by rice, with and without fish, in *Virippu* during 2016-17 were the periods investigated.

3.2 MATERIALS

3.2.1 Crop and Variety

3.2.1.1 Rice

The rice (*Oryza sativa* L.) variety used was Uma (MO-16), released from the Rice Research Station, Moncompu of Kerala Agricultural University. It is of medium duration (115-120 days), dwarf, medium tillering, non-lodging and resistant to brown plant hopper. The seeds of the variety were obtained from IFSRS, Karamana.

3.2.1.2 Amaranthus

The amaranthus (*Amaranthus tricolor* L.) variety Arun, developed through mass selection from 'Palapoor local' by the Kerala Agricultural University, which is high yielding, having purple colour foliage and photo insensitive, was selected for the study. Seeds were obtained from the Department of Olericulture, College of Agriculture, Vellayani.

3.2.1.3 Culinary melon

The culinary melon (*Cucumis melo* var *acidulus* L. Naudin) variety used was Vellayani local, a collection from Vellayani area of Thiruvananthapuram district. The variety is of short duration (70- 75 days), fruit is cylindrical shape, medium in size and creamy white in colour with green stripes.

3.2.1.4 Fodder cowpea

The fodder cowpea (*Vigna unguiculata* (L.) Walp.) variety Aiswarya, released by Kerala Agricultural University through hybridization and selection was used for the study. The single cut fodder cowpea variety tolerant to mosaic and moderately resistant to leaf spot and leaf hoppers, is recommended for uplands and homesteads in southern districts of Kerala.

3.2.1.5 Fish

The fish species used was catla (*Catla catla*) and rohu (*Labio rohita*). The fish fingerlings were obtained from the Department of Fisheries, Thiruvananthapuram.

3.2.2 Manures and Fertilizers

Manures and fertilizers were applied as per Package of Practices Recommendations of Kerala Agriculture University (KAU, 2016). Well decomposed farmyard manure (FYM) containing 0.50 per cent N, 0.20 per cent P_2O_5 and 0.40 per cent K_2O was applied as a source of organic manure. Urea (46 % N), factomphos (20 % N and 20 % P_2O_5), rock phosphate (20 % P_2O_5), and muriate of potash (60 % K_2O) were used as inorganic source of nitrogen, phosphorus and potassium respectively.

3.3 METHODS

3.3.1 Design and Layout

The experiment which formed a part of an ongoing experiment under the AICRP on IFS was laid out in Randomized Block Design and comprised of seven cropping systems replicated thrice. The layout of field is represented in Fig 2.

Treatments

T_1	:	Rice - Rice - Fallow
T_2	:	Rice - Rice - Amaranthus
T_3	:	Rice - Rice - Culinary Melon
T_4	:	Rice - Rice - Fodder Cowpea
T_5	:	Rice+Fish - Rice+Fish - Amaranthus+Fish
T_6	:	Rice+Fish - Rice+Fish - Culinary Melon+Fish
T_7	:	Rice+Fish - Rice+Fish - Fodder Cowpea+Fish

In the treatments involving fish, a trench was made for rearing the fish. The size of trench made was 6 m x 3 m x 1 m.

The present study was undertaken during summer 2015-16 and *Virippu* 2016-17, the details are given below.

Summer season (2015-16)

Design	:	Randomised Block Design
Treatments	:	7
Replication	:	3
Plot size	:	6 m x 6 m

Treatments

T_1	:	Fallow
T_2	:	Amaranthus
T_3	:	Culinary melon
T_4	:	Fodder cowpea
T_5	:	Amaranthus + Fish
T_6	:	Culinary melon + Fish
T_7	:	Fodder cowpea + Fish

***Virippu* season (2016-17)**

Treatments

T_1	:	Rice	(succeeding fallow)
T_2	:	Rice	(succeeding amaranthus)
T_3	:	Rice	(succeeding culinary melon)
T_4	:	Rice	(succeeding fodder cowpea)
T_5	:	Rice + Fish	(succeeding amaranthus + fish)
T_6	:	Rice + Fish	(succeeding culinary melon + fish)
T_7	:	Rice + Fish	(succeeding fodder cowpea + fish)

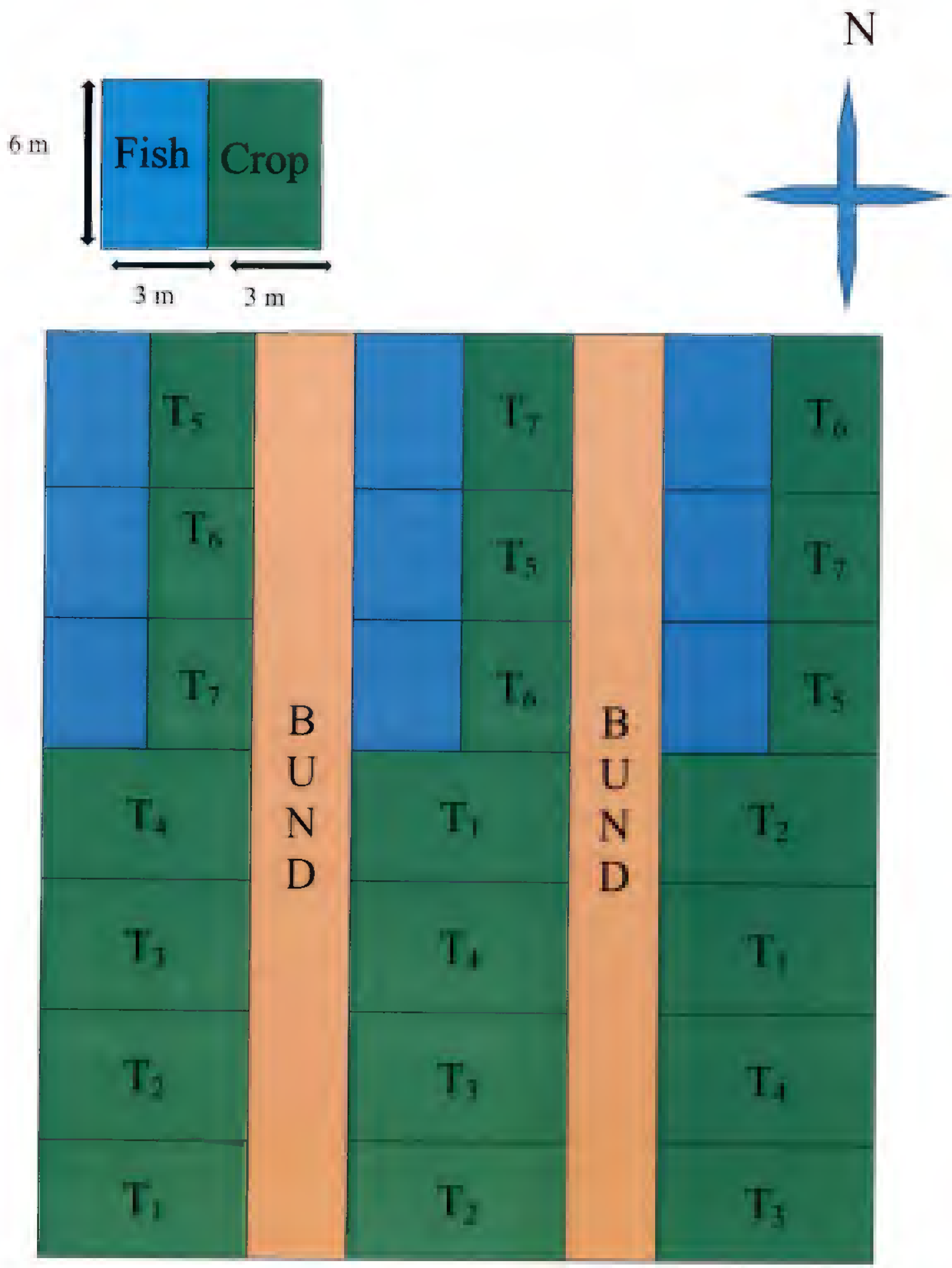

Fig 2. Layout of experiment field

3.3.2 Crop Management

All cultural practices, except weed management, were carried out as per the Package of Practices Recommendation of Kerala Agricultural University (KAU, 2016).

3.3.2.1 Summer Crop

3.3.2.1.1 Land Preparation

After the harvest of *Mundakan* rice crop 2015-16, weeds were removed and the field was modified into raised beds and furrows. In the treatments involving fish, raised beds of 30 cm height, 1 m width and 3 m length and 6 m length (for treatments without fish) were prepared and the beds were perfectly levelled and brought to a fine tilth.

3.3.2.1.2 Application of Manures and Fertilizers

Well decomposed farm yard manure was applied to all plots, except T_1 (fallow) at the rate of 5 kg m^{-2} (50 t ha^{-1}), 2.5 kg m^{-2} (25 t ha^{-1}) and 1 kg m^{-2} (10 t ha^{-1}) for amaranthus, culinary melon and fodder cowpea respectively, at the time of land preparation as per the Package of Practices Recommendations for crops (KAU, 2016).

3.3.2.1.3. Sowing

Amaranthus seeds were sown in lines at a spacing of 20 cm between rows @ 2 kg ha^{-1}. For culinary melon, shallow pits of 60 cm diameter and 30 cm depth were taken at a spacing of 2 m x 1.5 m. Seeds were sown @ 3-4 seeds per pit. Fodder cowpea seeds @ 15 to 40 kg ha^{-1} were sown at a spacing of 30 cm x 15 cm (KAU, 2016).

3.3.2.1.4 Irrigation

Need based irrigation was given with uniform quantity of water.

Plate 1. General view of experiment field during summer crops

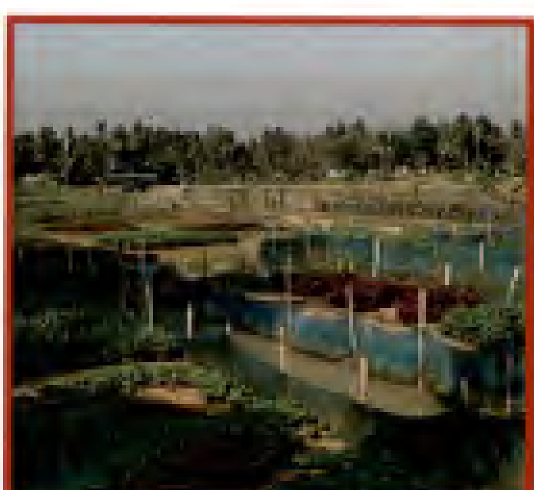

Plate 2. Summer crops: treatments integrated with fish

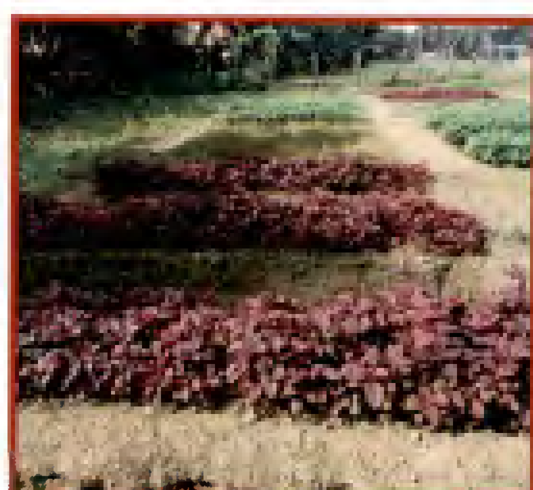

Plate 3. Summer crops: treatments without fish

3.3.2.1.5. Harvest

Harvest of amaranthus crop was done by pulling out the plants as and when they attained maturity, but prior to bolting (40 days after sowing). Culinary melon fruits were harvested as and when they attained maturity (40 DAS). Since fodder cowpea raised was a single cut variety, a single harvest was done when the plants just started flowering (45 DAS).

3.3.2.2. First Crop /Virippu Rice

3.3.2.2.1 Nursery

Wet nursery method was adopted for raising seedlings. The nursery area was ploughed, levelled and beds of 15 cm height, 1 - 1.5 m width and 10 m length were prepared with drainage channels between beds. Farm yard manure was applied @ 1 kg m^{-2} and thoroughly incorporated. Pre-germinated seeds were sown on the beds.

3.3.2.2.2 Land Preparation: Main Field

After harvesting the summer crops and fish, the raised beds were dismantled and plots were levelled. Bunds were cleaned and plastered and channels were cleaned. Water was pumped out of the trenches used for rearing fish and desilting of the trenches was carried out. The trench silt was added to the plots integrated with fish and incorporated well. The plots were puddled and perfectly levelled.

3.3.2.2.3 Application of Manures and Fertilizers

Farm yard manure was applied two weeks prior to the transplanting of rice crop @ 5 t ha^{-1} (0.5 kg m^{-2}) and incorporated. Chemical fertilizers *viz.*, urea, factomphos, rock phosphate and muriate of potash were applied to supply nutrients at the rate of 90:45:45 NPK per ha as per the schedule recommended for high yielding medium duration rice varieties in the Package of Practices Recommendation *i.e.* full dose of phosphorus and half of the recommended dose of nitrogen and potassium as basal and remaining half at panicle initiation (KAU, 2016).

3.3.2.2.4 Transplanting

Seedlings aged 18 days were transplanted to the plots at a spacing of 20 cm x 15 cm @ of 2-3 seedlings hill^{-1}.

3.3.2.2.5 Water Management

The water level was maintained at 2 cm at the time of transplanting the seedlings and was increased to 5 cm after one week of transplanting. Subsequently, a water level of 5 cm was maintained in the plots. However, the field was drained two weeks before harvest.

3.3.2.2.6 Harvest

The crop was harvested when the grains attained maturity, leaving two border rows on all sides. The net plot area was harvested, threshed, winnowed and dried separately. The fresh weight and dry weight of grains and straw from individual plots were recorded.

3.3.3 Fish Management

Trenches for rearing fishes [catla (*Catla catla*) and rohu (*Labio rohita*)] were prepared by digging and excavating the soil to obtain a dimension of 6 m length, 3 m width and 1 m depth. The excavated soil was added to the portion of the field where rice was to be raised. By virtue of the water table being high, water level in the trenches increased and filled within three days. The water in the trenches was left as such for a week for the colour of the scum (due to reduced iron) to disappear naturally. Fish fingerlings (one month old) of 5 cm size were released into the trenches at the rate of one m^{-2}. Fingerlings were fed with fish feed comprising of a mixture of powdered

Plate 4 Field after desilting

Plate 5. Transplanting of rice seedlings

Plate 6. General view of rice field during *Virippu*

coconut and groundnut cake in 1:1 ratio. The fish were fed with the feed at the rate of 50 g trench^{-1} (18 m^2) initially for two months. It was gradually increased to 75 g and by the fourth month to 100 g. the fishes were reared in the trenches from June 2015 to May 2016. After harvest of the fish, desilting of the trenches was done and the trench silt was added to the plots where the subsequent rice crop was to be planted. After transplanting of the rice crop during *Virippu* 2016-17, the new lot of fish fingerlings was released into the trenches at the rate of one m^{-2}. The surface and sides of the trench were protected with nets so as to prevent the attack of birds and to prevent escape of fish fingerlings in case of increase in water level owing to high rainfall.

***3.3.3.1 Harvest of Fish*:**

After summer crop, the water from trenches was pumped out and fish was harvested at the age of 11 months.

3.4 OBSERVATION ON CROPS

I. Summer Crops

3.4.1 Amaranthus

3.4.1.1 Plant Height (at harvest)

The plant height was recorded from observational plants at harvest. Plant height was measured from the base of the plant to the tip of the longest leaf and the average expressed in cm.

3.4.1.2 Number of Branches Plant^{-1}

Number of branches was recorded from tagged plants and the mean expressed as number of branches plant^{-1}.

3.4.1.3 Yield

The net plot was harvested individually, cleaned, and washed to remove mud. Then, fresh weight was recorded and the yield expressed in kg per 0.5 ha or 1 ha as per treatment.

3.4.2 Culinary Melon

3.4.2.1 Yield

Culinary melon fruits were harvested separately from each plot, weighed and yield expressed in kg per 0.5 ha or 1 ha as per treatment.

3.4.3 Fodder Cowpea

3.4.3.1 Yield

Fodder cowpea harvested from the plots were weighed and yield expressed in kg per 0.5 ha or 1 ha as per treatment.

3.4.3.2 Plant Height (at harvest)

The plant height was recorded from observational plants at harvest. Plant height was measured from the base of the plant to tip of the longest leaf and the average expressed in cm.

II Fish

3.4.4 Yield

Fishes were harvested from the trenches after dewatering, cleaned, weighed and yield expressed as kg from 0.50 ha.

3.4.5 Rice Equivalent Yield (REY)

Yield of component crops (amaranthus, culinary melon and fodder cowpea) and fish was expressed in terms of rice equivalent yield using the following equation.

$$REY = \frac{\text{Yield of component crop/fish x market price of component crop/fish}}{\text{Market price of rice}}$$

III. Rice

Two rows of plants were left as border on all the sides and observations on important parameters associated with growth and yield of rice were taken from the net plot area. Ten hills were randomly selected from the net plot area and plants were tagged for recording observations. The following observations were recorded from these sample plants and mean values were worked out.

3.4.6 Growth Attributes

3.4.6.1 Plant Height

The plant height was recorded at 20 DAT, 40 DAT and harvest following the method described by Gomez (1972). The plant height was measured from the base of the plant to tip of the longest leaf or tip of the longest ear head in cm and the average worked out.

3.4.6.2 Number of Tillers Hill^{-1}

The tiller number hill^{-1} was recorded at 20 DAT, 40 DAT and harvest from the observational plants, mean worked out and expressed as numbers hill^{-1}.

3.4.7 Yield and Yield Attributes

3.4.7.1 Productive Tillers m⁻²

The number of productive tillers at harvest was recorded from tagged plants in the net plot and expressed as number of productive tillers m^{-2}.

3.4.7.2 Grain Weight Panicle⁻¹

The panicles from tagged plants were harvested separately from each plot, weight of grains was recorded and expressed as g.

3.4.7.3 Thousand Grain Weight

Thousand numbers of clean, dry, fully filled grains were counted from the produce of each plot and the weight noted in g.

3.4.7.4 Grain Yield

Each net plot was harvested individually, threshed, dried, winnowed and air dry weight of grains recorded and expressed as kg ha^{-1}.

3.4.7.5 Straw Yield

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

3.4.7.6 Harvest Index

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

$$\text{Harvest index (HI)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}$$

3.5 OBSERVATION ON WEEDS

The observation on weeds was taken using a quadrat of size 50 cm x 50 cm which was placed randomly in each plot. The weeds which are present in quadrat were used to generate the following information. In the summer crop, observations were recorded at 20 and 40 DAS while in *Virippu* rice crop they were taken at 20, 40 and 60 DAT.

3.5.1 Weed Composition

Weeds from the sampled areas were identified and grouped into grasses, broad leaved weeds and sedges.

3.5.2 Absolute Density

Absolute density of weeds was recorded by counting the number of weeds coming under each group *viz*., grasses, broad leaved weeds and sedges. The absolute density was expressed as number m^{-2}. It was calculated using the formula suggested by Philips (1959).

Absolute density (Ad) = total number of weeds of a given species m^{-2}

3.5.3 Relative Density

Relative density was worked out separately for grasses, broad leaved weeds and sedges using the formula proposed by Philips (1959).

$$\text{Relative density} = \frac{\text{Absolute density of a species}}{\text{Absolute density of all species}} \times 100$$

Plate 7. Weed observations in rice fields

3.5.4 Absolute Frequency

Absolute frequency was calculated using the equation developed by Philips (1959). Absolute frequency of grasses, broad leaved weeds and sedges were recorded separately.

$$\text{Absolute frequency} = \frac{\text{Number of quadrates in which a given species occurred}}{\text{Total number of quadrats used}} \times 100$$

3.5.5 Relative Frequency

Relative frequency of grasses, broad leaved weeds and sedges were computed using the following relationship (Philips, 1959).

$$\text{Relative frequency} = \frac{\text{Absolute frequency of a species}}{\text{Total Absolute frequency of all species}} \times 100$$

3.5.6 Importance Value (IV)

Importance value of weeds was obtained by adding values of relative density and relative frequency of a given species (Kent and Coker, 1992).

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

3.5.7 Summed Dominance Ratio (SDR)

Summed Dominance Ratio (SDR) was worked out according to equation developed by Sen (1981). Summed Dominance Ratio (SDR) of grasses, broad leaved weeds and sedges worked out separately.

$$\text{Summed Dominance Ratio (SDR)} = \frac{\text{Relative density} + \text{Relative frequency}}{2}$$

3.5.8 Dry Matter Production

Weeds which are present in the quadrat were pulled out along with roots, washed, dried under shade and dried in hot air oven at $70 \pm 5\ ^{O}C$ to a constant weight. The dry weight of weeds was expressed in g m^{-2}

3.5.9 Weed Control Efficiency (WCE)

Weed control efficiency was computed using following formula suggested by Mani and Gautham (1973).

$$WCE = \frac{AdWC - AdWT}{AdWC} \times 100$$

Where,

WCE – Weed control efficiency

AdWC – Absolute density of weeds in control (fallow) plot

AdWT – Absolute density of weeds in treated plot

3.6 CHEMICAL ANALYSIS

3.6.1 Plant Analysis

The weed samples collected at 20 and 40 DAS in the summer crops and 20, 40 and 60 DAT in first crop rice were analyzed for their total N, P and K content. Samples were dried under shade and hot air oven at 70 ± 5 °C to a constant weight and powdered. Nutrients were extracted using single acid (Sulphuric acid) and analysed.

3.6.1.1 Total Nitrogen

Total nitrogen content of weeds were estimated by modified Microkjheldal method (Jackson, 1973) and expressed as percentage.

3.6.1.2 Total Phosphorus

Total phosphorus content (%) was determined by Vanadomolybdo phosphoric yellow colour method using spectrometer (Jackson, 1973).

3.6.1.3 Total Potassium

Total potassium content in percentage was found out using EEL Flame Photometer (Jackson, 1973).

3.6.1.4 Nutrient Removal by Weeds

The nutrient (N, P and K) removed by weeds was calculated using the formula given below and expressed as kg ha^{-1}.

$$\text{Nutrient uptake} = \frac{\text{Nutrient content (\%)} \times \text{Dry matter (kg ha}^{-1})}{100}$$

3.6.2 Soil Analysis

Composite soil samples were collected from each plot separately before summer crop, after summer crop and after *Virippu* rice and analyzed for following chemical properties.

3.6.2.1 Available N

Available nitrogen of the soil was estimated by alkaline potassium permanganate method (Subbiah and Asija, 1956) and expressed in kg ha^{-1}.

3.6.2.2 Available P

Available phosphorus was determined by Bray I (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) method as described by Jackson (1973) and estimated using spectrophotometer and expressed in kg ha^{-1}.

3.6.2.3 Available K

Available potassium was determined by neutral normal ammonium acetate extract method and estimated using Flame photometer (Jackson, 1973) and expressed in kg ha^{-1}.

3.6.2.4 Organic Carbon

Organic carbon of soil sample was estimated using wet digestion method given by Walkley and Black (1934) and expressed as percentage.

3.7 ECONOMIC ANALYSIS

As part of economic analysis the following parameters were worked out.

3.7.1 Gross income

Gross income was computed by multiplying the marketable yield of each component (crop and fish) with their market price and expressed as ₹ ha^{-1}. For calculating the annual gross income during 2015-16, the yield data of the Kharif/*Virippu* and Rabi/*Mundakan* rice crops raised during 2016 as part of the AICRP on Integrated Farming Systems was used (AICRP-IFS, 2016).

3.7.2 Net Income

Net income was calculated using the formula,

Net income (₹ ha^{-1}) = Gross income (₹ ha^{-1}) - Total cost of cultivation (₹ ha^{-1}).

For calculating the annual net income during 2015-16, the yield data of the Kharif/*Virippu* and Rabi/*Mundakan* rice crops raised during 2016 as part of the AICRP on Integrated Farming Systems was used (AICRP-IFS, 2016).

3.7.3 Benefit Cost Ratio

$$\text{B: C ratio} = \frac{\text{Gross income (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

3.7.4 Link Relative Index (LRI)

Link relative index (LRI) was calculated using the following formula (Mundra *et al*., 2003).

$$\text{Link Relative Index (LRI)} = \frac{NI_1}{NI_0} \times 100$$

NI_0 - mean net income of cropping system adopted by farmer (1.0 ha) (rice-rice-fallow in this study)

NI_1 - mean net income of the cropping system followed in the treatment (1.0 ha)

3.7.5 Crop Profitability

$$\text{Crop profitability} = \frac{\text{Net income (₹ ha}^{-1})}{\text{Actual number of days crop occupied the field (days)}}$$

3.7.6 System Profitability

$$\text{System profitability} = \frac{\text{Net income (₹ ha}^{-1})}{365}$$

3.8 STATISTICAL ANALYSIS

The data generated were statistically analysed using analysis of variance (ANOVA) for Randomized Block Design (Cochran and Cox, 1965). Wherever significant differences among treatments were observed, CD values at 5 per cent level of significance were calculated for comparison of means. Student's T test was carried out to compare treatments integrated with fish and without fish (Gomez and Gomez, 1984). Wherever the data was not within the statistical range, appropriate transformations *viz*., square root, log and angular transformation were used for analysis.

Results

4. RESULTS

The present investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with the objective of studying the performance and weed dynamics of different cropping sequences in rice based integrated farming system. The data generated from the study was statistically analyzed and are presented in this chapter.

4.1 SUMMER CROP (2015-16)

4.1.1 Growth and Growth Attributes

4.1.1.1Amaranthus

The data on plant height and number of branches in amaranthus are presented in the Table 3.

At harvest, plants were significantly taller (54.03 cm) when integrated with fish (T_5) than when raised as sole crop (T_2).

But, the number of branches did not differ significantly between the two treatments, though it was relatively higher in T_5 (7.30 plant^{-1}).

4.1.1.2 Fodder cowpea

The data on plant height and number of branches in fodder cowpea are furnished in the Table4.

Plant height (128.96 cm) and number of branches (5.40 plant^{-1}) were significantly higher when integrated with fish (T_7).

Table 3. Effect of treatments on plant height and number of branches in amaranthus

Treatment	Plant height (cm)	Number of branches
T_2: Amaranthus	37.90	6.70
T_5: Amaranthus+Fish	54.03	7.30
t value	6.592	1.610

Table values @ 5 % (2.101) and 1 % (2.878)

Table 4. Effect of treatments on plant height and number of branches in fodder cowpea

Treatment	Plant height (cm)	Number of branches
T_4: Fodder cowpea	102.48	4.30
T_7: Fodder cowpea+Fish	128.96	5.40
t value	7.305	6.328

Table values @ 5 % (2.101) and 1 % (2.878)

4.1.2 Yield

The data on yield of crops and fish and their respective rice equivalent yields (REYs) are abridged in Table 5.

Among crops, the highest yield (23703.70 kg ha^{-1}) was obtained from T_4 followed by T_6 and T_7. A notable fact was that T_6 yielded more than T_3 and T_5 more than T_2.The highest REY was obtained from T_6 (13572 kg ha^{-1} *i.e.* culinary melon in 0.50 ha) followed by T_3 and T_5 which were on par.

The yield of fish varied from 852.00 to 884.33 kg per 0.50 ha and the REY from 5793 to 6013 kg per 0.50 ha.

4.1.3 Weed dynamics during summer

4.1.3.1 Weed Composition

The composition of weeds noticed during first crop season in various treatments is presented in Table6.

Grasses dominated followed by sedges and broad leaved weeds. Among grasses, the population of *Echinochloa colona* was the highest followed by *Isachne miliacea*, *Digitaria ciliaris* and *Eragrostis tenella*. Among broad leaved weeds, *Lindernia grandiflora* ranked first followed by *Phyllanthus niruri*, *Oldenlandia umbellata* and *Cleome rutidospermum*. Among sedges, *Fimbristylis miliacea* population was highest.

In general, population of different weeds was less in T_6 (culinary melon+fish). *Echinochloa colona* was significantly higher in T_5 (amaranthus+fish), T_4 (fodder cowpea) and T_7 (fodder cowpea+fish). Population of *Isachne miliacea* was significantly more in T_1 (639.73 m^{-2}) followed by T_2. *Digitaria ciliaris* was significantly higher in $T_5$and T_7. *Eragrostis tenella* was significantly higher in T_2 (49.65 m^{-2}), while it was very low in T_6 (2.44 m^{-2}) and absent in T_5 and T_7.

Table 5. Yield and rice equivalent yield (REY) of the crops raised during summer and fish 2015-16, kg ha^{-1}

Treatments	Crop yield	REY of crop	Fish	REY of fish
T_1: Fallow	0	0	0	0
T_2: Amaranthus	5796.30	4637	0	0
T_3: Culinary melon	10882.41	7618	0	0
T_4: Fodder cowpea	23703.70	3556	0	0
T_5: Amaranthus+Fish*	8944.44	7156	884.33	6013
T_6: Culinary melon+Fish*	19387.96	13572	852.00	5793
T_7: Fodder cowpea+Fish*	11666.67	1750	854.00	5807
SEm (±)	-	1313.53	-	-
CD (0.05)	-	2926.5	-	-

*Yield from 0.50 ha

Sale price of commodities (2015- 16)

Rice: ₹. 22 kg^{-1} Amaranthus: ₹. 20 kg^{-1} Culinary melon: ₹. 15 kg^{-1}

Fodder cowpea: ₹. 7 kg^{-1} Fish: ₹. 150 kg^{-1}

Among broad leaved weeds, *Lindernia grandiflora* was significantly higher in T_1 (9.86 m^{-2}) followed by T_4, while it was absent in T_5, T_6 and T_7.

Among sedges *Fimbristylis miliacea* population was very high in T_1 (543.22 m^{-2}).

4.1.3.2 Absolute Density of Weeds

The data on absolute density of weeds in summer are abridged in the Table 7.

4.1.3.2.1 Absolute Density of Grasses

In general, the number of grassy weeds was more compared to broad leaved weeds and sedges.

Absolute density of grassy weeds significantly varied among treatments at 20 and 40 DAS and significantly high population was recorded in T1 (fallow) at both the stages. At 20 DAS, among the treatments significantly higher population was observed in T_5 (373.78 m^{-2}) this was followed by T_4 and T_2 which were on par. The absolute density of grasses was significantly less in T_3 (168 m^{-2}) and least in T_6 (96.44 m^{-2}). At 40 DAS, significantly high absolute density of grasses was recorded in T_2 (228.44 m^{-2}) which was followed by T_5 and T_4 which were on par. Absolute density was least in T_6 (51.11 m^{-2}).

4.1.3.2.2 Absolute Density of Broad Leaved Weeds

Absolute density of broad leaved weeds differed significantly among treatments at 20 DAS only. Density was very high in T_1 (28 m^{-2}). Among the other treatments, significantly higher population of broad leaved weeds was noticed in T_2 (10.78 m^{-2}). Weed population were on par in T_6, T_4, T_7 and T_3.

4.1.3.2.3 Absolute Density of Sedges

Absolute density of sedges varied significantly among treatments at 40 DAS only. A very high population (559.56 m^{-2}) was observed in T_1 (fallow). At 40 DAS, among the other treatments, density was significantly higher in T_2 (17.33 m^{-2}).

Table 6. Effect of treatments on the composition and population of weeds during summer, number m^{-2}

Treatments	T_1: Fallow	T_2: Amaranthus	T_3: Culinary melon	T_4: Fodder cowpea	T_5: Amaranthus +Fish	T_6: Culinary melon+Fish	T_7: Fodder cowpea+Fish	SEm(±)	CD (0.05)
Grasses									
Echinochloa colona	25.27*	89.04 (9.45)	100.39 (9.93)	253.95 (15.80)	316.98 (17.78)	86.59 (9.42)	193.74 (13.91)	1.80	3.930
Digitaria ciliaris	19.51(4.25)	15.52(3.93)	15.98 (3.94)	8.42 (2.70)	46.76 (6.83)	4.88 (2.17)	25.27 (4.56)	1.07	2.325
Oryza sativa	0*	17.29(3.56)	12.2 (3.59)	15.07 (3.95)	5.65 (2.44)	1.77 (1.40)	7.98 (2.84)	1.03	-
Cyanodon dactylon	0	0	0.44	0	0	0.89	0	-	-
Eluesine indica	0	0	0	0.44	0.44	0	0	-	-
Isachne miliacea	639.73	91.86	0.44	0	0	0	0	-	-
Panicum repens	0	0	0.89	0	0	0	0	-	-
Eragrostis tenella	6.99 (2.44)	49.65 (7.07)	37.24 (6.13)	14.63 (3.58)	0*	2.44 (1.70)	0*	1.00	2.305
Sub total	**691.5**	**263.36**	**167.58**	**292.51**	**369.83**	**96.57**	**226.99**	-	-
Broad leaved weeds									
Phyllanthus niruri	0*	4.43 (2.27)	0.44 (1.17)	0.44 (1.17)	3.10 (2.02)	2.66 (1.83)	0*	0.41	-
Cleome rutidospermum	0*	1.33 (1.52)	0.89 (1.30)	0.44 (1.17)	1.77 (1.65)	1.55 (1.54)	0*	0.27	-
Lindernia grandiflora	9.86 (3.35)	0.44 (0.92)	1.33 (1.18)	3.55 (1.99)	0*	0*	0*	0.45	1.091
Portulaca oleracea	0	0	0	0	0.55	0	0	-	-
Wedelia calendulacea	0	0.44	0	0	0.44		1.99	-	-
Euphorbia hirta	0	0	0	0	0	0.44	3.44	-	-
Marsilea quadrifolia	3.55	0.44	0.89	0	0	0	0	-	-
Mollugo sp.	2.22	0	0	0	0	0	1.11	-	-
Oldenlandia umbellata	6.31	0	0	0	0	0	0	-	-
Salvinia molesta	3.50	0	0	0	0	0	0	-	-
Ludwigia perennis	2.44	0.89	0	0	0	0	0	-	-
Sub total	**27.88**	**7.97**	**3.55**	**4.43**	**5.86**	**4.65**	**6.54**	-	-
Sedges									
Fimbristylis miliacea	535.11*	4.66 (2.14)	5.33 (2.31)	5.33 (2.31)	5.33 (2.30)	0*	3.11 (1.77)	0.16	0.344
Cyperus rotundus	8.11*	0.44 (0.92)	0.44 (0.92)	0.66 (0.99)	1 (1.09)	0*	0.89 (1.14)	0.40	0.875
Sub total	**543.22**	**5.10**	**5.77**	**5.99**	**6.33**	**0**	**4**	-	-

Figures in parentheses denote transformed values * significantly low and high values were not used for statistical analysis

Table 7. Effect of treatments on absolute density of weeds during summer,number m^{-2}

Treatments	Grasses		Broad leaved weeds		Sedges		Total density	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	691.55*	408*	28*	80.89*	543.11*	559.56*	1262.67*	1048.44*
T_2: Amaranthus	252.89 (15.86)	228.44 (15.12)	10.78 (3.26)	9.33 (3.05)	5.11	17.33 (4.16)	268.78 (16.35)	255.11 (15.97)
T_3: Culinary melon	168 (12.95)	104 (10.19)	4.56 (2.13)	6.00 (2.43)	5.89	7.78 (2.76)	178.44 (13.35)	117.78 (10.85)
T_4: Fodder cowpea	293.33 (17.06)	112.44 (10.59)	4.44 (2.09)	4.43 (2.08)	6.00	8.55 (2.92)	303.78 (17.36)	122.87 (10.98)
T_5: Amaranthus+Fish	373.78 (19.30)	122.89 (11.08)	6.78 (2.60)	7.56 (2.66)	6.22	8.22 (2.86)	386.78 (19.64)	138.67 (11.77)
T_6: Culinary melon+Fish	96.44 (9.82)	51.11 (7.14)	4.33 (2.08)	6.00 (2.43)	0*	6.67 (2.57)	100.78 (10.03)	63.78 (7.99)
T_7: Fodder cowpea+Fish	227.56 (15.07)	97.33 (9.87)	6.56 (2.54)	6.44 (2.51)	3.78	8.11 (2.84)	237.89 (15.41)	111.89 (10.58)
SEm (±)	0.67	0.29	0.25	0.49	1.40	0.24	0.67	0.32
CD (0.05)	1.490	0.679	0.548	-	-	0.546	1.496	0.708

Figures in parentheses denote transformed values; * significantly low and high values were not used for statistical analysis

4.1.3.2.4 Total Density of Weeds

At 20 DAS, weed density was maximum in T_5 (386.78 m^{-2}) followed by T_4 and T_2 which were on par. Total density was least in T_6 (100.78 m^{-2}) followed by T_3. At 40 DAS, total density was significantly higher in T_2 (255.11 m^{-2}) followed by T_5, while it was least in T_6 (63.78 m^{-2}).

4.1.3.3 Relative Density of Weeds

The data on relative density of weeds in summer are furnished in Table 8.

4.1.3.3.1 Relative Density of Grasses

At 20 DAS, relative density of grasses was significantly higher in T_4, T_5, T_6 and T_7 which were on par. At 40 DAS, relative density was significantly higher in T_2, T_3, T_4 and T_5. At both intervals, relative density of grasses was least in T_1 (fallow).

4.1.3.3.2 Relative Density of Broad Leaved Weeds

Significant difference among the treatments on relative density of broad leaved weeds was observed at 20 DAS only and it was significantly higher in T_6 (culinary melon+fish) and T_2 (amaranthus).

4.1.3.3.3 Relative Density of Sedges

At 20 DAS, relative density was significantly higher in T_1 (43.15 m^{-2}) followed by T_3. At 40 DAS, relative density was highest in T_1 (56.04 m^{-2}) followed by T_6.

4.1.3.4 Absolute Frequency of Weeds

The data on absolute frequency of weeds in summer are presented in Table 9.

Absolute frequency of grasses and broad leaved weeds did not differ significantly among treatments. Absolute frequency of sedges was nil in T_6 (culinary melon+fish). Comparatively lower values were recorded in T_4 and T_7.

Table 8. Effect of treatments on relative density of weeds during summer, per cent

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T$_1$: Fallow	54.66*	36.01*	2.19*	7.94*	43.15*	56.04*
T$_2$: Amaranthus	94.05	89.55	4.07 (2.01)	4.63	1.88	6.82
T$_3$: Culinary melon	94.11	88.35	2.56 (1.60)	5.05	3.33	6.59
T$_4$: Fodder cowpea	96.45	92.86	1.55 (1.22)	3.61	2.00	7.14
T$_5$: Amaranthus+Fish	96.55	88.60	1.78 (1.32)	5.47	1.68	5.93
T$_6$: Culinary melon+Fish	95.69	80.30	4.31 (2.07)	9.33	0*	10.34
T$_7$: Fodder cowpea+Fish	95.59	87.05	2.82 (1.66)	5.69	1.58	7.26
SEm (±)	0.49	2.34	0.16	1.77	0.40	1.10
CD (0.05)	1.098	5.219	0.320	-	0.929	2.444

Figures in parentheses denote transformed values; * Values were not used for statistical analysis

Table 9. Effect of treatments on absolute frequency of weeds during summer, per cent

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T$_1$: Fallow	100	100	100	100	100	100
T$_2$: Amaranthus	100	100	77.77	88.89	66.66	77.77
T$_3$: Culinary melon	100	100	44.44	77.77	66.66	66.66
T$_4$: Fodder cowpea	100	100	66.64	66.66	33.33	77.77
T$_5$: Amaranthus+Fish	100	100	77.77	77.77	77.77	77.66
T$_6$: Culinary melon+Fish	100	100	77.77	77.77	0	77.75
T$_7$: Fodder cowpea+Fish	100	100	44.44	77.77	33.33	66.66

4.1.3.5 Relative Frequency of Weeds

The data on relative frequency of weeds in summer are summarized in Table 10.

Relative frequency of grasses was not significantly influenced by the treatments. Relative frequency of broad leaved weeds and sedges differed significantly at 20 DAS only. With regard to broad leaved weeds, the highest relative frequency was in T_6 (43.34 %) which was on par with T_4. The highest relative frequency of sedges was in T_5 (30.35 %) which was on par with T_3 and T_2.

4.1.3.6 Importance Value of Weeds

The data on importance value of weeds in summer are presented in the Table11.

The importance value of grasses, broad leaved weeds and sedges varied significantly among treatments at 20 DAS only. Higher importance value of grasses was obtained in T_6, T_7, T_4 and T_3 which were on par. The importance value of broad leaved weeds was the highest in T_6 (47.65 %). With respect to sedges, T_1 (fallow) recorded highest value (76.33 %) followed by T_2, T_3 and T_5which were on par.

4.1.3.7 Summed Dominance Ratio of Weeds

The data on summed dominance ratio of weeds in summer are abridged in Table 12.

The Summed dominance ratio of grasses, broad leaved weeds and sedges varied significantly among treatments at 20 DAS only. Higher summed dominance ratio of grasses was obtained in T_6, T_7, T_4 and T_3 which were on par. The summed dominance ratio of broad leaved weeds was the highest in T_6 (47.65 %). With respect to sedges, T_1 (fallow) recorded highest value (76.33 %) followed by T_2, T_3 and T_5 which were on par.

Table 10. Effect of treatments on relative frequency of weeds during summer, per cent

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	33.33*	33.33*	33.33*	33.33*	33.33*	33.33*
T_2: Amaranthus	42.06	37.51	31.74 (5.64)	33.33 (5.74)	26.19 (5.07)	29.17 (5.37)
T_3: Culinary melon	49.17	41.66	20.55 (4.51)	31.95 (5.63)	30.27 (5.45)	26.38 (5.07)
T_4: Fodder cowpea	50.01	45.24	33.33 (5.78)	19.84 (4.40)	16.67 (4.09)	34.92 (5.88)
T_5: Amaranthus+Fish	39.28	39.30	30.35 (5.49)	30.37 (5.50)	30.35 (5.49)	30.33 (5.48)
T_6: Culinary melon+Fish	56.66	41.08	43.34 (6.57)	32.14 (5.49)	0*	30.36 (5.48)
T_7: Fodder cowpea+Fish	56.66	41.66	24.44 (4.91)	31.95 (5.63)	18.89 (4.34)	26.38 (5.07)
SEm (±)	5.61	2.543	0.38	0.539	0.25	0.622
CD (0.05)	-	-	0.859	-	0.580	-

Figures in parentheses denote transformed values; * Values were not used for statistical analysis

Table 11. Effect of treatments on importance value of weeds during summer, per cent

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	87.99*	69.34*	35.52*	41.28*	76.48*	89.37*
T_2: Amaranthus	136.12 (2.13)	127.05 (2.11)	35.81	36.96 (6.05)	28.08	35.98
T_3: Culinary melon	143.27 (2.15)	130.02 (2.11)	23.12	37.01 (6.06)	33.60	32.97
T_4: Fodder cowpea	146.47 (2.17)	134.85 (2.13)	34.87	23.34 (4.80)	18.68	41.80
T_5: Amaranthus+Fish	135.84 (2.14)	127.90 (2.11)	32.12	35.84 (5.97)	32.03	36.26
T_6: Culinary melon+Fish	152.35 (2.19)	119.59 (2.07)	47.65	39.68 (6.29)	0*	40.73
T_7: Fodder cowpea+Fish	152.26 (2.18)	128.71 (2.11)	27.26	37.64 (6.11)	20.47	33.65
SEm (±)	0.05	0.04	4.22	0.50	3.72	6.96
CD (0.05)	0.036	-	9.407	-	8.567	-

Figures in parentheses denote transformed values, *Values were not used for statistical analysis

Table 12. Effect of treatments on summed dominance ratio of weeds during summer

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	43.99*	34.67*	17.76*	20.64*	38.24*	44.69*
T_2: Amaranthus	68.06	63.53	17.90 (4.23)	18.49 (4.28)	14.03 (3.72)	17.99
T_3: Culinary melon	71.64	65.02	11.56 (3.39)	18.50 (4.28)	16.81 (4.09)	16.48
T_4: Fodder cowpea	73.22	67.42	17.43 (4.17)	11.67 (3.40)	9.33 (3.05)	20.90
T_5: Amaranthus+Fish	67.92	63.96	16.07 (3.99)	17.91 (4.22)	16.01 (3.99)	18.13
T_6: Culinary melon+Fish	76.18	59.79	23.82 (4.88)	19.85 (4.44)	0*	20.37
T_7: Fodder cowpea+Fish	76.14	64.35	13.62 (3.67)	18.82 (4.32)	10.23 (3.19)	16.83
SEm (±)	2.83	2.32	0.25	0.35	0.24	2.52
CD (0.05)	6.295	-	0.576	-	0.555	-

Figures in parentheses denote transformed values; *significantly low and high values were not used for statistical analysis

4.1.3.8 Dry Matter Production of Weeds

The data on dry matter production of weeds in summer are presented in Table13.

In general, very high weed dry weight of grasses, broad leaved and sedges was obtained at all stages in T_1 (fallow).

The dry matter production of grasses differed significantly among treatments at 20 and 40 DAS. Among the treatments except T_1 (fallow), significantly higher dry matter was recorded in T_2 (5.11 g m^{-2}). At 40 DAS, weed dry weight was the highest in T_2 (44.48 m^{-2}), followed by T_3, T_4 and T_5 which were on par.

Dry matter production of broad leaved weeds varied significantly among the treatments at 20 DAS only. Dry matter was the highest in T_2 (amaranthus) followed by T_7 (fodder cowpea+fish) which were on par and least (1.26 g m^{-2}) in T_6 (culinary melon+fish).

The treatments differed significantly in dry matter production of sedges at 20 DAS only. Dry matter of sedges was highest in T_4 and was on par with T_5 followed by T_2, T_3 and T_7 which were on par.

4.1.3.9 Weed Control Efficiency

The data on weed control efficiency in summer are given in Table14.

Weed control efficiency of grasses, broad leaved weeds, sedges and total weeds differed significantly among treatments at 20 and 40 DAS.

In grasses at 20 DAS, the highest (85.88 %) weed control efficiency was in T_6 (culinary melon+fish) and the least in T_5 (amaranthus+fish). At 40 DAS, highest (86.99 %) weed control efficiency was in T_6 (culinary melon+fish) and the least in T_2 (amaranthus).

With respect to broad leaved weeds, weed control efficiency was significantly higher in T_4, T_6, T_3, T_7 and T_5 which were on par while the least was in T_2 (57.17 %). At 40 DAS, all the treatments except T_2 were on par.

Regarding sedges, the highest weed control efficiency at 20 DAS, was in T_6 (100 %), while at 40 DAS highest weed control efficiency was in T_6 followed by T_5, T_7, T_3 and T_4 all of which were on par.

Total weed control efficiency at 20 DAS, was significantly the highest (91.96 %) in T_6 and the least (69.34 %) in T_5. At 40 DAS, the highest (93.79 %) total weed control efficiency was recorded in T_6 and the least (75.04 %) in T_2.

4.1.3.10 Nutrient Removal by Weeds

The data on nutrient removal by weeds in summer are furnished in Table 15.

Nutrient removal by weeds varied significantly among the treatments at 20 and at 40 DAS. At 20 DAS, higher removal of nitrogen was in T_2 (amaranthus) and it was on par with T_5 (amaranthus+fish). At 40 DAS, the highest removal was in T_2 and T_3 which were on par.

Regarding phosphorus, at 20 DAS removal was high in T_2, T_5 and T_3 which were on par while at 40 DAS, T_2 and T_3 were on par and recorded higher values.

With respect to potassium, at 20 DAS, the highest removal was in T_2 and was on par with T_3 and T_5, while at 40 DAS it was high in T_2 and T_3.

Table 13. Effect of treatments on weed dry matter during summer, g m^{-2}

Treatments	Grasses		Broad leaved weeds		Sedges	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	130.61*	101.81*	14.13*	61.31*	202.67*	116.10*
T_2: Amaranthus	5.11	44.48	3.18	0.73	0.35	1.27
T_3: Culinary melon	4.02	35.52	2.16	0.63	0.35	0.99
T_4: Fodder cowpea	4.28	28.91	2.02	0.35	0.60	1.07
T_5: Amaranthus+Fish	4.03	28.64	2.54	0.47	0.55	1.02
T_6: Culinary melon+Fish	3.41	23.16	1.26	0.37	0*	0.91
T_7: Fodder cowpea+Fish	3.62	28.09	2.64	0.48	0.30	1.03
SEm (±)	0.31	3.162	0.29	0.17	0.06	0.16
CD (0.05)	0.655	6.893	0.634	-	0.144	-

*significantly low and high values were not used for statistical analysis

Table 14. Effect of treatments on weed control efficiency during summer, per cent

Treatments	Grasses		Broad leaved weeds		Sedges		Total	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	-	-	-	-	-	-	-	-
T_2: Amaranthus	63.38	41.78	57.17	87.61	99.04	96.88	78.65	75.04
T_3: Culinary melon	75.48	73.36	83.30	91.75	98.91	98.56	85.81	88.47
T_4: Fodder cowpea	57.92	71.77	83.36	94.52	98.88	98.43	76.06	88.34
T_5: Amaranthus+Fish	45.92	68.61	75.17	90.94	98.85	98.53	69.34	86.35
T_6: Culinary melon+Fish	85.88	86.99	83.35	92.44	100	98.76	91.96	93.79
T_7: Fodder cowpea+Fish	66.91	74.88	75.44	91.17	99.31	98.53	81.11	88.92
SEm (±)	2.58	3.04	6.75	2.88	0.19	0.27	1.70	1.15
CD (0.05)	5.752	6.766	15.048	6.419	0.437	0.578	3.803	2.570

Table 15. Nutrient removal by weeds during summer, kg ha^{-1}

Treatments	Nitrogen		Phosphorus		Potassium	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
T_1: Fallow	35.68*	36.73*	12.68*	8.58*	42.33*	29.16*
T_2: Amaranthus	7.88	10.58	0.68	1.23	5.76	19.60
T_3: Culinary melon	3.94	8.96	0.56	1.07	4.39	13.84
T_4: Fodder cowpea	5.14	5.78	0.42	0.76	3.47	12.22
T_5: Amaranthus+Fish	6.61	7.47	0.59	0.77	5.01	10.04
T_6: Culinary melon+Fish	4.28	6.32	0.50	0.59	3.06	8.35
T_7: Fodder cowpea+Fish	5.16	8.36	0.41	0.67	3.42	9.57
SEm (±)	0.79	0.77	0.23	0.10	0.73	2.85
CD (0.05)	1.762	1.726	0.155	0.225	1.803	6.391

* Values were not used for statistical analysis

4.2 FIRST CROP/*VIRIPPU* RICE CROP

4.2.1 Growth Parameters

4.2.1.1 Plant Height

The data on plant height of rice of *Virippu* are presented in the Table 16.

Plant height differed significantly among treatments only at 40 DAT. Plants were significantly taller in T_7, T_6, T_5 and T_3 which were on par.

4.2.1.2 Number of Tillers Hill^{-1}

The data on number of tillers hill^{-1} of rice during *Virippu* are presented in the Table 17.

The number of tillers produced varied significantly among treatments at 20 and 40 DAT. Greater number of tillers was produced in T_6 (13.02 hill^{-1}), which was on par with T_7, T_5 and T_4. At 40 DAT, the number of tillers produced was significantly greater in T_7 (15.64 hill^{-1}), which was on par with T_6 and T_5. At harvest, though not significant, the number of tillers produced was relatively more in T_7 (17.20 hill^{-1}).

4.2.2 Yield Attributes and Yield

The data on productive tillers m^{-2}, grain weight panicle^{-1}and thousand grain weight of rice in *Virippu* are presented in Table 18.

4.2.2.1 Productive Tillers m^{-2}, Grain Weight Panicle^{-1}and Thousand Grain Weight

The number of productive tillers and thousand grain weight did not vary significantly among treatments. The number of productive tillers was relatively higher in T_7 (557.72 m^{-2}). However, there was significant difference in grain weight panicle^{-1}. Significantly higher grain weight panicle^{-1} was recorded in T_7 (4.08 g), which was on par with T_6, T_5 and T_1.

Table 16. Effect of treatments on plant height of rice, cm

Treatment	20 DAT	40 DAT	Harvest
T_1: Rice (Succeeding fallow)	47.72	60.74	109.27
T_2: Rice (Succeeding amaranthus)	50.01	64.64	107.27
T_3: Rice (Succeeding culinary melon)	52.62	71.93	110
T_4: Rice (Succeeding fodder cowpea)	49.08	67.67	111.13
T_5: Rice+Fish (Succeeding amaranthus+Fish)	47.53	72.81	109.06
T_6: Rice+Fish (Succeeding culinary melon+Fish)	48.50	74.98	109.93
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	49.03	77.94	111.13
SEm (±)	1.71	3.15	2.81
CD (0.05)	-	6.858	-

Table 17. Effect of treatments on number of tillers hill^{-1}of rice

Treatment	20 DAT	40 DAT	Harvest
T_1: Rice (Succeeding fallow)	8.44	10.63	14.10
T_2: Rice (Succeeding amaranthus)	9.30	11.39	14.47
T_3: Rice (Succeeding culinary melon)	9.72	11.83	15.40
T_4: Rice (Succeeding fodder cowpea)	10.28	12.19	15.13
T_5: Rice+Fish (Succeeding amaranthus+Fish)	12.25	13.94	15.13
T_6: Rice+Fish (Succeeding culinary melon+Fish)	13.02	14.44	15.60
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	12.61	15.64	17.20
SEm (±)	1.08	1.25	1.61
CD (0.05)	2.348	2.720	-

Table 18. Effect of treatments on productive tillers m^{-2}, grain weight $panicle^{-1}$ and thousand grain weight of rice

Treatment	Productive tillers m^{-2}	Grain weight $panicle^{-1}$(g)	Thousand grain weight(g)
T_1: Rice (Succeeding fallow)	426.62	3.61	24.80
T_2: Rice (Succeeding amaranthus)	442.17	3.33	24.53
T_3: Rice (Succeeding culinary melon)	452.17	3.22	24.87
T_4: Rice (Succeeding fodder cowpea)	468.84	3.40	24.90
T_5: Rice+Fish (Succeeding amaranthus+Fish)	482.17	4.02	25.53
T_6: Rice+Fish (Succeeding culinary melon+Fish)	486.61	3.91	26.33
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	557.72	4.08	24.87
SEm (±)	39.64	0.25	1.28
CD (0.05)	-	0.532	-

4.2.2.2 Grain Productivity, Straw Productivity and Harvest Index

The data on grain productivity, straw productivity and harvest index of rice in *Virippu* are furnished in Table 19.

Significantly higher (6623.94 kg ha^{-1}) grain yield was obtained in T_7 (rice+fish succeeding fodder cowpea+fish) and was on par with T_5 and T_6.

The straw yield was significantly higher (6837.61 kg ha^{-1}) in T_7 (rice+fish succeeding fodder cowpea+fish) and was on par with T_5 (rice+fish succeeding amaranthus+fish). Harvest index did not differ significantly among the treatments.

In general, the values of yield attributes and yield were less in T_1 (rice succeeding fallow).

4.2.3 Observations on Weed

4.2.3.1 Weed Composition

The composition of weeds noticed during *Virippu* in various treatments is abridged in Table 20.

In general, grasses predominated followed by sedges and broad leaved weeds. Among the grasses, population of *Eragrostis tenella* was the highest followed by *Echinochloa colona* and *Leptochloa* spp. Among the broad leaved weeds, population of *Salvinia molesta* was the highest followed by *Marsilea quadrifolia* and *Lindernia grandiflora. Fimbristylis miliacea* dominated among sedges.

The treatments exhibited significant differences. In general, significantly higher population of weeds was recorded in T_5, T_6 and T_7 (rice integrated with fish).

Table 19. Effect of treatments on grain productivity, straw productivity and harvest index in rice

Treatments	Grain productivity (kg ha^{-1})	Straw productivity (kg ha^{-1})	Harvest index
T_1: Rice (Succeeding fallow)	4890.78	5199.43	0.49
T_2: Rice (Succeeding amaranthus)	5365.62	5864.19	0.47
T_3: Rice (Succeeding culinary melon)	5318.14	5769.24	0.48
T_4: Rice (Succeeding fodder cowpea)	5508.07	5959.16	0.47
T_5: Rice+Fish (Succeeding amaranthus+Fish)	5876.06	6143.16	0.48
T_6: Rice+Fish (Succeeding culinary melon+Fish)	5769.24	5982.91	0.49
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	6623.94	6837.61	0.49
SEm (±)	441.97	357.50	0.07
CD (0.05)	963.040	779.003	-

4.2.3.2 Absolute Density of Weeds

The data on absolute density of weeds in rice during *Virippu* are presented in Table 21.

4.2.3.2.1 Absolute Density of Grasses

Significant difference in absolute density of grasses was noticed only at 20 DAT. The density of grasses was the highest in T_5 (34 m^{-2}) which was on par with T_7 and T_1. This was followed by T_6. Density of grasses was significantly lower in T_2, T_3 and T_4 which were on par.

4.2.3.2.2 Absolute Density of Broad Leaved Weeds

Absolute density of broad leaved weeds differed significantly among treatments at 20 and 40 DAT. At 20 DAT, the highest density (16 m^{-2}) was noted in T_1 (rice succeeding fallow) followed by T_4 and T_2 which were on par. However, at 40 DAT significantly higher density was recorded in T_5, T_6 and T_7 (treatments integrated with fish) which were on par. It is notable that the density of broad leaved weeds in these treatments was higher than in T_1.

4.2.3.2.3 Absolute Density of Sedges

Absolute density of sedges differed significantly among treatments at 20 and 40 DAT only. At 20 DAT, the absolute density of sedges was the highest in T_7, T_5 and T_6 which were on par. A more or less similar trend was noticed at 40 DAT. A notable fact is that sedges were absent in T_2, T_3 and T_4 at 20, 40 and 60 DAT.

Table 20. Effect of treatments on composition and population of weeds in *Virippu*, number m^{-2}

Treatments	T_1: Rice (Succeeding fallow)	T_2: Rice (Succeeding amaranthus)	T_3: Rice (Succeeding culinary melon)	T_4: Rice (Succeeding fodder cowpea)	T_5: Rice+Fish (Succeeding amaranthus+Fish)	T_6: Rice+Fish (Succeeding culinary melon+Fish)	T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	SEm (±)	CD (0.05)
GRASSES									
Echinochloa colona	7.33 (2.78)	0*	0*	3.00 (1.50)	17.33 (4.22)	13.33 (3.71)	12.67 (3.62)	0.588	1.351
Leptochloa spp.	0.67 (0.99)	0*	0*	5.00 (2.34)	11.67 (3.48)	9.00 (3.06)	13.33 (3.68)	0.410	0.950
Digitaria ciliaris	0*	0*	0*	0*	5.33 (2.28)	3.33 (1.69)	5.33 (2.30)	0.549	-
Isachne miliacea	5.67 (2.47)	0*	2.67 (1.44)	3.33 (1.80)	0*	0.67 (0.99)	1.33 (1.18)	0.756	-
Eragrostis tenella	15.67 (3.97)	14.67 (3.88)	14.00 (3.74)	10.00 (3.23)	0*	0.67 (1.05)	1.00 (1.09)	0.526	1.175
Subtotal (a)	**29.34**	**14.67**	**16.67**	**21.33**	**34.33**	**27**	**33.66**		
BROAD LEAVED WEEDS									
Ludwigia perennis	0*	0*	0*	0*	2.67 (1.78)	3.33 (1.89)	1.67 (1.38)	0.386	-
Lindernia grandiflora	2.33 (1.56)	0*	0*	1.33 (1.18)	2 (1.56)	0	2.33 (1.68)	0.538	-
Marsilea quadrifolia	2.33 (1.38)	3.33 (1.77)	2.33 (1.68)	2 (1.56)	0*	1.33 (1.29)	2.33 (1.54)	0.682	-
Salvinia molesta	11.33	7.67	4	6.33	0*	0*	0*	0.669	-
Eclipta alba	0*	0*	0*	0*	4 (2.11)	2.33 (1.38)	1.67 (1.38)	0.482	-
Subtotal (b)	**15.99**	**11**	**6.33**	**9.66**	**8.67**	**6.99**	**8**		
SEDGES									
Fimbristylis miliacea	14.67 (3.81)	0*	0*	0*	17.67 (4.18)	17 (4.08)	27.67 (5.25)	0.407	0.996
Cyperus spp.	0*	0*	0*	0*	3.67 (2.03)	4 (2.11)	0.67 (1.05)	0.167	0.460
Subtotal (c)	**14.67**	**0**	**0**	**0**	**21.34**	**21**	**28.34**		

Figures in parentheses denote transformed values; *values were not used for statistical analysis

4.2.3.2.4 Total Density of Weeds

The data on relative density of weeds in rice during *Virippu* are given in the Table 22.

Significant difference in total density of weeds was noticed at 20, 40 and 60 DAT. At 20 DAT, weed density was the highest in T_7 and T_5 which were on par, while it was the least in T_3 and T_2 which were on par. At 40 DAT, total density was the highest in T_5 and T_6 which were on par while it was the least in T_4, T_2, T_3 and T_1. At 60 DAT, total weed population was significantly higher in T_5 and T_7, while it was least in T_1, T_2, T_3 and T_4.

4.2.3.3 Relative Density of Weeds

The data on relative density of weeds in rice during *Virippu* are presented in the Table 23.

4.2.3.3.1 Relative Density of Grasses

Significant difference was observed in relative density of grasses at 20 and 40 DAT. At 20 DAT, relative density of grasses was significantly higher in T_3 and T_4 which were on par. At 40 DAT, relative density of grasses was significantly higher in T_2, T_3 and T_4 and they were on par.

4.2.3.3.2 Relative Density of Broad Leaved Weeds

At 20 and 60 DAT, relative density of broad leaved weeds was higher in T_2, T_3, T_4 and T_1, and they were on par.

4.2.3.3.3 Relative Density of Sedges

Relative density of sedges was higher in T_5, T_6 and T_7. Sedges were absent in T_2, T_3 and T_4.

Table 21. Effect of treatments on absolute density of weeds in *Virippu* rice, number m^{-2}

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	28.66 (5.35)	12.67 (3.54)	40.67	16.00 (3.98)	17.33 (4.17)	53.33	14.67 (3.81)	12.00 (3.45)	15.00 (3.86)
T_2: Rice (Succeeding amaranthus)	16.67 (4.06)	27.00 (5.16)	46.67	9.33 (3.04)	17.67 (4.16)	53.33	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	16.67 (4.08)	15.00 (3.84)	45.67	6.33 (2.51)	13.67 (3.69)	58.67	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	21.33 (4.60)	17.07 (4.19)	41.33	11.00 (3.30)	19.00 (4.35)	58.00	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	34 (5.82)	21.33 (4.58)	49.33	8.67 (2.93)	35 (5.92)	54.00	21.33 (4.61)	27.67 (5.23)	27.67 (5.24)
T_6: Rice+Fish (Succeeding culinary melon+Fish)	24.33 (4.93)	22.00 (4.63)	35.00	6.67 (2.57)	25.67 (5.03)	54.67	21.00 (4.55)	17.33 (4.13)	24.00 (4.86)
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	31.67 (5.62)	24.67 (4.93)	54.00	8.00 (2.81)	27.67 (5.23)	48.67	28.33 (5.31)	11.00 (3.30)	24.33 (4.90)
SEm (±)	0.31	0.55	5.60	0.27	0.45	6.68	0.35	0.45	0.46
CD (0.05)	0.675	-	-	0.613	0.976	-	0.862	1.092	-

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

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Table 22. Effect of treatments on total density of weeds in *Virippu* rice, number m^{-2}

Treatments	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	59.33 (7.70)	42 (6.48)	109 (10.44)
T_2: Rice (Succeeding amaranthus)	26 (5.08)	44.67 (6.64)	100 (10.00)
T_3: Rice (Succeeding culinary melon)	23 (4.79)	28.67 (5.34)	104.333 (10.21)
T_4: Rice (Succeeding fodder cowpea)	32.33 (5.67)	36.67 (6.05)	99.33 (9.97)
T_5: Rice+Fish (Succeeding amaranthus+Fish)	64 (8.00)	84 (9.16)	131 (11.43)
T_6: Rice+Fish (Succeeding culinary melon+Fish)	52 (7.20)	65 (8.01)	113.67 (10.67)
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	68 (8.25)	63.33 (7.96)	127 (11.27)
SEm (±)	0.31	0.54	0.29
CD (0.05)	0.670	1.166	0.634

Figures in parentheses denote transformed values

Table 23. Effect of treatments on relative density of weeds in *Virippu* rice, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	48.12	30.07 (5.46)	37.41	27.31 (5.18)	41.63	48.76	24.57 (4.95)	28.30 (5.32)	13.84 (3.72)
T_2: Rice (Succeeding amaranthus)	63.43	60.80 (7.80)	46.80	36.57 (6.02)	39.20	53.20	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	72.67	51.74 (7.18)	43.83	27.33 (5.22)	48.26	56.17	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	66.02	48.23 (6.94)	41.30	33.98 (5.82)	51.77	58.70	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	53.06	25.11 (4.99)	37.96	13.66 (3.68)	41.83	40.98	33.27 (5.75)	33.06 (5.74)	21.06 (4.58)
T_6: Rice+Fish (Succeeding culinary melon+Fish)	47.15	33.63 (5.78)	30.91	12.89 (3.57)	39.14	48.07	39.98 (6.32)	27.57 (5.24)	21.01 (4.58)
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	46.49	38.90 (6.19)	42.59	11.77 (3.41)	43.58	38.41	41.75 (6.45)	17.50 (4.17)	19.00 (4.35)
SEm (±)	3.88	0.50	5.57	0.40	4.44	4.64	0.29	0.33	0.21
CD (0.05)	8.443	1.095	-	0.878	-	10.116	0.706	0.800	0.492

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

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4.2.3.4 Absolute Frequency of Weeds

The data on absolute frequency of weeds in rice during *Virippu* are furnished in the Table 24.

There was no significant difference among treatments in the absolute frequency of weeds.

4.2.3.5 Relative Frequency of Weeds

The data on relative frequency of weeds in rice during *Virippu* are abridged in Table 25.

Relative frequency of grasses was significantly higher in T_4, T_2 and T_3 at 20, 40 and 60 DAT. There was significant difference among the treatments in relative frequency of broad leaved weeds at 40 and 60 DAT. Relative frequency was higher in T_2, T_3 and T_4. There was no significant difference among the treatments in the relative frequency of sedges.

4.2.3.6 Importance Value of Weeds

The data on importance value of weeds in rice during *Virippu* are given in Table 26.

Importance value of grasses, broad leaved weeds and sedges was significantly different at 20, 40 and 60 DAT.

For grasses, the highest values were obtained for T_4, T_2 and T_3. With respect to broad leaved weeds at 20 DAT, importance value was significantly higher in T_2 (74.35 %) followed by T_3, T_4 and T_1 which were on par. At 40 and 60 DAT, higher importance values were in T_4, T_3 and T_2 which were on par.

Importance value of sedges was significantly higher in T_5, T_6 and T_7 treatments involving fish) at 20, 40 and 60 DAT.

Table 24. Effect of treatments on absolute frequency of weeds in *Virippu* rice, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	91.67	100	83.33	58.33 (0.39)	100	100	58.33	50	66.67
T_2: Rice (Succeeding amaranthus)	83.33	100	83.33	50 (0.36)	100	83.33	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	91.67	100	100	41.67 (0.32)	100	100	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	100	83.33	100	33.33 (0.29)	100	100	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	100	100	100	50 (0.36)	100	100	91.67	83.33	83.33
T_6: Rice+Fish (Succeeding culinary melon+Fish)	100	100	100	66.67 (0.40)	100	100	100	83.33	83.33
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	100	100	100	66.67 (0.41)	100	100	83.33	83.33	100
SEm (±)	-	-	-	0.06	-	-	-	-	-
CD (0.05)	-	-	-	-	-	-	-	-	-

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

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Table 25. Effect of treatments on relative frequency of weeds in *Virippu* rice, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	44.29 (6.64)	40.00	36.67	27.85 (5.27)	40.00	40.00	27.85	20.00	28.33
T_2: Rice (Succeeding amaranthus)	62.22 (7.81)	50.00	50.00	37.78 (5.99)	50.00	49.99	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	68.89 (8.28)	50.00	50.00	31.11 (5.52)	50.00	50.00	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	75.56 (8.69)	44.44	50.00	24.44 (4.91)	55.56	50.00	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	41.48 (6.44)	35.56	35.56	20.37 (4.43)	35.56	35.56	38.14	28.89	28.89
T_6: Rice+Fish (Succeeding culinary melon+Fish)	38.04 (6.16)	35.56	35.56	23.91 (4.77)	35.56	35.56	38.04	28.89	28.89
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	40.90 (6.37)	35.56	33.33	26.51 (5.14)	35.56	35.56	32.58	28.89	33.33
SEm (±)	0.56	3.85	5.30	0.86	3.36	5.69	5.21	5.44	6.96
CD (0.05)	1.212	8.389	11.559	-	7.327	12.384	-	-	-

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

Table 26. Effect of treatments importance value of weeds in *Virippu* rice, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	92.41 (1.96)	70.07 (8.37)	70.74 (8.38)	55.17 (7.42)	81.63	88.76	52.43	48.30	40.49
T_2: Rice (Succeeding amaranthus)	125.65 (2.10)	110.80 (10.52)	96.80 (9.84)	74.35 (8.61)	89.20	103.20	0	0	0
T_3: Rice (Succeeding culinary melon)	141.56 (2.16)	101.74 (10.09)	93.83 (9.68)	58.44 (7.64)	98.26	106.17	0	0	0
T_4: Rice (Succeeding fodder cowpea)	141.59 (2.16)	92.68 (9.61)	91.30 (9.55)	58.41 (7.63)	107.32	108.7	0	0	0
T_5: Rice+Fish (Succeeding amaranthus+Fish)	94.56 (1.97)	60.66 (7.79)	73.52 (8.57)	34.03 (5.77)	77.38	76.54	71.42	61.95	49.95
T_6: Rice+Fish (Succeeding culinary melon+Fish)	85.20 (1.93)	69.19 (8.30)	66.47 (8.13)	36.79 (5.99)	74.69	83.64	78.02	56.11	49.89
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	87.40 (1.94)	74.47 (8.60)	75.92 (8.71)	38.28 (6.18)	79.15	71.75	74.31	46.39	52.33
SEm (±)	0.07	0.45	0.44	0.60	5.86	4.28	6.67	1.18	3.28
CD (0.05)	0.050	0.980	0.983	1.314	12.762	9.322	16.318	2.883	8.021

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

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4.2.3.7 Summed Dominance Ratio of Weeds

The data on summed dominance ratio of weeds in rice during *Virippu* are presented in Table 27.

For grasses, the highest values were obtained for T_4, T_2 and T_3. With respect to broad leaved weeds at 20 DAT, summed dominance ratio was significantly higher in T_2 (74.35 %) followed by T_3, T_4 and T_1 which were on par. At 40 and 60 DAT, higher summed dominance ratio were in T_4, T_3 and T_2 which were on par.

Summed dominance ratio of sedges was significantly higher in T_5, T_6 and T_7 (treatments involving fish) at 20, 40 and 60 DAT.

4.2.3.8 Dry matter production of Weeds

The data on dry matter production of weeds in rice during *Virippu* are furnished in Table 28.

Dry matter production of grasses varied significantly among treatments at 20, 40 and 60 DAT. At 20 DAT, dry matter of grasses was the highest in T_1 (11.75 g m^{-2}) while all other treatments were on par. At 40 DAT, the highest dry weight was in T_7, T_6 and T_1 which were on par, while it was the least in T_3 (23.87) and T_4. At 60 DAT, dry matter of grasses was highest in T_7 (78.70 g m^{-2}) and least in T_4.

Significant difference was recorded among the treatments in dry matter of broad leaved weeds at 20, 40 and 60 DAT. At 20 DAT, the highest dry matter was in T_1 (1.12 g m^{-2}) followed by T_4. At 40 DAT, the highest dry matter was in T_1 and T_7 which were on par. At 60 DAT, the highest dry matter was in T_5 (29.89 g m^{-2}).

Dry matter production of sedges differed significantly among the treatments at 20 DAT only. The highest dry matter was in T_1 (1.81 g m^{-2}) followed by T_5 and T_7 which were on par.

Table 27. Effect of treatments summed dominance ratio of weeds in *Virippu* rice, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	46.20	35.03	35.38	27.59 (5.25)	40.81	44.38	26.22	24.15	20.25
T_2: Rice (Succeeding amaranthus)	62.83	55.40	48.41	37.17 (6.08)	44.60	51.59	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	70.78	50.88	46.92	29.22 (5.40)	49.12	53.08	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	70.79	46.33	45.66	29.21 (5.39)	53.67	54.34	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	47.27	30.33	36.75	17.02 (4.08)	38.69	38.26	35.72	30.98	24.97
T_6: Rice+Fish (Succeeding culinary melon+Fish)	42.60	34.59	33.23	18.39 (4.25)	37.35	41.82	39.01	28.05	24.95
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	43.70	37.24	37.96	19.15 (4.38)	39.57	35.88	37.16	23.20	26.16
SEm (±)	3.04	4.02	3.86	0.42	2.93	2.14	3.33	0.59	1.64
CD (0.05)	6.625	8.768	8.408	0.920	6.382	4.661	8.159	1.446	4.015

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

Table 28. Effect of treatments on dry matter production of weeds in *Virippu*, g m^{-2}

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	11.75	38.83	46.21 (6.79)	1.12	13.24	16.27 (4.02)	1.81	4.99	6.92
T_2: Rice (Succeeding amaranthus)	5.04	35.73	45.79 (6.76)	0.58	8.91	10.15 (3.18)	0*	0*	0*
T_3: Rice (Succeeding culinary melon)	5.68	23.87	51.27 (7.15)	0.49	6.66	26.97 (5.14)	0*	0*	0*
T_4: Rice (Succeeding fodder cowpea)	4.99	30.03	30.13 (5.46)	0.90	7.59	13.57 (3.68)	0*	0*	0*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	3.94	34.93	54.69 (7.39)	0.39	5.26	29.89 (5.46)	0.90	8.63	11.34
T_6: Rice+Fish (Succeeding culinary melon+Fish)	5.06	39.57	60.90 (7.79)	0.40	5.08	14.07 (3.74)	0.62	4.80	8.67
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	4.65	44.73	78.70 (8.87)	0.48	11.33	18.29 (4.27)	0.84	5.45	12.23
SEm (±)	1.23	4.03	0.27	0.10	1.60	0.36	0.10	1.18	1.69
CD (0.05)	2.679	8.778	0.663	0.220	3.475	0.804	0.234	-	-

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

4.2.3.9 Weed Control Efficiency

The data on weed control efficiency during *Virippu* are presented in the Table 29a.

Weed control efficiency of grasses varied significantly among treatments at 20, 40 and 60 DAT. At 20 DAT, the highest weed control efficiency was in T_3 (50.76 %) followed by T_2 (50.35 %) which were on par. This was followed by T_4. The lowest was in T_5 followed by T_7. At 40 DAT, the highest (52.16 %) weed control efficiency was in T_1 (rice succeeding fallow) followed by T_3 (rice succeeding culinary melon) which were on par, while the lowest was in T_2. At 60 DAT, the highest (35.32 %) weed control efficiency was in T_6 (rice+fish succeeding culinary melon+fish).

With respect to broad leaved weeds, there was significant difference among treatments in weed control efficiency at 20 and 40 DAT only. At 20 DAT, higher weed control efficiency was noticed in all the treatments except T_4 (rice succeeding fodder cowpea). At 40 DAT, lowest weed control efficiency was in T_5 followed by T_6 and T_7 which were on par. The highest weed control efficiency was in T_3 (60.88 %) followed by T_1 and T_2 which were on par.

The lowest weed control efficiency of sedges at 20 DAT was in T_7 followed by T_6 and T_5. At 40 DAT, the lowest weed control efficiency was in T_5 followed by T_6. At 60 DAT, lowest weed control efficiency was in T_5 followed by T_6 and T_7 which were on par. Sedges were absent throughout in T_2, T_3 and T_4.

The data on total weed control efficiency during *Virippu* are abridged in the Table 29b.

The total weed control efficiency at 20 DAT, was higher in T_3, T_2 and T_4 which were on par and the least in T_7 (rice+fish succeeding fodder cowpea+fish). At 40 DAT, higher weed control efficiency was in T_3, T_4, T_1 and T_2 which were on par, while the least in T_5 (rice+fish succeeding amaranthus+fish). At 60 DAT, total weed control efficiency was higher in T_4, T_2, T_3 and T_1.

4.2.3.10 Nutrient Removal by Weeds

The data on nutrient removal by weeds in rice during *Virippu* are furnished in Table 30.

Nutrient removal by weeds differed significant among treatments at 20, 40 and 60 DAT. At 20 DAT, nitrogen removal by weeds was on par in all treatments except T_1 (3.01 kg ha^{-1}) where it was significantly high. At 40 DAT, the highest nitrogen removal by weeds was in T_7.At 60 DAT, highest nitrogen removal was in T_7 which was on par with T_5, T_6 and T_1.

With respect to phosphorus, at 20 DAT, significantly higher removal was in T_1 (0.21 kg ha^{-1}) followed by T_6, T_5 and T_7 which were on par. At 40 DAT, the highest (1.99 kg ha^{-1}) removal was in T_7 (rice+fish succeeding fodder cowpea+fish) followed by T_5 and T_6 which were on par. At 60 DAT, the highest removal was in T_7 which was on par with T_5.

Removal of potassium by weeds was significantly higher in T_1 and T_6 at 20 DAT. At 40 DAT, the highest removal was in T_7 (23.67 kg ha^{-1}) followed by T_5, T_1, T_6 and T_2 which were on par. At 60 DAT, the highest removal was in T_7 (25.21 kg ha^{-1}) followed by T_5, T_3 and T_6 which were on par.

Table 29a. Effect of treatments on weed control efficiency in *Virippu*, per cent

Treatments	Grasses			Broad leaved weeds			Sedges		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	15.48 (0.40)	52.16 (7.19)	23.87 (4.67)	-	50.39 (7.09)	9.45 (3.00)	47.72 (6.91)	56.21	46.15 (6.79)
T_2: Rice (Succeeding amaranthus)	50.35 (0.78)	-	13.33 (3.61)	40.14	50.05 (7.03)	8.91 (2.90)	100*	100*	100*
T_3: Rice (Succeeding culinary melon)	50.76 (0.79)	38.89 (6.20)	14.95 (3.70)	59.09	60.88 (7.80)		100*	100*	100*
T_4: Rice (Succeeding fodder cowpea)	36.70 (0.64)	30.86 (5.45)	23.28 (4.81)	29.02	44.71 (6.59)	1.22*	100*	100*	100*
T_5: Rice+Fish (Succeeding amaranthus+Fish)	-	21.24 (4.57)	8.45 (2.82)	44.57	-	7.97 (2.77)	25.16 (5.00)	-	-
T_6: Rice+Fish (Succeeding culinary melon+Fish)	28.22 (0.55)	20.17 (4.49)	35.32 (5.94)	57.64	25.41 (5.01)	6.61 (2.53)	26.28 (5.11)	36.31	13.79 (3.625)
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	7.86*	8.56*	-	49.28	20.39 (4.43)	17.21 (4.14)	-	57.02	12.23 (3.48)
SEm (±)	0.06	0.68	0.74	8.59	0.68	0.56	0.38	4.96	0.52
CD (0.05)	0.149	1.562	1.652	19.144	1.525	-	1.058	13.779	1.456

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

Table 29b. Effect of treatments on total weed control efficiency in *Virippu*, per cent

Treatments	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	12.80*	49.84 (7.05)	15.93 (3.97)
T_2: Rice (Succeeding amaranthus)	61.70 (7.84)	47.38 (6.86)	23.05 (4.80)
T_3: Rice (Succeeding culinary melon)	66.14 (8.13)	65.17 (8.05)	19.37 (4.38)
T_4: Rice (Succeeding fodder cowpea)	52.44 (7.22)	55.64 (7.44)	23.53 (4.80)
T_5: Rice+Fish (Succeeding amaranthus+Fish)	5.82*	-	-
T_6: Rice+Fish (Succeeding culinary melon+Fish)	23.28 (4.57)	22.36 (4.67)	13.08 (3.61)
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	-	23.45 (4.71)	2.93*
SEm (±)	0.77	0.60	0.36
CD (0.05)	1.888	1.341	0.841

Figures in parentheses denote transformed values; * Values were not used in statistical analysis

Table 30. Nutrient removal by weeds in *Virippu* rice, kg ha^{-1}

Treatments	Nitrogen			Phosphorus			Potassium		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
T_1: Rice (Succeeding fallow)	3.01	7.46	7.79	0.21	0.73	1.44	2.72	16.83	11.57
T_2: Rice (Succeeding amaranthus)	1.37	7.08	6.36	0.09	0.85	1.29	1.37	14.57	10.94
T_3: Rice (Succeeding culinary melon)	1.39	5.09	6.31	0.10	0.57	2.24	1.37	9.65	15.92
T_4: Rice (Succeeding fodder cowpea)	1.54	7.51	4.36	0.11	0.52	1.30	1.24	10.17	10.37
T_5: Rice+Fish (Succeeding amaranthus+Fish)	1.51	8.58	8.22	0.17	1.50	2.85	1.90	18.40	18.08
T_6: Rice+Fish (Succeeding culinary melon+Fish)	1.70	6.22	8.07	0.19	1.37	2.08	2.11	16.72	15.35
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	1.86	11.47	10.05	0.16	1.99	3.29	1.91	23.67	25.21
SEm (±)	0.36	1.07	1.31	0.05	0.18	0.48	0.35	2.29	1.66
CD (0.05)	0.776	2.335	2.561	0.084	0.396	1.036	0.775	4.997	3.615

4.3 NUTRIENT STATUS OF SOIL

4.3.1 Prior to Summer Crop

The data on nutrient status of soil before summer are abridged in Table 31.

Nitrogen content in the soil was significantly higher in T_2, T_3, T_5, T_6 and T_4 and they were on par. Phosphorus content was significantly higher in T_5 (35.36 kg ha^{-1}) followed by T_2 and T_6 which were on par. Potassium content was significantly higher in T_5, T_2, T_7 and T_3 which were on par.

4.3.2 After Summer Crop

The data on nutrient status of soil after summer are furnished in Table32.

Nitrogen content was significantly higher in T_2, T_3, T_5 and T_4 which were on par. Phosphorus and potassium content was significantly higher in T_5 and T_2 and they were on par.

4.3.3 After *Virippu* Rice

The data on nutrient status of soil after *Virippu* are presented in the Table 33.

Nitrogen content in the soil alone differed among the treatments. Significantly higher available nitrogen content was in T_5, T_2, T_6 and T_7 and they were on par.

Table 31. Available NPK status of soil prior to summer crop, kg ha^{-1}

Treatments	Nitrogen	Phosphorus	Potassium
T_1: Rice	217.04	13.02	122.91
T_2: Rice	266.66	27.01	154.96
T_3: Rice	265.52	19.58	147.26
T_4: Rice	250.43	15.44	124.31
T_5: Rice+Fish	256.19	35.36	165.26
T_6: Rice+Fish	256.08	23.31	144.56
T_7: Rice+Fish	235.34	18.44	154.75
SEm (±)	11.55	2.42	11.31
CD (0.05)	25.161	5.271	24.648

Table 32. Available NPK status of soil after summer crop, kg ha^{-1}

Treatments	Nitrogen	Phosphorus	Potassium
T_1: Fallow	192.34	14.74	122.69
T_2: Amaranthus	286.53	36.50	140.83
T_3: Culinary melon	281.49	25.18	129.12
T_4: Fodder cowpea	263.07	19.70	127.16
T_5: Amaranthus+Fish	280.86	38.07	149.74
T_6: Culinary melon+Fish	253.96	28.13	127.90
T_7: Fodder cowpea+Fish	255.46	22.86	133.70
SEm (±)	13.15	2.70	10.78
CD (0.05)	28.648	5.898	-

Table 33. Available NPK status of soil after *Virippu* crop, kg ha^{-1}

Treatments	Nitrogen	Phosphorus	Potassium
T_1: Rice (Succeeding fallow)	210.45	11.29	126.26
T_2: Rice (Succeeding amaranthus)	244.26	14.27	132.42
T_3: Rice (Succeeding culinary melon)	227.54	12.52	140.77
T_4: Rice (Succeeding fodder cowpea)	222.05	11.33	141.10
T_5: Rice+Fish (Succeeding amaranthus+Fish)	246.22	14.27	126.02
T_6: Rice+Fish (Succeeding culinary melon+Fish)	244.26	13.38	141.44
T_7: Rice+Fish (Succeeding fodder cowpea+Fish)	233.81	11.30	128.08
SEm (±)	6.27	2.15	7.07
CD (0.05)	13.662	-	-

4.4 SYSTEM ANALYSIS

4.4.1 System Productivity and System Rice Equivalent Yield

The data on the yield from different components of the rice based systems and the system rice equivalent yield (REY) are summarized in Table 34.

The production of rice grain and straw during *Virripu* 2015-16 and *Mundakan* 2015-16 was obtained from the ongoing AICRP trial of which this study formed a part. The yield of the crops raised during the summer 2015-16 and the fish is furnished earlier in Table 5 under section 4.1.2.

The REY differed significantly among the systems. The highest system REY was obtained from T_6 (24254 kg ha^{-1}) followed by T_5 and T_3 which were on par. The least REY was in T_1 (9180 kg ha^{-1}).

4.4.2 Economic Analysis

4.4.2.1 Gross Income

The gross income differed significantly among treatments (Table 35). Higher gross return was obtained from T_6 (526164 ₹ ha^{-1} $year^{-1}$). This was followed by T_5 (434021 ₹ ha^{-1} $year^{-1}$) which was on par with T_4 (377667 ₹ ha^{-1} $year^{-1}$).

4.4.2.2 Net Income

Significant difference was observed among treatments in net income (Table 35). Significantly higher net return was obtained from T_6 (₹ 360714). The treatment T_5 (₹ 264984) was the next most profitable followed by T_7 (₹ 194082) ranked third.

4.4.2.3 B: C Ratio

The B: C ratio varied significantly among treatments (Table 35). Significantly higher B: C ratio was obtained in T_6 (3.18), followed by T_5 (2.57) and T_7 (2.41) which were on par.

Table 34. Yield of the different components and system rice equivalent yield (REY) during 2015-16, kg ha^{-1}

Treatments	*Virippu* 2015		*Mundakan* 2015		Summer 2016		REY
	Grain	Straw	Grain	Straw	Crop	Fish	
T_1 (R-R- Fallow)	5259.26	5476.85	2122.59	2434.49	0.0	0.00	9180
T_2: (R-R-A)	4481.48	6229.17	2252.96	3240.97	5796.30	0.00	13524
T_3 (R-R-C)	5592.59	6861.11	1629.63	2557.87	10882.41	0.00	16981
T_4 (R-R-FC)	5888.89	6680.56	1686.67	2335.18	23703.70	0.00	13180
T_5: (R+F)-(R+F)-(A+F)	3111.11*	3761.58*	1283.33*	1399.31*	8944.44*	884.33*	18736
T_6 (R+F)-(R+F)-(C+F)	2814.82*	2858.80*	1053.56*	1629.21*	19387.96*	852.00*	24254
T_7: (R+F)-(R+F)-(FC+F)	3296.30*	3520.83*	1108.15*	1408.33*	11666.67*	854.00*	13082
SEm (±)	-	-	-	-	-	-	1266.8
CD (0.05)	-	-	-	-	-	-	2760.4

R: Rice; F: Fish; A: Amaranthus; C: Culinary melon; FC: Fodder cowpea *Yield from 5000 m^{-2}

4.4.2.4 Link Relative Index (LRI)

Link relative index values showed a trend similar to net income (Table 37). The highest link relative index was in T_6 followed by T_5 and T_7.

4.4.2.5 System Profitability

System profitability differed significantly among the treatments (Table 37). System profitability was higher in T_6 (₹ 988 day^{-1}) followed by T_5 (₹ 723 day^{-1}) and T_7 (₹ 531 day^{-1}).

4.4.2.6 Crop Profitability

Significant difference in crop profitability was noticed among treatments (Table 37). Significantly higher crop profitability was recorded in T_6 (₹ 941 day^{-1}) followed by T_7 and T_5 which were on par.

Table 35. Gross return of different components during 2015-16, ₹

Treatments	*Virippu* 2015	*Mundakan* 2015	Summer 2016	
			Crops	Fish
T_1: (R-R- Fallow)	143087.96	58869.49	0	0
T_2: (R-R-A)	129738.43	65770.05	115925.93	0
T_3: (R-R-C)	157342.59	48641.20	163236.11	0
T_4: (R-R-FC)	162958.33	48782.59	165925.93	0
T_5: (R+F)-(R+F)-(A+F)*	87252.31	35229.86	178888.89	132650
T_6: (R+F)-(R+F)-(C+F)*	76219.91	31324.29	290819.44	127800
T_7: (R+F)-(R+F)-(FC+F)*	90122.69	31420.93	81666.11	128100

R: Rice; F: Fish; A: Amaranthus; C: Culinary melon; FC: Fodder cowpea *Yield for 5000 m^{-2}

Table 36. Economics of different rice based systems (2015-16)

Treatments	Gross returns (₹ ha^{-1} $year^{-1}$)	Cost of Production (₹ ha^{-1} $year^{-1}$)	Net return (₹ ha^{-1} $year^{-1}$)	B:C ratio
T_1: (R-R- Fallow)	201957	183785	18173	1.10
T_2: (R-R-A)	311434	308730	2705	1.01
T_3: (R-R-C)	369220	301555	67665	1.22
T_4: (R-R-FC)	377667	245113	132554	1.54
T_5: (R+F)-(R+F)-(A+F)	434021	169037	264984	2.57
T_6: (R+F)-(R+F)-(C+F)	526164	165449	360714	3.18
T_7: (R+F)-(R+F)-(FC+F)	331310	137228	194082	2.41
SEm (±)	29240.16	-	29240.16	0.14
CD (0.05)	63714.300	-	63714.300	0.306

R: Rice; F: Fish; A: Amaranthus; C: Culinary melon; FC: Fodder cowpea

Prices of commodities (2015- '16)

Sale price of rice – ₹ 22 kg^{-1} Sale price of Amaranthus – ₹ 20 kg^{-1} Sale price of culinary melon – ₹ 15kg^{-1}

Sale price of fodder cowpea – ₹ 7kg^{-1} Sale price of fish – ₹ 150 kg^{-1}

Table 37. Effect of treatments on Link relative index, crop profitability and system profitability

Treatments	Link relative index (%)	Crop profitability (₹ day^{-1})	System profitability (₹ day^{-1})
T_1: (R-R- Fallow)	100	71.55	49.79
T_2: (R-R-A)	14.88	7.79	7.41
T_3: (R-R-C)	372.34	197.85	185.35
T_4: (R-R-FC)	729.40	400.46	363.16
T_5: (R+F)-(R+F)-(A+F)	1458.12	691.87	725.98
T_6: (R+F)-(R+F)-(C+F)	1984	941.81	988.26
T_7: (R+F)-(R+F)-(FC+F)	1067	506.74	531.73
SEm (±)	-	81.712	80.110
CD (0.05)	-	178.049	174.559

R: Rice; F: Fish; A: Amaranthus; C: Culinary melon; FC: Fodder cowpea

Discussion

5. DISCUSSION

The present investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with the objective of studying the performance and weed dynamics of different cropping sequences in rice based integrated farming system. The results obtained from the study are discussed in this chapter.

5.1 SUMMER CROP

5.1.1 Crop Growth and Yield

Growth of amaranthus and fodder cowpea was significantly superior when grown with fish, as evident from the greater height of amaranthus and fodder cowpea.

The highest yield was obtained from fodder cowpea grown as sole crop followed by culinary melon grown with fish and fodder cowpea grown with fish. A notable fact is that yield of amaranthus and culinary melon was higher when grown with fish than as sole crop. The highest rice equivalent yield (REY) was also obtained from culinary melon grown with fish. This was followed by culinary melon grown as sole crop and amaranthus grown with fish, which were similar.

The enhanced growth and yield of the crops when integrated with fish might be due to the favourable soil moisture condition resulting out of the capillary movement of water to the root zone from the fish trenches surrounding the raised beds on which the crops were raised.

5.1.2 Weed Dynamics

The analysis of weed composition revealed that grasses were dominant, followed by sedges and broad leaved weeds. Among the grasses, *Echinochloa colona* predominated followed by *Isachne miliacea*, *Digitaria ciliaris* and *Eragrostis tenella*. Among broad leaved weeds, *Lindernia grandiflora* dominated

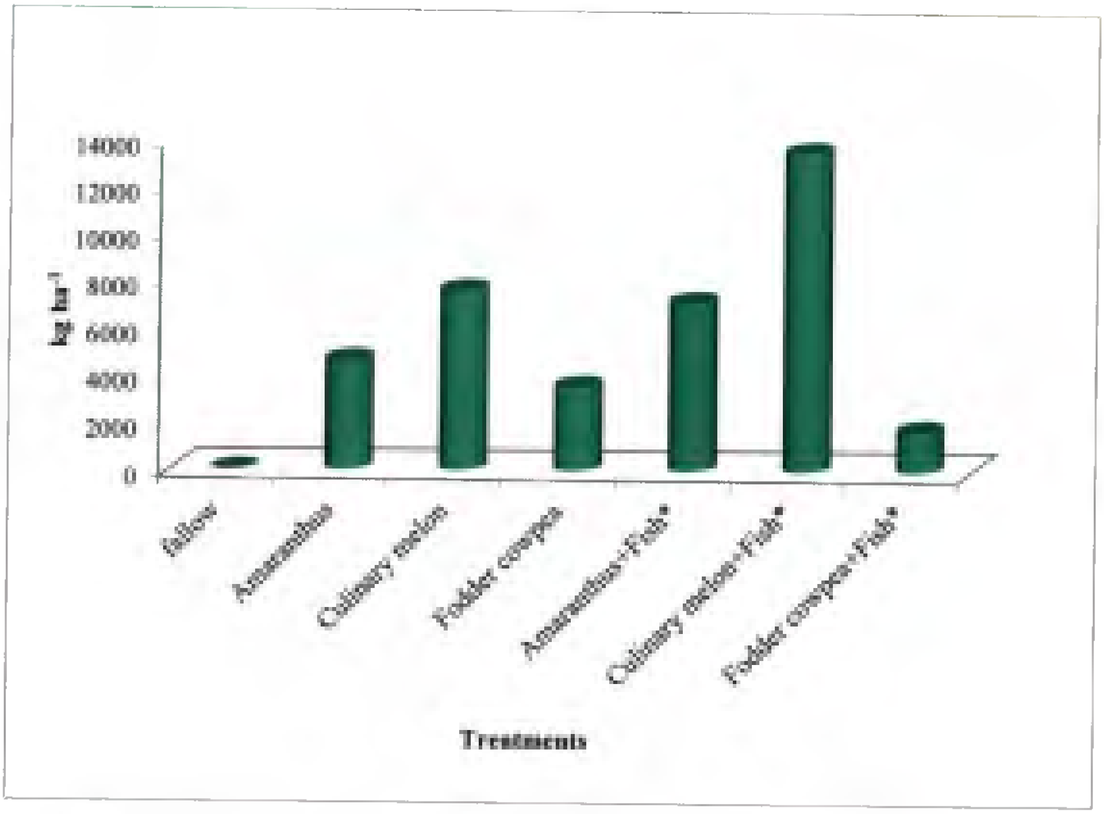

Fig. 3. Rice equivalent yield (REY) of the crops during summer 2015-16

followed by *Phyllanthus niruri*, *Oldenlandia umbellata* and *Cleome rutidospermum*. Among sedges, *Fimbristylis miliacea* population was the highest.

The population of individual weed species varied with crop and farming system. In general, the population of different weeds was less in culinary melon+fish system. *Echinachloa colona* was significantly higher in amaranthus+fish, fodder cowpea grown as sole crop and fodder cowpea+fish. The population of *Isachne miliacea* was significantly higher in the fallow plot followed by amaranthus sole crop. *Digitaria ciliaris* was significantly more in amaranthus+fish and fodder cowpea+fish system. *Eragrostis tenella* was significantly higher in amaranthus sole crop, while it was very low in culinary melon+fish and absent in amaranthus+fish and fodder cowpea+fish systems.

Among the broad leaved weeds, *Lindernia grandiflora* was totally absent in plots integrated with fish. *Fimbristylis miliacea* was very high in the fallow plot. Similarly, *Cyperus rotundus* population was high in the fallow plot while it was very low in all the other systems.

Dry matter production of grasses, broad leaved and sedges were significantly higher in the fallow plot. Higher weed dry weight was recorded in sole crops of amaranthus, culinary melon and fodder cowpea when compared the systems in which these crops were integrated with fish. Among the three crops, a higher weed dry weight was recorded in amaranthus whether grown as sole crop or combined with fish.

The higher weed population and weed dry weight in amaranthus can be attributed to the large quantity of cow dung added basally @ 50 t ha which would have contained greater number of weed seeds.

Weed control efficiency of grasses, broad leaved weeds and sedges were highest in the system when culinary melon was integrated with fish. Culinary melon grown as sole crop was also equally efficient in controlling the weeds.

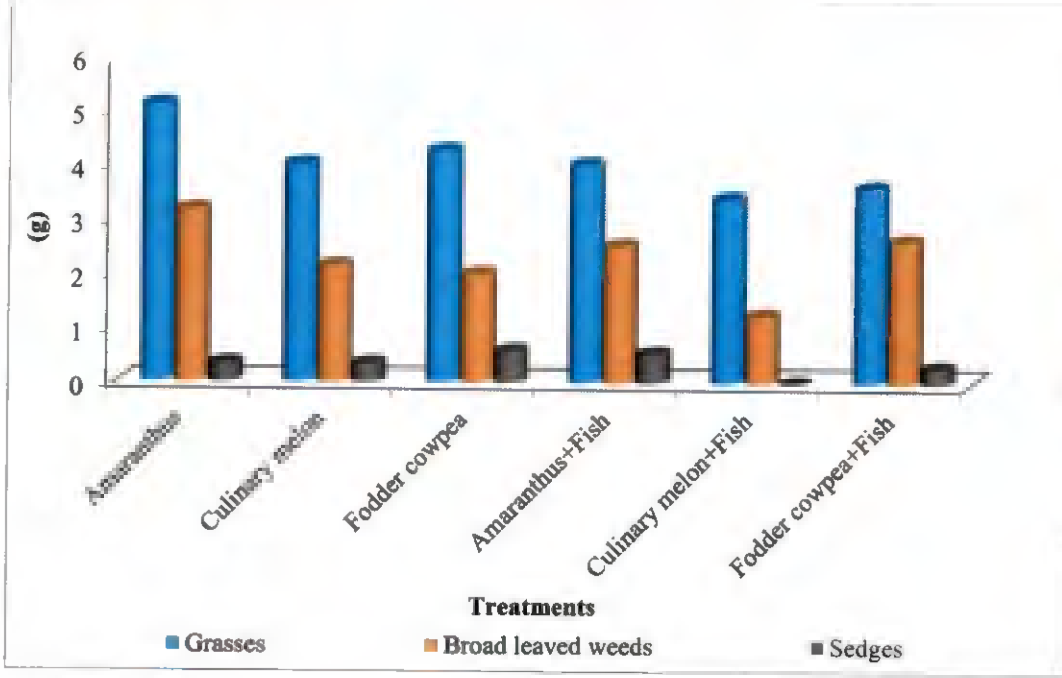

Fig. 4. Effect of treatments on weed dry weight (g) of weeds at 20 DAS during summer

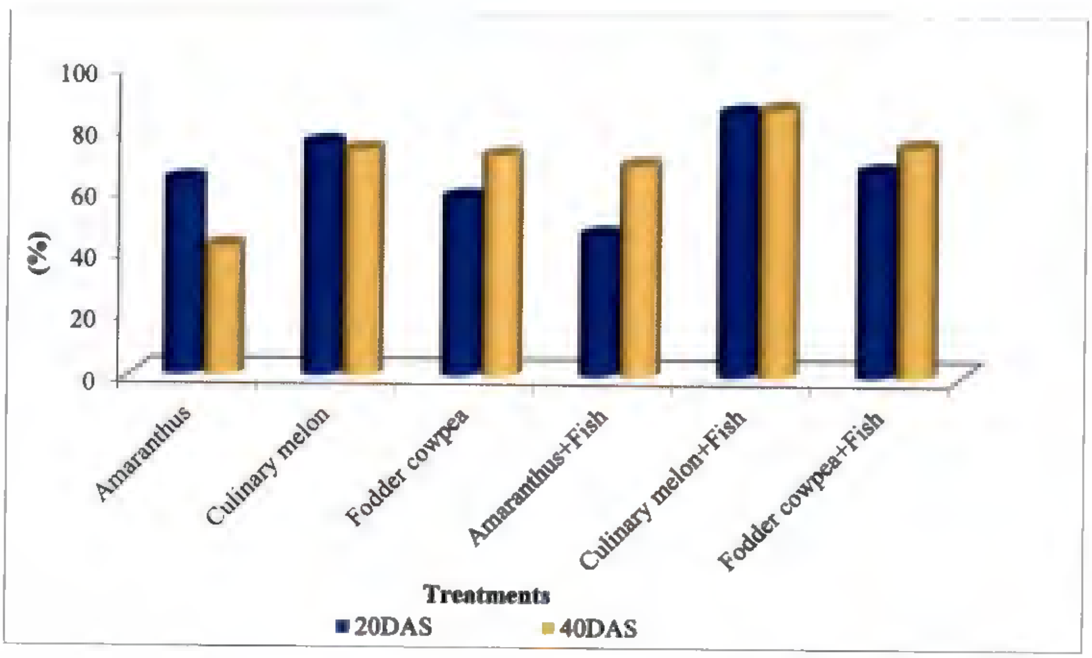

Fig. 5. Effect of treatments on weed control efficiency (%) of grasses

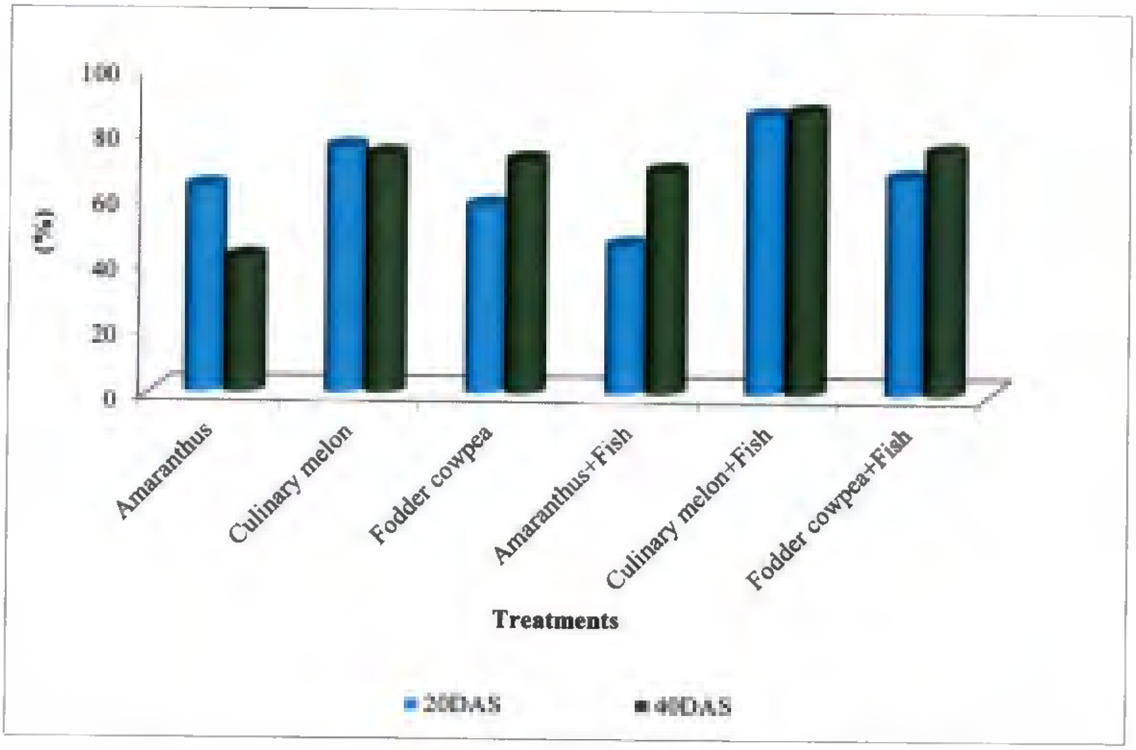

Fig. 6. Effect of treatments on weed control efficiency (%) of sedges

The observed differences in the predominance of weeds between treatments may be due to variation in the growth habit of the crop, land preparation, cultural practices followed, microclimate, and nutrient management. For instance, the trailing nature of culinary melon might have restricted the growth of certain weeds while the dense foliage and vigorous growth of fodder cowpea might have checked certain weeds. The presence of fish and water surrounding the raised beds might have prevented the proliferation of certain weeds. The absence of any crop or land modifications provided a hospitable ambience for several weeds to flourish in the fallow plot.

These inferences are also supported by the values of absolute density, relative density, absolute frequency, relative density, importance value and summed dominance ratio of weeds.

5.1.3 Nutrient removal by weeds

Removal of nitrogen, phosphorus and potassium by weeds was significantly higher in the fallow plot. Among the other treatments, significantly higher nutrient removal was in amaranthus sole crop and amaranthus+fish. Nutrient removal by weeds was also high when culinary melon was grown alone.

The higher nutrient removal by weeds in fallow plot, amaranthus grown either alone or with fish and culinary melon sole crop is proportionate to the high weed dry matter produced in these treatments. Similar findings of greater nutrient removal by weeds when the weed dry weight is more were reported by Singh *et al*. (2013).

5.2 FIRST CROP/*VIRIPPU* RICE

5.2.1 Growth characters

Plant height was significantly influenced only at 40 DAT. Rice plants were taller in the treatments in which fish was grown with rice and in the system where culinary melon was raised as sole crop during summer. The number of tillers produced at 20 DAT was significantly more in the treatments where rice was integrated with fish and also in the system where rice was preceded by sole crop of fodder cowpea during summer. However at 40 DAT, the number of tillers produced was significantly greater in the treatments where rice was grown with fish.

The greater height and higher tiller production in the systems where rice was integrated with fish might be due to the cumulative influence of trench silt that was added to the field prior to planting of rice. The added silt was enriched with the leftover left over fish feed and the fish excreta. Similar findings of improved rice growth in simultaneous systems of rice+fish cropping were reported (Sinhababu and Venkateswarlu, 1995; Rautaray *et al.*, 2005)

5.2.2 Yield attributes and Productivity

The number of productive tillers and thousand grain weight did not significantly vary between treatments. However, the number of productive tillers was relatively higher in the systems where rice was grown with fish and where rice was preceded by fodder cowpea sole crop in summer. Significantly higher and similar grain weight panicle^{-1} was obtained in all the systems where rice was integrated with fish.

The grain productivity was significantly higher and similar in the systems in which rice was integrated with fish. Similar reports of increase in rice yields integrated with fish were made by Gupta *et al.* (1998). Productivity of straw was significantly higher and comparable in the systems of rice+fish preceded by fodder cowpea+fish during summer and rice+fish preceded by amaranthus+fish during summer. The productivity of rice gain and straw was less in the system where the field was left fallow during summer.

It is evident that grain weight per panicle and the number of productive tillers were major factors that contributed to the higher productivity in the systems where rice was integrated with fish. Recycling of nutrient rich trench silt regularly for a period of four years prior to the *Virippu* crop and the large quantum of organic manure added to the preceding crops raised during summer might have resulted in the higher productivity in these treatments. Since fish excreta, unutilized fish feed and decayed *Azolla* are rich in nutrients, these can be recycled to enrich the soil (Balusamy, 1996). The nitrogen fixation by the fodder cowpea raised during summer may have also contributed to the relatively higher productivity of rice in the system of rice+fish preceded by fodder cowpea+fish during summer. A similar finding of higher grain yield of rice succeeding legumes was reported by Becker and Johnson (1998).

In the present study, it was observed that the status of available nitrogen in the soil was significantly higher after the *Virippu* rice crop in the systems where rice was integrated with fish. This too might have played a role in improving the productivity of rice in these systems.

Higher productivity of rice when grown simultaneously with fish was reported earlier by Haroon and Pittman (1997).

5.2.3 Weed dynamics

Among the different categories of weeds, grasses were dominant followed by sedges and broad leaved weeds. Among the grasses, population of *Eragrostis tenella* was the highest followed by *Echinochloa colona* and *Leptochloa* spp. Among the broad leaved weeds, *Salvinia molesta* predominated followed by *Marsilea quadrifolia* and *Lindernia grandiflora.* It is worth mentioning, that the population of weeds during *Virippu* was much less when compared to that in summer. However, population of broad leaved weeds was more during *Virippu* when compared to summer. Certain shifts in weed dominance were also observed between seasons. During summer, the dominant grass was *Echinochloa colona* followed by *Isachne miliacea* but in *Virippu* it was *Eragrostis tenella*. During *Virippu,* the dominant broad leaved weed was *Salvinia molesta* which was absent in all the treatments except fallow during summer. However, among sedges *Fimbristylis miliacea* predominated during both the seasons, but its population was very much reduced during *Virippu*.

There was significant difference in weed composition between the treatments. The population of most of the weeds was more in the systems where rice was grown with fish. Besides, a higher population was recorded in the system where field was left fallow during summer.

During *Virippu*, the absolute density of grasses was highest in the system (rice+fish)-(rice+fish)-(amaranthus+fish) and was comparable with (rice+fish)-(rice+fish)-(fodder cowpea+fish) and rice-rice-fallow. Density of grasses was significantly less in the systems without fish. The absolute density of broad leaved weeds and sedges were the highest and comparable in the treatments where rice was integrated with fish.

There was no significant difference in relative density of grasses. Relative density of broad leaved weeds was higher in the systems without fish whereas relative density of sedges was higher in the systems with fish. A notable fact is that sedges were totally absent in the systems without fish. Though a reduction in the population of broad leaved weeds and sedges in paddy fields integrated with fish has been recorded earlier (Piepho and Alkamper, 1991), this was not evident in this study.

Weed dry weight of grasses was, initially, highest in the system where field was left fallow during summer. Subsequently, dry weight of grasses was more and comparable in the systems where rice was grown with fish. Weed dry weight of broad leaved weeds and sedges were the highest in the systems (rice+fish)-(rice+fish)-(amaranthus+fish), (rice+fish)-(rice+fish)-(fodder cowpea+ fish) and rice-rice-fallow. Weed dry weight was less in the systems where rice was raised as sole crop.

Weed control efficiency of grasses, up to 40 DAT, was the highest and comparable in treatments where rice was grown without fish. Weed control efficiency of broad leaved weeds was the lowest in the plots where rice was grown with fish, while the highest weed control efficiency of sedges was noticed in rice devoid of fish. Weed control efficiency of sedges was lower and comparable in systems with fish.

It is obvious, from the analysis of weed population that the differences in type of crop, land preparation, cultural practices and water management during the summer and *Virippu* seasons have resulted in certain shift in the weed dynamics. These are some of the major reasons for the observed difference in order of predominance of weed categories, species wise predominance and absolute density. For instance, during summer, there was no standing water in treatments with sole crop, whereas, during *Virippu* season, in the systems with sole crop standing water was maintained throughout the crop period. This was the reason for the observed higher weed population in these treatments during summer when compared to *Virippu* season.

Carry over effects were also noticeable. For instance, the carry over effect of very high weed population in the treatment left fallow during summer was apparent during *Virippu*. Another case is the high weed population noticed in the systems where amaranthus was raised during summer. The high rate of addition of cow dung in amaranthus during summer @ 50 t ha^{-1} might be the reason for the high weed density recorded during summer and subsequent *Virippu* in these systems. Besides, the recycling of nutrient rich silt might have helped weeds to flourish during *Virippu* season in the systems where rice and fish were integrated.

Another interesting observation is that, rainfall received was very low (132.24 mm) during the period from 20th June to 8th July 2016 *i.e.* subsequent to transplanting of *Virippu* rice crop. In the systems where rice and fish were integrated the rainwater received was sufficient for maintaining water level in the trenches only thereby resulting in the transplanted rice plants being maintained in a more or less semidry condition. The greater intensity of weed proliferation under aerobic and semidry conditions of rice cultivation has been widely documented (Prasad, 2011; Singh *et al.*, 2013; and Matloob *et al.*, 2014). Had the rainfall received been higher, the water level in the trenches harbouring the fish would have increased and helped in maintenance of 5 cm of standing water in the portion of field where rice was planted.

5.2.4 Nutrient Removal by Weeds

Nitrogen removal by weeds was significantly high at 20 DAT in the system in which the field was left fallow. But, at 40 DAT, nitrogen removal was the highest in the systems where rice was integrated with fish and was similar to the system where the field was left fallow during summer. Removal of phosphorus by weeds was significantly higher in the systems where rice and fish were integrated. The higher removal of nutrients by weeds is proportional to the higher weed dry matter produced in the systems. Similar reports of greater nutrient removal by weeds when the weed dry weight is more were reported by Singh *et al*. (2013)

5.3 NUTRIENT STATUS OF THE SOIL

Prior to raising of summer crop, available nitrogen content was significantly higher and similar in rice-rice-amaranthus, rice-rice-culinary melon, rice-rice-fodder cowpea, (rice+fish)-(rice+fish)-(amaranthus+fish) and (rice+fish) - (rice+fish)-(culinary melon+fish). Phosphorus content was significantly more in (rice+fish)-(rice+fish)-(amaranthus+fish) followed by rice-rice-amaranthus and (rice+fish)-(rice+fish)-(culinary melon+fish). Potassium content was significantly higher and similar in rice-rice-amaranthus, rice-rice-culinary melon, (rice+fish)-(rice+fish)-(amaranthus+fish) and (rice+fish)-(rice+fish)-(fodder cowpea+fish).

It can be deduced, that a higher soil nutrient status with respect to all major nutrients existed in the rice-rice-amaranthus and (rice+fish)-(rice+fish)-(amaranthus+fish) systems. At the time of the present investigation, these cropping systems were being repeated for the fourth time. Amaranthus is manured with organic matter @ 50 t ha^{-1} (KAU, 2016). Moreover, in the (rice+fish)-(rice+fish)-(amaranthus+fish) system, desilting of trenches subsequent to harvest of fish and its recycling back to the field was done during the previous three years. These two factors might have contributed to higher soil nutrient status in the system.

A similar trend with respect to the major nutrients in the soil was noticed after the summer crop also. During summer, the same high quantum of organic manure was added to the amaranthus crop in the rice-rice-amaranthus and (rice+fish)-(rice+fish)-(amaranthus+fish) systems.

After the *Virippu* rice crop, there was significant difference in the available nitrogen status only. A higher and similar content was present in (rice+fish)-(rice+fish)-(amaranthus+fish), rice-rice-amaranthus, (rice+fish)- (rice+fish)-(culinary melon+fish) and (rice+fish)-(rice+fish)-(fodder cowpea+fish). This could, yet again, be attributed to the very high quantity of organic manure added and/or the trench silt that was recycled after harvesting of fish and prior to planting of *Virippu* rice crop.

5.4 ECONOMIC ANALYSIS

Among the different rice based systems, (rice+fish)-(rice+fish)-(culinary melon+fish) gave significantly higher gross return, profit (net return) and B: C ratio. The (rice+fish)-(rice+fish)-(amaranthus+fish) system was the next most remunerative. Though the rice-rice-fodder cowpea system ranked third with respect to gross income, (rice+fish)-(rice+fish)-(fodder cowpea+fish) ranked third with respect to net income and B: C ratio. This was because the cost of cultivation for raising fodder cowpea in one hectare is much more than the combined cost of raising fodder cowpea in 0.5 ha plus rearing fish in 0.50 ha *i.e.* the cost incurred for raising fish in 0.50 ha is much less than that for raising fodder cowpea in 0.50 ha. The link relative index values showed a trend similar to net income.

The profit generated per day in a year (system profitability) and that generated per day of the actual period the crop occupied the field (crop profitability) showed a trend similar to net returns and was significantly higher in (rice+fish)- (rice+fish)-(culinary melon+fish).

Higher productivity of rice and cucumber when grown along with the fish plus yield obtained from fish resulted in the (rice+fish)-(rice+fish)-(culinary melon+fish) system being more profitable.

In the systems where crop and fish was integrated, the fish component alone contributed a gross income ranging from Rs.1.27-1.32 lakhs from 0.5 ha. Similar observations of substantial contribution by the fish component to the income generated in rice based farming systems were made by Rangaswamy *et al.* (1992).

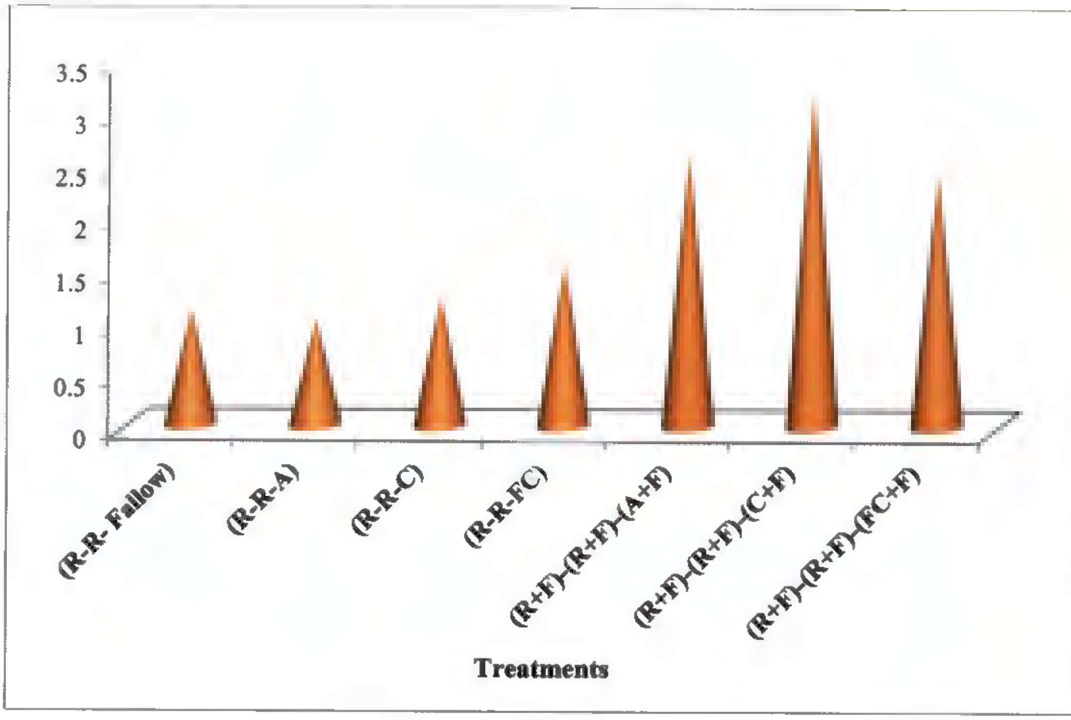

Fig. 7. Effect of treatments on B: C ratio of systems

Summary

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6. SUMMARY

The present investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with the aim of studying the performance and weed dynamics of different cropping sequences in rice based integrated farming system. The study was conducted as part of the ongoing All India Coordinated Research Project (AICRP) on Integrated Farming System being implemented in the Integrated Farming System Research Station (IFSRS) of the Kerala Agricultural University located at Karamana, Thiruvananthapuram.

The experiment was laid out in Randomized Block Design and comprised seven treatment combinations replicated thrice, distributed over summer 2015-'16 and *Virippu* 2016-'17 seasons. The treatments were, T_1 (rice-rice-fallow), T_2 (rice-rice-amaranthus), T_3 (rice-rice-culinary melon), T_4 (rice-rice-fodder cowpea), T_5 (rice+fish)-(rice+fish)-(amaranthus+fish), T_6 (rice+fish)-(rice+fish)-(culinary melon+fish) and T_7 (rice+fish)-(rice+fish)-(fodder cowpea+fish). The varieties of rice, amarathus, culinary melon and fodder cowpea used were Uma, Arun, Vellayani local and Aiswarya respectively. In treatments, T_5-T_7, the fish species *viz.*, catla (*Catla catla*) and rohu (*Labio rohita*) were introduced into the trenches of 6 m x 3 m x 1 m (length x width x depth) after transplanting of *Virippu* crop and were harvested after summer crop. The assessment of weed dynamics was done during summer 2015-'16 and *Virippu* 2016-'17. The data related to yield of rice during *Virippu* and *Mundakan* season of 2015-16, generated from the ongoing AICRP trial, were used for system analysis and working out the economics. The results of the study are summarized below.

SUMMER (2015-'16)

Among the summer crops raised, amaranthus and fodder cowpea were superior in terms of growth and growth attributes when integrated with fish. The highest yield was obtained from fodder cowpea grown as sole crop followed by culinary melon+fish and fodder cowpea+fish.

There was substantial diversity in weed composition during summer season. Among weeds, grasses dominated, followed by sedges and broad leaved weeds. Among the grasses, *Echinochloa colona* predominated followed by *Isachne miliacea*, *Digitaria ciliaris* and *Eragrostis tenella*. Among the broad leaved weeds, *Lindernia grandiflora* dominated followed by *Phyllanthus niruri*, *Oldenlandia umbellata* and *Cleome rutidospermum*. Among the sedges, the population of *Fimbristylis miliacea* was the highest. All categories of weeds were higher in fallow and in sole crop of amaranthus. However, culinary melon was effective in suppressing weeds.

In general, fallow plot recorded high weed dry weight with respect to grasses, broad leaved and sedges. Among the crops raised during summer, higher dry matter of grasses and broad leaved weeds was in amaranthus, whereas dry weight of sedges was more in fodder cowpea. A lower dry matter of weeds was noticed in culinary melon integrated with fish. Weed control efficiency of weeds was higher when culinary melon was integrated with fish while, lower weed control efficiency was noticed in amaranthus crop grown as sole crop or with fish.

Higher amount of nutrients (N, P and K) was removed by weeds in fallow plot at all the stages. Among the crops grown, significantly higher nutrient removal by weeds was in sole crop of amaranthus and in amaranthus+fish. Nutrient removal by weeds was also high when culinary melon was grown alone. But, it was the lowest in culinary melon integrated with fish.

FIRST CROP/ *VIRIPPU* RICE CROP (2016-'17)

In general, the growth and growth attributes were higher in the treatments where rice was integrated with fish. The rice plants were taller in the treatments in which fish was grown with rice and in the system where culinary melon was raised as sole crop during summer. The number of tillers produced at 20 DAT was significantly more in the treatments where rice was integrated with fish and also in the system where rice was preceded by sole crop of fodder cowpea during summer. However at 40 DAT, significantly greater number of tillers hill^{-1} was produced in the treatments where rice was integrated with fish.

The number of productive tillers m^{-2} and thousand grain weight did not vary significantly among treatments. Significantly higher and on par grain weight panicle^{-1} was obtained in treatments where rice was integrated with fish.

The grain productivity was significantly higher and similar in the systems in which rice was integrated with fish. Productivity of straw was remarkably higher and comparable in the systems of rice+fish preceded by fodder cowpea+fish and amaranthus+fish during summer. The productivity of rice grain and straw were less in the system where the field was left fallow during summer.

There was notable difference in the weed composition during *Virippu* when compared to summer season. Grasses predominated, followed by sedges and broad leaved weeds. Among the grasses, population of *Eragrostis tenella* was the highest followed by *Echinochloa colona* and *Leptochloa* spp. Among the broad leaved weeds, population of *Salvinia molesta* was the highest followed by *Marsilea quadrifolia* and *Lindernia grandiflora. Fimbristylis miliacea* dominated among sedges. The population of weeds during *Virippu* was, to a great extent, less compared to that in summer. The population of majority of the weed species was more in the systems where rice was grown with fish. Besides, a higher population was recorded in the system where field was left fallow during summer.

The absolute density of grasses was the highest in the system (rice+fish)-(rice+fish)-(amaranthus+fish) and was on par with (rice+fish)-(rice+fish)-(fodder cowpea+fish) and rice-rice-fallow. Density of grasses was significantly less in the systems without fish. The absolute density of broad leaved weeds and sedges were also higher and on par in the treatments where rice was integrated with fish. Sedges were absent in systems where rice was raised as sole crop.

Dry weight of weeds-grasses, broad leaved weeds and sedges was, initially, the highest in the system where rice was preceded by summer fallow during summer. In the later stages, dry weight of grasses was more in the system (rice+fish)-(rice+fish)-(fodder cowpea+fish). At 40 DAT, the highest dry matter of broad leaved weeds was in the system where the field was left fallow during summer, while at 60 DAT, it was in (rice+fish)-(rice+fish)-(fodder cowpea+fish). There was no significant difference among the treatments in dry weight of sedges in the later stages.

Weed control efficiency of grasses, up to 40 DAT, was the highest and comparable in treatments where rice was grown without fish. Weed control efficiency of broad leaved weeds was the lowest in the plots where rice was grown with fish, while the highest weed control efficiency of sedges was in rice devoid of fish. Weed control efficiency of sedges was lower and comparable in systems with fish. Among the treatments total weed control efficiency was higher in rice grown as sole crop and lower in rice integrated with fish.

Major nutrients removed by weeds was higher during initial stages in treatments where rice succeeded fallow but in the later stages, it was in the rice+fish system (*Virippu*) subsequent to fodder cowpea+fish (summer).

Regarding the nutrient status of soil before summer, available nitrogen was higher in rice-rice-amaranthus, whereas available phosphorus and potassium was higher in (rice+fish)-(rice+fish)-(amaranthus+fish). The available status of major nutrients was the lowest in rice-rice-fallow. The available nitrogen status of soil after summer was higher in rice-rice-amaranthus while, available phosphorus was higher in (rice+fish)-(rice+fish)-(amaranthus+fish) whereas, the lowest was noted in rice-rice-fallow. After *Virippu* rice the available nitrogen in soil was the highest in (rice+fish)-

(rice+fish)-(amaranthus+fish) and the lowest in rice-rice-fallow. There was no significant variation in available phosphorus and potassium.

The REY differed significantly among the systems. The highest (24254 kg ha^{-1}) system REY was obtained from T_6 (Rice+fish)-(rice+fish)-(culinary melon+fish) followed by T_5 and T_3 which were on par. The least (9180 kg ha^{-1}) REY was in T_1 (Rice-rice-fallow).

The economic parameters *viz.*, gross returns, net returns, B: C ratio, LRI (Link Relative index), system profitability and crop profitability were significantly higher in (rice+fish)-(rice+fish)-(culinary melon+fish). In general, the economic parameters were higher in the systems where fish was integrated with crops. The contribution of the fish component to the gross income varied from ₹.1.27 to 1.32 lakhs from 0.50 ha.

From the study, it could be inferred that the population of weeds was more in summer than in *Virippu*. During summer and *Virippu*, grasses dominated followed by sedges and broad leaved weeds, but broad leaved weeds were more in *Virippu* than in summer. In summer, weeds were more in fallow and in systems with sole crops. Among crops, weed growth was more in amaranthus. In *Virippu,* weeds were higher in the systems where rice was grown with fish. The productivity of summer crops and *Virippu* rice crop were more in cropping sequences integrated with fish. The system (rice+fish)-(rice+fish)-(culinary melon+fish) performed better in terms of weed control, yield and profit. This was followed by (rice+fish)-(rice+fish) - (amaranthus+fish).

Future line of work

- Explore the possibility of integrating other more profitable crops in rice based farming systems, especially during summer
- Investigate the carbon sequestration potential of different rice based farming systems.
- Evolve eco-friendly strategies for managing the weeds in rice when integrated with fish, especially in the eventuality of low rainfall.

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CROP PRODUCTIVITY AND WEED DYNAMICS IN RICE BASED FARMING SYSTEMS

by

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ABSTRACT

The investigation entitled "Crop productivity and weed dynamics in rice based farming systems" was undertaken with the objective of studying the performance and weed dynamics of different cropping sequences in rice based integrated farming systems. The experiment forms a part of ongoing All India Coordinated Research Project on Integrated Farming System and was carried out in the Integrated Farming System Research Station (IFSRS), Karamana, Kerala Agricultural University.

The experiment was laid out in randomized block design with seven treatments, replicated thrice, during the summer and *Virippu* seasons 2016. The treatments were, T_1 (rice-rice-fallow), T_2 (rice-rice-amaranthus), T_3 (rice-rice-culinary melon), T_4 (rice-rice-fodder cowpea), T_5 (rice+fish)-(rice+fish)-(amaranthus+fish), T_6 (rice+fish)-(rice+fish)- (culinary melon+fish) and T_7 (rice+fish)-(rice+fish)-(fodder cowpea+fish). The varieties of rice, amarathus, culinary melon and fodder cowpea used were Uma, Arun, Vellayani local and Aiswarya respectively. In treatments T_5-T_7 fish species *viz.*, catla (*Catla catla*) and rohu (*Labio rohita*) were introduced into the trenches of 6m x 3m x 1m after transplanting of *Virippu* crop and were harvested after summer crop. The data related to rice yield during *Virippu* and *Mundakan* season of 2015, generated from the ongoing trial, were used for working out the economics of the systems.

During summer, growth of amaranthus and fodder cowpea was superior when grown along with fish. The highest yield of fodder cowpea was obtained when it was grown as sole crop (T_4) followed by culinary melon grown with fish (T_6) and fodder cowpea grown with fish. However, significantly higher rice equivalent yield (REY) was obtained when culinary melon was integrated with fish (T_6).

During summer, among weeds, grasses dominated, followed by sedges and broad leaved weeds. Population of *Echinochloa colona, Lindernia grandiflora* and *Fimbristylis miliacea* predominated among the grasses, broad leaved weeds and sedges respectively. The absolute density of different weeds was significantly less in T_6 at all

the stages, whereas in T_2 and T_5 the population was higher. The highest dry weight of grasses, broad leaved and sedges were in T_1 at all stages. Among the other treatments, T_2 recorded significantly higher dry matter of grasses at both the stages. But dry weight of broad leaved weeds and sedges was significantly higher in T_2 and T_4 only at 20 DAS. The weed control efficiency (WCE) of grasses and sedges were significantly higher in T_6 at all stages, while in broad leaved weeds, WCE was similar in all treatments except T_2. In general, among the treatments except T_1 removal of all major nutrients (N, P and K) by weeds was significantly higher in T_2, T_3 and T_5 both at 20 and 40 DAS.

During *Virippu*, rice plants were taller when grown with fish (T_5, T_6, and T_7) and in the system where culinary melon sole crop preceded the rice crop (T_3) during summer. Significantly more number of tillers was produced in T_6 at 20 DAT and in T_7 at 40 DAT. The number of productive tillers m^{-2} and thousand grain weight did not vary significantly among treatments. However, significantly higher grain weight $panicle^{-1}$ was recorded in T_7 (4.08 g), which was on par with T_6 T_5 and T_1. Grain productivity was significantly higher and on par in the systems in which rice was integrated with fish (T_5, T_6, and T_7). In general, yield attributes and productivity of rice were less in rice-rice-fallow system.

During *Virippu*, season also grasses were dominated followed by sedges and broad leaved weeds.The highest absolute density of grasses was in T_5 at 20 DAT, broad leaved weeds in T_1 and T_5 and sedges in T_7 and T_5 at 20 and 40 DAT. Weed dry weight of grasses was initially the highest in rice-rice-fallow (T_1). At 40 DAT dry weight of grasses was the highest in T_7 and comparable with T_6 and T_1. Weed dry weight of broad leaved weeds was the highest in T_1 at 20 and 40 DAT and in T_5 at 60 DAT. Weed dry weight of sedges was more in T_1 at 20 DAT. The WCE of grasses was the highest in T_3, T_1 and T_6 at 20, 40 and 60 DAT respectively, while that of broad leaved weeds the highest in T_3 at 20 and 40 DAT and of sedges in T_1 at all the stages. Significantly higher amount of nitrogen was removed by weeds in T_1 at 20 DAT, while at 40 and 60 DAT, it was more in T_7. A similar trend was observed in phosphorus and potassium also.

Regarding soil nutrient status before summer, nitrogen content was higher in T_2, while phosphorus and potassium was higher in T_5. After the summer crop, nitrogen content was significantly higher in T_2, T_3, T_5 and T_4 which were on par. Phosphorus and potassium content was significantly higher in T_5 and T_2 and they were on par. After the *Virippu* rice crop, significantly higher available nitrogen content was in T_5, T_2, T_6 and T_7 which were on par.

The economic parameters *viz*., gross returns, net returns, B: C ratio, LRI (Link Relative index), system profitability and crop profitability were significantly higher in T_6. The contribution of the fish component to the gross income varied from ₹ 1.27 to 1.32 lakhs from 0.50 ha.

From the study, the investigations on weed dynamics revealed that the population of weeds was more in summer than in *Virippu*. During summer and *Virippu*, grasses dominated followed by sedges and broad leaved weeds, but broad leaved weeds were more in *Virippu* than in summer. In summer, weeds were more in fallow and in systems with sole crops. Among crops, weed growth was more in amaranthus. In *Virippu,* weeds were higher in the systems where rice was grown with fish. The productivity of summer crops and *Virippu* rice crop was more in cropping sequences integrated with fish. Rice+fish – rice+fish –culinary melon+fish system performed better in terms of weed control, yield and profit. This was followed by Rice+fish – rice+fish – amaranthus+fish system.

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സംക്ഷിപ്തം

നെല്ലധിഷ്ഠിത കൃഷി സമ്പ്രദായങ്ങളിലെ കളസാന്നിധ്യത്തെയും വിളവുല്പാദനത്തെയും അടിസ്ഥാനപ്പെടുത്തിയുള്ള ഒരു പഠനം കരമനയിലുള്ള സംയോജിത കൃഷി സമ്പ്രദായ ഗവേഷണ കേന്ദ്രത്തിൽ നടത്തുകയുണ്ടായി.

പഠനത്തിൽ ഏഴ് വ്യത്യസ്ത കൃഷി സമ്പ്രദായങ്ങളെയാണ് ഉൾപ്പെടുത്തിയിരുന്നത്. നെല്ല്-നെല്ല്-തരിശ്, നെല്ല്-നെല്ല്-ചീര, നെല്ല്-നെല്ല്-വെള്ളരി, നെല്ല്-നെല്ല്-തീറ്റപ്പയർ എന്നീ കൃഷി സമ്പ്രദായങ്ങൾക്ക് പുറമേ മത്സ്യകൃഷി കൂടി ഉൾപ്പെടുത്തിയിട്ടുള്ള (നെല്ല്+മത്സ്യം) – (നെല്ല്+മത്സ്യം) - (ചീര+മത്സ്യം), (നെല്ല്+മത്സ്യം) - (നെല്ല്+മത്സ്യം) - (വെള്ളരി+മത്സ്യം), (നെല്ല്+മത്സ്യം) – (നെല്ല്+മത്സ്യം) – (തീറ്റപ്പയർ+മത്സ്യം) എന്നീ വ്യത്യസ്ത കൃഷി സമ്പ്രദായങ്ങളായിരുന്നു ഇവ. ഉമ, എന്ന നെല്ലിനം, അരുൺ എന്ന ചീരയിനം, വെള്ളായണി ലോക്കൽ എന്ന വെള്ളരിയിനം, ഐശ്വര്യ എന്ന തീറ്റപ്പയറിനം എന്നിവയാണ് കൃഷി ചെയ്തത്. മത്സ്യ ഇനങ്ങൾ കട്‌ല, രോഹു എന്നിവയായിരുന്നു. രണ്ടായിരത്തി പതിനാറിലെ വേനലിലും തുടർന്നുള്ള വിരിപ്പ് കാലത്തുമുള്ള കളസാന്നിധ്യം സമഗ്രമായി പഠിച്ചു.

പഠനത്തിന്റെ പ്രധാന കണ്ടെത്തലുകളിവയാണ്. വേനൽക്കാലത്ത് കളകളുടെ സാന്നിധ്യം വിരിപ്പ് കാലത്തെ അപേക്ഷിച്ച് എട്ടിരട്ടിയോളമാണ്. ഇതിൽ, പുൽവർഗ കളകൾ 11.5 ഇരട്ടിയും, മുത്തങ്ങ വർഗ കളകൾ 6.52 ഇരട്ടിയോളവുമാണ്. എന്നാൽ, വീതി കൂടിയ ഇലകളോട് കൂടിയ കളകൾ വിരിപ്പിലാണ് വേനലിനെ അപേക്ഷിച്ച് കൂടുതൽ (1.14 ഇരട്ടി). വേനൽക്കാലത്ത് തരിശിടുന്ന വയലുകളും, മത്സ്യകൃഷി ഉൾപ്പെടുത്താത്ത കൃഷി രീതിയും കൂടുതൽ കളശല്യം നേരിട്ടു. വിളകളിൽ, ഏറ്റവും കൂടുതൽ കളശല്യം നേരിട്ടതു ചീരയിലാണ്. മത്സ്യകൃഷി കൂടി ഉൾപ്പെടുത്തിയപ്പോൾ വേനൽ വിളകളിലും തുടർന്ന് ചെയ്ത വിരിപ്പ് വിളയിലും ഉത്പാദനക്ഷമത 8.5-20 ശതമാനം വരെ വർദ്ധിച്ചു. ചെലവു കഴിഞ്ഞുള്ള ആദായവും (3,60,714 രൂപ ഹെക്ടറൊന്നിന്), വരവ് : ചെലവ് അനുപാദവും (3.18) കൂടുതലായി കണ്ടത് (നെല്ല്+മത്സ്യം) - (നെല്ല്+മത്സ്യം) - (വെള്ളരി+മത്സ്യം) എന്ന കൃഷി സമ്പ്രദായത്തിലാണ്.

നെല്ലിനൊപ്പം മത്സ്യകൃഷി കൂടി കൈക്കൊള്ളുക വഴി അറ്റാദായത്തിൽ 1.27 – 1.32 ലക്ഷം വരെ രൂപയുടെ വർധനവുണ്ടായി (അര ഹെക്ടർ കൃഷിയിടത്തിൽ നിന്ന്).

പഠനത്തിൽ നിന്ന്, പുൽവർഗ കളകളിൽ അധികമായി കണ്ടത് കവടയെന്നും (*Echinochloa colona*), മുത്തങ്ങ വർഗത്തിൽ മങ്ങ് (*Fimbristylis miliacea*) എന്ന കളയാണെന്നും, വീതി കൂടിയ ഇലകളോട് കൂടിയ ഇനത്തിൽ കാക്കപ്പൂവ് (*Lindernia grandiflora*) എന്ന കളയാണെന്നും മനസിലാക്കി.

സംയോജിത കൃഷി സമ്പ്രദായം വിളവുല്പാദനം മെച്ചപ്പെടുത്തുന്നതിനു പുറമേ കളനിയന്ത്രണക്ഷമത വർധിപ്പിക്കുന്നു എന്നു കണ്ടെത്തി. പ്രത്യേകിച്ച് (നെല്ല്+മത്സ്യം) - (നെല്ല്+മത്സ്യം) - (വെള്ളരി+മത്സ്യം) എന്ന കൃഷിരീതിയിൽ വിളവും ആദായവും വർധിക്കുന്നതിനു പുറമേ മികച്ച കളനിയന്ത്രണ ക്ഷമതയും രേഖപ്പെടുത്തി.

Appendices

Appendix I a.
Weather data during summer crop period (February to May 2016)

Standard week	Month and date	Temperature °C		Relative humidity (%)	Rainy fall (mm)
		Maximum	Minimum		
4	Jan 22-28	30.93	23.95	88.805	0
5	Jan 29-Feb 4	30.31	20.89	84.15	0
6	Feb 5-11	30.94	23.19	87.09	0
7	Feb 12-18	31.92	24.58	80.985	0.25
8	Feb 19-25	32.69	24.05	82.2	0
9	Feb 26-Mar 4	32.50	24.01	78.135	0.25
10	Mar 5-11	32.35	24.39	84.465	0.76
11	Mar 12-18	33.53	25.73	83.375	0
12	Mar 19-25	33.13	26.70	84.54	0
13	Mar 26-Apr 1	33.00	25.59	83.845	0
14	Apr 2-8	33.57	26.96	82.37	0
15	Apr 9-15	33.01	26.45	86.565	58.42
16	Apr 16-22	33.20	27.01	87.04	9.14
17	Apr 23-29	33.16	27.39	84.605	0
18	Apr 30-May 6	33.60	25.87	85.265	14.22
19	May 7-13	33.07	25.67	88.145	39.88
20	May 14-20	30.32	23.59	92.155	280.16
21	May 21-27	31.79	25.70	90.35	35.05

Appendix I b.
Weather data during *Virippu* crop period (June to October 2016)

Standard week	Month and date	Temperature °C		Relative humidity (%)	Rainy fall (mm)
		Maximum	Minimum		
22	May 28-Jun 3	31.32	24.79	86.73	7.11
23	Jun 4-10	30.07	24.58	97.53	167.13
24	Jun 11-17	30.38	23.97	89.38	128.52
25	Jun 18-24	29.79	23.49	84.32	68.33
26	Jun 25-Jul 1	30.45	24.21	83.48	25.91
27	Jul 2-8	31.71	24.57	80.07	35
28	Jul 9-15	29.86	23.86	83	60.4
29	Jul 16-22	30.64	25.21	80.64	0
30	Jul 23-29	29.93	24.57	83	36.8
31	Jul 30-Aug 5	30.21	25.29	82.5	8
32	Aug 6-12	30.93	25.21	77.86	0
33	Aug 13-19	30.57	25.07	83.21	11.3
34	Aug 20-26	30.29	25.14	82.79	17.6
35	Aug 27-Sep 2	30.36	24.71	81.57	2
36	Sep 3-9	29.79	24.07	84.36	3
37	Sep 10-16	30.50	25.07	81.57	0
38	Sep 17-23	30.43	25.00	83.36	0
39	Sep 24-30	30.79	25.00	81.93	0.6
40	Oct 1-7	30.36	24.12	94.88	0
41	Oct 8-14	30.68	23.94	94.12	1.27
42	Oct 15-21	30.33	24.62	96.56	33.53